VISUAL ERGONOMICS IN AGING PEOPLE

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Abstract

Even in healthy ageing, vision tends to deteriorate, causing increased risk of falls, isolation, depression and dependence on others.
The aim of this study was to recommend adaptations of visual characteristics in the environment of the nursing home in order to improve functioning of the residents.
Results have shown that even minor adaptations of visual characteristics in the environment have significantly improved (Z=3.30; p=0.001) visual functioning and participation in activities.
Adapting visual characteristics of the environment, based on individual assessment of visual functioning, can help ageing person to increase visual functioning and retain independence and participation in activities.

Keywords*:* *visual functioning, ageing, visual environment, environmental adaptations*

1. INTRODUCTION

Vision tends to deteriorate with age. According to WHO about 65 % of all people who are visually impaired are aged 50 and older, while this age group comprises about 20 % of the world's population [1]. Most common causes of low vision in persons over 50 years of age are age-related macular degeneration, diabetic retinopathy, glaucoma, cataracts and retinitis pigmentosa.
Nevertheless, since all organs, so as organs important for vision, changes during ageing, our visual functioning declines even in such healthy ageing. The eye is changing, ciliary muscle cannot control accommodation for viewing objects at varying distances as well as in young age, therefore person cannot see clearly in near distance. In ageing people anisometropia is more common than in children, it seems to develop through years and can influence stereovision [2]. Retina is changing, the cells of retina are deteriorating so ageing persons often have trouble recognizing colors, especially green and blue [3]. Because of changes in retina, they also have problems seeing in dim light. Ageing people need more time to adapt to dim light and dark than young ones. As changes also occur in posterior visual pathway, ageing persons can have reduced contrast sensitivity, problems in higher visual functions, recognizing things, finding the specific object among others etc.
Reduced vision caused either by healthy ageing or by eye diseases can lead to increased risk of falls it can foster conditions for isolation and depression and also can impact independence and quality of life [4]. Nevertheless, those risks and problems caused by reduced vision can be decreased or even avoided using non optical aids and

environment adaptations. Adaptations of visual characteristics of the environment can help ageing people to use their reduced vision and to retain their independence.

World Health Organization (WHO) recommends describing and organizing information on functioning and disability trough The International Classification of Functioning, Disability and Health (ICF) [5]. According to the ICF the functioning and disability of an individual occurs in a context, environment [5]. Therefore visual impairment should not only be defined by visual functions (visual acuity and visual field) but also by person’s ability to use vision in real life situations (functional vision). So, besides the legal definition of low vision defined by visual acuity under the 0.4, we use functional definition of low vision, where low vision is described as uncorrectable vision loss that interferes with daily activities. It is better to define low vision in terms of function, rather than vision acuity test results [6].

Therefore, in order to help ageing people retaining and/or regaining their independence in daily activities through the adaptation of visual characteristics of the environment, visual functions and functional vision in ageing person have to be assessed [5]. It is important to gather information about visual acuity which is important for recognizing small objects, than about contrast sensitivity which is important for seeing shadows and low contrast objects and faces, also about visual field defects which can influence orientation and mobility, about amplitude of accommodation which is important for seeing clearly at different distances and about dark adaptation which is important for seeing in dim light.

Besides that it is important to assess functional vision [5]. It has to be assessed how the person is using vision in different activities and situations, such as: orientation and mobility, meaning, how the person is using vision during transfer from one place to another; communication and interaction where should be assessed how the person is using vision wile communicating with others, how does person reacts at different facial expressions etc.; sustained near vision tasks where should be assessed how the person is using vision in activities such as reading, doing handcraft etc.; and daily living skills and the effect of reduced vision on independence in activities of cooking, cleaning, self-care activities etc.

The environmental visual characteristics affecting using vision also have to be assessed in order to make a plan for the adaptations. Therefore the lighting has to be considered, as ageing people have troubles seeing in dim light. Also the colors of the walls and the furniture have to be assessed as color can give more contrast and better lighting conditions in environment. Organization of furniture and objects used in activities has to be assessed in order to improve functioning [7].

Such environmental adaptations will not only improve visual functioning in persons with visual impairment, but also help them to function independently in activities. Nevertheless, some of the accessibility problems faced by people with visual impairments are also faced by people in general [8].

Since ageing persons may have problems in visual functioning, we carried out the project with the aim to design and to recommend adaptations of visual characteristics in the environment of the nursing home in order to improve functioning of the residents. Therefore we had to assess visual functioning in ageing people living in nursing home and to assess visual characteristics of the environment.

2. METHODOLOGY

During the project "Increasing the quality of visual functioning in ageing persons", implemented by Mali dom Zagreb, City of Zagreb and Nursing home Trešnjevka Zagreb, we assessed visual functions and functional vision in 30 ageing persons living in Nursing home. Within the Nursing home live around 200 residents. Every day residents have meals in a dining room, they have organized activities of handcraft, reading books and literary evenings, they meet at the hall for some leisure time over having coffee and playing cards or board games, and they visit relatives or take a walk around the City.

Residents who participated in our study were over 50 years of age, with the mean age of 76.1 years (SD=11.8) and the oldest one was 97 years of age. Most of them were females (62.9%). All participants were referred to functional vision assessment by nurses from the Nursing home because they had some problems in visual functioning. Most common reported eye problems were cataract (25.7%), glaucoma (20%), diabetic retinopathy (14.3%), high myopia (8.6%), age-related macular degeneration (5.7%) and optic nerve atrophy caused by insult or trauma (5.8%). Seven participants (20%) had no medical documentation, but they had problems in visual functioning, so they were referred to assessment.

Most of participants had visual problems over ten years. Almost all of them (90%) had corrective glasses, but some of them (28.9%) were not using them, because they did not benefit from them. Only two of participants had optical aid prescribed by ophthalmologist, telescopic glasses. Some of them (34.8%) had optical aids they purchased themselves, mostly hand held magnifiers.

Before assessments of visual functioning all participants have self-evaluated the effect of visual impairment in different activities. They were asked about activities they participate in, how is their visual functioning affecting their independence in activity. They were also asked about activities they could not participate in because of visual problems. After the changes have been made to environment and some optical and non-optical vision aid was introduced in use, we asked participants the same questions.

Visual functioning was assessed in the Nursing home, in rooms of participants. This way we could assess not only visual functions and functional vision, but also the environmental factors affecting visual functioning. We assessed main visual functions: visual acuity using near and distance vision test (Lea Numbers); contrast sensitivity using the LEA Numbers LOW Contrast Test 10M [9]; and peripheral visual field using the traditional confrontation test [10]. We also assessed functional vision in sustained near vision tasks, such as reading, where we assessed the fluency of reading black print, the distance of the text, head and body posture, but also lighting conditions, placement of the light and the window in relation to working area, size of the print, strategies for easier reading if participant used any. We assessed functional vision in orientation and mobility through familiar place by observation of walking through corridors and recognizing objects and people's faces at different distances and places. During this, we also observed environmental factors such as the lightening conditions in common walking areas, contrasts and colors of walls and the furniture, organization of the furniture, again the placement of the light and the window in relation to walking direction.

2.1. Statistical analysis

Descriptive statistics available in the programs STATISTICA 6.1 for Windows and Microsoft Office Excel 2007 was used for the analysis of visual functions and functional vision results. In order to evaluate the difference in activity participation based on self-evaluation, we used Wilcoxon Signed Rank Test. Confidence interval was 95%, and the level of significance was 0.05.

3. RESULTS

According to self-evaluation of visual impairment effect on activities 94.3% participants reported that they gave up participation in the sustained near vision activities, such as reading books and newspapers, handcraft and solving crossword puzzles, watching television etc. Problems in visual functioning caused problems in orientation and mobility in 33% of participants, which made them mostly stay in the room. As a consequence, a great number of participants (50.5%) reported that they are not satisfied with their vision and feel that their problems in visual functioning cause problems in activity participation and reduces their quality of life.
Tested distance and near visual acuity on a better seeing eye with the best possible correction is below the levels of normal vision in half of participants (Table 1). The difference between results of distance and near visual acuity in some participants implied that some of them did not have good correction in their glasses, they were mostly under corrected, and hence they were referred to ophthalmologist for a new correction glasses prescription.

Table 1. Distance and near visual acuity results

Level of visual impairment	Range of visual acuity results	% of participants	
		Distance visual acuity	Near visual acuity
Normal vision	1.0 – 0.8	3.2	3.2
Near normal vision	0.8 – 0.4	51.6	32.3
Moderate low vision	0.4 – 0.2	25.8	35.5
Severe low vision	0.2 – 0.05	12.9	22.6
Blindness	0.05 and less	6.4	6.4

Interestingly, most of participants had good results in contrast sensitivity test (Figure 1). Only 13.8% had problems in recognizing symbols in very low contrast.

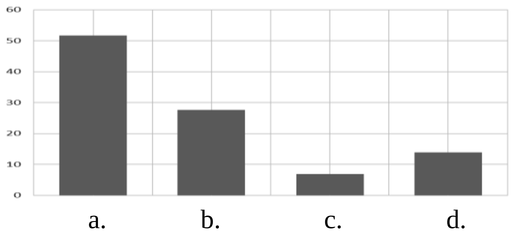
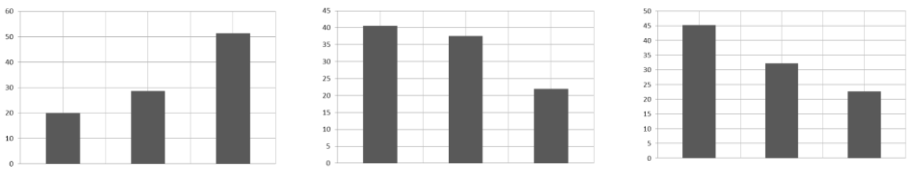


Figure 1. Contrast sensitivity (CS) results: a. normal CS results; b. near normal CS result; c. moderate loss of CS; d. severe loss of CS

Although 20% of participants had diagnosed glaucoma, we found visual field defects in only few of them, using the traditional confrontation test.
Most of participants had problems in sustained near vision activities. Although most of them reported giving up reading, during functional vision assessment they all could read, but most of them (63.7%) had insufficient reading speed. They read only large black print even with use of magnifiers. In some of them, the position of the head and the body was not suitable while reading, which was leading to fatigue very quickly.
During reading we assessed the environmental factors affecting using vision in sustained near vision tasks. In most of the participants (94.3%) rooms were in dark colors with dark furniture and low light. They had roofed balconies in front of the windows which hindered the lights entering the room. Some of participants (51.6%) even had large plants in front of the window. Introducing some additional light helped to most of participants (35.5%) to gain better reading speed and better head and body posture, although needed size of the print was not decreased with additional light, only with use of magnifiers.
Most of participants orientated through the corridors of the Nursing home with no problems, as they knew all the pathways and furniture positions by hard. Nevertheless, as shown in Figure 2, where the first columns presents % of participants who had no problems in functioning, the second one presents the % of participants who sometimes experienced problems in functioning, and the third one presents % of participants who had problems functioning in all the situations, participants had problems in recognizing familiar faces in halls (80%), problems in estimating distance (59.4%), and noticing objects while walking (54.8%).



a b c.

Figure 2. Problems in orientation and mobility caused by problems in visual functioning: a. Recognizing faces b. Estimation of the distance based on visual cues; c. Visual noticing of the objects while walking.

The corridors in the Nursing home are painted in dark colors, with very dim artificial light, and with big windows at the end of the long corridor. The floors of the corridors were covered with rather shiny surface which produced a lot of glare in places close to the window, and the glare caused discomfort in 87.1% of participants.
After the assessments we gave recommendations for using optical and non-optical visual aids. Main recommendations were aimed at lighting conditions. We recommended importing additional lights pointed towards working surface area from above the non-dominant shoulder, in order to get the best possible lighting conditions in short period of time, with no high expenses. This helped our participants to gain better environmental conditions for sustained near vision tasks, and significantly improved ($Z=3.30$; $p=0.001$) their abilities in such activities.
We also recommended changing the color of the walls and the furniture, overall lighting in the Nursing home, and getting lusterless floor surface in order to avoid glare

discomfort. Nevertheless, it was not done during that time because of high expenses. However, we gave recommendations to participants how to improve their visual functioning in orientation using other adaptations and strategies, such as position of the person in relation to the light, visual clues to help recognizing person they have to meet etc. Although those recommendations helped participants in some situations, they did not have significantly improved (Z=1.43; p=0.152) in orientation and mobility.

4. DISCUSSION

According to results of assessments and self-evaluations, residents of Nursing home have great difficulties in vision dependent activities, especially in sustained near vision tasks. Given recommendations, which could be implemented in a short time, have significantly improved participation of residents in different activities.

Kosnik revealed five dimensions that declined with increasing age: near vision, visual processing speed, light sensitivity, dynamic vision, and visual search [11]. Most of participants from our study gave up reading and other sustained near vision tasks (solving crossword puzzles, making handcraft) because of problems in visual functioning. Visual acuity is a major component for sustained near vision tasks, together with ability to accommodate to near distance and to converge eyes. Gittings and Fozard reported that older persons with no specific visual pathologies exhibited an age-related decline in acuity as did those with documented visual pathologies, so as most of participants from out study [12]. Nevertheless, adaptations in the environment can increase person's ability to participate in sustained near vision task. Even minor changes can improve reading ability. Using large print or regular print with hand held magnifier with magnification power of one to two times can make reading easier. Also, because of decreased ability of lens to transmit light [13] and reduced melanin in retina [3], ageing persons need more light in sustained near vision tasks. Therefore our participants had benefit from additional light. Nevertheless, when importing some additional light we have to take in concern the possibility of glare discomfort, even disability glare. According to our results, many ageing persons have problems with glare, making them discomfort in activities, or even disabling them in some visual activities. Most problems with glare were having our participants with cataracts, as cataract itself causes glare disability.

As we assessed orientation and mobility in familiar places, most of participants had no problems walking through corridors, because they know them by hard. Nevertheless they had problems in recognizing faces of approaching persons in halls and corridors. Reduced contrast sensitivity, found in some of our participants could cause problems in recognizing faces. Although optical characteristics (which include reduced retinal illuminance, increased intraocular light scatter, and increased aberrations of the ageing eye) reduce spatial contrast sensitivity [14] not many of our participants had decreased contrast sensitivity. It may be because we used screening test for low contrast sensitivity with large (10M) optotypes, and assessed contrast sensitivity in low special frequencies. Yet the efficiency of contrast sensitivity detection mechanisms is affected with aging at high, but not at low spatial frequencies [15]. Still, problems in recognizing faces in some situations were not caused by reduced contrast sensitivity but by inadequate lighting conditions. In some situations the light was coming from the end of the corridor and from behind of approaching person and the rest of the corridor or hall was dark. In order to gain good visual functioning, overall lighting conditions should be changed, more artificial light should be imported from the ceiling, walls and furniture should be

painted in bright colors (white or beige), but colors that produce glare (shiny colors) should be avoided.
Participants also had problems in noticing objects while walking. According to Kosnik, ageing persons have problems in visual processing speed and dynamic vision [11]. Therefore they experience problems in processing visual information in motion, especially if the information is not clear enough. Sometimes person has to stop walking, look around to see objects and persons around, and then continue walking. Besides the well-organized environment for comfortable visual functioning, ageing person can benefit from this kind of strategies while walking. These strategies can help avoiding falls and accidents. Therefore, even though we did not get the significant improvement in visual functioning during orientation and mobility, most of participants reported that they were significantly more independent and satisfied with their participation in vision dependent activities ($Z=2.99$; $p=0.003$) after applying suggested adaptations and following given recommendations.

5. CONCLUSION

Deterioration of visual functions during ageing can lead to problems in everyday functioning, increased risk of falls and accidents, dependence on others in activities, isolation and depression and reduced quality of life. Adapting visual characteristics of the environment to visual needs of a person can improve visual functioning and therefore increase independence and participation in activities, which will lead to preserving good quality of life in ageing persons. Considering individual differences in visual functioning and needs for adaptations but also the expenses of environmental adaptations, the assessment of person's visual functioning should always be done before giving recommendations and adapting environment.

REFERENCES

[1] World Health Organization: Visual impairment and blindness Fact Sheet N°282 Available from http://www.who.int/mediacentre/factsheets/fs282/en/ Accessed: 2014-08-12.
[2] Haegerstrom-Portnoy, G.; Schneck, ME.; Lott, LA.; Hewlett, SA. & Brabyn, JA.: Longitudinal Increase in Anisometropia in Older Adults, Optometry and Vision Science, Vol. 91 (2014) No. 1, pp. 60-67, doi:1040-5488/14/9101-0060/0
[3] Ivanišević, M.; Galetović, D.; Bućan, K.; Batistić, D. & Ivanišević, P.: Mrežnica oka i starenje. Med Jad Vol.43 (2013) No. 1-2, pp. 47-50, ISSN 1848-817X
[4] Lord, SR. & Dayhew, J.: Visual Risk Factors for Falls in Older People, Journal of the American Geriatrics Society Vol. 49 (2001) No. 5, pp 508–515, doi: 10.1046/j.1532-5415.2001.49107.x
[5] World Health Organization: The International Classification of Functioning, Disability and Health (ICF), Available from http://www.who.int/classifications/icf/en/ Accessed: 2001-04-16.
[6] Massof, RW. & Lidoff, L.: Issues in Low Vision Rehabilitation: Service Delivery, Policy, and Funding, American Foundation for the Blind; ISBN 978-0891283096, USA, (1999).

[7] D'Andrea, FM. & Farrenkopf, C. Looking to Learn: Promoting Literacy for Students with Low Vision (Paperback), American Foundation for the Blind Press ISBN 978-0-89128-346-1, USA, (2000)

[8] dos Santos, LN. & de Carvalho, RJM.: Ergonomics and accessibility for people with visual impairment in hotels, Work, Vol. 41 (2012) No.1, pp. 1417-1424, doi:10.3233/WOR-2012-0332-1417

[9] Hyvärinen, L. LEA Symbols and LEA Numbers LOW Contrast Test 10M, Available from: http://www.lea-test.fi/index.html?start=en/vistests/instruct/ instruct.html, Accessed: 2015-4-1.

[10] Elliott, DB.; North, I. & Flanagan, J.: Confrontation visual field tests. Ophthalmic and Physiological Optics, Vol. 17 (1997) No. 2, pp. S17–S24, doi:10.1016/S0275-5408(97)00045-8

[11] Kosnik, W.; Vinslow, L.; Kline, D.; Rasinski, K. & Sekuler, R.: Visual changes in daily life throughout adulthood, Journal of Gerontology, Vol. 43 (1988) pp. 63-70, doi: 10.1093/geronj/43.3.P63

[12] Gittings, NS. & Fozard, JL.: Age related changes in visual acuity, Exp Gerontol. Vol. 21 (1986) No.4-5, pp. 423-33, doi:10.1016/0531-5565(86)90047-1

[13] Weale, RA.: Age and the transmittance of the human crystalline lens, Jounal of Physiology, Vol. 395 (1988), pp. 577-587, doi:10.1113/jphysiol.1988.sp016935

[14] Fozard, JL.: Vision and Hearing in Aging, In: Handbook of the Psychology of Aging, 3rd Edition, Academic Press, Inc., ISBN 9781483288154, San Diego, California. (1990), pp. 150 – 170

[15] Allard, R.; Renaud, B.; Molinatti, S. & Faubert, J.: Contrast sensitivity, healthy aging and noise, Vision Research Vol. 92 (2013) pp. 47–52, doi:10.1016/j.visres.2013.09.004

ERGONOMIC ASPECT OF LCD DISPLAY PANELS IN FLIGHT TRAINING DEVICES

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Abstract

Use of liquid crystal display (LCD) in flight training devices can reduce human error during flight simulations. Projected instruments can easily be changed and modified according to pilot needs thus improving human-machine interaction as well as reducing possibility of misreading and wrongly interpreting instrument indication. Also, usage of LCD display in flight training devices allows operator to modify the flight training device for multiple aircraft types and train pilots in situations without the need of major changes in device itself. By replacing mechanical instruments with the ones projected on background LCD display, it is possible to remove parallax error that can happen during mechanical instruments readout. In using LCD display it is required to understand technical and application background before its implementation. By understanding working environment and human-machine interaction it is possible to increase pilot flight accuracy.

Keywords*:* *Human error, human-machine interaction, Flight training device, LCD display*

1. INTRODUCTION

Ergonomics, as defined by the Board of Certification for Professional Ergonomists (BCPE), is a body of knowledge about human abilities, human limitations and human characteristics that are relevant to design. Ergonomic design is the application of this body of knowledge in conceiving tools, machines, systems, tasks, jobs, and environments for safe, comfortable and effective human use [1]. By improving human-machine interaction (hardware ergonomics) it is possible to reduce number of errors made because of misinterpretation in a flight training device, thus reducing stress and increase learning efficiency. The first step is to analyze the ergonomic aspects of LCD display panels in a flight training device.
Flight Training Device (commonly known as Flight Simulator) has a major role in pilot training process because it allows pilots to train difficult procedures that are either dangerous or too complex to be done on actual aircraft. First flight simulators were created in 1920s. According to Koonec and Brambel [2], they were essentially tethered airplanes without the engines. As technology developed, flight simulators started to get more advanced. First full motion simulators were developed before World War II. After the war, flight simulators were commercially used, but only by major training organizations because of its high price. With a rapid development of computer technology, the prices of flight simulators dropped significantly and, currently, most

approved training organizations have at least fixed-base flight training device (Flight and Navigation Procedures Trainer - FNPT).

2. FLIGHT TRAINING DEVICES

Today most common aviation training devices used for initial training are Personal computer based aviation training devices and Flight and Navigation Procedures Trainers.

2.1. Personal computer based aviation training devices

Personal computer based aviation training devices (PCATDs), as defined by Reweti [3], are flight simulation devices that are based on desktop computer technology. Besides a personal computer (PC), the main components of PCATDs are software, flight controls and instrument display. The software, such as Flight Simulator or X-Plane, along with fast development of personal computer technology is most worthy for such rapid progress on PCATDs. Even though PCATD is fixed-base and doesn't have as good performance as traditional flight training devices, it still meets required fidelity to be certificated as approved flight training device to specific experience level. Advantage of PCATD over traditional flight training device is that it doesn't require switches for multiple mechanical instruments and its production and maintenance costs are considerably smaller. An example of PCATD is shown in Figure 1.

Figure 1. Example of PCATD [4]

2.2. Flight and Navigation Procedures Trainers

According to EASA [5] Flight and navigation procedures trainer (FNPT) means a training device which represents the flight deck/cockpit environment including the assemblage of equipment and computer programs necessary to represent an aircraft or class of airplane in flight operations to the extent that the systems appear to function as in the aircraft. It is in compliance with the minimum standards for a specific FNPT level of qualification. FNPT is fixed base system that is essentially designed to cross the gap in design complexity between the traditional subjectively created device and the objectively based full flight simulator. It is most commonly used flight simulation device in approved training organizations that educate student pilots. Figure 2. shows an example of FNPT.

Figure 2. Example of FNPT [6]

3. THE INDICATORS AND ERGONOMICS

First airplane indicators were mechanical devices that indicated aircraft parameters and attitude. Accordingly, the first flight simulating devices had mechanical instruments as well. Since approved training organizations that educate student pilots commonly use light aircraft equipped with mostly mechanical instruments, their flight training devices should also have similar instruments. Mechanical instruments for flight training devices are usually more complex than aircraft instruments because they need to convert PC-based electrical information to mechanical dial movements. Moreover, they are commonly customized, which makes them expensive both in purchasing and maintenance. Most contemporary flight training devices have replaced mechanical instruments with Flat Panel Displays (while LCDs – Liquid Crystal Displays being the most common ones) that project desired instrument panel layout.
The advantage of LCD displays over mechanical instruments is the versatility: they can project different instruments and different instrument layouts. That allows pilots to train for multiple aircraft types on a single flight training device.
Another advantage is the lack of parallax error, which causes instrument misreading in off-axis view. In mechanical indicators dial is not at the same plane as the scale due to mechanical constraints, so pilot can misread the indicated value if observing the instrument from incorrect angle of view.

3.1. LCD requirements

Jukes [7] states that the human eye has certain limits so technology needs to be adopted to those restrictions. Following limits of human eye are of the most influence to display performance: the resolution, display scan time and symbol size, shape and color.
The resolution of human eye is typically 1 minute of arc, which means that humans can make difference between two different objects that are divided by less than 1 minute of arc. For LCD display that means that it should have the resolution of around 100 pixels per centimeter if viewed from distance of 54 centimeters. Jukes [7] states that even though 100 pixels per centimeter is maximum resolution of human eye, studies have shown that in flight environments half of that resolution is sufficient.
Typical time for the human eye to fix on an object is 0.3 s. With roughly 20 instruments to scan, it would take 6 seconds just to fix once on every instrument. Therefore, every vital information regarding aircraft should be intuitive and attention-grabbing.
For a common display, an object needs to subtend at least 12 minutes of arc, while for an aircraft environment it is recommended that the object subtend at least 20 minutes of arc [7]. Information is classified by importance: the information of the highest importance will be shown with the largest font and the rest will decline follow accordingly.
The shapes and symbol colors are standardized and each system should match those standards.
Since most of indicators are made for view distance of 54 centimeters, any increase in distance from display will degrade instrument readability and it should be highly avoided.

3.2. Ergonomics

Most common types of indicators used in cockpit are quantitative indicators. As defined by Hendrick [8], quantitative displays are used to give the status of the system with precision. Quantitative displays may be either analog, such as aircraft airspeed indicator, or digital, such as Distance Measuring Equipment (DME) indicator. Quantitative analog indicators are made in two most common designs: round dial instruments and Head Down Displays (HDDs). Practically all mechanical aircraft instruments are round dial instruments. These instruments were commonly monochrome (black background with white dials and scale) and it was easy to misinterpret the readout. Newer versions of particularly essential instruments have multiple colors and vital information is easy to get.
With implementation of Flat Panel Displays in aircraft (and flight simulators), developers started combining multiple instruments on one display. The final result of that is the concept known as Glass Cockpit (shown in Figure 3) which integrates several instruments and indicators on one display. The concept simplifies aircraft operation and navigation and allows pilots to focus on the most pertinent information.

Figure 3. Example of glass cockpit [9]

4. CONCLUSION

With familiarizing with working environment and making it more user-friendly, human error can be reduced to minimum. By using LCD displays in flight simulators, human-machine interaction becomes improved and pilots are expected to make fewer instrument misreading. That could also reduce stress level enabling more focused completing of upcoming tasks. Possible future research would be real-time tests with human-in-the-loop on flight training device with various display setups.

REFERENCES

[1] ergoweb: "Ergonomic Concepts," *Available from* https://ergoweb.com/knowledge/ergonomics-101/concepts/ *Accessed:* 2016-03-14

[2] Koonce, J. M.; Bramble, W. J. J.: "Personal Computer-Based Flight Training Devices," vol. 841no. March, 2009

[3] Reweti, S.: "PC-Based Aviation Training Devices for Pilot Training in Visual Flight Rules Procedures," 2014

[4] T. A. University: "Tillman Aviation University," *Available from* http://www.romeaviation.com/simulator.php *Accesed:* 2016-03-13

[5] EASA: "Certification Specifications for Aeroplane Flight Simulation Training Devices," *Available from* https://easa.europa.eu/system/files/dfu/CS-FSTD(A) Initial Issue.pdf *Accesed:* 2016-03-13

[6] ELITE: "ELITE Products - Hardware > FNPT II MCC," *Available from* http://www.flyelite.ch/en/products/fnptmcc.php *Accesed:* 2016-03-13

[7] Jukes, M.: *Aircraft Display Systems*, 204th ed. Virginia: American Institute of Aeronautics and Astronautics, 2004

[8] Hendrick,H. W.: "Ergonomic Design Of Controls , Displays And Workspace Arrangements To Reduce Human Error," 2001.

[9] aviationknowledge: "Glass Cockpits in General Aviation - AviationKnowledge." *Available from* http://aviationknowledge.wikidot.com/aviation:glass-cockpits-in-general-aviation *Accessed:* 2016-03-14

THE SIGNIFICANCE OF ERGONOMIC APPROACH IN DESIGNING WORKING ENVIRONMENT OF AN AIR TRAFFIC CONTROLLER

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Abstract

There are a lot of ergonomic conditions that have to be satisfied in order to ensure good working conditions at air traffic controller working environment. No surprise, considering the nature of air traffic controller duties: working hours 24/7, continuous stress, multitasking, prompt adapting to new situations, all of these being some of the factors that they have to cope with constantly. Therefore, provision of required air traffic controller task performance is a matter of good ergonomics at working environment which could affect flight safety. Therefore, quality ergonomics should be a priority in designing air traffic controller working environment.

Keywords: *Ergonomics, Working Environment, Chairs, Air Traffic Controller*

1. INTRODUCTION

Air traffic controllers are mostly in a sitting position during their working hours. They are typically positioned in the middle or at the front of the chair with their hands recumbent on the console table where they interact with the system and the radar screen. Long sitting hours cause musculoskeletal discomfort and pain, particularly at the level of the neck, the shoulders and the lumbar tract. Some research shows that one hour of sitting in up-right, slumped, or forward leaning sitting posture led to increased discomfort at the neck, shoulder, upper back, low back and buttock [1]. In order to avoid such discomforts and health issues, ergonomic chairs are used on working positions of an air traffic controller which allow comfortable sitting posture while working, as well as useful muscle relaxation while on stand-by or resting in front of the screen.

An ergonomic chair of the good quality should be designed for forward and backwards sitting postures, adjustable in height and angle, as well as rotating and adjustable head rests. It should also have lumbar support, head rest and user-friendly controls. But chairs are not solely solution for better ergonomic working environment in air traffic control. To ensure better ergonomic environment in air traffic control, one must take into the consideration more than chairs. There are several other environment factors such as thermal, noise, lighting, colors, of the working environment which must be taken into the consideration to ensure good working environment ergonomics for an air traffic controller.

The aim of this paper is to see what kind of requirements need to be met in order to ensure good working environment in air traffic control and to conclude, through reviewing other research, what can be done to improve working environment of an air traffic controller.

2. ERGONOMICS IN WORKING ENVIRONMENT

In order to maintain safe, orderly and expeditious flow of air traffic, the air traffic controller must have a good working environment and system to interact with. Task performance depends on working environment specification and design. Throughout human-machine interactions, air traffic controller interrelates with system and controls the air traffic. Therefore, to meet all air traffic control requirements, air traffic controller working environment must be designed in accordance with correct ergonomics principles.
There are several characteristics in air traffic control working environment that need to be met in order to ensure appropriate working environment ergonomics. Some of them are thermal attributes, noise levels, radiation and visual appearance, the latter being a product of room size, lighting, the colors and surface textures.

2.1. Thermal environment

Thermal environment is important for keeping air traffic controllers concentrated, comfortable and for good working environment. It usually concerns temperature, humidity and air flow. Since air traffic controller work can be classified as sedentary, recommended air temperature for reasonable comfort is between 21 °C and 25 °C [2]. Air traffic control equipment usually generates a lot of heat which needs to be vented regularly in order not to become a major source of radiant heat for the air traffic controller.
Temperature is not the only factor to keep the controller comfortable. If the relative humidity is too high or too low it can cause discomfort as well. The optimal humidity is around 50 % or slightly higher [2]. Very high humidity makes the air seem stuffy and clothing becomes uncomfortable, while very low humidity can lead to throat dryness which deteriorates the speech intelligibility and endangers the safety of flight.
The last factor of thermal comfort is air flow. The air should move in a way that is not noticeable yet sufficiently refreshing the working environment. The speed of circulating air should be 10 meters per minute [2]. Devices that generate noise, like fans, should be avoided.

2.2. Noise

The main tool which air traffic controllers use in communication is speech, i. e. voice communication. If there is significant noise in their working environment it can cause decreased air traffic controller performance which could affect air traffic safety. Low ambient noise is necessary to maintain in order to transmit accurate radio telephony communication with pilots and sector coordination. Loudspeakers are not recommended and headphones are used instead. In order to reduce ambient noise, silent air conditioners are used, along with sound absorption material like carpeting. Well-isolated working environment should decrease not only ambient noise from the working environment but also the outdoor noise like aircraft taking-off and landing. It is desirable in air traffic control environment to keep the background noise level below 55 dBA, and to suppress the noise as much as possible. [2].

2.3. Visual appearance

The proportion adequacy of the building, room and working environment is the first factor of visual appearance. The benefits of the large and high ceiling rooms are impression of spaciousness where reasonably uniform lighting levels are scattered throughout the room. The lightning is not the only reason for high ceiling rooms, pleasant visual proportions and high ceilings also allow to accommodate any general wall-mounted displays. In area control centers wall-mounted displays are essential because they usually contain charts and weather data, which is essential information for the work of and air traffic controller.

2.3.1. Room layout

Room layout is also an aspect of the environment. The room needs to accommodate all the people that work in that working environment at the maximum capacity, including air traffic controllers, supervisors, on-the-job trainees, and the rest of the staff. Therefore, it needs to be spacious for smooth shift change between air traffic controllers, on-the-job training, and any on-the-job or controller assessments that might be underway without any distraction to the provision of air traffic control. There must be a back-up working position in the case something unexpectedly happens to the current working position and access to the safety equipment must be ensured at all times.
If the working environment is continuously staffed, the access to the room must be granted to the non-controller tasks such as regular maintenance, cleaning, visitors management, system checks, data gathering, upgrading the equipment and system, while the rest of the working environment is still operational. The idea is that the room layout is planned ahead and that all room activities and needs are planned in compliance with the working environment and tasks for that room, in order to avoid any impediments later on. However, if the room layout does not meet all the requirements, then the cost of upgrading and the later contentment is never the same as it was supposed to be initially. An example of room layout for area control center is shown in Figure 1.

Figure 1: Example of room layout for area control center [3]

2.3.2. Lighting

In air traffic control there are two major working environments. One is in area centers where en-route and approach controllers operate and second is in aerodrome towers where aerodrome control operates. These are two significantly different working environments regarding the lighting. In aerodrome towers, ambient lighting varies drastically, from direct sunlight over the day and to an artificial lighting over the night. Since all the displays operate 24/7, it is important to adjust display brightness either manually or automatically, ensuring the controller is able to see the information on the display. Inadequate adjustments can cause the screen being too dimmed during the day and too bright during the night. Another solutions is to reduce ambient light during the day, but not so too prevent the controller to see the situation outside the tower.
The lighting in area control centers differs in a way that it is usually in enclosed room with no or just few windows, mostly covered, so no daylight can interfere with ambient lighting. In area centers ambient light is controlled and maintained all the time. Display brightness does not need to be adjusted frequently as in the tower since there are almost no variations in ambient lighting.

2.3.3. Colors

In general, the unsaturated and pastel colors should be used on air traffic control (ATC) displays, while for important and temporary information the saturated colors are the sole choice. The latter should be used temporary because they can be visually disruptive. Some saturated colors, especially blue, can cause problems such as chromatic aberration and should not be used. To prevent confusion in air traffic controller work, chosen colors should be clearly distinguished from others and all should have clear names so there cannot be a mistake when pronouncing one. The background information on the air traffic controller displays should be made discreet and with low color ratios. The brightness contrast ratio between dynamic information and the background information should be approximately 8:1 [4].

3. ERGONOMIC CHAIRS IN ATC

The air traffic controllers usually spend their working hours in a sitting position. Although sitting requires less physical effort than standing or walking, it puts a lot of stress on lumbar area. Combined effects of a sedentary lifestyle and a job that requires sitting can lead to various health problems. Other research showed that lumbar pain is the most influential on general comfort when sitting on a chair, followed by neck and dorsal pain [5]. All these medical issues lead to inefficient work, and when it comes to air traffic control, inefficient work may cause safety risk. That is the main reason why air traffic controllers use one of the most sophisticated ergonomic chairs. As stated earlier, a quality ergonomic chair should have a variety of customizable features, as it can be seen in Figure 2. Their console profile is well defined as to what should be a good practical distance and height when sitting on a chair in front of a working air traffic control console. In order to accommodate all body sizes of the controller population, the profile must meet all the ergonomic requirements, even by making some profile surfaces adjustable if necessary, see Figure 3.

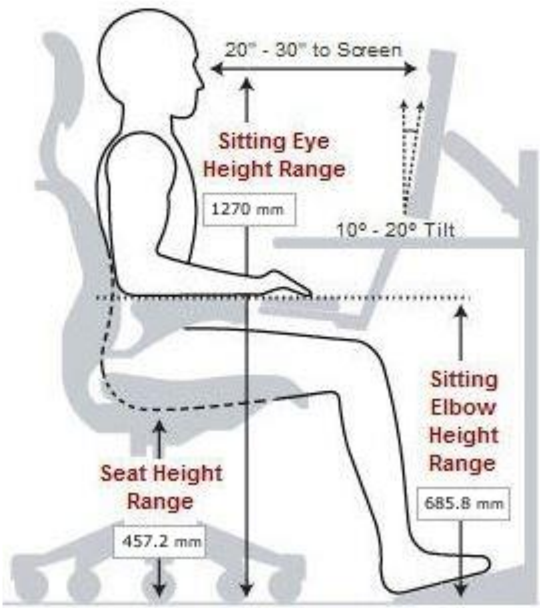

Figure 2: A preview of proper sitting posture in ergonomic chair [6]

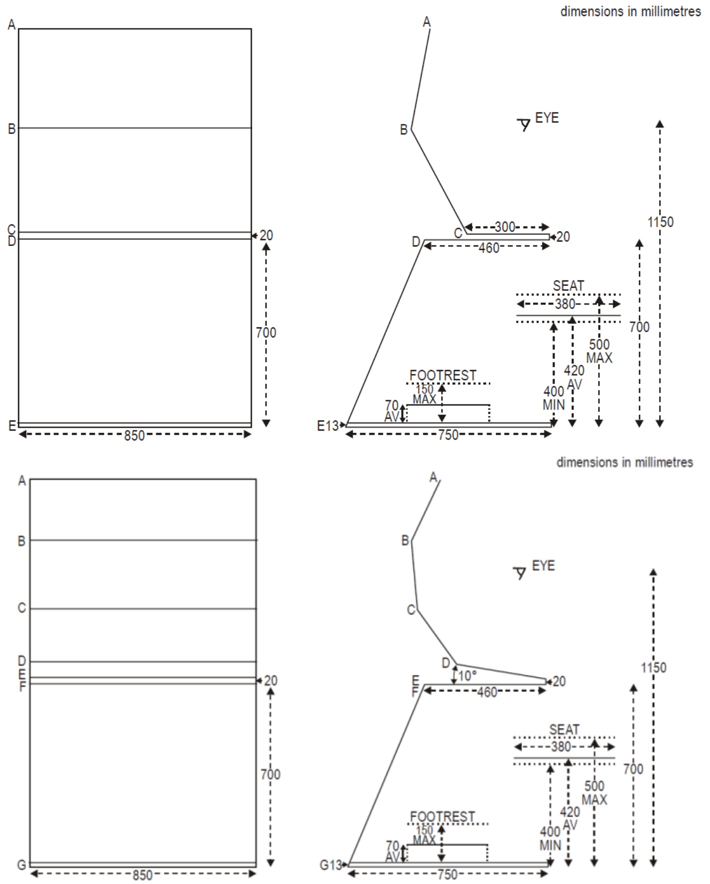

Figure 3: Side view of the outline formed by the set of surfaces presented to the controller seated at the work position and which contain the human machine interface. (Upper picture larger display, lower picture smaller display) [4]

3.1. Review of previous research

In this section a short review of a case study analysis done by authors W. Kleeman and T. Prunier [7] regarding evaluation of chairs used by air traffic controllers will be presented.

The chairs involved are task-intensive, meaning they are heavily used during three eight-hour shifts per day, seven days a week. 31.3% of the controllers spend sitting 4 hours or less during an eight-hour shift, 68.7% of them 5 to 8 hours per shift and 15% of them 7 to 8 hours per shift.

At the start of their shifts, 12.5% of them adjust their chairs, 41.2% find one that seems about right and 46.3% do neither, nor even do they adjust their chairs during the shift. Only 14.2% adjust their chairs during the shift.

The backrests are always used by 15.1% of controllers, 36.8% use them more than half the time, 30.4% use them about half the time, 17% use them less than half the time and only 0.7% never use them. Therefore, the controller's chair must have the backrest; a stool just would not do.

When enquired how they feel about their chair, 32.3% find their chairs unsatisfactory or barely satisfactory, 11.6% very satisfactory, 1.7% excellent and 54.4% find them satisfactory for a total of 67.7% favorable.

To question how do they feel while sitting in the chair, 4% are perfectly relaxed and 45.9% are very comfortable for a favorable total of 49.9%, while 39% are fairly uncomfortable, 8.5% are just plain uncomfortable, 1.9% feel acute discomfort and 0.7% feel pain for unfavorable majority of 50.1%; i. e. slightly more subjects are uncomfortable than comfortable.

There may be relationship between comfort and age. From age 15 through age 40, more people are uncomfortable than comfortable, 53.8% to 46.2%. From age 41 through age 65, more people are comfortable, 56.8% to 43.2%

Generally, the percentage of subjects who are comfortable declines as the length of time spent sitting increases. From 1 to 5 hours the percentages are on the comfortable side, 61.9% being comfortable at 1 hour; this declines to 50.5% being comfortable after 5 hours. At 6 hours the majority shifts to 51.4% uncomfortable and increases to 64.3% uncomfortable at 8 hours.

One more interesting thing to quote is that although the chairs are adjustable for back height, 53.1% of the subjects was not aware of it. This fact points up the requirement that complete user instructions of any adjustable chair must be given to the user and understood by the user.

Another case study analysis shows a theory of change model [8]. Where it shows the expectation that when an office ergonomics training program is implemented, an increase in ergonomics knowledge will motivate workers to modify working postures and behaviors (e.g., break patterns, workstation set-up). Thus ending with overall better sitting posture, satisfactory and in the end productivity. This relates to the previous paragraph where it shows that if not shown the instructions, controllers do not know how to properly operate with the chair.

4. CONCLUSION

People undertake many different positions when they sit at work. Movement while seated is healthy but few people actually adjust their chairs. The ones who sit at their work rarely sit still. Previous studies of air traffic controllers ergonomics at the working environment have shown that bad sitting posture could cause several unwanted health issues. To avoid this, a good ergonomic chair is needed. But, as it was outlined in previous chapter, not all the controllers feel comfortable with ergonomic chairs. Beside the ergonomic chairs, several other ergonomic factors need to be satisfied to ensure good working environment ergonomics.

At the end, it can be concluded that not only ergonomic chairs are mandatory on workplaces of an air traffic control but it is advisable that all controllers go through ergonomics training program. As previous researches have shown [7, 8] if not given the proper education in ergonomics, employees can not use the given equipment in the best possible way. That, at the end, can result in health issues, decreased task performance and ultimately can cause safety issues.

REFERENCES

[1] Waongenngarm, P.; Rajaratnam, B.S.; Janwantanakul, P.: Internal Oblique and Transversus Abdominis Muscle Fatigue Induced by Slumped Sitting Posture after 1 Hour of Sitting in Office Workers, *Elsevier*, *Safety and Health at Work*, ISSN: 2093-791, 2015

[2] AGARD: *Human Factors in Air Traffic Control*, North Atlantic Treaty Organization, Neuilly sur Sein, 1982

[3] Wikipedia: FAA room layout for area control center, *Available from* https://www.wikipedia.org/ *Accessed*: 2016-03-13

[4] ICAO: *Human Factors Digest No.8 Human Factors in Air Traffic Control*, ICAO, Montreal, 1993

[5] Vergara, M.; Page, A.: Relationship between comfort and back posture and mobility in sitting-posture, *Elsevier*, *Applied Ergonomics*, ISSN: 0003-6870, 2002

[6] Miller, H.: Proper sitting posture, *Available from* http://www.hermanmiller.com/ *Accessed*: 2016-03-13

[7] Kleeman, W.; Prunier, T.: Evaluation of Chairs Used by Air Traffic Controllers of the U.S. Federal Aviation Administration — Implications for Design, In *Anthropometry and Biomechanics*, Springer US, ISBN: 978-1-4684-1100-3, New York, 1982, pp. 235-239

[8] Robertson, M.; Amick III, B.C.; DeRango, K.; Rooney, T.; Bazzani, L.; Harrist, R.; Moore, A.: The effects of an office ergonomics training and chair intervention on worker knowledge, behavior and musculoskeletal risk, *Elsevier*, *Applied Ergonomics*, ISSN: 0003-6870, 2009

IMPLICATIONS OF DYNAMIC WORKING POSTURES IN GARMENTS' COMFORT

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Abstract

Most work and leisure activities imply the adoption of many dynamic postures, such as stretching the arms foreword or upwards. Some of these postures can be restricted or obstructed by the clothes people wear, as they may be too tight or too loose, limiting/obstructing the range of movements. In this paper, it will be presented a preliminary study to support the development of a prototype of a flexible garment that can be adapted to several dynamic postures. For this study, two female body basic patterns were created: one with the regular static body measurements and the other with the body measurements in a dynamic posture. These models were compared using 5 compression sensors that were used to evaluate the compression forces exerted on the participants' body. With this study, it was possible to conclude that clothes that are not designed taking in consideration the dynamic postures greatly affect the users' felling of comfort and performance.

Keywords: *dynamic postures, range of movements, comfort, clothing*

1. INTRODUCTION

The shape and size of the human body changes according to the posture adopted. Most of these modifications that occur on the body can become uncomfortable for people adopting prolonged postures, such as workers, especially when the clothes they wear are not adequate and cannot be adapted to the challenges of the tasks to be performed. As such, some of the negative issues can be attenuated when wearing appropriate clothing, preventing health issues and increasing perceived comfort.
However, some discomfort in clothing can be felt with movement or when dynamic postures are assumed. When the body moves the dimensions change, for example the increase of the length on one side of a bending joint and the decrease of the length on the other side [1]. If the clothing does not increase in dimension over a bending joint, or binds where body dimensions decrease, it will restrict movement or intensify its difficulty creating discomfort.
User-cantered design approaches, where ergonomic principles and anthropometrics are considered, should be preferred when creating new products as they aim to minimize the stress imposed to the users [2]. Tichauer [3] stated that considerable impacts on workers' productivity and occupational health and safety can be obtained with small changes to the items people interact with.

According to Cichocka et al. [4] developing a garment may be one of the most difficult problems in the field of textile engineering, and consequently, before designing a garment adapted to the human body, it is imperative to have an intimate knowledge of its morphology in order to meet the final style successfully. In the study of Imaoka and Atkinson [5], three models of representation to perform the simulation of garment design were presented (garment model, human body model and the environment model) – leading to the development of the human-clothing environment concept. In more recent years, Gupta et al. [6] defined the fundamental requirements of clothing as being the following: (i) ability to protect users from the external environment (heat, cold, wind and rain); (ii) capacity to maintain the internal microenvironment, allowing heat and moisture transport throughout the body; (iii) facility to exert minimal inhibition, allowing free range of movement and the accomplishment of desired tasks; and (iv) simplicity of use, specially regarding the donning and doffing of the garments.

Clothes are designed to fit people within a range of dimensions and general body types. However, clothing size and fit are concepts very difficult to quantify and analyse because the relationship between the human body and the clothing is complex and often ambiguous [7]. As such, the understanding of the relationship between garments and the human body implies the need to analyse many complex factors.

Ideally, clothing must have sufficient ease or enough elasticity, but not being too loose or too tight, allowing the worker to move uninhibited and to be comfortable [8]. In any of those cases, the wearer's mobility and the level of protection provided by the garment can be adversely affected [9].

A person with an active lifestyle is further at risk for fit challenges when sitting at work, driving, travelling, walking, bending, and riding a bike or a horse. The human body shape and size changes with motion, but the clothing worn is not designed to adapt to these dynamic postures [10]. Usually, what fits when people are in a static posture does not fit when they are in a dynamic posture, creating in some circumstances not just discomfort but even damage.

The purpose of this paper is to present a preliminary study that was conducted in order to develop a prototype of a flexible garment that can be adapted to several dynamic postures.

2. MATERIALS AND METHODS

Fifty participants volunteered to take part in this study, 12 of them were females and 38 were males. This sample had an average age of 36.49 ± 11.39 years old, an average height of 170.86 ± 6.93 cm and an average height of 71.30 ± 10.70 kg.

These participants worked in four different companies/institutions – one research centre, one software development company, one industrial company and one university. A formal contact was established with the companies, inviting them to participate in the study.

The participation in this study was voluntary and participants were selected by the management board of the company. When contacted, the participants were informed of the detailed procedures and requirements of the test.

After gathering all the necessary information, through questionnaires and anthropometric measurements, the development of a prototype was done in partnership with a specialized company – Weadapt – Inclusive Design and Engineering Solutions.

To create a base model that was form-fitting it was necessary to select the body measurements of a particular person, who was supposed to try on the prototypes and in whom all the tests were performed. The development of the prototypes started with the design of two base patterns for the women's upper body, using the ESMOD methodology [11].

For the first base model the measurements considered were those collected with the participant in position a static standing position (here on addressed as P1), while for the second base model, the measurements considered corresponded to a dynamic position (here on addressed as P3).

The two base models were constructed with a non-elastic woven fabric, fitting the garment as close to the skin as possible. The selected woven fabric can be characterized as a plain fabric with a composition of 43% cotton and 57% polyester.

To compare the two base models, five compression sensors were attached to the fabric with pins (Figure 1.). These sensors were physically connected to a device, which then transmitted recorded data via Bluetooth to a tablet.

The selection of the parts of the body where the sensors were placed was based on a previous test that revealed the areas more sensitive to tears when the participant moved from P1 to P3.

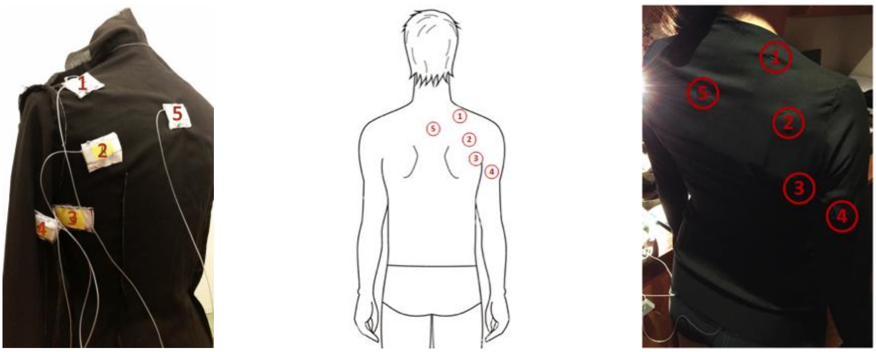

Figure 1: Compression sensors on the base models and their location on the body.

After correctly placing the sensors, the test was performed for both base model and for all the postures. In this compression forces test another posture was added, a variation of P3, identified here on as P3v. This posture was an exaggeration of P3, where the participant crossed his/her arms in the front, increasing even more the compression forces in some areas.

Most of the tasks performed by people at work only require them to lift their arms to the front. However, this additional posture was important to consider because it allowed understanding the impact of the amplification of the forces to the absolute maximum.

Figure 2. shows the postures made by the participant for this test.

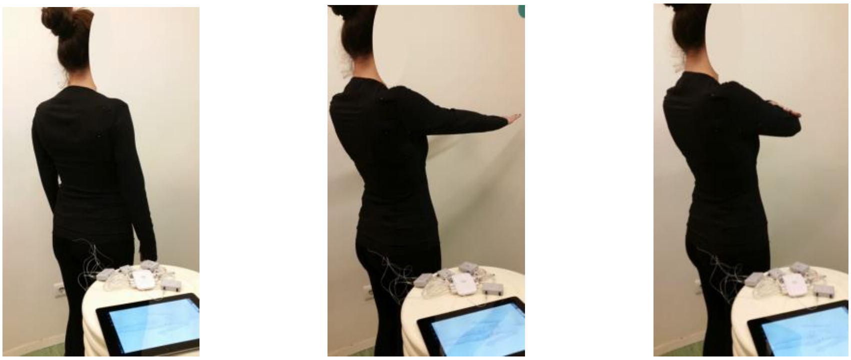

Figure 2: Participant in the several postures for Test 2 (P1, P3, P3v from left to right).

The test was developed as follows: the participant put on the first base model; the values of compression were recorded in P1, then participant switched to P3 and the values were recorded again and finally the participant switched to P3v and the values were also recorded. This process was repeated three times, totalling nine records.
The participant then donned the second base model with identically placed sensors, and took the three positions again to collect data for comparison. This process was also repeated three times, totalling nine more records.
The purpose of this test was to compare the compression forces present when a garment is designed taking in consideration only the static measurements (static base model) and those present when a garment is designed taking in consideration measurements in a dynamic position (dynamic base model).
Another goal was to quantify the percentage of increase in compression forces when people switch from a static standing posture to a more dynamic posture.
The mean of the three observations was calculated, as well as the variation that occurred between P1 and P3 and P1 and P3v in each base model and between the two base models when in the dynamic posture P3. These comparisons were analysed in terms of increase and/or decrease (in percentage) of the compression forces in the various predefined body locations

3. RESULTS AND DISCUSSION

The two base models constructed in the non-elastic woven fabric are presented in Figure 3. As can be seen, both models are skin-tight. However, in the dynamic model there is some slack in the upper back area due to the alteration in the back pattern to accommodate the P3 dimensions.
Nevertheless, to the naked eye and in the opinions of the authors, the dynamic version is not very pleasing in terms of fit and aesthetics, as in a static position there is an excess of material close to the armhole, thus the need to develop more satisfying prototypes.

Figure 3: Static and dynamic base models in fabric.

The test with the compression sensors demonstrated that there was a much higher increase in compression forces when changing from P1 to P3 and from P1 to P3v in the static model. Figure 4 shows the results of the mean of the three repetitions made in this test for each of the base models.

As expected, the compression increases very much when the arms are raised. The only exception occurred for sensor 1 that decreases, because when the arms are to the front the garment becomes looser in that upper area, reducing the contact between the fabric and skin.

Comparing P3 to P3v, it can be seen that this exaggeration in the posture has, in fact, a meaningful impact on the compression forces. The values recorded by all the sensors are higher in P3v than in P3. Still, as it happened with P3, in P3v the dynamic base model also showed better results.

When comparing the compression forces in P3 and in P3v in the two base models, it was concluded that all sensors presented a much smaller value when the participant was wearing the dynamic base model.

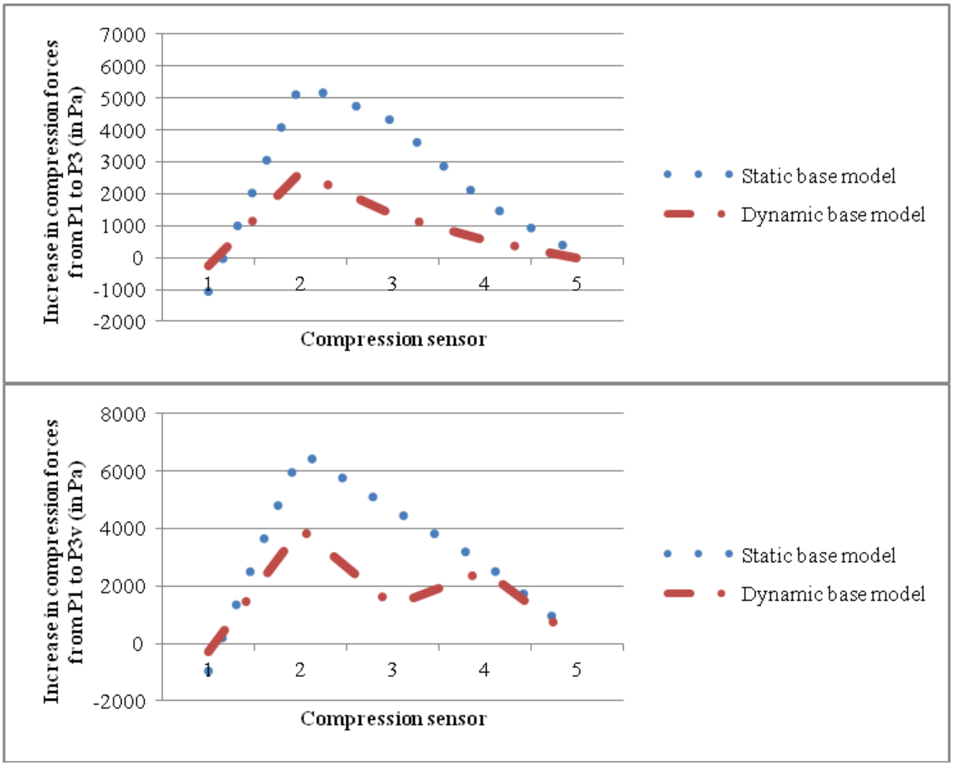

Figure 4: Mean increase of the compression forces when changing from P1 to P3 (up) and from P1 to P3v (down) for both base models.

Table 1 presents the compression forces values for each sensor in P3 and P3v. It noted that when in P3v the compression forces are higher than when in P3, for both base models and for every sensor. Figure 5 summarizes the improvements obtained for each sensor when changing from the static base model to the dynamic base model with the participant in P3. The results for P3v are very similar and as such not necessary to demonstrate.

Table 1: Values of the compression forces in each sensor (in Pa).

Sensor	Static model in P3	Dynamic model in P3	Static model in P3v	Dynamic model in P3v
1	160	23	387	53
2	5676	3070	6950	4333
3	5062	1644	5466	1680
4	2240	1240	3356	3196
5	196	156	244	249

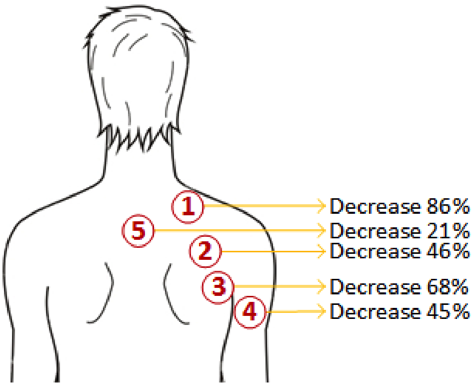

Figure 5: Improvement in terms of compression forces when in P3 from the static base model to the dynamic base model.

The static base model was so tight that the participant could barely raise their arms. Despite the fact that movement was made easier in the dynamic base model, it is important to note that this base model continues to be very form-fitting in the torso and arms. The only difference was that more space to accommodate the across back length increase was created.
Nevertheless, the results obtained show a very significant improvement from the static base model, with the minimum decrease in compression forces being 21%.

4. CONCLUSIONS

The compression forces tests clearly showed that the fact that clothes that are not designed taking in consideration the dynamic postures affect in great part the compression imposed to the user, limiting his/her movements and causing him/her discomfort.
It is understandable that fashion designers want to create models that fit the wearer perfectly. However, people's daily routines include much more dynamic postures than those performed on the catwalk. Everyday activities force people to changes postures rapidly, to sit and to stand, to put the arms in the air and so many other awkward postures. Nonetheless, with the results presented here it is possible to identify and to quantify some alterations that should be taken in consideration in the garments' design process.
Only when taking in consideration the variations that occur in the body with the several dynamic postures adopted during the day, it will be possible to create functional clothes that can adjust to people's daily activities and needs. These adjustments are fundamental to ensure the freedom of movements and users comfort, aspects that are so important when engaging in both labour and leisure activities. These characteristics, allied to a good looking and fashionable design, would surely make the people who value comfort and aesthetics much more satisfied.

ACKNOWLEDGMENTS

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REFERENCES

[1] Kirk, W., & Ibrahim, S. M. (1966). Fundamental relationship of fabric extensibility to anthropometric requirements and garment performance. Textile Research Journal, 36(1), 37–47. http://doi.org/10.1177/004051756603600105
[2] Wichansky, A. M. (2000). Usability testing in 2000 and beyond. Ergonomics, 43(7), 998–1006. http://doi.org/10.1080/001401300409170
[3] Tichauer, E. R. (1975). Occupational biomechanics: The anatomical basis of work-place design. New York University Medical Centre.
[4] Cichocka, A., Bruniaux, P., & Frydrych, I. (2014). 3D garment modelling-creation of a virtual mannequin of the human body. Fibres & Textiles in Eastern Europe.
[5] Imaoka, H., & Atkinson, J. (1996). Three models for garment simulation. International Journal of Clothing Science and Technology, 8(3), 10–21. http://doi.org/10.1108/09556229610120372
[6] Gupta, D., Gupta, D., & Zakaria, N. (2014). Anthropometry and the design and production of apparel: An overview. In Anthropometry, Apparel Sizing and Design (pp. 34–66). United Kingdom: Woodhead Publishing Ltd.
[7] Loker, S., Ashdown, S. P., & Schoenfelder, K. (2005). Size-specific analysis of body scan data to improve apparel fit. Jounral of Textile and Apparel Technology and Management, 4(3), 16–33.
[8] Dorman, L. E., & Havenith, G. (2007). Examining the impact of protective clothing on range of movement. Loughborough University, Environmental Ergonomics Research Centre.
[9] Huck, J., Maganga, O., & Kim, Y. (1997). Protective overalls: Evaluation of garment design and fit. International Journal of Clothing Science and Technology, 9(1), 45–61. http://doi.org/10.1108/09556229710157876
[10] Bragança, S., Fontes, L., Arezes, P., Edelman, E. R., & Carvalho, M. (2015). The impact of work clothing design on workers' comfort. Procedia Manufacturing, 3(1), 5889–5896. http://doi.org/10.1016/j.promfg.2015.07.898
[11] GUDI. (2007). Método de corte: Vestuário feminino. In Manual de Formação. Porto: Escola de Moda GUDI.

DESIGN AND RAPID PROTOTYPING OF ERGONOMIC PRODUCTS

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Abstract

The article presents possibilities of using 3D CAD systems and incremental methods of rapid prototyping in the production of ergonomic products. The first part of the publication describes an approach to the design process, which takes into account the ergonomic design. An analysis of the various design stages was performed - from the concept and drawing through making of a 3D CAD model to the physical prototype. The article also presents short description of incremental rapid prototyping methods that can be applied in the design and manufacture of ergonomic products. It referred possibilities of the use of various methods of rapid prototyping permitting the production of ergonomic prototypes, visual prototypes, functional prototypes or finished products.

Keywords: *design, rapid prototyping, industrial design, ergonomics*

1. INTRODUCTION

Industrial products, for which it's visuals and ergonomic side is important can be successfully subjected to a preliminary analysis of ergonomics at certain stages of the prototype production using incremental methods (Fig. 1).

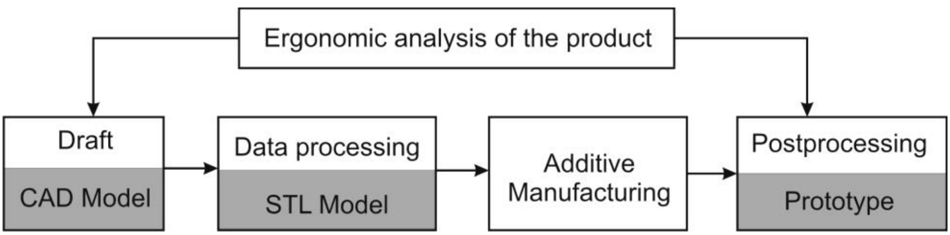

Figure 1: Schema of Rapid Prototyping process

Project analysis is performed at the beginning of the RP (Rapid Prototyping) process, a sketch of the model and model 3D-CAD could be a subject to the assessment [1]. CAD systems allows extensive analysis of visual and functional model, among others, analysis of a single object, group of objects or photorealistic visualization. In contrast, rapid prototyping method allows you to quickly produce a model for functional

analysis. In this case, the finishing of the prototype [2] is necessary. It may be the minimum processing operations to produce only a prototype body or include, for example sanding or applying surface coatings to approximate the appearance of the prototype to the target product [3, 4].
The use of CAD and AM (Additive Manufacturing) systems to the ergonomic design of the product was presented at the example of a small model of wireless screwdriver (Fig. 2).

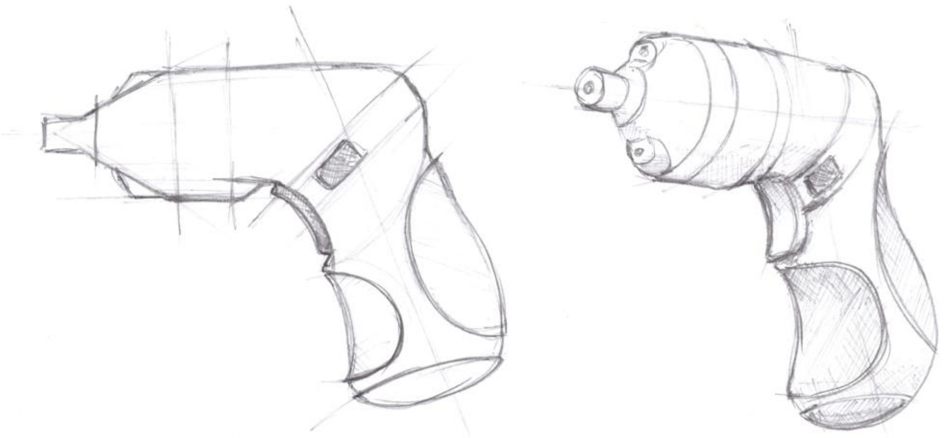

Figure 2: Draft of the small wireless screwdriver

2. 3D-CAD MODELING

The idea of ergonomic design using rapid prototyping allows a relatively quick production of physical prototypes directly from 3D-CAD model [5]. This dramatically reduces the process of analyzing the product, minimizing the manual work of modeling. Some methods also allow for incremental production of prototypes with colour texture defined in the CAD system at the design stage [6]. The use of 3D-CAD systems allows preliminary comparison of geometry in terms of ergonomics at the stage of modeling. Figure 3 shows 3D-CAD models of small screwdriver. The first model (Fig. 3a) concerns screwdrivers, which was designed only to fulfill its function - screwing. In the second case, the design takes into account the ergonomics and visual appeal of the product (Fig. 3b). As you can see the model has not lost its main function. In this model, one can distinguish improved ergonomics associated with a corresponding shaping of the handle. There can also be used here, for example linings of flexible materials of different colours with reduced slip, which increases device operator’s comfort, especially during long work [7, 8].

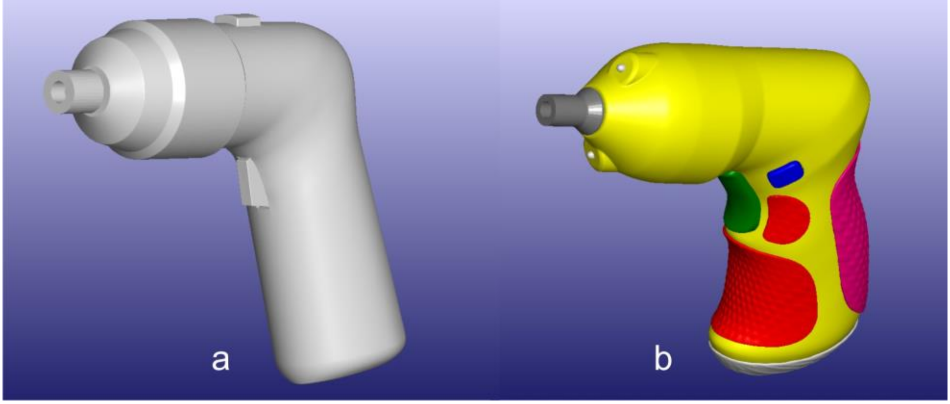

Figure 3: 3D-CAD model of screwdriver: a) functional model, b) ergonomic model

3. DATA PROCESSING

In the process of rapid prototyping important step is to prepare the data. Proper processing of the data ensures that you receive a prototype of the assumed accuracy of mapping geometry to the model 3D-CAD. In most systems of rapid prototyping incremental data exchange between the CAD program and the machine tool is done by the STL format. STL format describes the surface of the model using a grid of triangles (Fig. 4). The shape and size of triangles is responsible for the accuracy of the mapping model geometry. Programs for 3D-CAD engineering applications (CATIA, Inventor) include modules which are exporting data that allow you to accurately determine the accuracy of the model geometry STL [9]. Programs to perform visual models (3D MAX, MAYA) do not always allow to carry a precise description of the model by triangle grid, and on the maintenance of the units used in the construction of the machines (e.g. Mm). These programs, however, allow for the execution of realistic renderings.

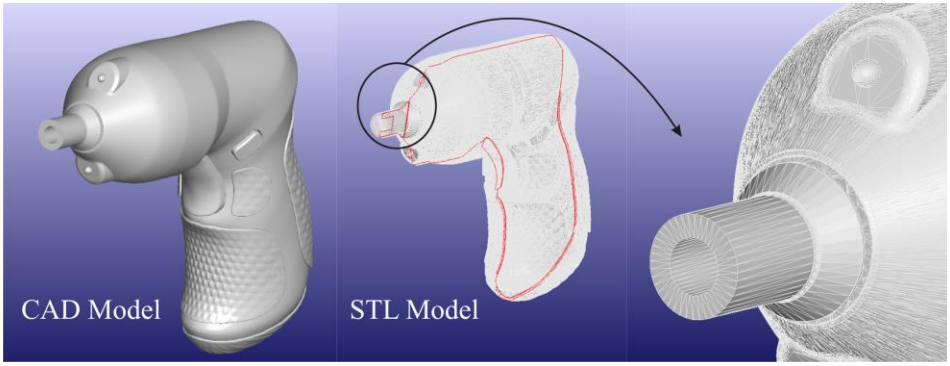

Figure 4: Export 3D-CAD model to 3D-STL model

4. PROTOTYPE MANUFACTURING

Prototypes screwdrivers were made by two methods of rapid prototyping: using MEM and PolyJet. MEM method involves laying layer of thermoplastic material displaced through the head. Stacking the material takes place after the predefined paths for each layer [3]. PolyJet method belongs to a group of 3D printing methods and involves printing the photopolymer layer, which polymerizes under the influence of UV light emitted from the lamp integrated with the print head [3]. For each of the methods for machine control program data are entered as a model STL.
Prototypes using MEM were made using a machine type UP3D, controlled by software UP! View of program space with dimensions of 130x130x130mm loaded model screwdriver is shown on Figure 5a. This program allows you to analyze the correctness of STL model and set parameters for the manufacturing process. Fixing model is formed as a shell-shaped and is therefore set in the working space in a way that minimizes the support model, while maintaining the accuracy of the manufacturing process, without the risk of deformation of the prototype.
Prototypes using PolyJet were done using the printer OBJET EDEN 260. The printer is controlled by program Objet Studio (Fig. 5b). Because the workspace printer EDEN 250 has dimensions 260x260x200mm it was possible to perform both models in a single process.

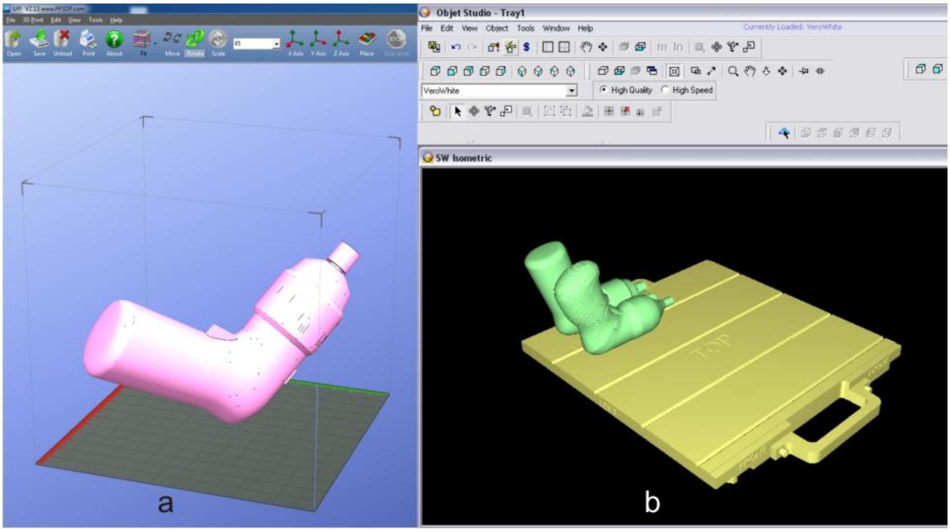

Figure 5: Distribution models in the program workspace:
a) UP! Program, b) Objet Studio program

The MAM method of making prototypes used thermoplastic material ABS in two colours, blue and black (Fig. 6).

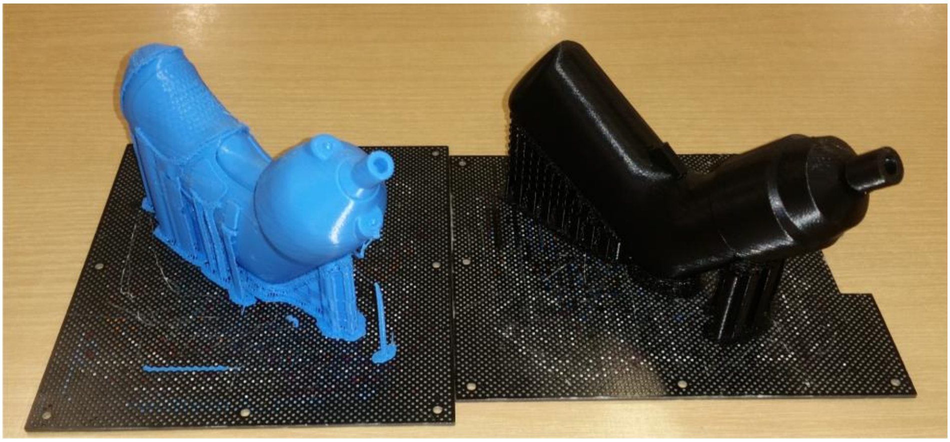

Figure 6: Models made by MEM method

The PolyJet method to execute models used photopolymer VeroWhite (Fig. 7), which allows you to make prints with high resolution.

Figure 7: Models made by PolyJet method

5. CONCLUSION

The analysis of the ergonomic product with the use of computer aided design (3D-CAD) systems and rapid prototyping to production allows to speed up the implementation work at the design stage. CAD systems have developed modules for analyzing the shape of the prototype, the collision examination and visualization of bands. Some CAD systems allow to perform photorealistic renderings and animations. This enables us to evaluate the product also in visual terms.
Physical prototype manufacturing by incremental methods gives further options of analyzing the product, that can be placed in a real environment or make it as a fully functional model with geometric features and functionality similar to the finished

product. This prototype can be perfectly suitable for the analysis of ergonomics and introduce changes in the design of the final product.

REFERENCES

[1] *Ergonomic checkpoint*, International Labour Office, International Ergonomic Association, ISBN 978-92-2-122666-6, Geneva, Switzerland 2010
[2] Liou, W.: Rapid Prototyping and engineering applications – a toolbox for prototype development, Taylor & Francis Group, ISBN 0-8493-3409-8, Boca Raton FL, USA 2008
[3] Sieminski, P.; Budzik, G.: *Incremental Techniques, 3D Printing, 3D Printer (in Polish)*, Oficyna Wydawnicza Politechniki Warszawskiej, ISBN: 978-83-7814-255-3, Warszawa, Poland 2015.
[4] Budzik, G.; Kozik, B.; Pacana, J.; Żmuda, B.: Modelling and prototyping of aeronautical planetary gear demonstrator, *Journal of KONES Powertrain and Transport*, **Vol.** 17 (2010) No 3, pp. 345-351, ISSN: 1231-4005
[5] Carayon, P.; Kianfar, S.; Li, Y.; Xie, A.; Alyousef, B.; Wooldridge, A.: A systematic review of mixed methods research on human factors and ergonomics in health care, *Applied Ergonomics*, **Vol.** 51 2015 No 12 pp. 291-321, ISSN: 0003-6870
[6] Edwards, K.; Jensen, P.L.: Design of system for productivity and well being, *Applied Ergonomics*, **Vol.** 45 2014 No 1, pp. 26-32, ISSN: 0003-6870
[7] Oleksy, M.; Budzik, G.; Heneczkowski, M.: Hybrid polymer composites for rapid prototyping of gears, *POLIMERY* **Vol.** 5 (2010), pp. 403-407, ISSN: 0032-2725
[8] Oleksy, M.; Heneczkowski, M.; Budzik, G.: Application of computer simulation of thermoset resins casting in rapid prototyping techniques, *POLIMERY* **Vol.** 11/12 (2010), pp. 895-898, ISSN: 0032-2725
[9] Rokicki, P.; Budzik, G.; Kubiak, K.; Bernaczek, J.; Dziubek, T.; Magniszewski, M.; Nowotnik, A.; Sieniawski, J.: Rapid prototyping in manufacturing of core models of aircraft engine blades. *Aircraft Engineering and Aerospace Technology: An International Journal*, **Vol.** 86 (2014) No 4, pp. 323–327, ISSN: 1748-8842

EFFECTS OF WORKING SURFACE HEIGHT ON MENTAL STRESS IN HIGH-VOLTAGE TRANSMISSION TOWER CONSTRUCTION ASSISTANTS AND MASTER WORKERS

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Abstract

High-voltage transmission tower construction is a high-risk operation. To comprehensively enhance our understanding of the psychophysiological phenomena of workers in extremely high tower constructions, we carried out a series of field experiments to test and compare three working surface heights and two role groups in terms of frequency-domain heart rate variability measurements. Twelve experienced male workers participated in this experiment. The dependent variables, namely, HR, nLF, nHF, and LF/HF ratio, were measured with the Polar RS800CX heart rate monitor. The experimental results indicated that the task workload was similar between role groups and working surface heights. Tower construction workers perceived an increased level of mental stress as working surface height increased. Moreover, the assistants experienced higher mental stress.

Keywords*:* *High-voltage transmission tower, heart rate variability, working surface height*

1. INTRODUCTION

For several decades, there have been more than ten thousand high-voltage transmission towers in Taiwan. Most of the towers need to be maintained regularly or rebuilt. High-voltage transmission towers are built in a wide variety of shapes and sizes, with a typical height ranging from 60 to 70 meters. Because most of the high-voltage transmission tower construction sites are on remote, exposed mountainsides at an elevation of about 850 meters, workers have to climb up and down the tower to lift all the steel components up and deliver them manually with a mall winch, instead of using a crane. Slopes have been shown to have a negative impact upon worker productivity [1] and workload [2, 3]. Differences in physiological responses between high-elevation and ground-level workers have also been reported [4]. Some tasks that are easy at ground level become more difficult when performed in high-elevation workplaces [5].
Additionally, high-elevation workers might encounter some difficulties in physiological adjustment when performing heavy duties or delicate tasks. The effects of extreme weather conditions, such as thermal or cold stress and strong winds, on the work performance and safety of high-rise building construction workers is greater than those of ground-level workers[6]. As the thermal stress increases, workers have a natural tendency to reduce their work pace to keep their average heart rates within a relatively narrow range [7]. However, these findings provide somewhat limited understanding of the physiological phenomena, for only heart rates have been monitored in past

experiments. Furthermore, the working heights and spaces in previous studies were quite different from those involved in high-voltage transmission tower construction.
As shown in Figure 1, while working on a high-voltage transmission tower with a typical height exceeding 60 m, workers have to stand on steel bars that are 15 cm wide to conduct the lifting, delivery, and assembly tasks manually. In previous studies of the effects of elevation on physiological measurements, the workers typically performed high-rise building construction activities upon flat and broad floors at heights up to 40 m [4, 6, 8]. To date, few studies on extremely high tower constructions have been reported.

Figure 1: The working environment and workplace of high-voltage transmission tower construction activities

Fear of heights, or acrophobia, is characterized by marked anxiety upon exposure to heights, by avoidance of heights, and by interference in functioning caused by this fear [9, 10]. The hazardous nature of tower construction work requires constant vigilance in order to prevent serious or fatal injuries. A multitude of factors need to be continually monitored and observed, with corrective action taken for sudden occurrences. If any one of these factors is misread, neglected, or incorrectly diagnosed, these workers may face serious injury or death. In the extremely elevated and rather limited standing space, workers, and novices in particular, suffer from acrophobia and the fear of falling, even when equipped with a safety harness. Previous studies have shown that novice workers experience a great increase in heart rate and have difficulty in maintaining postural stability at higher scaffold heights [11]. In the high-voltage transmission tower construction industry, workers are mainly categorized into two role groups. The master workers were mainly responsible for putting steel beams of different shapes and sizes together to construct the primary structure of a high-voltage transmission tower and further install other electrical components. The assistants supported the assembly process by lifting the materials and instruments, delivering them to the master workers, and checking the assembly status. Based on the findings mentioned above, it would be expected that one’s role should be considered as important as elevation issues at a high-voltage transmission tower construction site. So far, little research has reported differences in psychophysiological phenomena among role groups responsible for the various tasks of tower construction.
Numerous studies have demonstrated that heart rate variability (HRV) is sensitive to any change in mental or physical state, despite a minimal physical load [12-14]. Several studies have shown that physical tasks [15], mental stress in laboratory experiments[16], and both physical and mental loads [17] influence HRV indices related to the ANS. Furthermore, some recent studies have highlighted the fact that the analysis of HRV and its connection with anxiety may provide a useful field-based assessment tool [18]. For

this reason, HRV measurement was applied in the present study to assess psychophysiological phenomena.
To contribute to the understanding of the psychophysiological phenomena of workers in extremely high tower constructions, and to establish some guidelines to ensure adequate protections for them, we carried out a series of field experiments to test and compare three working surface heights and two role groups in terms of HRV. Based on these insights into high-rise building construction tasks, we hypothesized that HRV for construction workers would be susceptible to the effects of working surface height and role group.

2. METHOD

2.1. Participants

Twelve experienced male workers participated in this experiment. All participants were healthy and had no musculoskeletal disorders that could detrimentally influence their performance. The demographic information for participants was shown in Table 1

Table 1: Mean (SD) demographic information for participants

	Assistant (*n* = 6)	Master Worker (*n* = 6)
Age (years)	40.05 (10.11)	43.83 (9.60)
Experience (years)	4.83 (3.13)	10.83 (2.04)
Weight (kg)	70.50 (14.44)	71.55 (8.91)
Height (cm)	167.71 (4.03)	172.50 (5.47)
BMI (kg/m^2)	25.16 (4.59)	24.09 (3.11)

2.2. Apparatus

Heart rate variability (HRV) was measured for the entire working day, including during rest and lunch breaks, with the Polar RS800CX (Polar Electro Oy, Kempele, Finland) heart rate monitor. The RS800CX consists of a pericardial heartbeat capturing and transmitting unit in a 2.5cm wide chest band, and a receiver storage unit similar to a digital wristwatch. The electrode belt and transmitter support recording and processing of R-R intervals at a frequency of 1000 Hz and 2.4 GHz transfer between the belt and heart rate monitor.

2.3 Experimental Design

In this study, a 2×3 mixed-factor design Analysis of Variance was used with the following independent variables: role (master worker and assistant; between-subjects factor) and working surface height (15, 35, and 55 m; within-subject factors).
The participants in this study were six assistant and six master workers with experience in high-voltage transmission tower construction. None of the participants had previously experienced a fall or had musculoskeletal disorders that had restricted their activities in the preceding 12 months.
Heart rate (HR), normalized low-frequency power (nLF), normalized high-frequency power (nHF), and LF-to-HF power ratio (LF/HF) were recorded as the dependent

variables and computed after each task was completed. It is recommended that LF and HF be measured in normalized units (n.u.)[19, 20], which represent the relative value of each power component in proportion to the total power minus the VLF component. The LF-to-HF power ratio of R-R variability is considered to be an index of the balance of sympathovagal input to sinoatrial node activity and has been found to be representative of sympathetic to parasympathetic balance in both physiological and pathophysiological conditions [19, 21].

2.4 Procedure

After the installation of the heart rate monitor, participants climbed onto working surfaces set at different heights to conduct construction activities. For each task, the data were collected continuously for at least 60 min. The heart rate monitor data were transmitted to a laptop computer via a bidirectional infrared interface using the Polar software Polar Protrainer 5 after the task.

3. RESULTS

A 2 (Role group) × 3 (Working surface height) mixed-factor design ANOVA was performed on the dependent measures of HR, nLF, nHF, and LF/HF. No significant two-way interactions were found for any of the dependent variables.

3.1 Heart Rate (HR)

There were no significant differences in heart rate between the role groups ($F_{1,10} = 0.229$, $p = 0.642$) and working surface heights ($F_{2,20} = 0.392$, $p = 0.681$). Mean HRs (Standard Deviation) for the two role groups, assistants and master workers, were 102.94(14.44), and 99.94(8.21) bpm; for the three heights of 15, 35, and 55 m, they were 102.83 (10.01), 100.25 (14.26), and 101.25 (11.25) bpm.

3.2 Normalized Low-Frequency Power (nLF)

There were significant differences in normalized low-frequency power between the role groups ($F_{1,10} = 6.030$, $p = 0.034$) and working surface heights ($F_{2,20} = 9.835$, $p < 0.001$). The mean *nLF* for the master workers (M = 57.27, SD = 10.35) was significantly higher than that for the assistants (M = 45.81, SD = 11.84). Mean *nLFs* and standard deviations for the 15, 35, and 55 m working surface heights were 35.73 (12.31), 50.38 (10.38), and 45.50 (11.51) n.u., respectively. Further post hoc *Tukey HSD* test results showed that the *nLF* of the 15 m working surface height was significantly higher than those of the 35 and 55 m heights.

3.3 Normalized High-Frequency Power (nHF)

There were significant main effects of the role groups ($F_{1,10} = 432.709$, $p = 0.035$) and working surface heights ($F_{2,20} = 9.811$, $p < 0.001$) on normalized high-frequency power. The mean *nHF* for master workers (M = 53.99, SD = 11.80) was significantly lower than that for assistants (M = 42.64, SD = 10.29). Mean *nHFs* and standard deviations for the 15, 35, and 55 m working surface heights were 41.16 (12.21), 49.45 (10.35) and 54.33 (11.46) nu, respectively. Further post hoc *Tukey HSD* test results showed that the *nHF* of the 15 m working surface height was significantly lower than those of the 35 and 55 m heights.

3.4 LF-to-HF power ratio (LF/HF)

There were significant differences in LF-to-HF power ratio between the role groups ($F_{1,10}$ = 9.566, p = 0.011) and working surface heights ($F_{2,20}$ = 7.211, p = 0. 004). The mean *LF/HF* ratio for the master workers (M = 1.478, SD = 0.612) was significantly higher than that for the assistants (M = 0.944, SD = 0.464). Mean *LF/HF* ratios and standard deviations for the 15, 35, and 55 m working surface heights were 1.60 (0.664), 1.11 (0.464) and 0.93 (0.478), respectively. Further post hoc *Tukey HSD* test results showed that the *nLF* of the 15 m working surface height was significantly higher than those of the 35 and 55 m heights.

4. Discussion

4.1 Working surface height

The ANOVA results showed that as the working surface height increased, nLF and LH/HF declined and nHF increased. These findings indicate that high-voltage transmission tower construction workers perceived an increased level of stress as working surface height increased [22].
One possible reason for the stress is the sense of insecurity and uncertainty. Given the hazardous nature of tower construction work, the workers must maintain vigilance, monitoring and observing numerous factors continually and taking immediate corrective actions for unexpected occurrences. A single mistake can cause serious injury or death.
Another contributor to stress is the working environment. The HRV and HR have been shown to be closely related to thermal comfort sensations [7, 23, 24]. To minimize ultraviolet exposure, most construction workers wear long-sleeved shirts and trousers, even in hot and humid weather. However, this clothing might cause heatstroke and prostration if body heat is not properly released or if the worker perspires excessively [25]. Stronger winds at higher working surface heights also pose a threat for high-voltage transmission tower construction workers. Safety concerns arise in strong wind conditions because working off balance or dealing with the fear of falling or flying objects can cause the workers extra stress.
The third possible explanation for the stress is visual issues. The magnitude of the change in CFF values and the prevalence of subjective fatigue symptoms showed that as workers experience visual fatigue at higher elevations, their physiological condition and instinctive fear might impair their capacities for judgment [6]. Therefore, it seems that visual fatigue among high-voltage transmission tower construction workers could be a life-threatening factor, one that should not be underestimated. In addition to visual fatigue, the differences within the visual field might be another concern related to visual issues. When standing at elevated surface heights, the eye-to-horizon distance may increase. Consequently, the inability to focus on close focal visual cues may contribute to postural height vertigo and increased postural sway, both of which can elevate stress [26].

4.2 Role

Previous research has provided some justification for using the LF frequency band and the LF/HF ratio as indicators of stress, for a decrease in either of the two measures represents an increase in individual stress levels [19]. In this study, the assistant group was found to have a significantly lower nLF frequency and lower LF/HF ratio than those of the master workers. These findings indicate increased stress levels in the assistants [22]. This mental stress may have resulted from a higher fear of falling on the part of the assistants. In comparison with master workers, assistants had relatively less work experience. Min, et al. [11] reported that novice workers experienced a greater increase in their subjective difficulty at higher elevation floors. Experts may experience lower stress due to their work experience and enhanced postural stability during construction activities at higher elevation working sites [11].

4.3 Limitations

Although the present study demonstrated some positive results to support the purposes and hypotheses, the major limitation of this study is that all results were based on 12 experienced workers. As an idea for future study, the researchers are suggested to use subjective questionnaire in their studies. This would allow the workers to rate their own perceptions of anxiety/fear and these results could then be compared to the HRV results.

5. Conclusion

The current study tested the effects of role group and working surface height on the HRV of workers during high-voltage transmission tower construction activities on a remote and exposed mountainside at an elevation of about 850 meters. Based on the results of the study, the following conclusions can be drawn. First, the effects of working surface heights on HRV suggest that high-voltage transmission tower construction workers perceive an increased level of mental stress as working surface height increases due to the sense of insecurity and uncertainty, the working environment, and visual issues. Second, it is found that the role group does indeed affect the HRV during the activities of high-voltage transmission tower construction; assistants experience higher mental stress due to a greater fear of falling and insufficient experience with maintaining postural stability.

REFERENCES

[1] E. Apud and S. Valdes, "Physical workload and output for planting on grounds with different slopes," presented at the International IUFRO/NEFU/FAO Seminar on Forest Operations Under Mountainous Conditions with special attention to Ergonomics, Accessibility and Environmental Protection, Harbein, P.R. of China, 1994.

[2] P. M. Kirk and R. J. Parker, "The impact of spiked boots on the safety, workload and productivity of breaking out," *LIRO Brief Report* vol. 18, 1993.

[3] P. M. Kirk and M. J. Sullman, "Heart rate strain in cable hauler choker setters in New Zealand logging operations," *Applied Ergonomics,* vol. 32, pp. 389-398, 2001.

[4] I. Mao, M. Chen, J. Huang, C. Chen, C. Lin, and S. Cheng, "The subjective symptom of work fatigue, heart rate, blood pressure and life style of the high elevation operators," *Journal of Labor Safety and Health*, vol. 8, pp. 127-143, 2000.

[5] M. H. Steven and K. Y. Mohamed, *Environmental Physiology: Aging, Heat and Altitude*. North Holland, New York: Elsevier, 1979.

[6] D. Hsu, Y. Sun, K. Chuang, Y. Juang, and F. Chang, "Effect of elevation change on work fatigue and physiological symptoms for high-rise building construction workers," *Safety science*, vol. 46, pp. 833-843, 2008.

[7] L. A. Smith and R. B. Rummer, "Development of a heat stress prevention activity guide for use by southern forest harvesting managers," New Orleans, Final Report 19-87-065, 1988.

[8] F.-L. Chang, Y.-M. Sun, K.-H. Chuang, and D.-J. Hsu, "Work fatigue and physiological symptoms in different occupations of high-elevation construction workers," *Applied ergonomics*, vol. 40, pp. 591-596, 2009.

[9] American Psychiatric Association, "Diagnostic and statistical manual of mental disorders (DSM)," *Washington, DC: American psychiatric association*, pp. 143-7, 1994.

[10] Y. Choy, A. J. Fyer, and J. D. Lipsitz, "Treatment of specific phobia in adults," *Clinical psychology review*, vol. 27, pp. 266-286, 2007.

[11] S.-N. Min, J.-Y. Kim, and M. Parnianpour, "The effects of safety handrails and the heights of scaffolds on the subjective and objective evaluation of postural stability and cardiovascular stress in novice and expert construction workers," *Applied ergonomics*, vol. 43, pp. 574-581, 2012.

[12] A. Garde, B. Laursen, A. Jørgensen, and B. Jensen, "Effects of mental and physical demands on heart rate variability during computer work," *European journal of applied physiology*, vol. 87, pp. 456-461, 2002.

[13] N. Hjortskov, D. Rissén, A. K. Blangsted, N. Fallentin, U. Lundberg, and K. Søgaard, "The effect of mental stress on heart rate variability and blood pressure during computer work," *European journal of applied physiology*, vol. 92, pp. 84-89, 2004.

[14] X. Zhong, H. J. Hilton, G. J. Gates, S. Jelic, Y. Stern, M. N. Bartels, *et al.*, "Increased sympathetic and decreased parasympathetic cardiovascular modulation in normal humans with acute sleep deprivation," *Journal of applied physiology*, vol. 98, pp. 2024-2032, 2005.

[15] R. González-Camarena, S. Carrasco-Sosa, R. Román-Ramos, M. J. Gaitán-González, V. Medina-Bañuelos, and J. Azpiroz-Leehan, "Effect of static and dynamic exercise on heart rate and blood pressure variabilities," *Medicine & Science in Sports & Exercise*, pp. 1719-28, 2000.

[16] M. Myrtek, D. Weber, G. Brugner, and W. Muller, "Occupational stress and strain of female students: results of physiological, behavioral, and psychological monitoring," *Biol Psychol*, vol. 42, pp. 379-91, Feb 5 1996.

[17] J. Taelman, S. Vandeput, E. Vlemincx, A. Spaepen, and S. Van Huffel, "Instantaneous changes in heart rate regulation due to mental load in simulated office work," *European Journal of Applied Physiology*, vol. 111, pp. 1497-1505, 2011.

[18] E. Filaire, H. Portier, A. Massart, L. Ramat, and A. Teixeira, "Effect of lecturing to 200 students on heart rate variability and alpha-amylase activity," *European journal of applied physiology*, vol. 108, pp. 1035-1043, 2010.

[19]M. Malik, J. T. Bigger, A. J. Camm, R. E. Kleiger, A. Malliani, A. J. Moss, *et al.*, "Heart rate variability standards of measurement, physiological interpretation, and clinical use," *European heart journal,* vol. 17, pp. 354-381, 1996.
[20]A. Malliani, M. Pagani, F. Lombardi, and S. Cerutti, "Cardiovascular neural regulation explored in the frequency domain," *Circulation,* vol. 84, pp. 482-492, 1991.
[21]M. Pagani, G. Malfatto, S. Pierini, R. Casati, A. M. Masu, M. Poli, *et al.*, "Spectral analysis of heart rate variability in the assessment of autonomic diabetic neuropathy," *Journal of the autonomic nervous system,* vol. 23, pp. 143-153, 1988.
[22]A. Sonderegger and J. Sauer, "The influence of laboratory set-up in usability tests: effects on user performance, subjective ratings and physiological measures," *Ergonomics,* vol. 52, pp. 1350-1361, 2009.
[23]J. Vogt, J. Libert, V. Candas, F. Daull, and P. Mairiaux, "Heart rate and spontaneous work-rest cycles during exposure to heat," *Ergonomics,* vol. 26, pp. 1173-1185, 1983.
[24]Y. Yao, Z. Lian, W. Liu, C. Jiang, Y. Liu, and H. Lu, "Heart rate variation and electroencephalograph–the potential physiological factors for thermal comfort study," *Indoor air,* vol. 19, pp. 93-101, 2009.
[25]M. L. Chen, J. W. Huang, C. J. Chen, S. F. Cheng, and I. F. Mao, "Effect on heart rate of performing workload in hot environment.," *Journal of Occupational Safety and Health,* vol. 6, pp. 115-129, 1998.
[26]W. Bles, T. S. Kapteyn, T. Brandt, and F. Arnold, "The mechanism of physiological height vertigo: II. Posturography," *Acta oto-laryngologica,* vol. 89, pp. 534-540, 1980.

EFFECTS OF LIGHTING ENVIRONMENT ON VISUAL SENSITIVITY, COGNITION MEMORY, PERFORMANCE, FATIGUE AND COMFORT IN LITHOGRAPHY AREA

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Abstract

To clarify the possible association between lighting environment and visual performance of workers, this study was carried out in the lithography area and its adjacent area of a LED fab. Twelve workers from the lithography area and 12 from its adjacent area were recruited. Light with wavelength less than 500 nm were blocked in lithography area, and the illumination (292 lux) and correlated color temperature (2223 K) were therefore much lower. Moreover, poorer visual performance was found among workers in lithography area. The error scores of color perception test for the lithography area workers were 91.5 points, significantly higher than that of controls (p<0.0001). Workers in lithography area were prone to get visual fatigue and feel uncomfortable. It implied that the illumination in lithography area need to be increased and the workers should be alternatively rotated in order to prevent adverse effect on visual performance.

Keywords: *lithography area, lighting, visual sensitivity, visual cognition, visual fatigue and comfort*

1. INTRODUCTION

In the past decades, the semiconductor and the light emitting diode (LED) industries grew rapidly in Taiwan and the number of fab with lithography area kept increasing. Thus, workers exposed to yellow light at work in the lithography area increased as well. In the manufacture of LED, wafers are applied with photo resistor in the lithography area. Since photo resistor is sensitive to light wavelength ranging from 200 to 500 nm and using 360 nm UV light to present wiring diagram, the light wavelength less than 500 nm is blocked in this work area and only yellow fluorescent lighting applied, which might modify workers' perception of color as well as visual performance.

It has been well known that human eyes are most sensitive to wavelength of 550 nm, and the secretion of melatonin would be suppressed by the light of wavelength between 446 and 477 nm [1]. Previous study also indicated that ultraviolet B (UVB) might be associated with cataract. As to the effects of illumination, it would dominate the effects of physiological systems, and lighting with above 90-180 lux would elevate alertness and induce changing of brainwave.

Previous studies also indicated that color temperature would affect cardiovascular system, digestive system and endocrine system [2]. Color temperature of 6500 K would enhance alertness and attention, while lower color temperature might result in fatigue and negative moods and higher color temperature might shorter responding time. As to the effects of color rendering index, it has been demonstrated to affect the ability of color perception [3].

For the effect of yellow lighting, it has been reported that workers dislike yellow lighting, and yellow lighting in work area might lead to visual fatigue, visual performance such as poor word recognition [4], decreasing ability of color perception for green, blue, purple and red.

In order to assess the workers' exposure to the particular lighting at work in a wafer fab, this study was therefore carried out to characterize on-site lighting environment in both lithography area and its adjacent area, and to clarify the possible association between lighting environment and visual performance of workers.

2. TECHNICAL REQUIREMENTS

The study area was a LED fab, including the lithography area, 16.5×10.5 m^2 and lit with yellow fluorescent (>500 nm), and the adjacent area, 40.5×18.9 m^2 and lit with white fluorescent. Indoor average temperature was 23 ℃ and average humidity was 55 %.

Workers in the study area were invited to participate in this study with exclusion criteria of achromatopsia, color weakness, critical illness of eyes, such as cataract, retinal detachment, etc. Totally, there were 24 workers recruited in this study, half of them working in lithography area (exposed group), and the others working in the adjacent area (control group). The work-shifts involved day-shift, 07:30~19:30, and night-shift, 19:30 ~ 07:30, including two one-hour breaks within twelve-hour work-shift. Workers were on and off every couple of days with work-shift rotated every 5 months. This study has been approved by the Research Ethics Committee of the College of Medicine, National Taiwan University (201410046RINC).

Lighting conditions of both study areas were measured with Spectrometer (HSM-01, Rainbow Light Technology Co., LTD.), including spectrum (nm), illumination (lux), correlated color temperature (K), color rendering index, CRI (Ra) and purity (%). Each study area was measured three times per day for six consecutive days with spectrometer set on working table of 76 cm height.

For the assessment of workers' visual performance, visual sensitivity test, cognition memory performance test, fatigue and comfort assessment were applied.

(1) Visual Sensitivity Assessment:

There were two parts for visual sensitivity assessment, i.e., visual acuity and contrast sensitivity. For binocular visual acuity test, the Landolt ring eye chart was applied and each study subject standing 3 meters in front of the chart was asked to point out the direction of each open of gradually decreasing '**C**'.

For contrast sensitivity, the Mars contrast sensitivity chart was applied, with 48 mono Arabic numbers (0 ~ 9) and decreasing contrast by 0.04. Each study subject standing 0.5 meters in front of the chart was asked to read the number sequentially. Test terminate once two consecutive mistakes occurred and the corresponding contrast sensitivity was then recorded.

(2) Cognition Memory Performance Test:

Two tests were used for visual cognition memory performance assessment. The first one is the Farnsworth-Munsell 100-hue test, which is the most appropriate to examine human color cognition performance under yellow light, using No. 21-43 color caps from yellow to green with 20 sequential removable caps and 2 stationary guide caps at both ends. Study subjects were asked to rearrange the at-random color caps into sequential order. Error scores were recorded as summing up the color number difference of every two color caps not in sequential order and used as indicator for visual cognition performance in further statistical analysis. Indeed, in this test, this performance in accuracy is more important than in speed.

The second test for visual cognition memory performance assessment was visual pursuit test, using the Vienna Test System (Schuhfried GmbH Hyrtlstrasse 45 2340 Moedling, Austria). Each study subject was asked to find the end of a specified line among an array of 9 lines at his own speed and then released these lines on screen and press the line-corresponding key within a limited time. Prior to taking the formal test of 18 items, each study subject was allowed to practice for 8 items until total number of error was less than 3 items. Both the score of correct number among 18 items and viewing time were used as visual cognition memory performance for further analysis.

(3) Visual Fatigue and Comfort Assessment:

This part of assessment involved in flicker fusion test and subjective visual fatigue and comfort questionnaires. For flicker fusion test, a red flickering light with increasing frequency, starting from 25 Hz, in the flicker fusion instrument was applied and augmented until a constant light was perceived by the study subject. Prior to the formal test, each study subject was allowed to practice for 5 times. Critical fusion frequency (CFF) was defined as the median value of the 8 times of formal test.

Two types of questionnaire were applied for the visual fatigue and comfort assessment. The subjective visual fatigue questionnaire included 6 questions regarding visual fatigue symptoms after work [5]. Meanwhile, subjective visual comfort questionnaire had 14 questions regarding comfort of lighting environment while working [6]. No neutral response in both questionnaires to avoid ambiguity in classification.

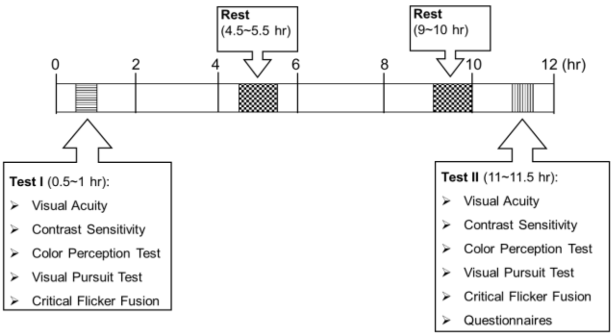

Figure 1: Flowchart of the study procedures

All the statistical analyses were performed using SAS 9.3 (Cary, North Carolina, U.S.), including Student's paired t test, Student's t test, Pearson correlation, and generalized linear model with statistical significant level set at $p<0.05$.

3. RESULTS & DISCUSSIONS

Lighting Environment

Lighting conditions between lithography area and control area were quite different, not only because the lithography area was lit with only light wavelength higher than 500 nm, but also because of the lower illumination of about 292 lux, about 40% less than the controlarea, and lower relative color temperature of around 2223 K, as compared to 3839 K of the control area.

Table 1: Characterizations of lighting environment by working area

		Avg.	SD	Medium	Min.	Max.
Lithography area (n=18)	Peak Wavelength (nm)	612	0.00	612	612	612
	Illumination (lux)	292	10.6	290	279	314
	Correlated Color Temp. (K)	2223	9.95	2225	2204	2240
	Color Rendering Index (Ra)	43.8	27.8	55.9	0.00	73.0
	Purity (%)	99.4	0.522	99.4	98.3	100
Control area (n=18)	Peak Wavelength (nm)	612	0.00	612	612	612
	Illumination (lux)	512	1.48	512	509	515
	Correlated Color Temp. (K)	3839	7.68	3841	3823	3851
	Color Rendering Index (Ra)	79.3	0.167	79.4	78.9	79.6
	Purity (%)	44.8	0.317	44.8	44.2	45.5

With respect to the assessment of visual sensitivity, 3 versions of Landolt ring eye chart were used alternatively to avoid memory effect on the assessment of binocular visual acutiy. Results indicate that average visual acuity of the controls, 1.11, was a little bit better than that of lithography area workers, 0.958, though not reaching statistical signficance. As to contrast sensitivity assessment, results show that average visual contrast sensitivity of the lithography area workers was 1.73, as compared to 1.76 of the controls, accounting for only one digit difference in the Mars contrast sensitivity chart and not reaching statistical sifnificance, either. Nevertheless, these findings might suggest the particular lighting condition in the lithography area would potentially affect the visual sensitivity of the workers in this working area. Further comprehensive field study with larger sample size is warranted to examine such an inference since the number of study subjects in the present study was limited.

As to visual cognition memory performanace, error score of the Farnsworth-Munsell 100-hue test for the lithography area workers was 91.5, substantially higher than that of workers in the control area, 26.8, indicating the deteriorated capability in color differentiation for workers under yellow lighting condition. This is corresponding with the measurements for environment lighting, i.e., color rendering index (CRI) for the lithography area 43.8 Ra only, while for the control area 79.3 Ra, making workers in the lithography area harder to tell the color purity in correct order. Boyce and Simons [7] ever reported that CIE color area and color rendering index (CRI) are superior to illuminance in the prediction of error score of the Farnsworth-Munsell 100-hue test. Besides, although illuminance was also reported as a significant factor affecting cognition memory performance, the deterioration in visual cognition for color differentiation in this case might not be affected so much by the relatively low illuminace in the lithography area since the illuminace level of 292 lux in the lithography area was still good engough for color cognition, and those workers in both study areas were relatively young and belived to perform better in color cognition as compared to relatively old people [8].

Table 2: Error scores of color perception test by working area

		Avg.	SD	Medium	Min.	Max.	p [b]	p [c]
Lithography Area (n=12)	Pre-test	92.5	12.7	96.5	67.0	109		
	Post-test	90.4	21.6	88.5	62.0	135		
	Diff.[a]	-2.08	23.3	-1.00	-47.0	35.0	0.763	
Adjacent Area (n=12)	Pre-test	22.4	10.3	19.5	7.00	45.0		<0.0001
	Post-test	31.2	15.1	30.0	9.00	59.0		<0.0001
	Diff.[a]	8.75	18.2	7.00	-16.0	44.0	0.125	0.218

[a] Diff.: score difference between pre-test and post-test.
[b] p value of Student's paired t test between scores of pre-test and post-test.
[c] p value of Student's t test between scores of lithography area and control area.

Table 3: Scores of visual pursuit test by working area

		Avg.	SD	Medium	Min.	Max.	p [b]	p [c]
Lithography Area (n=12)	Pre-test	11.9	4.44	12.5	4.00	17.0		
	Post-test	13.3	3.14	13.5	8.00	18.0		
	Diff.[a]	1.42	3.73	0.500	-2.00	10.0	0.215	
Adjacent Area (n=12)	Pre-test	13.8	2.76	13.0	9.00	17.0		0.217
	Post-test	13.7	3.75	15.0	7.00	18.0		0.816
	Diff.[a]	-0.167	2.21	0.00	-4.00	4.00	0.799	0.219

[a] Diff.: score difference between pre-test and post-test.
[b] p value of Student's paired t test between scores of pre-test and post-test.
[c] p value of Student's t test between scores of lithography area and control area workers.

On the other hand, visual pursuit test was also carried out in the lithography area and the adajacent area, respectively, to reflect the effects of actual working conditions. Results indicate that the performance of workers of the control area was better than those of the lithography area in both viewing time (60.1s vs. 63.7s) and correct score (13.8 vs. 12.6) for 18 items test. The effects resulting from sleep deprivation [9] and biological clock interference due to shift-work [10] were reported to affect the visual cognition memory performanace as well and should be paid attention to in this kind of study assessing visual cognition performance. In the present study, study subjects in both study areas were distributed equally in terms of day-and-night work-shift. Therefore, directional bias of sleep deprivation and biological clock interference on visual cognition memory perfromance was expected limited, if any.

Visual fatigue and comfort assessment involved in both objective and subjective measurements. Critical flicker fusion (CFF) test is objective measurement as sensitive tool for visual fatigue assessment and indicator of attention and information processing. Results of this study indicated that the average CFF of workers in the lithography area, 34.7 Hz, was less than that of the workers in the control area, 36.3 Hz. Since low CFF tends to be used as an indication of fatigue, the relative low average CFF observed for the workers in the lithography area was expected, though the difference did not reach statistical significance.

Subjective information on visual fatigue and comfort was collected through two types of questionnaires. Results indicated that statistically higher scores for the items of 'My eyes feel tired', 'I feel numb' and 'I feel headache' were obserevd for workers of the lithography area as compared to those of the control area. As to the lighting environment, workers of the lithography area were more likely to positively respond to the item of 'The lighting in this working area is too warm', and negatively to the items of 'I like the lighting in this working area', 'In general, the lighting in this working area is comfortable.' These findings derived from the questionnaire administration implied that workers' fatigue and discomfort while working in the lithgography area could probably be attribtuted to low illuminace and low color temperature in th lithography area.

4. CONCLUSIONS

Poor visual performance was found among workers in lithography area, especially for color perception and visual pursuit. These workers were also more likely to get visual fatigue and feel uncomfortable. Though light wavelength <500 nm is inevitably blocked in lithography area, the illumination in working environment need to be increased and the workers should be alternatively rotated in order to prevent potential adverse effects on their visual performance.

REFERENCES

[1] West, K.E.; Jablonski, M.R.; Warfield, B.; Cecil, K.S.; James, M.; Ayers, M.A.; Maida, J.; Bowen, C.; Sliney, D.H.; Rollag, M.D.; Hanifin, J.P. & Brainard, G.C.: Blue light from light-emitting diodes elicits a dose-dependent suppression of melatonin in humans, *J Appl Physiol*, **110(3)** (2011), 619-26.

[2] Su, D.Y.; Liu, C.C.; Chiang, C.M. & Wang, W.: Analysis of the long-term effect of office lighting environment on human responses. *World Academy of Science, Engineering and Technology*, **67** (2012), 332-339.

[3] Lee, D.S.; Ko, Y.H.; Shen, I. & Chao, C.Y.: Effect of light source, ambient illumination, character size and interline spacing on visual performance and visual fatigue with electronic paper displays. *Displays*, **32(1)** (2011), 1-7.

[4] Wu, H.H.: Effects of illumination color, screen text/background color combination and Chinese character complexity on character legibility and visual fatigue, [Master Thesis], *National Chiao-Tung University*, Hsin-Chu, 1998.

[5] Heuer, H.; Hollendiek, G.; Kröger, H. & Römer, T.: Rest position of the eyes and its effect on viewing distance and visual fatigue in computer display work. *Zeitschrift fur experimentelle und angewandte Psychologie*, **36(4)** (1988), 538-566.

[6] Eklund, N.H. & Boyce, P.R.: The development of a reliable, valid, and simple office lighting survey. *Journal of the Illuminating Engineering Society*, **25(2)** (1996), 25-40.

[7] Boyce, P.R. & Simons, R.H.: Hue discrimination and light sources, *Lighting Research and Technology*, **9(3)** (1977),125-140.

[8] Knoblauch, K.; Saunders, F.; Kusuda, M.; Hynes, R.; Podgor, M.; Higgins, K.E. & De Monasterio, F.M.: Age and illuminance effects in the Farnsworth-Munsell 100-hue test, *Applied Optics*, **26(8)** (1987), 1441-1448.

[9] Lo, J.C.; Groeger, J.A.; Santhi, N.; Arbon, E.L.; Lazar, A.S.; Hasan, S.; Von Schantz, M.; Archer, S.N. & Dijk, D.J.: Effects of partial and acute total sleep deprivation on performance across cognitive domains, individuals and circadian phase, *PLoS One*, **7(9)** (2012), e45987.

[10]Kyriacou, CP & Hastings, M.H.: Circadian clocks: genes, sleep, and cognition, *Trends in Cognitive Sciences*, **14(6)** (2010), 259-267.

TARGET SHAPE AND SIZE EFFECTS ON REACH TO GRASP MOVEMENT FOR OLD ADULTS

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Abstract

This study aims to realize the effects of target shape and size on reach-to-grasp movement for old adults. Ten young adults and 10 old adults were recruited to participate in this experiment. Five target shapes with five sizes were present randomly. Each subject was asked to reach and grasp the target as usual. An ultrasonic 3D motion analysis system was used to collect kinematic data. The results indicate that target shape influence the time percentage to maximum aperture and target size affect maximum aperture and the time percentage to maximum aperture for both groups ($p <.05$). For older adults, target shapes influence the wrist joint range of motion and target sizes have effect on the maximum aperture and time performance ($p <.05$).This study illustrated that target shape and size have different influence for young and old adults during reach to grasp movement and provide useful information for product and environment design.

Keywords : *Reach to grasp, target shape, size, kinematics*

1. INTRODUCTION

Aging is an inevitable process with sensorimotor degeneration and functional movement decline. Previous studies indicated that physiological changes with advanced age including reduction of muscle mass, slowing down of muscle contractions, and impairment of tactile sensitivity [1]. Varadhan's study group revealed that age effects on rotational hand action and found that elderly group performed slower reaction and lower safety margins for the thumb than young [2]. Moreover, for grasping changes in older adults while reaching for objects with varied texture, it indicated that elder adults have slower peak speed, a greater propensity to stop the hand adjusting finger position and struggled to lift wide slippery objects [3].

For reach to grasp movement, both visual and tactile cues are used to modulate the hand and arm movement during the process. To describe the act of reaching to grasp an objects involving at least three phases: arm moving from the initial place to a location near the object (transport phase), adjusting hand posture to approach the object (grasping phase), and finally actual manipulation of the object (manipulation phase) [4]. More and more kinematic features of hand were disclosed. The hand aperture which is defined as the distance between thumb and other fingers occurs maximally during the deceleration phases of the reach to grasp movement. Moreover, the maximum hand aperture occurs at approximately 70% of the total movement time and the maximum aperture increase with the target size [4].

Although previous studies revealed many factors which would influence reach to grasp movement. Each of these changes may contribute to the overall decline in hand function associated with aging. How target shape and target size affect reach to grasp movement for older adults is still unclear. Therefore, this study aims to realize the influence of target shape and size on reach-to-grasp movement for both young and old adults.

2. METHDOLOGY

2.1. Subjects

Ten young adults (averaged age 24±0.82 years) and 10 older adults (averaged age 71.8 ± 2.97 years) were recruited and were voluntary to participate in this study. All subjects claimed without neurological and musculoskeletal illness and signed an informed content.

2.2 . Experimental design

For experimental design, the dependent variables were target shape and target size. Five target shapes including round, cylinder, square, vertical rectangle and horizontal rectangle with five sizes respectively were present randomly. The detail dimensions were listed as table. 1. Each subject was asked to reach and grasp the target which is located in front of the desk with the distance of subject’s arm length. An ultrasonic three-dimensional motion analysis system (Zebris CMS 20S, Zebris Medical GmbH, Germany)(as fig. 1) was used to collect relevant kinematic data comprising the maximum aperture, time percentage to the maximum aperture, maximum velocity, time percentage to the maximum velocity, maximum acceleration, time percentage to the maximum acceleration during reach to grasp. Moreover, the joint range of motion of wrist and time performance were measured and calculated in this experiment. The dependent variables were defined as following:

(a) Maximum aperture (MA): the straight distance between thumb and index during reach to grasp movement (centimeter, mm).

(b) Time percentage to the maximum aperture (t % to MA): the time percentage while occurs the maximum aperture during reach to grasp movement.

(c) Maximum velocity (MV): the maximal velocity of wrist during reach to grasp movement (centimeter per second, cm/s).

(d) Time percentage to the maximum velocity (t % to MV): the time percentage while occurs the maximum velocity during reach to grasp movement.

(e) Maximum acceleration (MAC): the maximal acceleration of wrist during reach to grasp movement (centimeter per square second, cm/s^2).

(f) Time percentage to the maximum acceleration (t % to MAC): the time percentage while occurs the maximum acceleration during reach to grasp movement.

(g) Wrist radial deviation (WR): joint range of motion of wrist radial deviation during reach to grasp (degree).

(h) Wrist ulnar deviation (WU): joint range of motion of wrist ulnar deviation during reach to grasp (degree).

(i) Time performance (T): total time while reach to grasp movement (millisecond, ms).

Table 1: The detail size of five targets

Shape	Dimension (cm)
Round	Diameter: 5, 3, 2, 1, 0.5
Cylinder	Diameter×Height: 5×5, 3×3, 2×2, 1×1, 0.5×0.5
Square	Length×Width×Height:5×5×5, 3×3×3, 2×2×2, 1×1×1, 0.5×0.5×0.5
Vertical rectangle	Length×Width×Height:5×5×10, 3×3×6, 2×2×4, 1×1×2, 0.5×0.5×1
Horizontal rectangle	Length×Width×Height: 10×5×5, 6×3×3, 4×2×2, 2×1×1, 1×0.5×0.5

a. b. c.

Figure 1: 3D motion capture system: a. Zebris CMS 20S system, b. triangle and T-sensors, and c. single sensors

2.3 . Data analysis

For statistical analysis, two-factor analysis of variance (ANOVA) was performed to analyze the target size and target shape effects on kinematics, joint range of motion and time performance with the software of SPSS version 20. Post hoc testing with Duncan multiple range tests was then conducted. Significant level is set at $p<.05$.

3. RESULTS AND DISCUSSIONS

3.1 Taget size and shape affect reach to grasp movement

The effects of target size and shape on reach to grasp movement were summarized as table 2. There was no interaction between target size and shape ($p>.05$). Target size have statistical significant on maximum aperture and time percentage to the maximum aperture ($p <.05$). Different target shape causes significant influence on time percentage to the maximum aperture ($p <.05$).

Table 2: The ANOVA analysis for target size and shape on reach to grasp movement.

Variables	Size	Shape	Size*Shape
Maximum aperture (mm)	**.00***	.08	.79
Time percentage to the maximum aperture (t % to MA)	**.00***	**.00***	.91
Maximum velocity (mm/s)	.92	.20	.41
Time percentage to the maximum velocity (t % to MV)	.56	.33	.99
Maximum acceleration (mm/s^2)	.93	.14	1.00
Time percentage to the maximum acceleration (t % to MAC)	.89	.43	.97
Wrist radial deviation (degree)	.52	.08	.74
Wrist ulnar deviation (degree)	.90	.17	.99
Time performance (ms)	.14	.55	.86

*Significant level is set at α< .05

Table 3 revealed that Post hoc testing with Duncan multiple range tests for target size. The maximum aperture significantly increases with target size (p <.05). It is similar to the findings of Jones and Lederman (2005) that maximum aperture increase with the target size. Grasp with size 0.5 and 1 cm objects have less maximum aperture than size of 2 and 3 cm objects. Grasp with size 5 cm object displays greater maximum aperture. Moreover, time percentage to the maximum aperture (t % to MA) remarkably delay occurrence with increasing target size (p <.05). Grasp with target size of 0.5 and 1 cm show early to reach the maximum aperture than target size of 1, 2 and 3 cm. Grasp with target size of 5 cm appear the latest time percentage to reach the maximum aperture than other size in this study. Previous study indicated that maximum hand aperture occurs at approximately 70% of the total movement time (Jones and Lederman, 2005). In this study, the time percentage to maximum aperture occurs more early than previous findings and appears around at 44.7 to 50.5 % of the total time. It is possible the target location was fixed with the distance of individual's arm length.

Table 3: The Duncan multiple range tests for target size (means and standard deviation)

Variables \ Size	0.5	1	2	3	5
Maximum aperture (mm)	67.0 (17.6)	69.1 (17.3)	78.3 (16.2)	80.4 (15.8)	89.3 (16.2)
Time percentage to the maximum aperture (t % to MA)	44.7 (10.24)	46.2 (12.11)	48.3 (11.69)	49.1 (12.66)	50.5 (13.75)

Table 4 revealed that Post hoc testing with Duncan multiple range tests for target shape. Target shape remarkably affect the time percentage to the maximum aperture (t % to MA) (p <.05). Grasp with target shape of round show early to reach the maximum aperture than target shape of vertical rectangle. Grasp with target shape of horizontal rectangle appear the latest time percentage to reach the maximum aperture than others.

Table 4: The Duncan multiple range tests for target shape (means and standard deviation)

Variables \ Shape	Round	Cylinder	Square	Vertical rectangle	Horizontal rectangle
Time percentage to the maximum aperture (t % to MA)	43.5 (10.34)	45.9 (11.61)	46.8 (10.09)	49.1 (11.97)	53.2 (14.80)

3.2 Taget size and shape influence the reach to grasp movement for old adults

For older adults, target size has significant effect on the maximum aperture and time performance and target shape has significant effect on wrist joint range of motion ($p < .05$). As fig. 2, the maximum aperture significantly increases with target size ($p < .05$). Grasp with size 0.5 and 1 cm objects have less maximum aperture than size of 2 and 3 cm objects. Grasp with size 5 cm object displays greater maximum aperture.

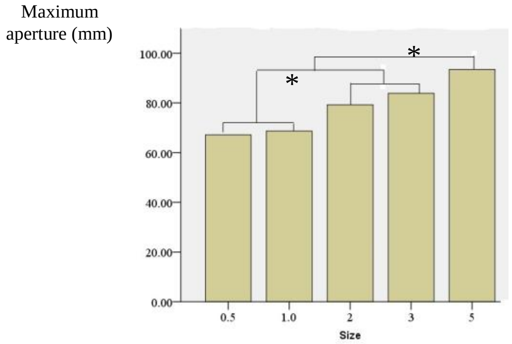

Figure 2: The target sizes influence maximum aperture

Fig. 3 demonstrates the performance time decrease with increasing target size ($p < .05$). Grasp with size 0.5 and 1 cm objects have greater performance time than size of 1, 2, 3 and 5 cm objects. It is reasonable that grasp tiny target requires longer reaction time for old adults. Furthermore, target shape affects wrist radial deviation ($p < .05$). As fig. 4, grasp square and vertical rectangle require more wrist radial deviation than other shape. It is interesting to find that target shape might influence the hand posture for reaching to grasp for old adults.

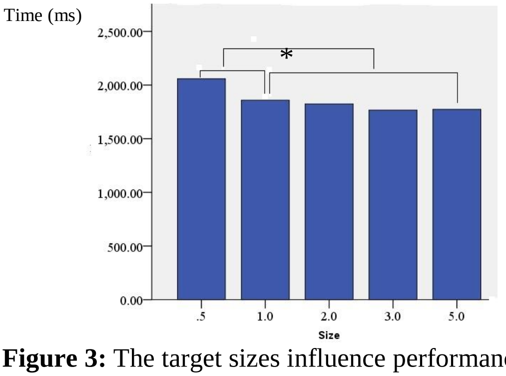

Figure 3: The target sizes influence performance time

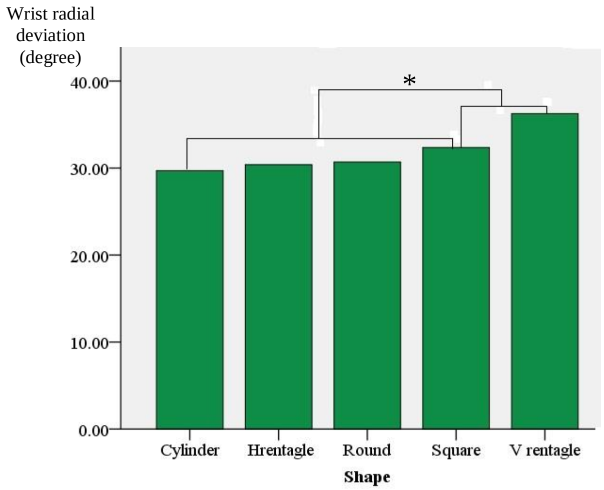

Figure 4: The target shapes influence wrist radial deviation

4. CONCLUSIONS

This study illustrated that target shape and size have different influence for old adults during reach to grasp movement In generally, target size affect significantly on maximum aperture and time percentage to the maximum aperture. Different target shape causes significantly influence on time percentage to the maximum aperture. For older adults, target size has significant effect on the maximum aperture and time performance and target shape has significant effect on wrist joint range of motion. These findings could provide useful information to understand the how aging affect the reach-to-grasp movement for old adults.

REFERENCES

[1] Shiffman, LM.: Effects of Aging on Adult hand function. *The American Journal of Occupational Therapy*, 46(1992) 9., 785-92.

[2] Varadhan, SKM.; Wei Z.; Vladimir MZ. & Mark LL.: Age effects on rotational hand action. *Human Movement Science*, 31 (2012)., 502–518.

[3] Raymond, JH.; Alexis, SL.; Ian, JF.; Pete, C.; Richard, MW.; Brian, WH.; Geoff PB. & Mark, MW.: Grasping the changes seen in older adults when reaching for objects of varied texture. *PLOS ONE*, 8 (2013) 7., 1-7. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0069040

[4] Jones LA. & Lederman SJ.: Chapter 8. Prehesion , *Human hand function,* Oxford, New York (2006).

EFFECT OF HANDLE POSITION AND HANDLE ANGLE ON BI-MANUAL LIFTING TASKS WITH IPSILATERAL HANDLES

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Abstract

This study aimed to apply psychophysical method to investigate the effects of ipsilateral handle position and angle on bi-manual lifting tasks. A completely randomized block design was applied in this study. The independent variables included subject (12 two-man teams), handle angle (0° and 30°) and handle position (left, centre and right). The subject effect was regarded as block effect. The dependent variables included decrement in strength of power grip (ΔGrip), increment in heart rate (ΔHR), rating of perceived exertion (RPE) at fingers (RPE_f), palm (RPE_p), wrist (RPE_w), arm (RPE_a), shoulder (RPE_s), low back (RPE_b), leg (RPE_l) and whole body (RPE_{wb}). The results showed that the handle angle has a significant influence on ΔGrip. The handle position significantly affected ΔHR, RPE_f and RPE_p. The interaction effect of handle angle and handle position on ΔHR was significant. The 30° handle angle induced significantly greater ΔGrip and ΔHR than those of the 0° handle angle. Handle position at left had significantly smaller ΔHR, RPE_f and RPE_p than those at centre. Based on the above findings, the best combination of handle position and angle for bi-manual materials lifting tasks using ipsilateral handles is the center of mass of load on the right hand, the handle position at left, and 0° handle angle.

Keywords: *manual material handling, bi-manual lifting tasks, ipsilateral handle, handle position, handle angle*

1. INTRODUCTION

It is well known that bi-manual or team-manual lifting tasks have quite extensive applications in manual material handling (MMH), especially for lifting heavier or bulky objects. It is common seen that each of the team members lifts a bulky object with two ipsilateral handles, which positioned on the same side of a material container. In other words, each of the team members coupled with the two handles which positioned on one of the two frontal planes of a materials container. Although the previous psychophysical or biomechanical studies in individual [1, 2, 3, 4], bi-manual [5, 6, 7, 8, 9, 10, 11] or team-manual material handling tasks have paid more attention to the lifting tasks with two bilateral handles, each of the two bilateral handles positioned on one of the two sagittal planes of a material container, no study has investigated the effect of handle angle and handle position for the ipsilateral handles on bi-manual lifting. Some of the above mentioned studies have examined a number of factors associated with handles of a container including with/without handle [7], handle angle [1], handle type and handle position [11]. It is likely that manual material handling capacity or perceived exertion was significant influenced by the factors associated with bilateral handles. However, the effects of the factors associated with handles of a container on manual material handling capacity or perceived exertion would alter for ipsilateral handles. Therefore, this study aimed to apply psychophysical method to investigate the effects of ipsilateral handle position and angle on bi-manual lifting tasks.

2. METHODOLOGY

2.1. Subjects

Twenty four healthy, right-handed, male students with no history of musculoskeletal problems were selected from the University of Huafan, Taiwan for this experiment. Every two subjects, within the limits of a 5-cm difference in stature [12], was treated as a team, which team members were fixed. Twelve two-man teams participated in this study. All of the twenty-four subjects had signed an informed consent and were compensated for their participation in this study before the experiment began. Each subject had at least one year of experience working in psychophysical study and was asked to participate in training sessions, at least one session, for familiarizing with the experimental procedure before the experimental data were collected. The subjects' mean age, height and weight was 21.42 years old (SD=1.73 years old), 171.06 cm (SD=5.77 cm), and 71.10 kg (SD=16.24 kg), respectively.

2.2. Experimental Designs

A completely randomized block design was applied in this study. Subject, handle angle (an angle between the longitudinal axis of handle and horizon) and handle position (the middle of the two ipsilateral handles on the container) were the independent variables. Each subject was considered as a block. Two different handle angles (0° and 30°) and three different handle positions (left, centre and right) were investigated. A total of 72 trails (12 teams *2 handle angles*3 handle positions) were conducted. The dependent variables included maximum acceptable weight of lift (MAWL), decrement in strength of power grip (ΔGrip), increment in heart rate (ΔHR), wrist deviations (flexion/extension, radial/ulnar deviation) and ratings of perceived exertion (RPE) at different parts of body, including finger (RPE_f), palm (RPE_p), wrist (RPE_w), arm (RPE_a), shoulder (RPE_s), low back (RPE_b), leg (RPE_l) and whole body (RPE_{wb}). The containers, applied in this study, lifting frequency, lifting duration, laboratory environment, and vertical lifting range, simulating lifting a box on the floor onto a 20-cm height pallet, were controlled. The containers were a wooden rectangular box measuring 80*100*30 cm^3 (length*width*depth) with two handhold-cutout ipsilateral handles at 15 cm height above the bottom of the box were used. The size of handle was 12*5 cm^2 (length*width). The lifting frequency and lifting duration was controlled at 6 liftings/min and one hour [13, 14], respectively. The laboratory environments were controlled at 20°-26° and 50%-70% relative humidity. The vertical lifting range was from 70-cm height, the handle height above the floor, to 90-cm height, the handle height above the floor.

2.3. Experimental Procedure

Each subject's anthropometric measurements were measured first. Upon the completion of anthropometric measurements, each subject attended at least one of training sessions for totally familiarizing with the psychophysical weight adjustment method and understanding how cooperate with the experimenter to collect another dependent variables. After training, each subject was asked to perform six trials (2 handle angles*3 handle positions) on different days. Each subject conducted one of six trials only on one day, in random order. Before a trial began, the subject's resting heart rate (HR_{rest}) was measured. Then, a 5-minute warm up was provided and the subject's strength of power grip (power-grip strength of pre-trial, $Grip_{pre}$) was measured. Upon the completion of warmup and power-grip strength measurements, the subject was asked to perform a simulated household-appliance lifting task, lifting the container from the floor to the pallet, 20 cm height above floor, at 6 listings/min. The initial load, placed under a false bottom in the container, was random, between 5 kg and 20 kg. Based on the psychophysical method, each subject was encouraged to adjust the amount of weight in the container by adding or removing uneven-weight metal blocks during the trial for approximating the MAWL. A 40-minute weight adjustment was provided to each subject for each trial to determine the MAWL for a 1-hour work period [13, 14], without straining himself or becoming unusually tired, weakened, overheated or out of breath [15].

As the MAWL was approached, each subject was asked to perform a 10-minute lifting task with MAWL. Meanwhile, the subject's working heart rate (HR_{work}) was continuously monitored by HR Monitor (Exersentry Model TM 3A). After finishing the 10-minute lifting task, the subject's power-grip strength of post-trial ($Grip_{post}$) was measured again. Then, the subject had to use the "Borg's RPE 6-20 scale" to rate the perceived exertion at finger, palm, wrist, arm, shoulder, lower back, leg and whole body [16]. Finally, the subject lifted MAWL three more times for measuring wrist deviations.

2.4. Statistical Analysis

Before statistical analysis, the ΔGrip and ΔHR had been calculated with the two following equations. In order to determine the effect of carrying frequency and hand condition, analysis of variance (ANOVA) was conducted using the SAS 9.1 software (SAS Institute, Inc., Cary, NC). Duncan's multiple range test was applied for post hoc comparison. An alpha level of 0.05 was selected as the minimum level of significance.

$$\Delta Grip = Grip_{post} - Grip_{pre} \qquad (1)$$

$$\Delta HR = HR_{work} - HR_{rest} \qquad (2)$$

3. RESULTS AND DISSCUSSION

The means and standard deviations of the dependent variables for the six experimental combinations are summarized in Table 1. The ANOVA results of the dependent variables are shown in Table 2. The subject effects on all of the dependent variables are significant, except for on ΔGrip. That is because of individual difference. The handle angle had significant influence on ΔGrip. The handle position had significant influence on ΔHR, RPE_f and RPE_p. There was only one significant interaction effect of handle angle and handle position on ΔHR (Table 2).

Table 1: Means (SD) of the dependent variables for 6 combinations of handle angle and handle position

Handle Angle	0°			30°		
Handle Position	Left	Centre	Right	Left	Centre	Right
ΔGrip	-1.57 (-3.34)	-2.21 (-2.85)	-1.57 (-3.22)	-3.33 (-1.80)	-3.57 (-4.66)	-2.93 (-3.20)
ΔHR	40.36 (5.66)	41.10 (5.51)	41.00 (3.56)	38.61 (3.97)	47.15 (6.64)	43.36 (7.73)
RPE_f	14.63 (1.51)	15.33 (1.54)	15.33 (1.07)	15.00 (1.21)	15.79 (1.16)	15.25 (1.57)
RPE_p	14.50 (1.62)	15.17 (1.91)	15.46 (1.23)	14.42 (1.61)	15.42 (1.29)	14.88 (1.52)
RPE_w	14.75 (1.23)	15.25 (1.89)	15.13 (1.00)	14.96 (1.54)	15.75 (1.66)	15.29 (1.57)
RPE_a	14.71 (1.75)	15.04 (1.53)	14.75 (1.29)	15.00 (1.46)	15.42 (1.14)	14.63 (1.30)
RPE_s	14.21 (1.78)	14.67 (1.44)	14.50 (1.30)	14.46 (1.25)	14.75 (1.20)	14.00 (1.35)
RPE_b	13.79 (1.92)	14.04 (1.16)	13.92 (1.16)	14.21 (0.99)	14.04 (1.14)	13.75 (1.42)
RPE_l	13.96 (1.47)	13.96 (1.53)	13.75 (1.10)	13.79 (1.30)	14.08 (1.06)	13.88 (1.09)
RPE_{wb}	14.29 (1.60)	14.33 (1.39)	14.25 (1.53)	14.58 (1.35)	14.46 (1.45)	14.21 (1.30)

Table 2: The ANOVA results of the dependent variables

Source	Subject	Handle (A)ngle	Handle (P)osition	A*P
DF	11	1	2	2
ΔGrip	0.0519	0.043	0.7588	0.9663
ΔHR	0.0183	0.0724	0.0108	0.0389
RPE_f	0.0010	0.0911	0.0494	0.4461
RPE_p	0.0023	0.8074	0.0193	0.4818
RPE_w	<0.0001	0.3833	0.2240	0.7739
RPE_a	<0.0001	0.5483	0.1078	0.2344
RPE_s	<0.0001	0.6250	0.0754	0.2411
RPE_b	<0.0001	0.6376	0.6464	0.4242
RPE_l	<0.0001	0.7375	0.3760	0.3173
RPE_{wb}	<0.0001	0.9288	0.9920	0.4625

3.1. Handle Angle

The handle angle had a significant effect only on ΔGrip ($p<0.05$), but not on ΔHR, RPE at different body parts. For the ΔGrip, it indicated that different handle angles resulted in significantly different level of local fatigue on hands. As Figure 1 shown, the ΔGrip for the 30° handle angle (-3.28 kg) was significantly greater than that for the 0° handle angle (-1.78 kg). This result was similar to the results of the other previous studies [17, 18] (Table 3). The ΔGrip for the 0° handle angle was about 54.3% of the 30° handle angle. The reason is because of applying ipsilateral handles. When the subjects applied ipsilateral handle to perform lifting task, their wrists were forced to extremely extend, over 45° which was classified as extreme posture by Moore and Garg [19], to couple with handles. The ipsilateral handles with the 30° handle angle induced subjects to exert greater strength against the sliding force, the component force of gravity, to grasp the handles firmly. For the ΔHR, the 30° handle angle had greater ΔHR (43.04 beats/min) than that for the 0° handle angle (40.82 beats/min). The ΔHR for the two handle angles were greater than 35 beats/min, the recommended workload for manual materials handling [20, 21]. The ΔHR for the 0° handle angle was about 94.8% of the 30° handle angle. The difference in ΔHR between the 0° and 30° handle angle was minor, but greater for the difference in ΔGrip. It seems that handle angle is a dominate factor relative to local muscle fatigue for manual materials handling tasks. Therefore, the 0° handle angle is recommended for bi-manual materials lifting tasks applying ipsilateral handles in order to lower local muscle fatigue.

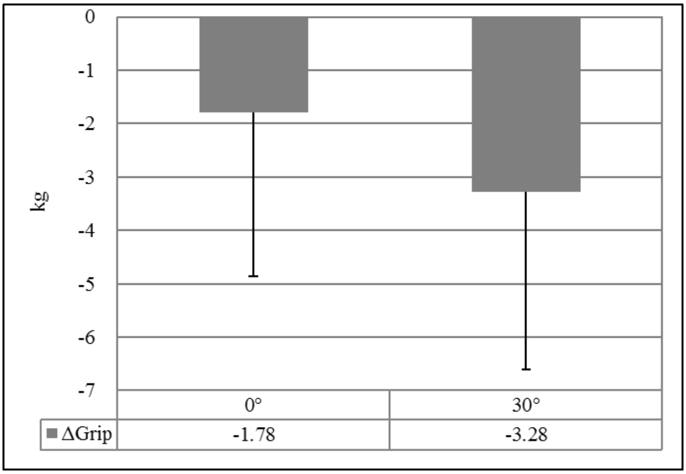

Figure 1: Effect of handle angle on ΔGrip

Table 3: Comparison of ΔGrip (kg) for present study and previous studies

	Handle Angle		
	0°	30°	60°
Present study	-1.78	-3.28	
Lin et al. (2012)	-1.77	-1.86	-2.60
Lin (2015)	-1.76	-3.01	

3.2. Handle Position

The handle position had significant influence on ΔHR, RPE_f and RPE_p ($P<0.05$), as Table 1 shown. Table 4 showed that the greatest ΔHR appeared at centre (44.12 beats/min), followed by right (42.12 beats/min); the smallest was at right (39.48 beats/min). Further Duncan’s multiple ranges test indicated that the ΔHR at centre was significantly greater than that at left; there is no significant difference in ΔHR between centre and right, and between left and right. The ΔHR for all of the three different handle positions were greater than 35 beats/min. It implied that the subjects overestimated their lifting capacity by psychophysical method. In other words, it would be risky to lift the MAWL determined by the subjects for an 8-hour shift [20, 21]. Table 4 also showed that the handle position at centre had the greatest RPE_f (16.46) and RPE_p (16.17), followed by right (16.21, 15.88); the smallest values were at left (15.54, 15.00). The perceived extion was between strong and very strong for the three different handle positions. These results indicated that applying ipsilateral handles to lift the container with MAWL from 70 cm height to 90 cm height induced similar stress on fingers and palm for the three different handle positions (i.e. left, centre, and right). That is because that subjects' hands coulped with ipsilateral handls with a palm-up posture. As above mentioned, the handle positon at left had the lowest ΔHR, RPE_f and RPE_p. That is due to the fact that the center of mass of load positioned on the dominate hand of the right-handed subjects while the handle position was at left. In addition, the handle position at centre induced not only the greatest perceived exertion at fingers and palm, but also the greatest ΔHR. It indicated that the handle position at centre was not suitable for ipsilateral handles during bi-manual materials lifting.

Table 4: The effect of handle position on ΔHR, RPE_f, and RPEp

Dependent Variables	Handle Position		
	Left	Centre	Right
ΔHR (beats/min)	39.48 (B)	44.12 (A)	42.12 (AB)
RPE_f	15.54 (B)	16.46 (A)	16.21 (AB)
RPE_p	15.00 (B)	16.17 (A)	15.88 (A)

Means with the same letter are not significnatly different.

3.3. Interaction

The interaction effect of handle angle and handle positon was significant on ΔHR (Table 1). The interaction effect of handle angle and handle position on ΔHR was shown on Figure 6. For the 30° handle angle, the greatest ΔHR (47.15 beats/min) appeared at left, followed by at right (43.36 beats/min), the smallest ΔHR at left (38.61 beats/min). For the 0° handle angle, the three handle positions (left, centre and right) had similar ΔHR (40.36, 41.10 and 41.00 beats/min, respectively). The ΔHRs of all of the six combinations of two handle angles and three handle positions were greater than the recommended workload limit, 35 beats/min, for manual materials handling tasks. To lower physiological cost, the ipsilateral handles with 30° handle angle were recommended to position at left.

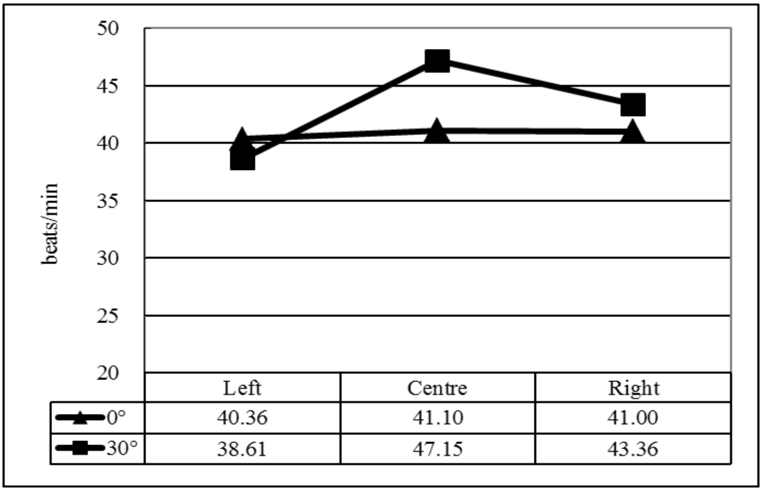

Figure 2: Interaction effect of handle angle and handle position on ΔHR

4. CONCLUSIONS

Handle angle of 30° induced significantly greater ΔGrip and ΔHR than those of 0°. Handle position at left had significantly smaller ΔHR, RPE_f and RPE_p than those at centre. The handle position effect on ΔHR was minor for the 0° handle angle. On the other hand, the handle position effect was marketable for the 30° handle angle. A greater handle angle, 30°, should be avoided applying for bi-manual materials lifting tasks using ipsilateral handles. To lower local muscle stress, physiological cost and perceived exertion at fingers and palm, the handles with 0° handle angle positioned at left were recommended for bi-manual materials lifting tasks using ipsilateral handles.

REFERENCES

[1] Wang, M. J. J.; Chung, H. C. & Chen, H. C.: The effect of handle angle on MAWL, wrist posture, RPE, and heart rate, *Human Factors: The Journal of The Human Factors and Ergonomics Society*, **42** (2000), pp. 553-565.
[2] Pinder, A. D. J. & Boocock, M. G.: Prediction of the maximum acceptable weight of lift from the frequency of lift, *International Journal of Industrial Ergonomics*, **44** (2014), pp. 225-237.
[3] Amazeen, E. L.: Box shape influences the size-weight illusion during individual and team lifting, *Human Factors: The Journal of The Human Factors and Ergonomics Society*, **56** (2014), pp. 581-591.
[4] Fox, R. R. & Smith, J. L.: A psychophysical study of high-frequency arm lifting, *International Journal of Industrial Ergonomics*, **44** (2014), pp. 238-245.
[5] Lee, K. S. & Lee, J. H.: A study of efficiency of two-man lifting work, *International Journal of Industrial Ergonomics*, **28** (2001), pp. 197-202.
[6] Dennis, G. J. & Barrett, R. S.: Spinal loads during two-person team lifting: effect of load mass distribution, *International Journal of Industrial Ergonomics*, **32** (2003), pp. 349-358.

[7] Wu, S. P. & Chang, S. Y.: Effects of carrying methods and box handles on two-person team carrying capacity for females, *Applied Ergonomics,* **41** (2010), pp. 615-619.

[8] Lee, T. H.: Effects of range and mode on lifting capability and lifting time, *International Journal of Occupational Safety and Ergonomics,* **18** (2012), pp. 387-391.

[9] Van der Molen, H. F.; Visser, S.; Kuijer, P. P. F. M.; Faber, G.; Hoozemans, M. J.; Van Dieën, J. H. & Frings Dresen M. H.: The evaluation of team lifting on physical work demands and workload in ironworkers, *Work,* **41** (2012), pp. 3771-3773.

[10] Visser, S.; Faber, G. S.; Hoozemans, M. J.; Van der Molen, H. F.; Kuijer, P. P. F.; Frings-Dresen, M. H. & Van Dieën, J. H.: Lumbar compression forces while lifting and carrying with two and four workers, *Applied Ergonomics,* **50** (2015), pp. 56-61.

[11] Wu, S. P.; Loiu, Y. W. & Chien, T. H.: Effects of box handle position and carrying range on bi-manual carrying capacity for females, *Industrial Health,* **53** (2015), pp. 410-416.

[12] Wu, S. P. & Lin, C. H.: The study of –bimanual lifting tasks in Chinese males, *Journal of Technology,* **20** (2005), pp. 175-183.

[13] Yoon, H. & Smith, J. L.: Psychophysical and physiological study of one-handed and two-handed combined tasks, *International Journal of Industrial Ergonomics,* **24** (1999), pp. 49-60.

[14] Wu, S. P. & Chung, H. C.: The effect of operating height and holding mode on holding capacity for female subjects, *Journal of Industrial and Production Engineering*, **30** (2013), pp. 248-255.

[15] Snook, S. H. & Irvine, C. H.: Maximum acceptable weight of lift, *American Industrial Hygiene Association Journal*, **28** (1967), pp. 322-329.

[16] Borg, G.: *Physical Performance and Perceived Exrtion*, Gleerup, Lund, (1962).

[17] Lin, Y. L.; Chen, G. L. & Zeng, Y. C.: *Effect of Handle Angle and Handle Position on Bi-manual Lifting Tasks for Male*s, Department of Industrial Engineering and Management Information, University of Huafan, New Taipei City, (2012).

[18] Lin, Y. R.: *Ergonomic Assessment of The Effect of Ipsilateral Handles on Bi-manual Lifting Capacity*, Department of Industrial Engineering and Management Information, University of Huafan, New Taipei City, (2015).

[19] Moore, S. & Garg, A.: Upper extremity disorders in a pork processing plant: relationships between job risk factors and morbidity, *American Industrial Hygiene Association*, **55** (1994), pp. 703-715.

[20] Kroemer, K. H. E. and Grandjean, E.: Heavy Work, *Fitting The Task to The Human*, 5th Edition, Taylor & Francis, (1997), pp. 119.

[21] Stellman, J. M.: Ergonomics: Muscular Work, *Encyclopaedia of Occupational Health and Safety*, 4th Edition, International Labour Organization, (1998), pp. 2928-2929.

EFFECT OF HAND CONDITION AND CARRYING FREQUENCY ON COMBINED CARRYING TASKS

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Abstract

It is well known that carrying tasks have quite extensive applications in manual material handling (MMH). Lower back pain and musculoskeletal injury caused by MMH have been confirmed as the main causes of financial losses for companies. The most of previous studies regarding with hand condition focused on carrying tasks, without lifting and lowering activities, but researches on combined carrying tasks, with lifting and lowering activities, remain scarce. This study applied the psychophysical method to evaluate the effect of hand condition on maximal acceptable weight of carrying (MAWC). The hand condition has significant effect on low back RPE, and whole-body RPE. The carrying frequency significantly influence on RPE of each body part. There is no significant interaction on RPE of each body part. The best combination of hand condition and carrying frequency for carrying tasks should be with higher performance and induce lower strain. When the carrying frequencies is 1 carrying/5 min or1 carrying/min, using two hands to carry is recommended. The high carrying frequency, 6 carryings/min, is not recommended since it induces greater strain.

Keywords*: manual material handling, combined carrying tasks, hand condition, frequency*

1. INTRODUCTION

In spite of advance in material-handling automation, manual handling is widely applied to handle materials in work sites. It is well known that carrying tasks have quite extensive applications in manual materials handling (MMH). Low-back pain and other musculoskeletal injuries caused by MMH have been confirmed as the main causes of financial losses for companies [1, 2, 3, 4]. For lowering the prevalence rate of these disorders, extensive studies, considered of carrying tasks, had conducted. The summary results of studies about carrying tasks indicated that the subject's carrying capacity increases as applying the container with handles; males' carrying capacities are greater than females'; increasing carrying distance, frequency, height or container's size decreases carrying capacity [4, 5]. To our knowledge, the most of previous studies regarding with hand condition focused on carrying tasks, without lifting and lowering activities, [6, 7, 8, 9, 10, 11] but researches on combined carrying tasks, with lifting and lowering activities, remain few [3, 11, 12, 13, 14, 15]. Most of these studies, focused on combined carrying tasks, considered of using two hands. Very few studies had payed attention on one-handed combined carrying tasks [11, 16, 17]. These studies showed that one-handed carrying capacity was about 70%-80% of two-handed carrying capacity. However, one-handed combined carrying tasks are common seen in workplaces, e.g. carrying a briefcase-style tool box or materials container, or daily living activities, e.g. carrying shopping bags, carrying a briefcase and carrying a music instrument, a cello. Unfortunately, studies on one-handed combined carrying tasks for Taiwanese were scarce. The objective of this study was to apply the psychophysical method to evaluate the effect of hand condition and carrying frequency on maximal acceptable weight of carrying (MAWC) for combined carrying tasks.

2. METHODOLOGY

2.1. Subjects

Fifteen healthy, right-handed, male students with no history of musculoskeletal problems were selected from the University of Huafan, Taiwan for this experiment. All of the subjects signed an informed consent and were compensated for their participation in this study. Each subject had at least one year of experience working in psychophysical study and was asked to participate in training sessions, at least one session, for familiarizing with the experimental procedure before the experimental data were collected. The subjects ranged in age from 18 to 22 years with a mean age of 20.47. The subjects' mean height was 171.06 cm (SD=5.77 cm), and the mean weight was 71.10 kg (SD=16.24 kg). Isometric strengths of the subjects, including power grip strength of right hand and left hand, arm strength, shoulder strength, back strength, leg strength and composite strength, were measured and the mean values were 355.8 N (SD=6.39 N), 308.4 N (SD=4.75 N), 315.0 N (SD=11.52 N), 333.0 N (SD=14.37 N), 51.84 N (SD=13.21 N), 730.9 N (SD=23.51 N), and 719.0 N (SD=23.63 N), respectively.

2.2. Experimental design

A completely randomized block design was applied in this study. The independent variables included subject, carrying frequency and hand condition. Each subject was considered as a block. Three different carrying frequencies (1 carrying/5 min, 1 carrying/min and 6 carryings/min) and two different hand conditions (one-handed and two-handed) were investigated. A total of 90 trails (15 subjects *3 carrying frequencies*2 hand conditions) were conducted. For one-handed carrying, each subject was asked to use his dominate hand, right hand. The dependent variables included MAWC, HR (heart rate), and RPE (rating of perceived exertion, which was developed by Borg with 6-20 scale and applied to rate the degree of perceived exertion at different boy part [18]) scores at different parts of body (finger, wrist, arm, shoulder, low back, leg and whole body). The containers, applied in this study, carrying distance, carrying duration and laboratory environment were controlled. The containers were the same with Yoon and Smith [11]. For one-handed carrying, a wooden rectangular tool box measuring 49*16 *20 cm^3 (length*width*depth) with a 2 cm-diameter pipe handle running through the length of the box at 30 cm height above the bottom of the box were applied. For two-handed carrying, a wooden box with two 2 cm-diameter bilateral pipe handles at 30 cm height above the bottom of the box were used. The size of the box was 46*30 *30 cm^3 (length*width*depth). The carrying distance and carrying duration were 4.3 meters and one hour, respectively. The laboratory environment was controlled at 20℃-26℃ and 50%-70% relative humidity.

2.3. Experimental procedure

Each subject's anthropometric measurements and isometric strengths were measured first. Upon the completion of anthropometric measurements and isometric strengths, each subject attended at least one of training sessions for totally familiarizing with the psychophysical weight adjustment method and understanding how cooperate with the experimenter to collect another dependent variables.

After training, each subject was asked to perform six trials (3 carrying frequencies*2 hand conditions) on different days. Each subject conducted one of six trials only on one day, in random order. The subjects were asked to perform a simulated combined carrying task, lifting the container from the floor of initial position, and carrying the container to the destination, 4.3 meters away from the initial position, at knuckle height, and then lowering the container to the floor, by one hand or two hands at the prescribed frequency. The initial load, placed under a false bottom in the container, was random, either light or heavy, up to 12 (7) kg for two handed (one handed) carrying. Based on the psychophysical method, each subject was encouraged to adjust the amount of weight in the container by adding or removing uneven-weight metal blocks during trials for approximating the MAWC. A 40-minute weight adjustment was provided to each subject for each trial to determine the MAWC for a 1-hour work period [10], without straining himself or becoming unusually tired, weakened, overheated or out of breath [19].

As the MAWC was determined, each subject was asked to perform a 10-minute combined carrying task with MAWC. Meanwhile, the subject's HR was continuously monitored by HR Monitor (Exersentry Model TM 3A). After finishing the 10-minute combined carrying task, each subject had to use the "Borg's RPE 6-20 scale" to rate the perceived exertion at finger, wrist, arm, shoulder, lower back, leg and whole body [17].

2.4. Statistical analysis

In order to determine the effect of carrying frequency and hand condition, analysis of variance (ANOVA) was conducted using the SAS 9.1 software (SAS Institute, Inc., Cary, NC). Duncan's multiple range test was applied for post hoc comparison. An alpha level of 0.05 was selected as the minimum level of significance.

3. RESULTS

The means and standard deviations for the RPE score at finger (RPE_f), wrist (RPE_w), arm (RPE_a), shoulder (RPE_s), low back (RPE_b), leg (RPE_l) and whole body (RPE_d) for the six combinations of hand condition and carrying frequency are summarized in Table 1. Analysis of variance was conducted to reveal the significant main effects or interaction effects on the RPE score of different parts of body. The ANOVA results were summarized in Table 2. It is logical that the subject effect were significantly on all of RPE scores (Table 2), because of individual difference. Further Duncan multiple range test was conducted for the significant main effects or interaction effects. The results of Duncan multiple range test were summarized in Table 3.

3.1. Effect of hand condition

The ANOVA results indicated that the hand condition had significant influence only on lower back and whole body (Table 2). The average perceived exertion ratings by hand condition and carrying frequency were summarized in Table 3. For the low back, the level of perceived exertion of two hands was significant than that of one hand. The similar result appeared at RPE_d.

Table 1: Average RPE (SD) at various hand condition and carrying frequency

Hand Condition	Carrying Frequency	Finger	Wrist	Arm	Shoulder	Low Back	Leg	Whole Body	Average
One Hand	1 carrying /5 min	13.33 (2.46)	12.86 (1.99)	13.26 (2.43)	12.73 (2.46)	12.80 (2.70)	12.40 (2.55)	12.66 (2.41)	12.86
	1 carrying /min	13.66 (1.79)	13.06 (1.99)	13.86 (1.50)	13.46 (0.91)	13.46 (1.72)	12.53 (2.19)	13.13 (1.55)	13.31
	6 carryings /min	14.93 (1.57)	14.26 (1.22)	14.60 (1.45)	14.06 (1.43)	15.26 (1.79)	13.53 (1.40)	14.60 (1.50)	14.46
Two Hands	1 carrying /5 min	13.20 (1.97)	12.86 (2.16)	13.53 (2.19)	12.93 (2.01)	13.80 (2.07)	12.80 (2.62)	12.93 (2.15)	13.15
	1 carrying /min	14.13 (1.88)	13.80 (1.82)	14.26 (1.86)	13.46 (1.18)	14.06 (1.86)	12.66 (1.83)	13.93 (1.53)	13.76
	6 carryings /min	15.00 (1.85)	14.40 (1.59)	14.93 (1.66)	14.20 (1.52)	16.13 (1.30)	14.33 (1.44)	15.33 (0.97)	14.90
Average		14.04	13.54	14.07	13.47	14.25	13.04	13.76	

Table 2: Summary of the NOVA results of RPE of each body part.

Source	DF	Finger	Wrist	Arm	Shoulder	Low Back	Leg	Whole Body
Subject	14	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
(H)and Condition	1	0.5827	0.2863	0.2132	0.6424	0.0062*	0.0871	0.0167*
Carrying (F)requency	2	<0.0001*	<0.0001*	0.0004*	0.0002*	<0.0001*	<0.0001*	<0.0001*
H*F	2	0.5891	0.4982	0.9792	0.9410	0.8502	0.5669	0.6268

Note: The numeral with * means the effect is significant (P-value<alpha level).

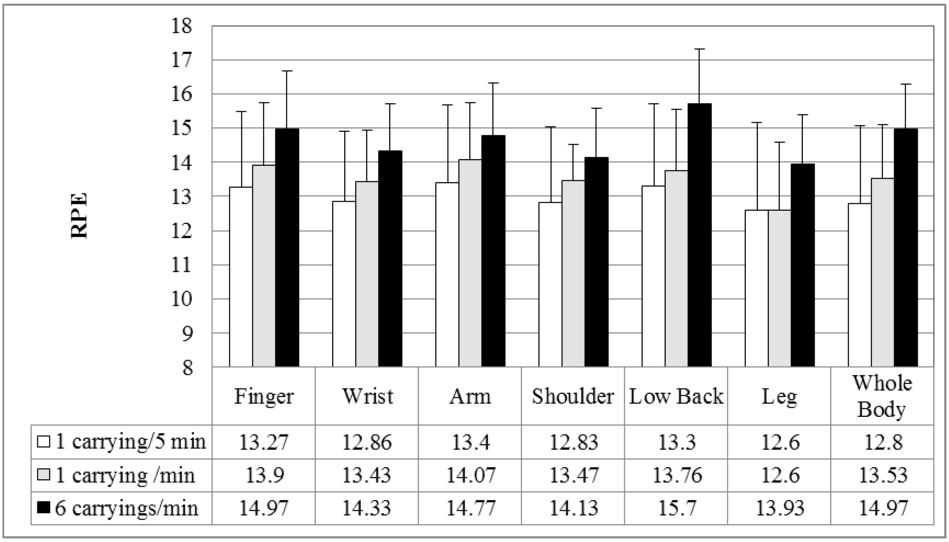
Table 3: The Duncan multiple range test results of RPE of each body part.

Variables	Level	Finger	Wrist	Arm	Shoulder	Low Back	Leg	Whole Body
Hand condition	One Hand	13.98	13.40	13.91	13.42	13.84B	12.82	13.47B
	Two Hand	14.11	13.69	14.24	13.93	14.66A	13.26	14.06A
Carrying Frequency	1 carrying /5 min	13.27C	12.87B	13.40C	12.83C	13.30B	12.60B	12.80C
	1 carrying /min	13.90B	13.43B	14.06B	13.46B	13.76B	12.60B	13.53B
	6 carryings /min	14.96A	14.33A	14.76A	14.13A	15.70A	13.93A	14.97A

Note: Means with same letter are not significantly different.

3.2. Effect of carrying frequency

The ANOVA results indicated that the hand condition had significant influence on all RPEs at different body parts (Table 2). The higher RPE score, the higher carrying frequency is for all different parts of boy, as shown in Figure 1. The results of Duncan multiple range test were shown in Table 3. It was seen that the RPE score of finger, arm, shoulder and whole body for 6 carryings/min were significantly larger than those for 1 carrying/min and 1 carrying/5 min and the RPE scores of finger, arm, shoulder and whole body for 1 carrying/min were significantly greater than those for 1 carrying/5 min. The RPE value of wrist, low back and leg for 6 carryings/min were significantly greater than those for 1 carrying/min and 1 carrying/5 min, but the RPE value of wrist, low back and leg for 1 carrying/min were not significantly greater than those for 1 carrying/5 min.



	Finger	Wrist	Arm	Shoulder	Low Back	Leg	Whole Body
□ 1 carrying/5 min	13.27	12.86	13.4	12.83	13.3	12.6	12.8
□ 1 carrying /min	13.9	13.43	14.07	13.47	13.76	12.6	13.53
■ 6 carryings/min	14.97	14.33	14.77	14.13	15.7	13.93	14.97

Figure 1: Effect of carrying frequency on all RPEs at different body parts

4. DISCUSSION

4.1. Effect of hand condition

The mean of RPE_f, RPE_w, RPE_a, RPE_s, RPE_b, RPE_l and RPE_d for one hand were lower than those for two hands (Table 3). It was logical that RPE_b, RPE_l and RPE_d were greater at two-handed because of heavier MAWC, similar to the result of Wu and Chung [20], and Yoon and Smith [11]. In contrast with the result of Yoon and Smith [11], RPE_f, RPE_w, RPE_a, RPE_s at one-handed condition were lower (Table 4), even though the average load on each hand for two-handed condition was lighter than that of one-handed condition. The handles, applied in this study, positioned at 30 cm above the bottom of the container, were different from the centered handles, applied by Yoon and Smith [11]. In order to walk fluently, subjects were forced to hold the container more away from body as carrying the container with the handles at 30 cm above the bottom of the container. Therefore, the RPE of arm was greater at two-handed, opposite to the result of Yoon and Smith [11].

Table 4: Comparison of RPEs at hand condition for the present and previous study

	Arm		Low Back		Whole Body	
	One Hand	Two Hands	One Hand	Two Hands	One Hand	Two Hands
Present study	13.91	14.24	13.84	14.66	13.47	14.06
Wu and Chung (2013)	-	-	-	-	13.35	14.60
Yoon and Smith (1999)	13.70	12.93	13.27	14.03	12.70	13.53

4.2. Effect of carrying frequency

The higher carrying frequency, the higher RPE score is, as shown in Table 5. This was same with Yoon and Smith [11]. Table 5 showed that the RPE value of 6 carryings/min at arm, low back and whole body were similar to Yoon and Smith's [11], instead of 1 carrying/5 min and 1 carrying/min. Figure 1 showed the effect of carrying frequency on the body parts' RPE scores. Further statistic test for different body parts in Table 6 indicated that there are significant differences in the RPE score among different body parts. The highest RPE value was at low back. The lowest RPE value was at leg. The RPE of low back was significantly greater than that of wrist. These results were different from Wu and Chung's results [20], RPE of arm and wrist greater than that of whole body and low back. That means wrist is not a limitation factor for manual material handling tasks with whole –body exertions [21].

Table 5: Comparison of RPEs at carrying frequency for the present and previous study

	Carrying Frequency	Arm	Low Back	Whole Body
Present study	1 carrying/5 min	13.40	13.30	12.80
	1 carrying/min	14.06	13.76	13.53
	6 carryings/min	14.76	15.70	14.97
Yoon and Smith (1999)	1 carrying/5 min	12.55	12.45	12.10
	1 carrying/min	12.65	12.70	12.55
	6 carryings/min	14.75	15.80	14.70

Table 6: Duncan results of body parts' RPE scores

Body Part	Low Back	Arm	Finger	Whole Body	Wrist	Shoulder	Leg
mean	14.25	14.07	14.04	13.76	13.54	13.47	13.04
	A	A	A				
		B	B	B			
				C	C	C	
							D

Note: Means with same letter are not significantly different.

5. CONCLUSION

Hand condition and carrying frequency are significantly affected RPE_f, RPE_w, RPE_a, RPE_s, RPE_b, RPE_l and RPE_d. The greater RPEs appeared at two hands. Infrequent carrying frequency, 1 carrying/5 min and 1 carrying/min, induced lower RPEs, RPE_f, RPE_w, RPE_a, RPE_s, RPE_b, RPE_l and RPE_d. Low back is the most strained region for combined carrying tasks.

REFERENCES

[1] Ciriello, V. M.: The effects of container size, frequency and extended horizontal reach on maximum acceptable weight of lifting for female industrial workers, *Applied Ergonomics*, **38** (2007), pp. 1-5.

[2] Wu, S. P.; Ho, C. P. & Chi, H. C.: Ergonomic study of a vertical rope-pulling task from a scaffolding, *Ergonomics*, **51** (2008), pp. 345-354.

[3] Li, K. W., Yu, R. F., Gao, Y., Maikala, R. V. & Tsai, H. H.: Physiological and perceptual responses in male Chinese workers performing combined manual materials handling tasks, *International Journal of Industrial Ergonomics*, **39** (2009), pp. 422-427.

[4] Tiwari, P. S., Gite, L. P., Majumder, J., Pharade, S. C. & Singh, V. V.: Push/pull strength of agricultural workers in central India, *International Journal of Industrial Ergonomics*, **40** (2010), pp. 1-7.

[5] Lu, H., & Aghazadeh, F.: Psychophysical determination and modelling of load carrying capacity. *International Journal of Industrial Ergonomics*, **13** (1994), pp. 51-65.

[6] Snook, S. H.: The design of manual handling tasks, *Ergonomics*, **21** (1978), pp. 963-985.

[7] Mital, A. & Okolie, S. T.: Influence of container shape, partitions, frequency, distance, and height level on the maximum acceptable amount of liquid carried by males, *American Industrial Hygiene Association Journal*, **43** (1982), pp. 813-819.

[8] Ciriello, V. M. & Snook, S. H.: A study of size, distance, height, and frequency effects on manual material handling tasks, *Human Factors*, **25** (1983) 5, pp. 473-483.

[9] Morrissey, S. J. & Liou, Y. H.: Maximum acceptable weights in load carriage, *Ergonomics*, **31** (1988), pp. 217-226.

[10] Snook, S. H. & Ciriello, V. M.: The design of manual handling tasks: revised tables of maximum acceptable weights and forces, *Ergonomics*, **34** (1991), pp. 1197-1213.

[11] Yoon, H. & Smith, J. L.: Psychophysical and physiological study of one-handed and two-handed combined tasks, *International Journal of Industrial Ergonomics*, **24** (1999), pp. 49-60.

[12] Jiang, B. C. Smith, J. L. & Ayoub, M. M.: Psychophysical modelling for combined manual materials handling activities, *Ergonomics*, **29** (1986), pp. 1173-1190.

[13] Chung, H. C. & Wang, M. J.: The effects of container design and stair climbing on maximal acceptable lift weight, wrist posture, psychophysical, and physiological responses in wafer-handling tasks, *Applied Ergonomics*, **32** (2001), pp. 593-598.

[14] Chung, H. C. & Wang, M. J.: Ergonomics interventions for wafer-handling task in semiconductor manufacturing industry, *Human Factors and Ergonomics in Manufacturing*, **12** (2002) 3, pp. 297-305.

[15] Lee, T. H. & Yeh, Y. C.: Effects of carrying handles, materials and distance on carrying capability, *International Journal of Occupational Safety and Ergonomics*, **21** (2015) 3, pp. 250-255.

[16] Mital, A. & Manivasagan, I.: Subjective estimates of one-handed carrying tasks, *Applied Ergonomics*, **14** (1983), pp. 265-269.

[17] Mital, A. & Manivasagan, I.: Load characteristics and manual carrying capabilities, *Proceedings of the 27th Annual Meeting of Human Factors Society*,

pp. 274-278, 9994614916, December 1983, Human Factors & Ergonomics Society, (1983).

[18] Borg, G.: *Physical Performance and Perceived Exrtion*, Gleerup, Lund, (1962).

[19] Snook, S. H. & Irvine, C. H.: Maximum acceptable weight of lift, *American Industrial Hygiene Association Journal*, **28** (1967), pp. 322-329.

[20] Wu, S. P. & Chung, H. C.: The effect of operating height and holding mode on holding capacity for female subjects, *Journal of Industrial and Production Engineering*, **30** (2013), pp. 248-255.

[21] Al-Eisawi, K. W., Kerk, C. J. & Congleton, J. J.: Limitations of Wrist Strength to Manual Exertion Capability in 2D Biomechanical Modeling, *Proceedings of the 38th Annual Meeting of Human Factors Society*, pp. 559-563, October 1994, Human Factors & Ergonomics Society, (1994).

ERGONOMIC ANALYSIS IN THE MANUFACTURE OF FLOOR TILES

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Abstract

The purpose of this study is to identify and summarize the evidence of ergonomic risks that can lead to musculoskeletal disorders in the manufacture of floor tiles in a small industry located in the metropolitan area of Buenos Aires.
This is a biomechanical analysis of two sub processes applying ergonomic evaluation methods, based on the results of this assessment improvement ideas are generated, including improvements in tools and equipment, engineering measures and administrative measures, which shows that the ergonomic risk can be reduced or even eliminated.
The role of the organization for improvements implementation will depend on its policy of occupational safety and health.

Keywords: *musculoskeletal health, industrial ergonomics, safety and risk ergonomics, tools and ergonomic equipments, task rotation.*

1. INTRODUCTION

This study has two objectives: to determine whether there are potential risks of musculoskeletal disorders in industry of the manufacture of mosaics and to determine a set of ergonomic recommendations that lead to better performances in daily work and in everyday worker's life. Methodology evaluation of sub processes is done in a small tiles factory (the area is about 1600m^2) with 25 years of experience in the market is capable to manufacture 850 m^2 per day. Currently it is operating under the control of employees as a cooperative group. The observations and instrumental measurements were applied to the affected workers who perform tasks normally and the actual elements used in practice for this purpose.
A press is used to make floor tiles, consists on a rotating disc of 2mts diameter with capacity for six mold pairs for tiles of 30x30cm, which weight is 3kg.
Two sub processes were analyzed, the mold fulfill and the disassembly of the product that will continue in the processes line.

2. SUBPROCESSES ANALISYS: MOLD FULFILLING

2.1 Task description:

To develop this task the worker takes the mixture from a rectangular container with a spoon and then drops the contents onto the mold, assists with his free hand to spread the mixture on a regular base using a palette knife (See figure 1). Repeating this operation (fulfilling the two molds corresponding to the cycle) lasts 15 seconds.

Figure 1: Worker filling the molds on the press

2.2 Ergonomic methods

2.2.1 Hand Activity Level

Is developed to determine whether an operator can come down with a musculoskeletal disorder (MSD) in his hand, wrist and forearm related to the activity of the work. The method shows a limit threshold that is based on epidemiological, psychophysical and biomechanical studies of work carried out in four or more hours per day in single tasks [1] (similar movements and repetitive strain set), considering the average of hand activity level. The level of hand activity is determined by the frequency of hand effort and duration of the work cycle, including rest periods. The measures were taken by analyzing force peaks in the Borg scale. The top strength hand is normalized to a 0-10 scale, which corresponds to 0% to 100% of the reference force applied to the workers. It is legal compliance in Argentina. Results for hand activity level under Resolution Nº. 295/03 MTEySS Argentina are: Normalized Peak Force: 6 (movements/steady effort, infrequent breaks) and Hand Activity Level: 4 (0,5 effort per second; 20-40 % occupational cycle). The result shows that mold filling sub-process risks are above the action limit, near the limit threshold value as seen in figure 2.

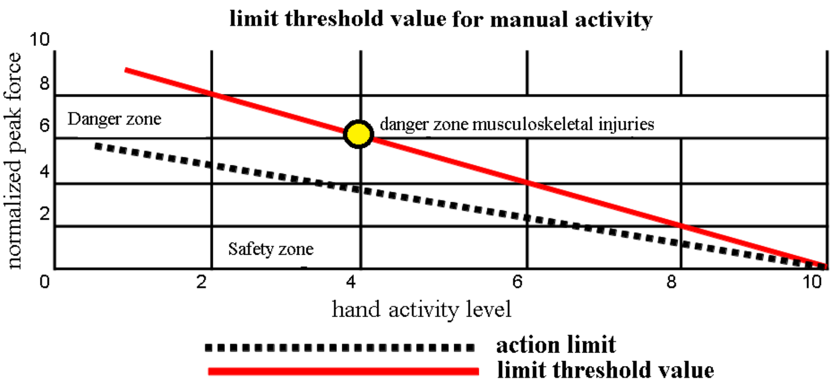

Figure 2: Yellow mark is in danger zone

2.2.2 "Sue Rodgers"

This method consists of evaluating three factors for each body segment: The load, duration and frequency of the effort that is made [2]. The evaluation is carried out in defined body segments; each factor can have values between 1 (low) and 3 (heavy). The range value obtained for each body segment is between {1-1-1} and {3-3-3}. The appreciation of the effort level is subjective, not so the duration of the effort, ranging from 1 (0-5 seconds) to 3 (more than 20 seconds), and the amount of effort per minute, ranging from 1 (0-1 effort per minute) to 3 (more than 5 efforts per minute). To develop this comparison the worst result is used, contrasting the values obtained with reference values of the method. (See table 1)

Table 1: Results of "Sue Rodgers' method for the filling of molds

	Effort level	Continuous effort duration	Effort frequency	Risk Results indicator	
Neck	3	2	2	High (H)	
Shoulders	2	2	2	Moderate (M)	
Back	3	2	2	High (H)	
Arms/ Elbows	2	2	2	Moderate (M)	
Wrists/Hands/Fingers	2	2	2	Moderate (M)	
Legs/Knees	2	2	2	Moderate (M)	

2.2.3 Moore-Garg Exertion Index

It is applied to determine an index that is the product of different factors, each value is rated in an individual and own scale; the factors involved are: intensity, duration and frequency of the effort, the posture of the hand-grip, the speed and duration of work [3]. If the value is less than 3, it is considered that the task does not present any risk, and if it is between 3 and 7, the task does not involve a significant risk, but improvements would be developed to reduce the workload. If the value is up than 7, indicates a high risk of damage to the worker and should be studied immediately. (See table 2)

Table 2: Values for the filling of molds according to "Moore and Garg" index

Risk Factor	Rating Criterion	Observation	Ratings
Intensity of exertion (IOE)	Somewhat Hard	Notable or definite effort	3
Duration of exertion (% of Cycle) (DOE)	30% - 49%		1,5
Efforts per minute (EPM)	4 – 8		1
Hand/ Wrist posture (HWP)	Bad	Marked deviation	2
Speed of work (SOW)	Fair	Normal speed of motion	1
Duration of Task (DOT	4 – 8 hours	Per Day	1
Index: IOE x DOE x EPM x HWP x SOW x DOT			**9**

2.3 Diagnosis

The methods used shows evidences of an inadequate working posture, mainly in the neck and trunk. One of the weakest points is the monotony of the task, added to a high level of hand activity and enforced labor posture. Equipment and the design of the tool are also deficient. In visual aspects the distribution of space is inadequate. There are chemical and physical contaminants that influence the comfort and health of workers; these final aspects should be measured in a hygienic study.

2.4 Possible improvements

As a result of this analysis an alternative would be to upgrade the loading tool: making shure that the worker has the wrist at normal position closer to neutral. Changing the grip of the loading tool, placing finger grips to balance the distribution of weight in his hand (see figure 3), the fist would be in a better position for the worker, the movement that the worker would make to put the mixture into the mold, it would diminish the torque on the elbow (pronosupination).
Another alternative is the incorporation of a hopper with manual discharge, the worker decreases significantly the level of hand activity, and would not use the hand to load the mixture, and it would also reduce the stress on the neck and arms. To fill the hopper, the company must incorporate a conveyor belt and a new container to place the material, which would imply more investment (See figure 4).
Designing and positioning of the container of the mixture: the incorporation of wheels for movement is required. If the container is located on the side of the worker, the trunk rotation will decrease, and if one curved side has the same radius of the rotating disk of the machine, it will diminish the distance to the molds, improving distances of movement and reducing the effort time
(See figure 5).
Incorporating a chair to work in standing position, these seats are used for tasks next to machine tools in which the worker can not go away or even sitting, they allow the worker to reduce from 25 to 35% of body weight, relieving the legs and decreasing the possibility of getting varicose veins [5]. Semi-Sitting posture is good for active workers, to encourage mobility, to preserve lumbar lordosis. The inclination of the seat starts just in front of the ischial tuberosity to have full support of the trunk (See figure 6).

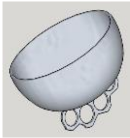

Figure 3: Alternative new grip tool.

Figure 4: Manual discharge hopper

Figure 5: metal container with wheels

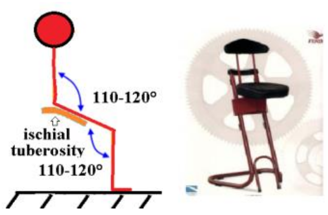

Figure 6: Left: Semi-sitting posture scheme, right: chair of Argentinian origin.

3. SUB-PROCESSES ANALISYS: END OF LINE

3.1 Task description

Analysis of "End of line sub-process”: two operators perform this task simultaneously. Each worker removes the fresh pressed tiles, deploying them from a nonstick plate (see figure 7), where both copies are supported in a movable part of the machine. Then, the tiles are put in mobile racks, for drying and subsequent storage. This sub process cycle lasts 15 seconds.

Figure 7: Worker removing the pressed tile

3.2. Ergonomic methods

3.2.1 Hand Activity Level

Results for hand activity level under Resolution Nº. 295/03 MTEySS Argentina are: normalized peak force: 4, hand activity level: 2. Intersection between normalized peak force and hand activity level is within safety zone (see figure 8)

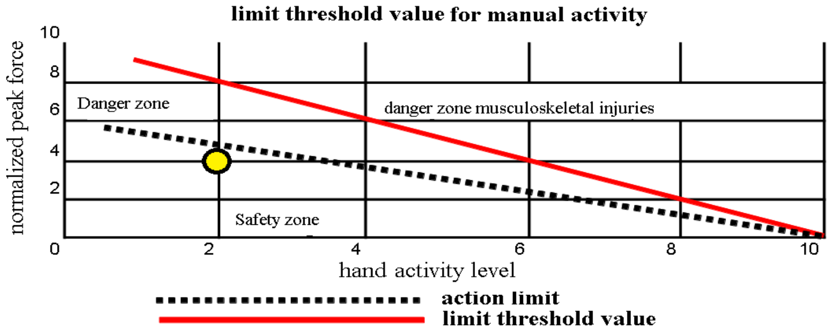

Figure 8: Yellow mark is in safety zone

3.2.2 Manual lifting of loads

This method determines the limit values for manual lifting, for two kinds of load handling, horizontally and in height, in mono task manual lifting within 30 ° sagittal neutral plane as in this case. These limit values are defined by the action’s duration (less than or more than 2 hours per day) and its frequency (number of manual lifts per hour).
The frequency lifts per hour is 240 and the weight of the tiles is 3 kg, this means the task is within the legal compliment which is 9 kg limit for horizontal (lifting that starts 30 cm from middle point between ankles) and in height manual lifting (from middle of the shinbone up to the knuckles).

3.2.3 "Sue Rodgers" method application (See table 3)

Table 3: Results

	Effort Level	Continuous Effort Duration	Effort Frequency	Results indicator
Neck	1	2	2	Low (L)
Shoulders	3	2	2	High (H)
Back	3	2	2	High (H)
Arms/ Elbows	3	2	2	High (H)
Wrists/Hands/ Fingers	2	2	2	Moderate (M)
Legs/ Knees	2	2	2	Moderate (M)

3.3. Diagnosis

The deficient point of the "end of line" sub process is monotony of tasks. Also methods used indicate inadequate movements and postures, especially in arms, shoulders and back.

From visual inspection the distribution of space is inadequate and can lead to accidents as impact and concussion. The chemical and physical contaminants exposition that influences in the comfort and health of workers should be measured in a hygienic study.

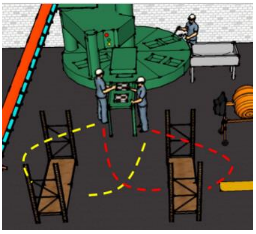

Figure 9. Possible path of end of line

3.4. Recommendations

Redistribution of the space: notice that workers hindered each other to reach the mobile racks. If the mobile racks are placed parallel as shown in the figure (see figure 9); and changing the direction of one of the nonstick plate of the machine, the tasks of removing the tiles would be performed easier without having to wait or hampering the activity partner.

4. SYNERGIC ROTATION SYSTEM

Alternatives were listed for the improvement opportunities found to eliminate the most damaging moves, and if not possible, to substitute or economize them applying a rotation system: After 80 minutes the workday started, the operator who occupies No. 1 position, filling the molds, passes to No. 2 position, there performs the task of collecting the tiles at the end of the line for another 80 minutes, while the operator who is in No. 3 position removing the tiles, passes to No. 1 position to fulfill molds.

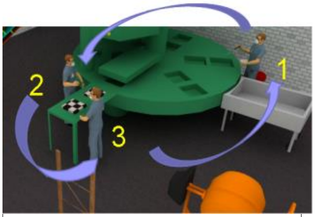

Figure 10: Possible rotation scheme.

Meanwhile the operator, who is in No. 2 position removing the tiles, passes to No. 3 position to continue removing tiles, but on the other side of the machine (See figure 10). Each worker would be 2 times at each position during the workday. The complete rotation cycle time lasts 240 minutes.

5. ANALISYS OF THE IMPROVEMENS IMPLEMENTATION

Both sub processes, the filling of molds and the position of the end of the line, ceases to be single tasking, so the level of hand activity will no longer apply according to the national legislation method regulation. If sue Rodgers method is applied for the mold fulfilling task the ergonomic improvement in neck and back is evident. (See table 4).
Moore & Garg method shows a decrease in the effort indicators from 9 to 2,25 (see table 5).
As regards to end of line sub process, sue Rodgers method shows a clear improvement Shoulders, back, arms and elbows comfort (see table 6).

Table 4. Results by the method "Sue Rodgers" of mold filling job

	Effort Level	Cont. Effort Duration	Effort Frequency	**Results indicator**		Results without improvements
Neck	1	2	2	Low (L)		High (H)
Shoulders	3	2	2	Moderate (M)		Moderate (M)
Back	3	2	2	Low (L)		High (H)
Arms/ Elbows	3	2	2	Moderate (M)		Moderate (M)
Wrists/Hands/ Fingers	2	2	2	Low (L)		Moderate (M)
Legs/ Knees	2	2	2	Low (L)		Moderate (M)

Table 5. Results by the method "Moore & Garg" of mold filling job

Risk Factor	Rating Criterion	Observation	Ratings
Intensity of Exertion (IOE)	Somewhat Hard	Noticeable or definite effort	3
Duration of Exertion (% of Cycle) (DOE)	10 – 29%	-	1
Efforts Per Minute (EPM)	4 – 8	-	1
Hand/ Wrist Posture (HWP)	Good	Near neutral	1
Speed of Work (SOW)	Fair	Normal speed of motion	1
Duration of Task Per Day (DOT)	2 – 4	In hours	0,75
Index: IOE x DOE x EPM x HWP x SOW x DOT			**2,25**

Table 6. Results by the method "Sue Rodgers" of end of line sub process.

	Effort Level	Continuous Effort Duration	Effort Frequency	Results indicator		Results without improvements
Neck	1	2	2	Low (L)		Low (L)
Shoulders	2	2	2	Moderate (M)		High (H)
Back	2	2	2	Moderate (M)		High (H)
Arms/ Elbows	1	2	2	Low (L)		High (H)
Wrists/ Hands/ Fingers	2	2	2	Moderate (M)		Moderate (M)
Legs/Knees	1	2	2	Moderate (M)		Moderate (M)

6. CONCLUSION

If the policy of the company decides to implement the proposed recommendations, the possible results of ergonomic analyzes will show clear improvements.
Indicators shows that the implementation of the improvements suggested for the work processes, together with a following up of the worker´s occupational health, would lead to improvements in the indicators of the applied methods, transforming the operator's daily tasks in a dynamic and synergic way, lowering the risk of getting musculoskeletal disorders.

REFERENCES

[1] Resolución 295/03 of the Ministerio de Trabajo, Empleo y Seguridad Social. Especificaciones técnicas sobre ergonomía y levantamiento manual de cargas, y sobre radiaciones, 2003, *Available from Infoleg* http://infoleg.mecon.gov.ar. Accessed: 2015-11-15

[2] Rodgers, S.: Job evaluation in worker fitness determination*; Occupational Medicine: State of the Art Reviews,* **Vol** (1988) No.3, pp. 219-239

[3] Moore, J.; Garg, A.: The Strain Index: A proposed method to analyze jobs for risk of distal upper extremity disorders; *American Industrial Hygiene Association Journal* (1995) No.56, pp. 443-458, ISSN 0002-8894

[4] Melo, J.L.: Ergonomía: El Asiento - Parte 14, available from: https://www.estrucplan.com.ar Accessed: 2015-11-15

DESIGN OF THE SCHOOL CHAIR MECHANISM FOR DYNAMIC SITTING

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Abstract

The aim of this research was to design a unique school chair with an adjustment mechanism for students from 5th to 8th grade, that would meet ergonomic and biomechanical requirements and provide comfortable and healthy sitting for students of different ages and anthropomeasures. The anthropometric measurements and an analysis of the existing school furniture with regard to ergonomic and biomechanical requirements were carried out in a primary school in the North of Croatia, on students from 5th to 8th grade. Based on the measured anthropomeasures and the biomechanical analysis of sitting, user needs were recognized and the list of requirements was made for designing a school chair. According to the list, solutions for individual parts of the adjustment mechanism were proposed and a concept with elaborated design was created. The mechanism allows adaptability of the chair to students of different ages and anthropomeasures, dynamic sitting and provides safety preventing injuries due to falls.

Keywords: *ergonomics, sitting biomechanics, school chair, dynamic sitting, mechanism*

1. INTRODUCTION

Significant physical development of children takes place between 6 and 18 years of age. During this period children spend a big part of the day in school, mostly sitting [1], and this is why appropriate school furniture is very important for proper physical development. In primary schools the selection of furniture is made according to the average height of students. There are two sizes of chairs and desks that are commonly used: one size for the students from 1st to 4th grade (classroom classes) and another size for students from 5th to 8th grade (subject classes). Due to the rapid development during puberty, the differences in anthropomeasures between students of higher primary school grades are particularly accentuated and therefore the equal dimensions of the furniture are not appropriate for most of the students from 5th to 8th grade [2].
When considering biomechanical and ergonomic sitting requirements, what is most examined is the impact of sitting on the spine [3]. However, the impact of sitting on upper and lower extremities should not be ignored. In the lumbar spine, the minimal forces will occur if that part is concave, that is if there is a proper lordosis in the lumbar spine. Research has shown that the existence of support in the lumbar spine prevents the flattening of that part of the spine and contributes to maintaining the concave shape in which the minimal load occurs [4].

Through many studies that have been conducted to determine the „correct“ ways of sitting, the conclusion was made that no position is correct if it is held too long [5]. In previous studies it was found that mobility of the body and activation of different muscle groups should be enabled during sitting in order to avoid fatigue due to continuous loading of individual muscle groups [5]. In this way, the abdominal and back muscles strengthen, the load on the spine is reduced and the blood circulation and oxygen supply of the body is improved [2]. The way of sitting in which different muscle groups are active is called dynamic sitting. For more than a decade there is a production of dynamic office chairs, but there are almost no school chairs that allow dynamic sitting and adjustment to different anthropomeasures of students.
The aim of this paper is to design a unique school chair for students from 5th to 8th grade with an adjustment mechanism, that would meet ergonomic and biomechanical requirements and provide dynamic sitting for students of different ages and anthropomeasures.

2. METHODS AND SUBJECTS

Analysis of the use of current furniture, and measurements of the students' anthropomeasures according to ISO 7250:1996 (E) standard [6], was carried out in a primary school in the North of Croatia. There were 86 students from 5th to 8th grade included in the research. The students came from 7 different student classes. The recorded measures included heights of students while standing, and the lengths of their legs observed from the back while sitting: from the floor plane up to the seat-surface. Also, the lengths from students' backs to their lower legs were measured while they were sitting, which represents the seating surface depth and determines the distance of the backrest to the front edge of the seat. The mean value, standard deviation and 5th and 95th percentile were calculated from the measured anthropomeasures. The mentioned percentiles were used to determine the range of motion of the seat for adapting the seat height and seating surface depth, which would be enabled by the adjustment mechanism. The students were recorded during class (Figure 1) in order to analyse the body positions that students take while sitting and suitability of the existing furniture with regard to ergonomic and biomechanical requirements. Based on the analysis, the list of mentioned requirements was determined with the aim of designing a chair that would meet those requirements and enable dynamic sitting and adaptability to anthropomeasures of the students from 5th to 8th grade. The requirements that the chair has to meet arise from the standards for school furniture design HRN EN 1729-1:2008 and HRN EN 1729-2:2012 [7, 8], also from the biomechanics of sitting and the obtained data from the users (through research). The requirements were set with: the aim to maintain lordosis in the lumbar spine (the chair should have lumbar support, the seat should enable a forward tilt, that is rotation around transverse horizontal axis of at least 5°), the aim to customize the dimensions of the chair to its user (the chair should have the possibility of adjusting the seat height and lumbar support height), the aim to reduce the pressure on the intervertebral discs (the chair should have the possibility of changing the angle of inclination of the backrest), the aim to maintain active sitting (the chair should enable rotation of the seat around horizontal longitudinal axis of at least 5°, backrest should follow the movement of the users), the aim to maintain safety of the users (all moving mechanisms should have the blocking ability, the inclination of the seat should not be too large to avoid slipping of the chair, the inclination of the backrest should ensure stability of the chair against overturning backwards). The standard HRN

EN 1729-1:2008 specifies the following requirements: the front edge of the seat must be curved, none of the edges of the seat must exceed 15 mm from the lowest point on the surface, the adjusting mechanisms must be easily accessible, the mechanisms must be easy to operate (without tools), adjusting of the dimensions can either be continuous or stepwise, all the surface edges that are in contact with the user must be rounded (or bevelled) by at least 2 mm, the lever edges must be rounded by at least 2 mm.

Figure 1: Recording of the students' sitting postures during class

3. RESULTS

Biomechanical analysis of the body postures and the load on body segments was carried [9]. While recording the students' postures it was noticed that during class students most frequently change the posture of the legs, by flexing and extending of the legs at the knee. They also change the position of resting their backs, that is the position of the bottom in the seat (Figure 1). As the changes occur every few minutes, it is obvious that the body requires dynamic sitting, however, current school chairs are intended for static sitting and they do not provide the necessary support of the body during different sitting positions.

Figures 2, 3 and 4 show minimum and maximum values and the mean value of the measured anthropomeasure distributed according to grades and classes and the mean value of the anthropomeasure for all the measured students. The biggest height difference between students was determined in the class 6.c (Figure 2) and it amounts to 45.5 cm, which matches the data from the previous research from the literature [2]. For all the measured students, 5th percentile for height was 142,6 cm, while the 95th percentile was 174.8 cm. The 5th percentile for seating surface height was 36,7 cm, while the 95th percentile was 47.7 cm. The 5th percentile for seating surface depth was 37.0 cm, while the 95th percentile was 48.3 cm. Figure 5 shows the required range of seating surface heights (a), seating surface depths (b) and the dimensions of the current chair. It is evident that the current chair seat is within hatched area, closer to the 95th percentile. This leads to conclusion that the seating surface is too high and does not meet the needs of a large percentage of users.

Requirements on the chair were converted into functions that concept solution of the school chair must include [9]. The mechanism was divided into subsystems: the system for height adjustment of the seat, the system for rotation of the seat around the transverse axis, the system for rotation of the seat around the longitudinal axis, the system for adjusting the height of the lumbar support, the system for changing the tilt of the backrest, the system for rotating the backrest around its vertical axis [9]. Each system was developed separately, by functional modelling using flowcharts [9]. The morphological matrix contained all the functions listed through the systems along with the solutions and implementations for each function [9]. Concepts for backrest and seat mechanisms were designed, but for a detailed development the selected concepts were the ones that offered the largest number of degrees of freedom, adjustment of the lumbar support height without having to stand up and design based on movability of the components, not the elasticity.

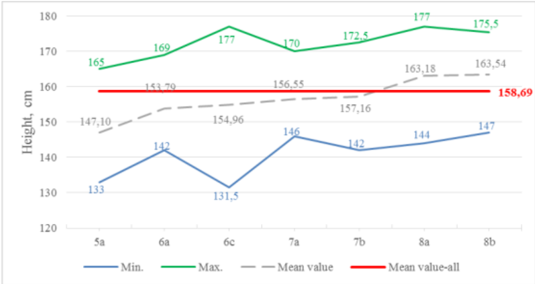


Figure 2: Range of student heights while standing, distributed according to grades and classes

Figure 3: Range of students' leg lengths observed from the back side, from the floor plane up to the seat-surface, distributed according to grades and classes

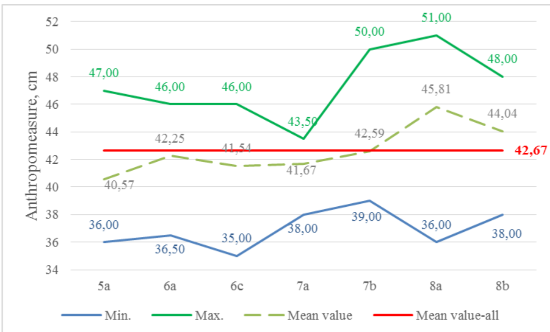
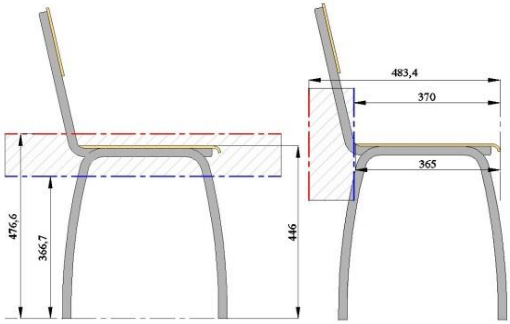


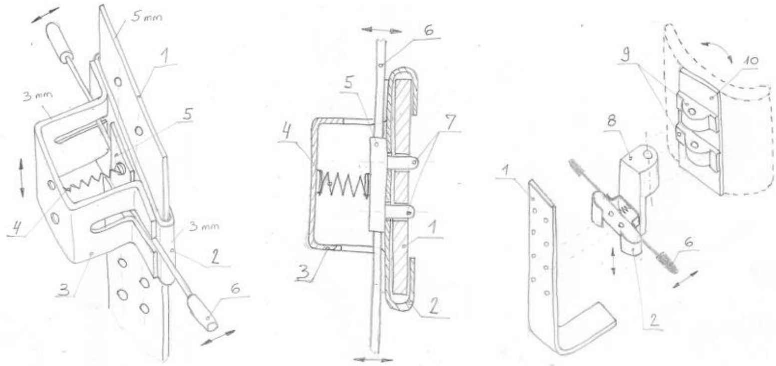
Figure 4: Range of distances between students' backs and their lower legs – the seating surface depth, distributed according to grades and classes



a. b.

Figure 5: Dimensions of the current school chair and required range of heights (a) and depths of the seating surface (b)

The chosen concept of the backrest mechanism included the function of rotation of the backrest around the vertical axis and the adjustment of the backrest height (Figure 6). The mechanism moves vertically along the girder that has a series of holes (1). Guiding is done by sliding of the sheet metal (2) along the girder. The joint of the girder and the mechanism is carried out with two bolts (7) that the compression spring (4) presses over a plate with bolts (5) into the holes of the girder. The mechanism is freed by pulling levers (6) that are connected to the plate with bolts resulting in compression of the spring and bolts coming out of the holes. The spring is positioned within the housing made from bent sheet metal (3). The rotation of the backrest is carried out through joints (8) and (9). The stationary part (8) is attached to the sheet metal, while the mobile part (9) is attached to the plate carrying joints (10). Bolts are pulled through the holes in parts 8 and 9 resulting in a joint with one degree of freedom, rotation.



a. b. c.

Figure 6: Backrest mechanism concept: a. sketch of the backrest height adjustment mechanism; b. sketch of the mechanism details; c. sketch of the backrest rotation mechanism

The chosen concept of the seat mechanism has been designed with the ability to tilt the seating surface around the longitudinal and transverse axis of the seat (Figure 7). The inclination is carried out by a single joint comprising of 3 parts: stationary part (1), a part for longitudinal inclination (2) and part for transverse inclination (3). Parts of the joint are connected with bolts (4), while the slide bearings are made of bronze sleeves (5). The housing of the mechanism (6) serves as a limitation of certain angles of inclination and it also has ridges at its edges, in which the following surface overlies. For shock absorption of the housing there are 4 compression springs (7) located around the joint and fixed on a support plate of the seat (8). The front end of the housing is lower than the rear because the transverse inclination of the seat allows only forward motion, resulting in an increase in lumbar angle and maintained concavity of the lumbar spine. The seating surface is mounted on the support plate (8) with screws.

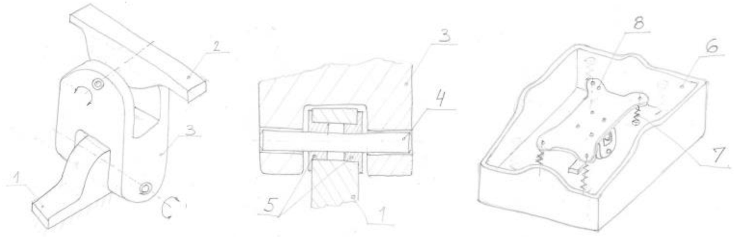


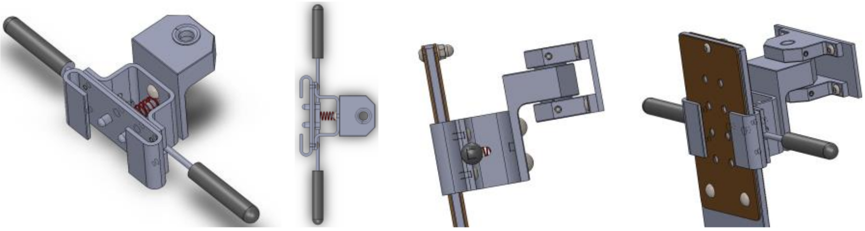
Figure 7: Seating mechanism concept: a. sketch of the joint with dual rotation; b. sketch of the joint details; c. sketch of the mechanism housing

The chosen backrest and seat concepts were developed in regards to the design. The strengths of the mechanism parts were calculated: of the bolt that carries the backrest during the shear load and of the main girder of the backrest loaded on bending. The dimensions of the bolt and the girder were calculated and chosen. The contact stresses were calculated in the joint of the seat mechanism, which consists of bolts loaded to shear stress and bronze sleeve bearings loaded on the stress from the side. Backrest mechanism springs were selected assuming that the maximum force on each lever does not exceed 10 N. The mechanism for mitigating the seat inclination was dimensioned according to the 5th percentile of weight.

The 3D model of the lumbar support height adjustment mechanism is shown in Figure 8. The sliding sheet metal is used to move the mechanism along the main girder. It is in contact with sliding surface made of bronze. By pulling the lever, the compression spring is compressed and the bolts come out of the main girder. The location is determined by pulling two bolts through the holes on the main girder. The total travel length of the mechanism is 80 mm. The mechanism is hinged to the mobile parts of the joint using bolts and by that it allows the rotation. The mobile part is connected to a plate that connects to the backrest.

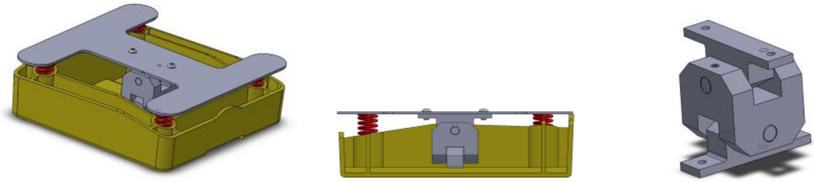
Figure 9 shows the 3D model of the seat tilting mechanism. It consists of a joint that allows rotations around transverse and longitudinal axis of the seat, housing of the mechanism which includes arrangement of 4 compression springs for shock absorption and reduction of inclination speed, and a plate for attachment of the seat. The shape of the housing is made in a way that allows the forward seat inclination of 10° and sideways seat inclination of 10°.

The mechanism for seat height adjustment is connected to the housing of the seat mechanism. It includes an attachment to the gas cylinder and a lever for starting of the cylinder (Figure 10).



a. b. c. d.

Figure 8: 3D model of the lumbar support height adjustment mechanism: a. mechanism assembly; b. mechanism ground plan; c. mechanism hinged to the mobile part of the joint using bolts; d. mobile part connected to a plate that connects to the backrest



a. b. c.

Figure 9: 3D model of the seat tilting mechanism: a. mechanism assembly; b. cross section of the mechanism housing; c. main joint

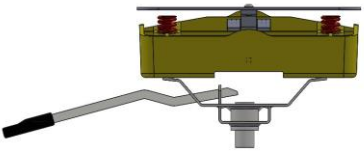


Figure 10: 3D model of the mechanism for seat height adjustment

All the mechanisms are connected to the main girder that is bent at 110°. The whole mechanism allows the movement of the backrest up and down, the rotation of the backrest, the inclination of the seat around two axes and a vertical translation of the seat (Figure 11).

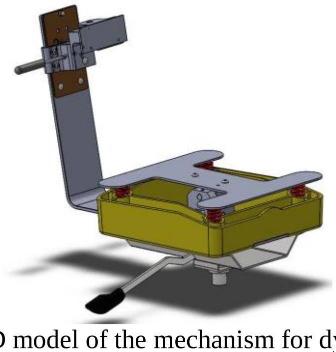


Figure 11: 3D model of the mechanism for dynamic sitting

4. CONCLUSION

In this paper, the biomechanical analysis of sitting was conducted on students from 5th to 8th grade of a primary school. By analysing the user needs, biomechanical factors and regulation standards for school furniture, the list of requirements that the chair must meet was determined. Mechanism of a school chair must allow movements of pelvis and trunk of the body, rotation of the body and movements of the legs, but also the adjustment of the seating surface height and lumbar support height. The mechanism of a chair that allows dynamic sitting was designed. The whole mechanism was divided into several subsystems, and for each individual different solution was sought. The final design was created by connecting solutions of individual subsystems into a whole. For the chosen design, a CAD model was created along with a detailed development plan regarding strength of materials. The final design allows seating surface height adjustment, lumbar support height adjustment and rotation of the pelvis and the trunk of the body.
For the complete analysis of the functions and properties of the mechanism it is necessary to conduct tests on a prototype, record the behaviour of the users and optimize the design of the construction with the aim to reduce the dimensions and the production cost.

Remark: The study was conducted in compliance with ethical norms and the approval of the school and students' parents. Guarantee of protection and anonymity of students are provided.

REFERENCES

[1] Linton, S.J.; Hellsing, A.L.; Halme, T. & Akerstedt, K: The effects of ergonomically designed school furniture on pupils' attitudes, symptoms and behaviour, *Applied Ergonomics*, 25(5), 299-304, 1994, ISSN 0003-6870
[2] Domljan, D.; Grbac, I & Hađina, J.; Classroom Furniture Design – Correlation of Pupil and Chair Dimensions, *Coll. Antropol.*, 32(1), 257-265, 2008, ISSN 1848-9486
[3] Lueder, R.; Berg Rice, V.J: *Ergonomics for Children*, Taylor & Francis, ISBN 0-415-30474-1, New York, 2008
[4] Andersson, G.B.J.: Loads on the Spin during Sitting, *The Ergonomics of Working Postures*, Taylor & Francis, London, 1986, 309-318
[5] Wang, H.; Weiss, K.J.; Haggerty M.C. & Heath J.E.: The effect of active sitting on trunk motion, *Journal of Sport and Health Service,* Vol 3 (4) , 333-337, 2014, ISSN 2095-2546
[6] ISO 7250:1996 (E) Standard
[7] HRN EN 1729-1: 2008 Standard
[8] HRN EN 1729-2: 2012 Standard
[9] Čabradi. B.: Design of the mechanism of school chair for dynamic sitting (in Croatian), Master Thesis, 2015, University of Zagreb, FAMENA

INCIDENCES OF WORK-RELATED MUSCULOSKELETAL DISORDERS IN PHYSICIANS AND SURGEONS

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Abstract

Musculoskeletal disorders (MSDs) are a major reason leading to loss of work efficiency. MSDs affect a wide variety of workers in the healthcare industry. This cross-sectional study was conducted among 108 medical practitioners comprising physicians and surgeons who were randomly selected from four different medical institutions located in India. The aim of this study was to elucidate the incidences of WMSDs experienced by physicians and surgeons. Several measures were obtained: which included computation of demographic and workload data, Nordic Musculoskeletal Questionnaire (NMQ) and Visual Analogue Scale (VAS). Results revealed physicians and surgeons reported low back trouble (62.5% and 76.92%) respectively in last 12-months as the major MSD, followed by neck (37.5%), upper back (33.33%), and shoulders (31.25%) in physicians and ankles/feet (25.64%), neck (23.07%), knees (17.94%) in surgeons. The analysis of VAS revealed magnitude of musculoskeletal discomfort is greater in post-exposure of work in both physicians and surgeons. No significant difference was found in the frequency of WMSDs between physicians and surgeons. Occupational characteristics was found to have a significant influence on MSDs. MSDs appeared to decrease with increasing age, but the severity continued to increase with increasing age.

Keywords: *work-related musculoskeletal disorders, physicians, surgeons*

1. INTRODUCTION

Bernardino Ramazzini (1633–1714) was arguably the first physician who went beyond the usual doctor's practice of his time and began to systematically investigate the 'role of work in determining diseases' [1].The phrase, 'Work-related musculoskeletal disorders' was first coined in 1971, in a report on Australian telegraph operators [2]. Therein, complaints were described as "occupational cramps" or "occupational myalgias". Previously labeled as repetitive motion disorders, cumulative trauma disorders, or overuse syndromes. Work-related musculoskeletal disorders became a generic nomenclature associated with numerous occupations [2], [3], [4], [5] and the incidence has been increasing [3], [5].
Work-related musculoskeletal disorders (WMSDs) is a collective and descriptive phrase for symptoms caused or aggravated by work and characterized by discomfort, impairment, disability or persistent pain in joints, muscles, tendons and other soft tissues with or without physical manifestations [6], [7]. Generally, fatigue and discomfort initiate the injury development process, and under certain conditions the

symptoms persist, possibly resulting in damage to the musculoskeletal structures causing impairment and disability [8].

According to U.S Bureau of Labor Statistics, 2009; WMSDs affect nearly a million workers in the United States alone each year. It can affect the ability of workers to perform the required occupational activities which could have a negative effect on productivity [9]. Economic loss due to WMSDs in the Korea is estimated to be about US$ 1 billion, which is approximately 0.3 % of GNP [10].

The occurrence of musculoskeletal symptoms may indicate an exposure to workplace risk factors that can lead to a WMSD. Strong causal relationships have been found between WMSD and biomechanical risk factors such as repetition, posture, force and vibration [11]. WMSDs require workers to generate low levels of muscle force and adopt awkward postures or static postures for prolonged periods during the performance of their duties. Furthermore, individual and psychosocial factors may also contribute to the development of WMSDs [11], [12], [13].

Doctors and nurses are an extremely important part of the healthcare team. Healthcare is one of India's largest and rapidly expanding sectors, in terms of revenue and employment. During the 1990s, Indian health care grew at a compound annual rate of 16%. Today, the total value of the sector is more than $34 per capita or roughly 6% of GDP. According to Technopak Advisors, India Healthcare Trends (2008), healthcare, which is now a US $35billion industry in India, is expected to reach over US$ 150 billion by 2017 (National Health Profile, 2008). It has been reported that 7 of the 20 fastest growing sectors in India are healthcare related; nearly 77% of healthcare establishments are offices of physicians, dentists or other health practitioners. In India, hospitals and nursing homes contribute 49% of the Indian healthcare delivery [14].

Studies have revealed that the healthcare professionals are vulnerable to musculoskeletal disorders during the course of their work routine [13], [15], [16]. Musculoskeletal complaints (MSCs) affect a wide variety of workers in the healthcare industry and appear to be a particularly imperative problem for physicians. Physical workplace tasks of these practitioners include regular walking from ward to ward, constant bending over the bed while physically examining patients [17], [18], which may be associated with considerable physical stress resulting in many complaints relating to the musculoskeletal system [19].

The work of surgeons can involve high levels of mental concentration synergized with very precise movements of the arms and fingers that may place mild-to-moderate physical demands [20].Working in operating rooms involves a considerable amount of static posture which could be responsible for discomfort and disorders of the musculoskeletal system [21].Their work is exclusively done in a standing position with bend trunk and neck over operation table for a prolonged period in long duration surgeries, causing significant strain on the neck and back. Since the diversity of operating skills imposes different demands of physical efforts on surgeons, it would be prudent to conjecture that surgeon of different specialties may also be at high risk for precipitation of WMSDs for different body parts, apart from the neck and back, which may be common for all [13]. Other elements of their jobs include ward rounds, surgical meetings, patient consultations, and report-writing. It would be expected that surgeons are constantly exposed to both physical and psychosocial workplace demands, as they have to manage not only the physical work of performing surgery but also to communicate with both the patients and their families [13].

An observation by the Indian Medical Association's (IMA) Pune chapter says that an Indian doctor's average lifespan is 55-59 years, almost 10 years lesser than that of the general population. It was based on the analysis of the association's social security scheme (SSS) with 5,500 doctors from Maharashtra, India and over 11,000 doctors from across the country registered [22]. Prolonged posture, demands of the job, patient's expectations, interruptions, practice administration, work-home interface and social life, dealing with death and dying, medical responsibilities for friends and relatives, all these precipitate in copious amounts of strain and stress among physicians [23]. Since doctors are lifesavers, if they come under stress, their efficiency is reduced, directly affecting the lives of a large number of people who they treat [24].

Sixty years ago, the total number of accredited physicians was 47,524, with doctor /population ratio of 1 to 6300 [25]. According to the Rural Health Statistics, in India, in 2011, the number of registered medical practitioners is 840,130. Despite this increase in the number of doctors, the doctor/population ratio now stands at a staggering 1:1800 (Gulf Medical University website). The shortage of doctors create enormous work demands on the beleaguered practitioners, who are already a potentially high-risk group for WMSDs because of their occupational demands, maintaining awkward postures for long working hours, coupled with a heavy workload [22], [26]. Other than these physical risk factors, other potential contributing risk factors for the development of WMSDs may be organizational, psychosocial as well as individual factors that may lead to ergonomic-related problems. Emerging reports have begun to show that MSCs are increasingly becoming important occupational concerns for workers all over the world [15], [27], [28], [29] including doctors [11], [17], [18], [19]. Since musculoskeletal disorders are a major reason leading to loss of work efficiency; therefore, there is an imperative need to explore the incidence of WMSDs among medical practitioners in India. The aim of this study is (i) to study the incidences of WMSDs experienced by physicians and surgeons (ii) to evaluate the intensity of pain pre and post exposure of work by physicians and surgeons (iii) to analyze the occupational characteristics of medical practitioners and its association with WMSDs.

2. METHODOLOGY

2.1. Study design and Selection of subjects

A cross-sectional study was conducted among 108 medical practitioners comprised physicians (55.6%) and surgeons (44.4%), that comprised males (80.6%) and females (19.4%) who were randomly selected from four different medical institutions located in Mumbai and Kolkata, India. Practitioners working at least for one year at the present workplace were included in the study. Ethics approval was obtained from a multi-specialty medical center involved, prior to the commencement of the study. A written informed consent was taken from all the respondents wherein, the confidentiality clause as well as the details of the study explained. Selection of the subjects was based on purposive sampling technique. Selection of hospitals had been a mix of convenience and chance. Based on the results suitable ergonomic intervention is suggested for the attenuation of WMSDs.

2.2. Measures

Questionnaires were used to find out the risk factors. Questionnaires were completed through face to face interviews. Interviews were confidential, undertaken during the work shift which approximately lasted for 30 minutes for each individual. The height was measured with the help of stadiometer, weight was recorded with the help of weighing machine respectively. The aim of the risk assessment process was to remove the hazard or reduce the level of its risk by adding precautions or control measures as necessary in future studies. This phase is subdivided into sub-phases viz., (i) Computation of Demographic and workload data **(**ii) MSD Assessment iii) Visual Analogue Scale.

- ***Computation of Demographic and workload data***

Demographic and workload-related information was collected from the medical practitioners through the application of a structured questionnaire during a personal interview. The demographic information included age, gender, height and weight. The workload data covered work experience, working hours, working days, average number of operations and operating hours per week, and the department where the respondents worked.

- ***Musculoskeletal Disorder Assessment***

Nordic Musculoskeletal Questionnaire (NMQ) was used to find the prevalence of work-related musculoskeletal disorders in nine anatomical regions. These are three upper limb segments (shoulder, elbows, wrist/hands), three lower limb segments (hip/thighs, knees, ankle/feet) and three trunk segments (neck, upper back, lower back). The questionnaire involved information including the location of symptoms in the past 12 months, past 1 week and whether it interfered with daily activities in the previous 12 months. The structured questionnaire was employed during a personal interview. NMQ has been widely used as a screening tool for work-related musculoskeletal and found to have good reliability and validity [30].

- ***Visual Analogue Scale***

A Visual Analogue Scale (VAS) is a tool that measures the characteristics or attitude that is believed to range across a continuum of values and cannot be directly measured. For example, the amount of pain that a patient feel ranges across a continuum from none to an extreme amount of pain [31]. Operationally a VAS is usually a horizontal line, 100 mm in length, anchored by word descriptors at each end. Post evaluation with NMQ, the respondents who were found to be suffering from MSD either in last l2 months or in last 7 days was asked to mark on the line the point that they feel represents their perception of their current state. They rated their pain on the VAS scale before starting the work and after finishing their work. The VAS score has been determined by measuring in millimeters from the left-hand end of the line to the point that the patient marked.

3. RESULTS

The demographics and workload data were collected from all the 108 medical practitioners who participated in the study. The mean age of the medical practitioners (n=108) comprising physicians (55.6%) and surgeons (44.4%) was 34.78±9.19 years and half of them belong to 25-30 year old age group (50%). The mean height and weight of the respondents were 167.21±8.68 cm and 73.99±13.20 kg. The majority of the medical practitioners was males (83.3%) and rest were females (16.6%). The mean age of males and females were 33.50±8.25 and 41.17±11.08 years respectively. The mean height of males and females were 169.06±7.33 and 158.00±9.24cms respectively. The mean weight of males and females were 75.76±12.16 and 65.17±14.92kgs respectively.

Regarding employment characteristics, the total work experience of the participants were 8.53±6.91yrs working for 11.22±2.11 hours/day. More than half of the medical practitioners (61.1%) were having work experience less than 10 years and were working 6 days per week while 58.3% were found to be working for greater than or equal to 12 hours/day.
The data was collected from different surgeons (n=48) who were working in various departments that included Orthopedics (31.3%), General Surgery (25%), ENT (18.8%), Ophthalmology (12.5%), Anesthesiology (6.3%) and Obstetrics &Gynecology (6.3%). The average number of operations performed by surgeons was 7.83±5.228 per week, averaging 12.46±6.378 hours of work in the operation theater, per week.

3.1. Characteristics of work-related musculoskeletal disorders in physicians and surgeons

The medical practitioners reported a high prevalence of work-related musculoskeletal symptoms. The 12-month and 7-days prevalence rates of WMSDs reported by physicians and surgeons are presented in Fig. 1 and 2.

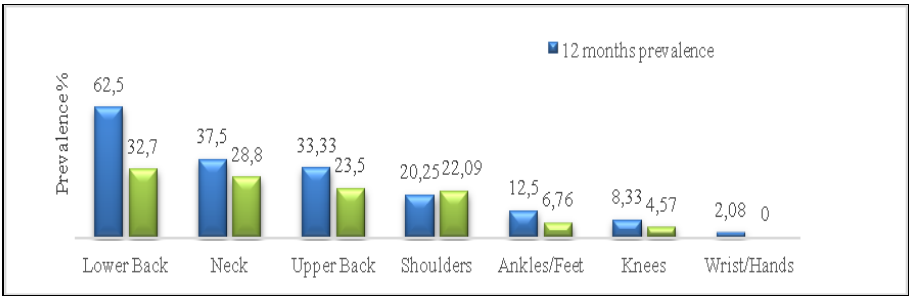

Figure 1: Prevalence of symptoms in last 12months and last 7 days in physicians

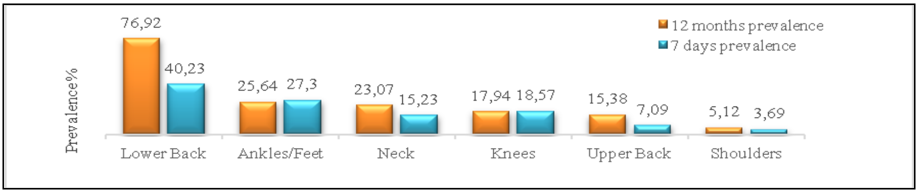

Figure 2: Prevalence of symptoms in last 12months and last 7 days in surgeons

Figure 1 and 2 shows that both physicians and surgeons have reported low back trouble (62.5% and 76.92%) respectively in last 12-months as the major MSD followed by neck (37.5%), upper back (33.33%), shoulders (31.25%), ankles/feet (12.5%), knees (8.33%), wrist/hands (2.08%) in physicians and ankles/feet (25.64%), neck (23.07%), knees (17.94%), upper back (15.38%), shoulders (5.12%) in surgeons. It shows that low back and neck are the most commonly affected body parts among the medical practitioners. Figure 3 indicates the reported reasons for musculoskeletal discomforts.

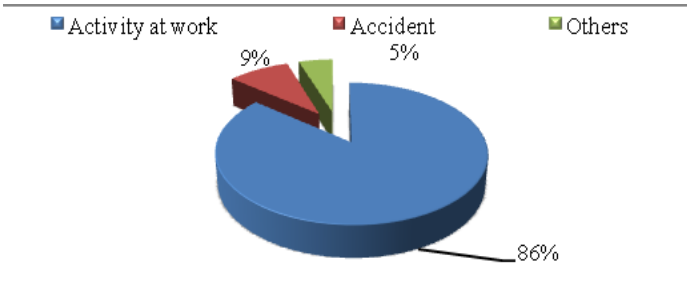

Figure 3: Reported reasons for musculoskeletal discomfort

Fig. 3 reveals that majority (86%) of the respondents had reported work as the cause for their musculoskeletal symptoms while very few (9%) reported accidents as the causal factor for their musculoskeletal symptoms.

3.2. Magnitude of the musculoskeletal discomfort in physicians and surgeons

Visual Analogue Scale (VAS) was used to measure the magnitude of the musculoskeletal discomfort experienced by the physicians and surgeons. It was used to analyze the musculoskeletal strain in different body parts as perceived by the medical practitioners. They rated the strain before and after their work exposure. The pre and post-test exposure for the physicians and surgeons are represented in table 1 and 2 respectively.

Table 1: Reported intensity of pain before and after exposure to work in physicians

Regions	Pre-test	Post-test	t-value	p-value
Lower Back	1.52	3.38	-15.51	0.001*
Neck	1.72	3.4	-8.79	0.001*
Upper Back	1.11	2.44	-7.71	0.001*
Shoulders	1.28	2.22	-6.77	0.001*
Ankles/Feet	1	2.85	-5.25	0.006*
Knees	0.86	1.76	-4.32	0.024*
Wrists/Hand	0.25	0.95	-2.33	0.128

*Significance at the level of $p<0.05$

Table 2: Reported intensity of pain before and after exposure to work in surgeons

Regions	Pre-test	Post-test	t-value	p-value
Lower Back	1.59	4.18	-12.68	0.001*
Ankles/Feet	1.28	3.41	-9.67	0.001*
Neck	1.73	3.91	-8.12	0.001*
Knees	1.81	3.91	-7.48	0.001*
Upper Back	1	2.55	-4.34	0.011*
Shoulders	0.96	2.26	-3.60	0.034*

*Significance at the level of $p<0.0$

Table 1 and 2 shows that there is a significant difference between the pre and post work exposure scores and magnitude of musculoskeletal discomfort is greater in post-exposure of work in both physicians and surgeons. The negative‘t’ value shows that the intensity of pain has increased in these regions from pre-work exposure to post work exposure.

3.3. Frequency of WMSDs between physicians and surgeons

After the assessment of the prevalence of musculoskeletal symptoms among physicians (80%) and surgeons (81.25%), chi-square test was conducted to assess any difference in the frequency of WMSDs between the medical practitioners. The level of significance was set at 0.05.

Table 3: Chi square test on frequency of WMSDs of physicians and surgeons (n=108)

MSD	Physicians		Surgeons		Chi-square ($\chi 2$)	p-value
	Observed	Expected	Observed	Expected		
Present	48	48.33	39	38.66	0.026	0.870
Absent	12	11.66	9	9.33		

Chi-square test at α=0.05 conducted shown in table 3, that p-value is 0.87 (>0.05), which points out that no significant difference exists in the frequency of WMSDs between physicians and surgeons.

3.4. Association of work-related musculoskeletal disorders and the occupational characteristics

Table 4 shows frequency of WMSDs based on demographic characteristics of the medical practitioners. Table 5 shows the association between reported 12-month prevalence of WMSDs with the occupation characteristics among the medical practitioners. The rates of WMSDs were significantly associated with work experience (χ^2 = 5.81; p= 0.015), working hours ($\chi 2$ = 6.70; p= 0.009).

Table 1: Frequency of 12-month prevalence of WMSDs based on demographic characteristics of the medical practitioners.

Independent Variables	**Categories**	**Incidence of WMSDs(N)**	**WMSDs Percentage (%)**
Age	25-30yrs	42/54	77.77
	31-40yrs	24/27	88.88
	>=41yrs	21/27	77.77
Height	145-160cms	15/22	68.18
	161-170cms	42/43	97.67
	>=171cms	30/43	69.76
Weight	50-65kgs	23/33	69.69
	66-80kgs	28/34	82.35
	>=81kgs	36/41	87.80
Gender	Male	75/90	83.33
	Female	12/18	66.66

Table 2: Association of 12-month prevalence of WMSDs and occupational characteristics among the medical practitioners

Independent Variables	Categories	Incidence of WMSDs (N)	WMSDs Percentage	Chi-square (χ2)	p-value
Total work Experience	<10 yrs	58/87	66.66	5.81	0.015*
	≥10 yrs	29/87	33.33		
Working days/week	6-working days	51/87	58.62	0.45	0.499
	7-working days	36/87	41.37		
Working hours/day	<12 hrs	31/87	35.63	6.70	0.009*
	≥ 12 hrs	56/87	64.36		

*Significance at the level of p<0.05

The prevalence of work-related musculoskeletal disorders was observed to be higher amongst the medical practitioners in the age group of 31-40 years, height group of 161-170 cm, weight group of >=81kgs compared to other respective groups. The highest percentage of respondents (66.66%) experienced their first episode of WMSDs in the first ten years of clinical practice. Further, it was observed that practitioners (64.36%) working more than 12 hours/day were seen to be more prone to WMSDs.

3.5. Self-reported severity of pain by the medical practitioners

Table 6 shows the self-reported intensity of pain with the demographic and occupational characteristics of the medical practitioners. It was observed that majority of the respondents who reported their pain intensity as severe (55.5%) were in the age group of 31-40 years and very severe (55.5%), in the age group of ≥41 years. It was found that while considering the work experience of the medical practitioners, the majority of them reported their intensity of pain as very severe (56.6%) and reported that this 'very severe' pain had been persistent for a period greater than ten years of practice.

Table 6: Self-reported severity of pain with the demographic and occupational characteristics of the medical practitioners

Variables	Categories	Pain Intensity		
		Mild (N %)	Severe (N %)	Very Severe (N %)
Age				
	25-30 years	21/54 (38.8)	21/54 (38.8)	-
	31-40 years	-	15/27(55.5)	9/27 (33.3)
	≥41 years	3/27(11.1)	3/27(11.1)	15/27(55.5)
Gender				
	Males	27/75 (36.0)	33/75(44.0)	15/75(20.0)
	Females	-	6/12(50.0)	6/12 (50.0)
Working Experience				
	<10 years	26/58(44.8)	27/58(46.5)	5/58(8.6)
	≥10 years	2/29 (6.8)	10/29 (34.4)	17/29 (58.6)
Working Hours				
	<12 hours	12/33 (36.3)	18/33(54.5)	3/33(9.09)
	≥12 hours	12/54(22.02)	18/54(33.3)	24/54 (44.4)

4. DISCUSSIONS

This study brought out the fact that the MSS in medical practitioners was high (80.55%) and the medical practitioners in India worked for long hours due to high workload. This study is the first cross-sectional investigation of MSCs among physicians and surgeons practicing in Indian hospitals, so no Indian data was available for comparison. The study showed that low back and neck were the most commonly affected body parts among the physicians and surgeons which corroborated the findings of a previous MSC study conducted across a cross-section of Chinese hospital physicians [17] and in a study conducted by general surgeons in Hong Kong [13]. Studies have reported that low back pain was found to be the most prevalent MSD in adult and about 60-80% of all individuals might experience the condition at some stage in their life [32]. Physicians had either prolonged sitting posture or constant bending over the bed while physically examining patients in indoor, ICU and outpatient departments. While physically examining patients in outpatient/inpatient or constant monitoring in ICU may lead to constant bending over the bed, which may be associated with considerable physical stress resulting in complaints predominantly of back and neck pain [19]. Surgeons worked exclusively in the standing position with mild to moderate bend trunk and neck over operation table for prolonged periods, especially in long duration surgeries which may have precipitated significant strain on the lower back and neck [13]. 67% of surgeons reported that their major part of the time were carried out by the activities in standing posture. Physical workplace tasks of the surgeons also included regular walking from ward to ward, observing/ attending and assisting seniors in outpatient department for prolonged duration may load forces over knees and ankle/feet. Statistical test in our study has revealed that there were no significant differences in the frequency of WMSDs between physicians and surgeons.

A high percentage (88.88%) of the medical practitioners in this study experienced WMSDs in the age group of 31-40 years compared to other age groups. The reason behind this may be due to the degenerative changes, which may have initiated after the age of 30. The present study concluded that practitioners aged ≥41 years were afflicted with MSDs of significantly intense severity than the younger age groups [(25-30) and (31-40)]. Similarly, it was also observed that the prevalence of WMSDs was highest among the medical practitioners with the work experience (<10 years), although the intensity of pain was very severe among the practitioners having greater work experience (>10 years). Our findings were consistent with other studies that reported that the prevalence of MSD appears to decrease with increasing age, but the severity continues to increase with increasing age [33], [34].This might be due to modification of lifestyle because of MSD, having an increased level of knowledge about injury prevention and developing better coping strategies for musculoskeletal problems than the less experienced and younger practitioners. Another possible reason might be that older and experienced practitioners handle relatively lesser number of patients and sometimes perform only the crucial part of the surgeries and remain involved in other activities like administrative duties and supervision work [13]. Statistical test in our study has revealed significant association between rates of WMSDs with working hours/day. 58.3% of medical practitioners were found to work ≥ 12 hrs/day, which might be a contributing factor for MSCs (64.36% of them reported MSCs). The effect of work on the perceived strain was also observed among both physicians and surgeons, through VAS in the present study.

5. CONCLUSION

The study concludes that MSDs were reported by a very high proportion of practitioners and no significant differences was observed in the frequency of WMSDs between physicians and surgeons. ‘Work’ was found to be the most common perception amongst the practitioners, for their musculoskeletal symptoms. The study also observed occupational characteristics to have a significant influence on WMSDs in medical practitioners. Future studies may be undertaken to determine other precipitating factors for the etiology of WMSDs in medical practitioners to get concrete results. This article may help ergonomists and medical practitioners to give better tools to set priorities in the attenuation of WMSDs.

REFERENCES

[1] Franco G., (2000): Ramazzini’s De Morbis Artificum Diatriba and Society, culture, and the human condition in the seventeenth century. *Int. J. Occup. Environ. Health* 6, 80–85.
[2] Tittiranonda P., Burastero S., and Rempel D., (1999): Risk factors for musculoskeletal disorders among computer users. *Occupational Medicine*; 14(1), 17–38.
[3] Abbas M.A., Afifi A.A., Zhang Z.W. and Kraus J.F. (1998): Meta-analysis of published studies of work-related carpal tunnel syndrome. *International Journal of Occupational and Environmental Health*; 4(3), 160–167.
[4] Lincoln A.E., Vernick J.S., Ogaitis S., Smith G.S., Mitchell C.S. and Agnew J. (2000): Interventions for the primary prevention of work-related carpal tunnel syndrome. *American Journal of Preventive Medicine*, 18(4), 37–50.
[5] Nordstrom D.I., DeStefano F., Veirkant R.A., Layde P.M. (1998): Incidence of diagnosed carpal tunnel syndrome in a general population. *Epidemiology*; 9(3), 342–345.
[6] Kroemer K.H.E, (1989): Cumulative trauma disorders, their recognition and ergonomics measures to avoid them. *Applied Ergonomics*, 20(4), 274-280.
[7] Polanyi M.F.D., Cole D.C., Beaton D.E., Chung J., Wells R., Abdolell M., Hawley L.B., Ferrier S.E., Mondloch MV, Shields SA, Smith JM, Shannon HS., (1997): Upper limb work-related musculoskeletal disorders among newspaper employees: cross-sectional survey results. *Am J Ind Med*, 32(6):620-8.
[8] Das, S. K., Sen, S., & Mukhopadhyay, S. (2015). The influence of head–neck position on wrist flexor strength. *International Journal of Human Factors Modelling and Simulation*, 5(1), 53-60.
[9] Escorpizo R., (2008): Understanding work productivity and its application to work-related musculoskeletal disorders. *International Journal of Industrial Ergonomics* 38(3-4), 291 – 297.
[10] Kee, D., Chung, M. K., & Kim, J. H. (2011). Legal system and its effect on prevention of work-related musculoskeletal disorders in Korea. *International Journal of Industrial Ergonomics*, *41*(3), 224-232.
[11] Das, S. K., Mukhopadhyay, S., & Koilakuntla, M. (2015). Analytic Hierarchy Process to Rate Risk Factors Associated with WMSDs in General Physicians. *Journal of Health Management*, *17*(2), 241-247.

[12] Bongers, P.M., C.R. Winter, M.A. Kompier & V.H. Hildebrandt (1993). Psychosocial factors at work and musculoskeletal disease. *Scandinavian Journal of Work, Environment, and Health*, 19(5), 297–312.

[13] Szeto G. P. Y., Ho P., Ting A. C. W., Poon J. T. C., Cheng S. W. K. and Tsang R. C. C., (2009): Work-related Musculoskeletal Symptoms in Surgeons. *Journal of Occupational Rehabilitation*, 19(2), 175-184.

[14] Pathak, V., Chakraborty, T., & Mukhopadhyay, S. (2013). Reliability and Validity Analysis of Modified Nursing Stress Scale for Indian Population. *Journal of nursing measurement*, *21*(2), 224-245.

[15] Bork B. E., Cook T. M., Rosecrance J.C., Engelhardt K., Thomason M.J., Wauford I.J., Worlq R. K.,(1996): Work-Related Musculoskeletal Disorders Among Physical Therapists. *Physical Therapy*, 76 (8), 827-835.

[16]Russo A., Murphya C., Lessoway V. and Berkowitz J., (2002): The prevalence of musculoskeletal symptoms among British Columbia sonographers. *Applied Ergonomics*, 33, 385–393.

[17] Smith D. R., Wei N., Zhang Y.J. and Wang R. S., (2006a): Musculoskeletal complaints and psychosocial risk factors among physicians in mainland China. *International Journal of Industrial Ergonomics*, 36, 599 – 603.

[18] Smith D. R., Zhang X., Zheng Y., Zhang B. and Wang R. S. (2006b): Musculoskeletal disorders and their after-effects among health professionals in Beijing. *Occupational Ergonomics*, 6(1), 25-34.

[19] Long, M. H., Johnston, V., & Bogossian, F. (2012). Work-related upper quadrant musculoskeletal disorders in midwives, nurses, and physicians: a systematic review of risk factors and functional consequences. *Applied ergonomics*, *43*(3), 455-467.

[20]Berguer R, Rab GT, Abu-Ghaida H, Alarcon A, Chung J. A comparison of surgeons' posture during laparoscopic and open surgical procedures. *Surg Endosc*. 1997; 11:139–42.

[21] Kant, I. J., de Jong, L. C. G. M., van Rijssen-Moll, M., & Borm, P. J. A. (1992). A survey of static and dynamic work postures of operating room staff. *International archives of occupational and environmental health*, *63*(6), 423-428.

[22] Umehara, Katsura, Yukihiro Ohya, Norito Kawakami, Akizumi Tsutsumi, and Masanori Fujimura. 2007. "Association of Work-Related Factors with Psychosocial Job Stressors and Psychosomatic Symptoms Among Japanese Pediatricians." *Journal of Occupational Health* 49 (6): 467-481.

[23]Sutherland V.J (1995): Stress and the new contract for general practitioners. *Journal of Managerial Psychology*, 10(3), 17–28.

[24]Sharma, E. (2005). Role stress among doctors. *Journal of Health Management*, *7*(1), 151-156.

[25] Deo, Madhav G. 2013. "Doctor Population Ratio for India - The Reality." The Indian Journal of Medical Research 137 (4): 632.

[26] Morse T., Bruneau H. and Dussetschleger J., (2010): Musculoskeletal disorders of the neck and shoulder in the dental professions. *Work: A Journal of Prevention, Assessment, and Rehabilitation*, 35(4), 419-429.

[27] Bernard BP., (1997): Musculoskeletal disorders and workplace factors-A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati, OH: National Institute for Occupational Safety and Health.

[28]Gangopadhyay S., Das B.,Das T. and Ghoshal G., (2005): An ergonomic study on posture-related discomfort among preadolescent agricultural workers of West Bengal, India. *Int J Occup Saf Ergon*; 11(3):315-22.
[29]Roy S., Dasgupta A., (2008): A study on the health status of women engaged in a home-based "Papad-making" industry in a slum area of Kolkata. *Indian J Occup Environ Med*; 12(1):33-6.
[30]Kuorinka I, Jonsson B, Kilbom A, et al (1987): Standardized Nordic questionnaires for the analysis of musculoskeletal symptoms. *Applied Ergonomics*; 18:233-237.
[31]Aitken, R. C. (1969). Measurement of feelings using visual analogue scales. *Proceedings of the royal society of medicine*, *62*(10), 989.
[32]Waddell, G., & Burton, A. K. (2001). Occupational health guidelines for the management of low back pain at work: evidence review. *Occupational medicine*, *51*(2), 124-135.
[33]Anderson, R. (1992). The Back Pain of Bus Drivers: Prevalence in an Urban Area of California. *Spine*, *17*(12), 1481-1488.
[34] Frymoyer, J. W., Pope, M. H., Clements, J. H., Wilder, D. G., MacPherson, B., & Ashikaga, T. (1983). Risk factors in low-back pain. An epidemiological survey. *The Journal of bone and joint surgery. American volume*, *65*(2), 213-8.

A PROPOSED APPROACH FOR THE ERGONOMICS USABILITY INTERVENTIONS EVALUATION

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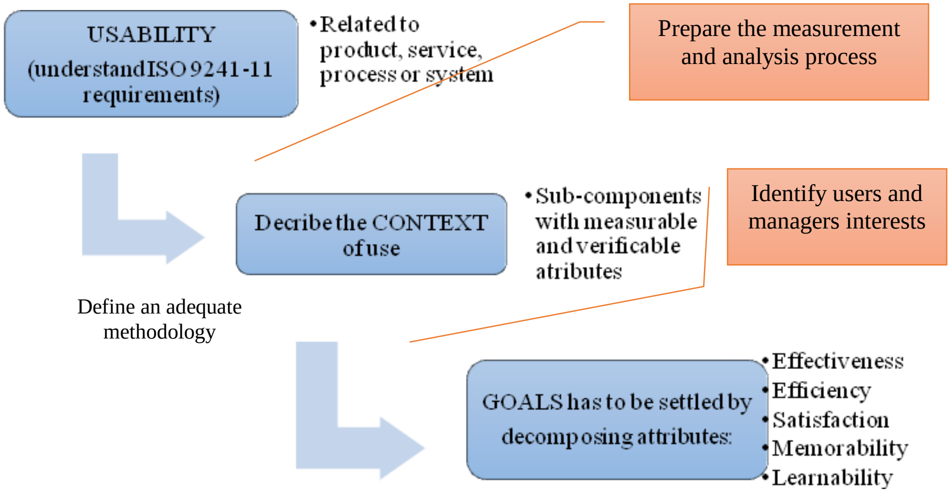
Abstract

ISO 9241-11 and ISO 13407 are recognized as important standards related to usability. ISO 9241-11 suggests that usability measures should cover: effectiveness (the ability of users to complete tasks using the system, and the quality of the output of those tasks), efficiency (the level of resource consumed in performing tasks) and users' satisfaction (subjective perception when using the product, process or system). Based on these basic knowledge on usability concept the article describes a proposed methodology for the global assessments of the ergonomics interventions in the case of industrial system. The research scenario consists in a survey based on a developed questionnaire that evaluate the ergonomics interventions, in terms of usability. In addition, the results of an experimental research demonstrate the testing and validation of the proposed approach. The method could be seen as an ergonomics continuous improvement one.

Keywords*:* *ergonomics, usability, assessment, improvement*

1. INTRODUCTION

The concept of usability has evolved in the man-machine-environment system studies and was strongly debated for users interface, user-centered design subject of interest [4, 5]. Usability is "*about learnability, efficiency, memorability, errors, and satisfaction*" [5]. The above definition refers in addition to efficiency in normal use and satisfaction with use, learnability in early use, memorability after a period of non-use and aspects related to errors during use, in order to avoid undesirable consequences.
ISO 9241 series and ISO 13407 are two important standards related to usability: the former one (part 11) provides the definition of usability and the latter one guidance for designing usability [2, 3]. According ISO 9241-11 usability is seen as "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" (this is the main reference of usability) [2]. The standardize approach of the concept represent both users and business requirements: effectiveness means success in achieving goals, efficiency means not wasting time and satisfaction means willingness to use the system. In addition, Figure 1 shows the main aspects that have to be considered when a usability analysis and evaluation is developed, together with its benefits. The perspective introduce by the ISO 9241-11 standard has been extended to product, service, processes and systems.



The approach is used to identify the usability measures and context of use when designing, analysis or evaluating usability.	Attributes are used to analysis and measure the extent to which a product, process or system is usable in a particular context.	Measures of usability attributes can provide the basis for comparison and dynamics analysis.

Figure 1: Aspects related to usability approach (derived from ISO 9241-11)

In this context, the article describes a proposed methodology for the global assessments of the ergonomics interventions in the case of industrial system. The research scenario consists in a survey based on a developed questionnaire that evaluate the ergonomics interventions impact, in terms of usability. In addition, the results of an experimental research demonstrate the testing and validation of the proposed approach. The method could be seen as an ergonomics continuous improvement approach, too.

2. TECHNICAL REQUIREMENTS AND METHDOLOGY

The continuous improvement dynamics in the case of industrial systems is high. Ergonomics interventions and corrections are correlated with the health and safety strategy, with quality management requirements and finally, to ergonomics improvements that support workplace well-being [7, 9]. Usability is seen as an adequate attribute to a purpose (applicable for ergonomics continuous improvement) of any particular product, service, process or system. It means to collect structured feed-back from users that express their opinions regarding a particular context of use, relatively to their work place. This is related to participatory ergonomics.
When selecting usability metrics, it is often desirable to have measures which do not require vast effort and expenses to collect and analyze data. Complex systems or tools of participatory ergonomics were analyzed but their main disadvantage is related to additional high costs for external consulting and implementation [4, 6]. Other references have indicated methods or techniques for participatory ergonomics having the primary purpose of: idea generation and concept development, concept evaluation, problem solving or process recording [4, 8].

For practical purposes, there have been adopted the survey approach developed with the support of the work places users, employees of an industrial system. A questionnaire was developed and it was inspire by the System Usability Scale (SUS) described in [1].

Table 1: The questionnaire for ergonomics usability interventions evaluation

#	Question/usability item evaluated: Strongly disagree … Strongly agree 1 2 3 4 5	Usability capacities or attributes evaluated*:
1	I think that I would like to use the new working system frequently	S (-1)
2	I found the new working system un-useful un-helpful, too complicated, too complex	M (-5)
3	I suppose that the new working system was easy to use in terms of my work effectiveness including error avoiding	O (-1)
4	I think that I would need guidance from the technical person in order to attend high level of efficiency of my work in the new conditions	E (-5)
5	I found the different handling working movements very easy to be learned within the new working system	L (-1)
6	I think that I can do the different handling working movements more quickly, but after a period of adaptation and conformation	O (-5)
7	I imagine that most of my co-workers would learn to use this new working system quickly	E (-1)
8	I found the new working system very difficult to use: embarrasses me sometime or limited my working movements	S (-5)
9	I am very confident using the new working system	M (-1)
10	I have to learn a lot of things before I could get using the new working system very good	L (-5)

*) E – Efficiency including error avoiding; O – Effectiveness including error avoiding; L – Learnability; S – Satisfaction; M – Memorability

The questionnaire has been developed during three focus groups done with the involvement of the external consultants (the researchers), supervisors and the middle managers of the industrial system. The creative sessions have been take into considerations the objectives followed by the ergonomics intervention. Based on the final solutions implementation, positive/negative aspects related to usability have been considered for the questions formulation (Table 1). Each item that was evaluate has been measure using a 5 point Likert scale in order to identify aspects or things which lead to extreme expressions of the attitude being captured by users collected opinions.
The questionnaire was distributed after users had a period of time of using (get familiar with) the facilities created by the ergonomics, but before any debriefing or discussion between them or with their supervisors. Users/respondents were asked to record their responses as spontaneous opinions, rather than reflecting about items for a long time. If a user feels that he/she cannot respond to a particular question, this was marked in the center point of the respond scale (3). The final score has been calculated similar to the procedure mention in [1]. First there have to be sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1, 3, 5, 7 and 9 the score contribution is the scale position minus 1; for items 2, 4, 6, 8 and 10, the

contribution is 5 minus the scale position. The final ergonomics usability interventions evaluation score is the result of multiplying the sum of the scores by 2.5.

3. CASE STUDY

The proposed approach has been developed, tested and validated in the case of an assembly line for automotive cables and wires where different ergonomics interventions were implemented as described in Figure 2 and Table 2. After these processes the ergonomics usability interventions evaluation has been done and the results are shown in Table 3.

Table 2: Main ergonomics interventions

Work places or areas of intervention	Improvements operated	Benefits
Control and defect prevention work places (Figure 2a)	Re-organizing work places with respect of succession movements; Re-organization of the local logistics; Re-orientation in an horizontal plan of the control and test panels	Improve employees postures (reduce back pains); Increase work rhythms and efficiency; Use of gravity for handling materials; Improve work place design
Cables assembly work places (manual operation with visual inspection) (Figure 2a)	Correct gripping and grasping of objects; Eliminate repetitive tasks; Tools were suspended when possible; Implement ergonomic chairs	Avoid hands fatigue and adopt good tool-work piece contact; Improve reaching and grasping; Assembly time cycle reduction; Improve employees postures
In-circuit defection work places	Eliminating postures as bending, twisting, eye movements, lifting against gravity by re-organization and re-design	Eliminate back pain, shoulder pain, wrist pain, neck pain etc.; Increase of work efficiency
Packaging work places	Re-design of the work place by intensive using of gravity; Introduce a handling system for big packages (vacuum grip)	Reduce back injuries; Eliminate some human movements because of using gravity; Automate the process of packaging and shipment
In-door training area (Figure 2c)	Design and implementation of an adequate area of training; Define a group of Ergo Coaches to support employees	Reduce time for adopting a new assembly tasks through demonstrations and practical exercises; New employees are taught the proper technique, including safety and quality

a. b. c.

Figure 2: Details of the ergonomic intervention final solutions: a. re-orientation in an horizontal plan of the control and test panels, b. ergonomic organization of the work places, c. in-door training program

Table 3: The ergonomics usability interventions evaluation – research results

Work places or areas of intervention	Global score gained by each user / questionnaire applied	Average	Conclusions
Control and defect prevention work places (10 users investigated)	55, 67.5, 84, 72.5, 70, 77.5, 90, 95, 100, 67.5	77.90	Most of the improvements were made in these areas. Users appreciate well the usability but new developments should positively affect *learnability* and *satisfaction* attributes.
Cables assembly work places (manual operation with visual inspection) (24 users investigated)	75, 80, 77.5, 55, 62.5, 87.5, 84, 90, 90, 55, 80, 80, 65, 67.5, 84, 72.5, 70, 77.5, 90, 95, 100, 82.5, 90, 77	78.65	
In-circuit defection work places (10 users investigated)	65, 77.5, 67.5, 90, 84, 72.5, 70, 77.5, 90, 84	77.80	
Packaging work places (6 users investigated)	75, 80, 77.5, 82.5, 70, 95	80.00	Usability has been very well appreciated. Improvements can be done for *effectiveness* attribute.
In-door training area (10 users investigated)	90, 82.5, 87.5, 84, 90, 95, 100, 95, 82.5, 87.5	89.40	
Total users investigated: 60 subjects		80.75	Very good score gained in comparison with the investments done for the ergonomic interventions.

4. CONCLUSION

The presented research approach has underlined the strong link of usability with ergonomics (improvements done exploiting ergonomics knowledge have a positive, direct impact on usability attributes). The perspective of usability is closely aligned with business goals: effectiveness, efficiency and satisfaction have a direct impact on work productivity and finally, on profitability. The presented approach has demonstrate that the framework defined by ISO 9241-11 and ISO 13407 standards (refers to visual display terminals work places*)* could be extended to other working areas, from different industries. The developed questionnaire has proved to be a valuable evaluation tool, accepted by researchers and managers, practitioners from the industrial system; the questionnaire is considered robust and reliable.

Future applicative researches should extend the data process, as suggested by the SUMI inventory, in order to refine the description of users' behavior related to the usability attributes.

REFERENCES

[1] Brooke, J.: SUS - A quick and dirty usability scale, *Usability evaluation in industry*, 189 (1996) 194, pp. 4-7, ISBN 9780748404605

[2] ISO 9241-11: *Ergonomic requirements for office work with visual display terminals (VDTs) - Part 11 Guidance on usability*, (1998)

[3] ISO/IEC. *13407 Human-Centred Design Processes for Interactive Systems*, (1999)

[4] Karwowski, W. (Ed.): *International encyclopedia of ergonomics and human factors*, second edition, CRC Press, Taylor & Francis Group, ISBN: 978-0-415-30430-6, New York, 2006

[5] Nielsen, J.: *Usability Engineering*. Academic Press Inc., ISBN 0-12-518405-0, San Diego, 1993

[6] Robertson, M.; Henning, R.; Warren, N.; Nobrega, S.; Dove-Steinkamp, M.; Tibirica, L.; ... ; CPH-NEW Research Team: The intervention design and analysis scorecard: a planning tool for participatory design of integrated health and safety interventions in the workplace, *Journal of Occupational and Environmental Medicine*, **55** (2013), pp. S86-S88, ISSN 1076-2752

[7] Yazdani, A.; Neumann, W. P.; Imbeau, D.; Bigelow, P.; Pagell, M.; Theberge, N.; & Wells, R.: How compatible are participatory ergonomics programs with occupational health and safety management systems? *Scandinavian Journal of Work Environment & Health*, **41** (2015) 2, pp. 111-123, ISSN 1795-990X

[8] Waterson, P.; Robertson, M. M.; Cooke, N. J., Militello, L.; Roth, E. & Stanton, N. A.: Defining the methodological challenges and opportunities for an effective science of sociotechnical systems and safety, *Ergonomics*, **58** (2015) 4, pp. 565-599, ISSN

[9] Wilson, J. R.: Fundamentals of systems ergonomics/human factors, *Applied ergonomics*, 45 (2014) 1, pp. 5-13, ISSN 1872-9126

SYNERGY OF KNOWLEDGE MANAGEMENT AND ERGONOMICS FOR OCCUPATIONAL RISKS MITIGATION

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Abstract

Results of the interdisciplinary traditional approach of ergonomics has been better implemented through the exploitation of knowledge management methods and tools. Using these innovative idea, there have been developed a systematic approach to better support the decision-making process for the occupational risks mitigation by creating a related ontology. The acquired wisdom (results of the knowledge synergy created between ergonomics, knowledge and risk management sciences) was exploited for creating a software tool (OnRisk web platform) in order to increase assessment efficiency of the occupational risks management. The created ontology is a more effectiveness tool, better than a classical check-list used for risk assessment. It takes into consideration aspects as: risks characterization, impact, health problems, and corrective measures. The developed OnRisk tool facilitate companies' occupational risks mitigation approach toward sustainable development.

Keywords*:* *ergonomics, knowledge management, occupational risks, ontology, OnRisk platform*

1. RESEARCH MOTIVATION AND APPROACH

Occupational risk mitigation is defined as a systematic reduction (minimization and/or elimination) in the extent of exposure to a risk and/or the likelihood of its occurrence. According to the Council Directive 89/391/EEC from 1989, risk mitigation is related to the prevention behaviour that is seen as "*all the steps or measures taken or planned at all stages of work in the undertaking to prevent or reduce occupational risks*". Furthermore, Article 1 of the Directive, argue the strong objective of "*the prevention of occupational risks, the protection of safety and health, the elimination of risk and accident factors the elimination of risks and accident factors"*.
Article 6, refers explicit to the *general principles of risk prevention* (considered part of their mitigation in the presented research) that should be implemented by the employer: (a) avoiding risks; (b) evaluating the risks which cannot be avoided; (c) combating the risks at source; (d) adapting the work to individual; (e) adapting technical progress; (f) replacing the dangerous by non-dangerous or less dangerous; (g) developing a coherent overall prevention policy; (h) giving collective protective measures priority; (i) giving appropriate instructions to workers." Description is useful for understanding the risk mitigation activities and their impact (attending the objectives), in the context of a managerial preventive behaviour [1, 2, 3]. In synthesis, Figure 1 describes the occupational risk tracking process as an iterative one. The occupational risk mitigation

step involves the development of mitigation plans designed to eliminate or reduce risks to an acceptable level [1, 3], which is in consensus with the Council Directive 89/391/EEC and for the application of Council Directive 89/656/EEC related to the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace.

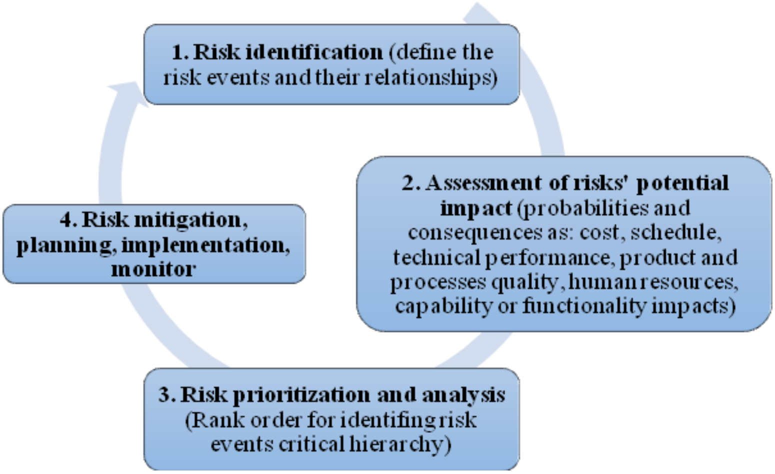

Figure 1: The occupational risks tracking process

According to [4], the adopted behaviour (avoid, control, transfer, monitor, assume/accept) when implementing a risk mitigation initiative is associated with the *consequence severity* and *occurrence probability* dimensions combination.

Occupational risk mitigation and tracking process (Figure 1) have been recognized as a complex, interdisciplinary and time consuming one. Furthermore, the occupational risk tracking process has to be developed fast and accurate (effectively and efficient) and usually involved an interdisciplinary team working with a large quantity of information, knowledge. Specialists, managers and employees are working together for the work conditions improving, with respect to the quality, occupational health and safety and environment standards and regulations, and simultaneously in concern with workplace well-being [3, 5]. In addition, there have been observed that occupational risk mitigation activities are strongly related to corrective ergonomics or process and systems ergonomics when the interdisciplinary team is trying to find an adequate solution (optimal) on diminishing or eliminating a specific risk [3, 6].

During the last five year, results of the interdisciplinary traditional approach of ergonomics has been better implemented through the exploitation of knowledge management methods and tools. Using these innovative idea, there have been developed a systematic approach to better support the decision-making process for the occupational risks mitigation by creating a related ontology [3, 6]. The acquired wisdom (results of the knowledge synergy created between ergonomics, knowledge and risk management sciences) was exploited for creating a software tool (OnRisk web platform) in order to increase assessment efficiency of the occupational risks management. The proposed approach is described in Figure 3.

Based on these preliminary considerations, the paper will outline the details of the systematic approach used to build the risk ontology and complementary knowledge map for the occupational risk mitigation. The main reason for this approach is to unify the different checklists available for the risk assessment process that are applied in different enterprises. This will better support the decision-making process in terms of identifying the corrective measures for the risks mitigation by using the created software tool developed based on the occupational risks ontology. In the final part of the article is described the design process of a web platform (so called, OnRisk) that support the occupational risks mitigation processes.

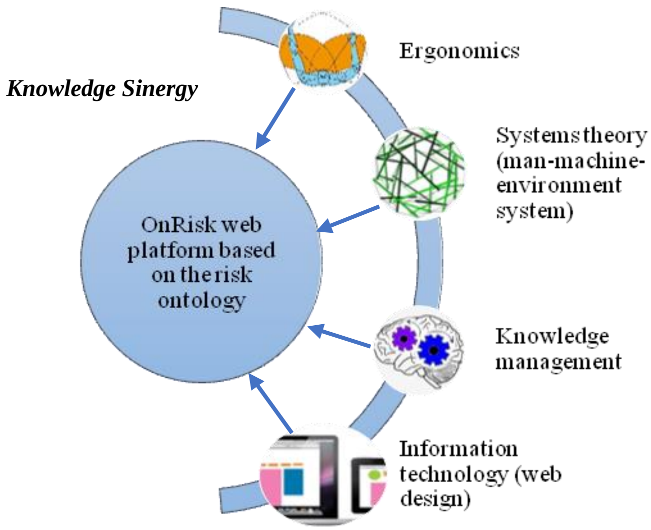

Figure 2: The research approach logic

2. THE OCCUPATIONAL RISK ONTOLOGY

The central aim of the research was to create synergy and integration of the expertise and capabilities of different sciences (ergonomics, knowledge management, and systems theory, together with information technology) in order to support the risk mitigation process in enterprises. The research results were:

1. Building an occupational risk ontology for generating a common reference language among researchers and future users that can overcome differences in culture, location and fields of expertise. This will facilitate the implementation of the occupational health and safety regulations and standards, too;
2. Implementing a knowledge management system that will support the knowledge-sharing capabilities in the case of a particular economic field (enterprise) and the decision-making process for risks mitigation;
3. Implementing an information technology application enabled the monitor and control processes for occupational risks.

During the creative process of the risk ontology development, several iterative actions (as bottom-top and top-bottom) were implemented, in order to collect, acquire and structure the data, information and knowledge. Several focus group and team working

sessions within an interdisciplinary team of experts, were held to define the basic structure and instances of the ontology.
The developed ontology focuses on all the terms as: different risks aspects/context, impact related to work diseases and work accidents, preventive and corrective measures. They were described based on the related knowledge of the occupational health and safety management, ergonomics and environmental management; relationships and implications between them were considered, too. This has supported a holistic approach of the occupational risks mitigation process. Figure 3 summarizes the results of the work done (tree structure) [5].

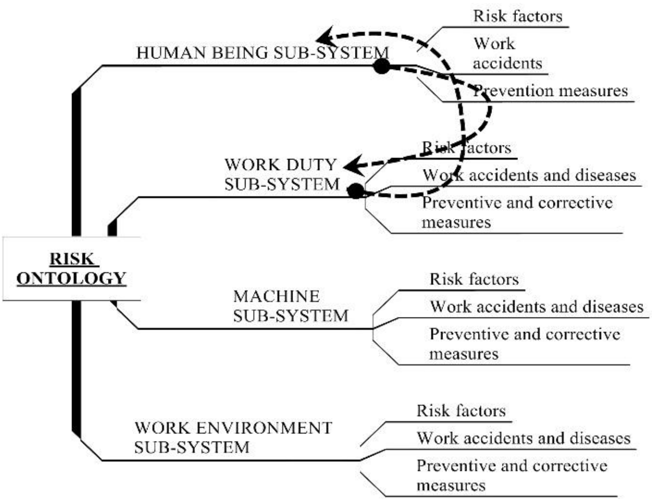

Figure 3: The basic structure of the designed risk ontology

Each item of the knowledge taxonomy were described in a specific file (notes) that include the details according to existing regulation, standards and relevant references, with some examples and case studies for particular fields. In addition, there were created links between different branches of the ontology in order to show potential correlations or parallel assessments that should be done.
The tree structure creation and the easy visualisation process of the ontology were demonstrated during several demonstration sessions that were developed with industry representatives (pilot testing of the solution) [5].

3. THE RISK MITIGATION SOFTWARE TOOL

The OnRisk platform consists of several pages created in HTML and PHP scripts, based on the predefine risk ontology. WampServer 2.1 (running under Windows operating systems) was used in order to run the application; this is a mini-server that provides users access to the web page. The main advantage of the OnRisk platform solution is its dynamic development that allows creating, adding new sources of danger risks (knowledge entities) [5].
The risk mitigation process is developed by querying users and managers of different workplace systems about the presence and evolution of different risk sources (described

in the ontology). For each category of risk, the answers are coding in the form of bits (0 - negative response; 1 - positive response) and then is developed a qualitative analysis on the exposure, impact and consequence (using qualitative imperative as low, medium, high). For the medium and high risks impact, the OnRisk platform support a quantitative assessment for which the specialist associates the events occurrences probabilities (ultimately yielding the rule, as bits) and they consequence with adequate measures of risks prevention and treatment.
These iterative actions define the risk mitigation process and its final report can be downloaded and printed. During several pilot testing sessions, the OnRisk platform utility have been positively confirmed. In addition, there have been identified its high rate of acceptance (because of low costs for implementation, user-friendly interface and the exploitation benefits for training sessions).

4. CONCLUSION

The article has presented a brief description of our research results in the field of risk mitigation based on the synergy created because of the ergonomics way of action. Initially, there have been shown the context and motivation of the proposed approach for the risk ontology design.
The ontology is based on a design taxonomy that consist the following items or sub-ontology: risk factory, work diseases/accidents related to each risk factor and the possible and allow prevention/corrective measures. This description was structured for the corresponding part of the man (work duty) – machine – environment system. The ontology development and visualization was done using MindManager software.
Secondly, there were described the functionalities created for the OnRisk web platform created to support the risk mitigation process in enterprises. The risk ontology was the basis the OnRisk web platform development and its exploitation will increase the efficiency and effectiveness of the risks mitigation processes and will support the preventive strategy, behaviour for the occupational health and safety.

5. AKNOWLEDGEMENT

The research results were tested and validated through several industrial cases. The related findings were gained through our work in the national project: Researches based on Knowledge Management Approach Concerning Industry–University Collaboration in the Open Innovation Context (UNIinOI). This work was undertaken through the Partnerships in Priority Domains Programme-PN II, developed with the support of MEN-UEFISCDI, Project no. 337/2014 in Romania. Any findings, results, or conclusions expressed in this article belong to authors and do not necessarily reflect the views of the national authority UEFISCDI.

REFERENCES

[1] Badri, A.; Gbodossou, A. & Nadeau, S.: Occupational health and safety risks: Towards the integration into project management, *Safety science*, **50** (2012) 2, pp. 190-198.

[2] Moraru, R. I.: *Current Trends and Future Developments in Occupational Health and Safety Risk Management*, INTECH Open Access Publisher, (2012) *Available from* http://cdn.intechopen.com/pdfs/36096.pdf *Accessed*: 2016-02-04.

[3] Yoon, S. J.; Lin, H. K.; Chen, G.; Yi, S.; Choi, J. & Rui, Z.: Effect of occupational health and safety management system on work-related accident rate and differences of occupational health and safety management system awareness between managers in South Korea's construction industry. *Safety and health at work*, **4** (2013) no. 4, pp. 201-209, ISSN 2093-7911

[4] Garvey, P. R.: *Analytical Methods for Risk Management: A Systems Engineering Perspective*, Chapman-Hall/CRC-Press, Taylor & Francis Group (UK), Boca Raton, ISBN 1584886374, London, New York, (2008)

[5] Ivascu, L.; Draghici, A.; Fistis, G.; Harpan, I. & Farkas, Z.: A Proposed framework for the risk management evaluation, *Proceedings of the 2014 International Conference on Production Research–Africa, Europe and Middle East and 3rd International Conference on Quality and Innovation in Engineering and Management*, Popescu D. (Ed.), pp. 266-271, ISBN: 978-973-662-978-5, Cluj-Napoca, Romania, July 2014, Technical University of Cluj-Napoca, (2014)

[6] Dragoi, G.; Draghici, A.; Rosu, S.M.; Radovici, A. & Cotet, C.E.: Professional Risk Assessment Using Virtual Enterprise Network Support for Knowledge Bases Development, *ENTERprise Information Systems*, *Communication in Computer and Information Science*, Part II, **110**, pp. 168-177, ISSN 1865-0929

AN ANALYSIS OF TRAIN DRIVER'S COGNITIVE WORKLOAD RELATED TO CROATIAN NATIONAL SIGNALLING SYSTEM

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Abstract

Train driver's cognitive workload represents a key factor for efficiency and safety of train operations. Thus, modern requirements for efficiency of train operations regarding to railway timetable stability and energy efficiency can lead to very high level of train driver's workload and this can result with a negative impact on level of railway safety. In this paper the train operation process related to Croatian national signalling system is explained and analysed regarding to driver's cognitive workload.

Keywords*: train operation, transport ergonomics, railway signalling*

1. INTRODUCTION

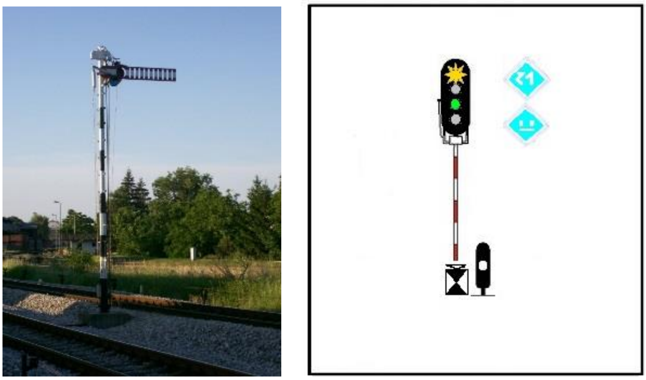
Train driver's cognitive workload represents a key factor for efficiency and safety of train operations. Modern requirements for efficiency of train operations regarding to railway timetable stability and energy efficiency can lead to very high level of train driver's workload and this can result with a negative impact on level of railway safety. The purpose of this work is to research the possibility of future introduction of driver advisory systems with purpose of improvement of existing train and traffic control efficiency in Republic of Croatia, regarding the existing train driver workload and its potential increase. According to this, the aim of this paper is to conduct an analysis of the factors influencing the driver's cognitive workload during the train driving process. Related to this a key factors related to the driving process have to be distinguished. By an analysis provided for train driver's workload related to Croatian railway system several key factors were distinguished as follows:

- Complexity of signalling system
- Train driver's actions related to automatic train protection system Indusi I60
- Train driver's actions with dead-man's control system and supervision of other on-board functions
- Reading of timetable data and application of train driver advisory system

In the next chapters the train operation process related to Croatian national signalling system will be explained and regarding to this the key factors related to driver's cognitive workload will be analysed.

2. COMPLEXITY OF SIGNALLING SYSTEM

Railway operations include large number of different processes controlled by clear definite rules which have to be respected by all railway workers including the train drivers. One part of these rules related to movement authority for trains are presented to the train drivers by means of wayside signals. Although the effort for signal aspects to be less complicated railway signaling is still very complex and specific for different national signaling systems. However some rules are established and logic, for example: red means stop, green means free driving. Considering the fact that railway vehicles are very heavy they need specific time for acceleration to wanted speed or to slowdown or brake to stop. Proscribed breaking distance for lines in Republic of Croatia depends on the maximum speed limit on the line and can be 700, 1000 and 1500 meters and because of limited train driver sighting distance of signals this significantly affects the number and complexity of railway signals placed along the line and therefore have an influence on the train driver workload. In rail operations railway workers from various segments of the railway system e.g. from infrastructure manager or different numbers of cargo and passenger railway operators, are involved. Infrastructure manager's staff is mainly responsible for traffic regulation issues and staff involved by railway operators is responsible for driving and manipulating with trains. In order for train driver to be sense how to safely drive a train in every single moment, he must be able to read all those signal aspects given by wayside railway signals, warning signs and signs given by other mentioned staff participated in the railway process. Movement authority given by signals is related to station interlocking system which is responsible for route setting based on the railway safety logic. Beside this, Croatian national railway signaling system contains two different versions of railway signals, respectively color light and mechanical signals (see fig. 1), and this can additionally affect train driver workload.
In Croatian signaling system main color light signals have to be able to show 11 different signal indications, distant signals and their repeaters have to be able to show 6 different indications and other various signals combined with main signals have to be able to show 6 different indications. Also, there are additional wayside signals used for a warning the train driver on upcoming speed limits and level crossings. Also, if the line is electrified there is additional number of signals, as well as 14 boards, related to the train traction issues which have to be monitored by the train driver [1].
Furthermore, there are signal indications given by executive staff and various warning signs. Beside main signals there are also distant signals have to must constantly be monitored by a train driver so he can adjust the train speed to the actual track conditions.
Regarding the meaning of signal aspects a main signals can be derived as single or ambiguous. Thus, ambiguous main signal shows to driver how to drive a train in the block behind this signal and additionally behind the successive one.
The sketch shows the appearance of such ambiguous signals and explains the symbols that identify specific information for the train driver [2]. The figure 1 is showing sketch of one ambiguous main signal with additional 5 signs.



a. b.

Figure 1. a. Mechanical main signal, b. Sketch of main signal with additional signs

Figure 1, part b.) shows the ambiguous signal that simultaneously giving two warning signal indications i.e. indication free with limited speed and an additional indication that on the successive main signal train driver can expect a green light which allows train to pass it with the track speed or yellow light with the meaning of free pass with caution because on the next successive signal stop indication can be expected.
Also on the sketch one additional square plate with two black triangle tops facing inwards can be seen. This sign represents the information for the train driver that this main signal also has a role of distant signal of the next successive main signal. Beside that there is an additional sign of triangle with the top down, which indicates that this signal is set to the distance shorter than proscribed one needed for stopping train until the next signal.
Beside those signals there is also the switching signal and the warning signs of the electric traction that indicate that the electric traction drive is permitted with one raised current collector and with the main power switch off. The train driver has to process all of this information and to comply with them [1].

3. TRAIN DRIVER'S ACTIONS RELATED TO AUTOMATIC TRAIN PROTECTION SYSTEM INDUSI I60

Traffic safety is the key issue related to the train driver cognitive workload. During the driving process train driver doesn't have the same level of ability for driving. The reason for this can be his level of mood for driving or tiredness. So far there were numerous cases where train driver didn't respect speed restrictions or passed signal at danger. Some of these cases finished with tragic consequences like the accident that happened on the Zagreb Main station in August 1974 (Fig. 2).

Figure 2. Railway accident caused by train not controlled by ATP system

After this accident an automatic train protection system Indusi I60 was introduced on Croatian Railways. Purpose of these devices is to prevent passage over the places on the track where the trackside equipment of ATP system is installed, if conditions for such passage are not met.

In case that engine driver does not respond with expected actions in front of the signal or on places equipped with track magnets, trackside devices influence locomotive part of ATP, which induces emergency braking. Operation of the system is based upon transferring a signal from the track onto the train using the principle of the inductive coupling.

Automatic train stopping device (ATP) consists of track and locomotive part (Fig. 3) With locomotive ATP device switched on, locomotive magnet radiates AC electromagnetic field of three frequencies, 500, 1000 and 2000 Hz. In case this field passes over the active track magnet of which the resonant circuit corresponds to one of three frequencies generated by the locomotive magnet, interference between locomotive and track magnet occurs – this is the way information is transferred from the track to the vehicle.

Three frequencies of the system correspond to the following functions:

- 2000 Hz influence immediately activates emergency braking. This influence is used on main signal for red light. When crossed, system will force emergency stopping. In the case that train driver gets a movement authority to pass signal at danger from the dispatcher, he has to activate the override button/switch. In that case the system will not force emergency stopping but it will be recorded that the override button/switch has been used by the train driver

- 1000 Hz influence activates alertness control of the engine driver and time control and activates speed control once the time control is over. After crossing the 1000 Hz track magnet, driver has to push acknowledge button within 4 seconds. If driver does not respond within 4 seconds, system will force emergency stopping. At the same time when influence 1000 Hz is detected, another timer is activated. If driver has pushed the acknowledge button within 4 seconds, that timer will continue. After time elapses, system will check velocity to confirm that everything is all right. If velocity exceeds speed limit, system will force emergency stopping

- 500 Hz influence controls speed on detection point placed on the certain distance in front of the main signal which is showing the red light i.e. the end of movement authority. This type of track magnet is always installed to control lower speed limit on entrances to stations, protection of shunting point and similar places. When it is crossed by train, system compares it's speed with speed limit and if it's speed is higher than the speed limit, it will force emergency stopping of the train.

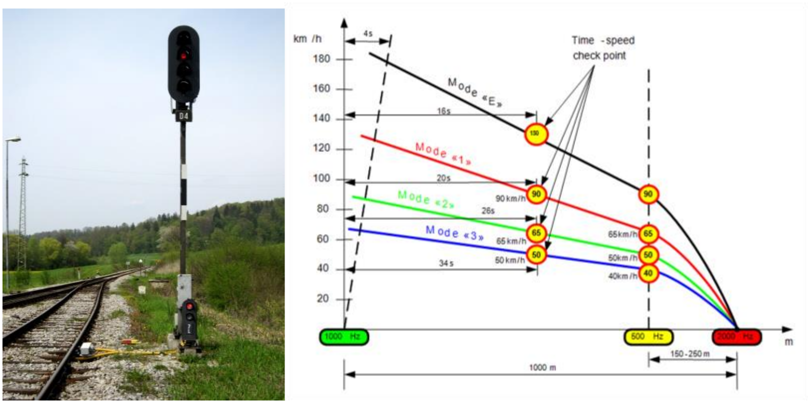


Figure 3. Automatic train protection system "Indusi 60"

All actions taken by the train driver related to the correct use of this system are recorded and can be subsequently supervised especially in case of some traffic accident. Due to this fact train drivers are encouraged to consciously use this system and this affects their cognitive workload during the driving process.

4. TRAIN DRIVER'S ACTIONS RELATED TO DEAD-MAN'S CONTROL SYSTEM AND SUPERVISION OF OTHER ON-BOARD FUNCTIONS

Driver vigilance device is protect system in a train, a locomotive, or a train motor unit which control vigilance respectively conscience diver which have to control the train. Control is performed, depending on the type of device, in a way that a train driver have to use push button in certain intervals so that the machine can recognize that the driver is awake and conscious. The device works in a way that the driver must press the push button, or pedal if the device is designed that the push button serves foot, at the certain intervals. Usually device is designed in both ways. [3]
Train driver has to press button or pedal continuously 25 seconds and after that he has to stop pressing it and then press it again. Another way is to make a short press on button or pedal and than in interval of 25 seconds press it again in order to the reset the process i.e. to restart time counter so it can start counting the time from the beginning.
If train driver doesn't serve device on these two described ways (which one will be in use depends on design of the train driver vigilance device) lamps light blink for 2,5 second. If he still doesn't serve the device, it turns on an audible alarm. Train driver has

2,5 additional seconds to serve device, otherwise an engine is automatically moved to a higher level of safety, i.e. quick braking will be activated to stop the train. The device is constructed to protect the driver and passengers of the train from any danger but it is also an important issue regarding the train driver cognitive workload [3].

On the railway lines equipped with radio communication system for continuous radio communication between train and traffic dispatching center the train driver is obliged to handle with radio communication device placed on the driver desk in the train cab. This system increases railway safety and it has an important role in optimization of rail traffic management process. By using this device a train driver can communicate with a railway line dispatcher. On this way the train driver is able to receive commands and other important information regarding his trip from the line dispatcher. Handling with the device for radio communication with line dispatcher makes an additional workload for train driver who drive a train on the railway lines equipped with radio communication system.

An additional important task for the train driver in passenger trains is to pay a lot of his attention on passenger’s safety during a boarding and alighting process, especially in case of crowded suburban services during the train doors closing action before its departure from station.

Furthermore, new generations of engines are more sophisticated by means of number of different devices installed onboard so they are usually equipped with monitoring systems to enable the train driver to recognize any disturbances or fault in the system. For instance, he is responsible to monitor the work of various devices (e.g. for braking traction, air conditioning etc.) in the train by looking in the special display aimed for supervision of these systems, so he can be able to react on time and correctly to avoid possible unwanted consequences.

5. READING OF TIMETABLE DATA AND TRAIN DRIVER ADVISORY SYSTEMS

Reading of timetable data is important task in train driving process. Traditionally for each train there is a timetable book (Fig. 4) and a book of railway line sections with temporary speed restrictions where train driver can read data e.g. about the arrival and departure times for his train in relevant railway stations and train stops, speed restrictions and other important data related to the specified trip.

EKVR-PP 36

DOBOVA–ZAGREB GLAVNI KOL.

R p=96% SW:1 141 Q=400t SV Kdk

KM. POLOŽAJ	SLUŽBENA MJESTA	BRZINA: PREKO SKRETNICA RED.	BRZINA: PREKO SKRETNICA OGR.	BRZINA: NAJVEĆA DOPUŠTENA	VRIJEME: DOLASKA	VRIJEME: ODLASKA	SASTAJANJA
1	2	3	4	5	6	7	8
499							
453.3	**DOBOVA**			30	(7.50)	**8.05**	
	RD A-63; AS R-1						
	km 452+600			100			
	km 451+200 dg			95		8.08	
	km 451+150			120			
	km 446+410			55			
446.1	SAVSKI MAROF		40			8.12	
	km 445+165			60			
439.6	ZAPREŠIĆ		40			8.19	
434.0	PODSUSED TVOR.		20			8.25	
426.6	ZAGREB ZAP. KOL.		35			8.33	
	km 425+385			50			
424.4	**ZAGREB GLAVNI KOL.**	■	30		**8.37**		

Figure 4. Timetable book for train in HŽI network

In some countries these books are replaced by electronic format of timetable where all necessary train's data are displayed on a flat screen. This can also be achieved by usage of train driver advisory systems which represent an on-board computer based support systems for train drivers. Purpose of such system is to offer an optimal driving strategy to the train driver regarding the timetable stability and energy efficient train driving (Fig.5). These systems are aimed to improve efficiency of traffic management process in the case of limited infrastructure capacity by means of improvement of timetable stability but in addition several other measures for increase of railway efficiency can be achieved. One of the most important from these measures is energy efficient train driving based on the optimization of train speed profile e.g. in commuter train operation the main saving strategy is coasting, i.e. switching off traction as early as possible before stations, and therefore the purpose of driver advisory system is to inform train driver when to start to coasting the train [5]. Train driver advisory systems do not represent safety systems but only give optional advices to the train driver how to drive a train. Regarding to this, a train driver should not accept recommendations offered by the system if he considers that they could endanger traffic safety.

Figure 5. Interface of train driver advisory system

In Republic of Croatia the traditional timetable books are still in use but there is a high possibility for usage of train driver advisory systems in the very near future.

6. CONCLUSION

In this paper the main factors influencing train driver workload in Croatian railway system were analyzed. Regarding the existing workload and its increase due to future introduction of driver advisory systems with purpose of improvement of existing train and traffic control efficiency, it is a question of how this incensement will affect the railway safety. According to this question it can be concluded that only reasonable solution can be implementation of semi-automatic train operation system (ATO GoA2). In that case the train driver shouldn't make an additional effort for the control of train's optimal speed profile during its run and thereby he will be more able to focus on the safety related issues like recognition of events or obstacles on the railway line critical for railway safety or more efficient reading of movement authority given by wayside sings and signals. In the near future it is expected that Croatian national railway signaling system will be replaced by European train control system (ETCS) which assumes transmission of movement authorities to the driver by cab signaling instead of wayside signals. In this case a new analysis of train driver's cognitive workload should be provided. Additionally, such analysis should include use of possible version of more sophisticated dead-man's control system provided by European train control system.

REFERENCES

[1] Ministry of the Sea, Transport and Infrastructure, *Ordinance on the meaning and use of the signals indications and signs in railway traffic*, NN 40/07, 120/08. (In Croatian)

[2] Toš, Z.: *Railway Signalling*, Faculty of Transport and Traffic Sciences, Zagreb, 2013. (In Croatian)

[3] Zavada, J.: *Railway Vehicles and Train Traction*, Faculty of Transport and Traffic Sciences, Zagreb, 2004. (In Croatian)

[4] Ministry of the Sea, Transport and Infrastructure, *Ordinance on the Way and Conditions for the Safe Performance of Railway Traffic*, NN 133/09, 14/10, 56/12. (In Croatian)

[5] Hansen, I.A. & Pachl, J.: *Railway Timetable & Traffic*, Eurailpress, Hamburg, 2008.

ERGONOMIC DESIGN OF PRODUCTION MACHINES – TRENDS AND EMPIRICAL RESULTS

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Abstract

The requirements for the ergonomic design of user interfaces on production machines acquire an increasing importance in the context of »Industrie 4.0« [1,2]. The trend of increasing technological complexity of machines mainly correlates with the integration of additional functions in machines. Increasing functionality of the machines leads to a cumulative number of control elements, which limits the clarity of the machine operation [3] and leads to higher cognitive demands in the machine operation [4]. The aim of the paper is to demonstrate technological trends of the design of production machines. Based on this, the importance of ergonomics for production machines and concrete design recommendations with reference to study results of investigations on production machines are presented. The results of this study arose in the context of the research focus »ProErgo« (Ergonomic design of production machines in the context of the industry 4.0), which is funded by the State of North Rhine-Westphalia in Germany.

Keywords: *Ergonomic design, production machines, usability, user interface, human-machine compatibility*

1. INTRODUCTION

The ergonomic design of production machinery has a positive effect on all involved – firstly, on those employees involved in production, secondly on production companies as the operators of these machines, and thirdly on the manufacturers of the machines. For those working as the direct users of the production machines, ergonomic operating designs contribute to work satisfaction and help avoid unilateral stresses and the negative consequences of strain. For production companies, ergonomically designed machines generally have a clear, positive effect on the economic efficiency of their investment, as ergonomic design solutions contribute to the efficiency of setup, operating and maintenance procedures. For machine manufacturers, ergonomically designed production machines represent a strategic competitive advantage and a tangible selling point.
The positive effects of ergonomically designed production machines are amplified by additional challenges and trends in machine and plant construction. Machine and plant construction is undergoing a technological change. This means on the one hand the integration of an increasing number of functions in machines, and on the other hand, the networking of machines over the internet. This development is also known in Germany by the term »Industrie 4.0«.

2. DESIGN OF PRODUCTION MACHINES IN THE CONTEXT OF »INDUSTRIE 4.0«

At the core of »Industrie 4.0« is the vision of the »Smart Factory« [5], in which a range of »cyber-physical systems« (CPS) operates together. This vision also extends to include equipment, people and products, which represent the essential components of a work system [6]. Increased networking of these components is leading to growing volumes of information, additional functions and greater effort involved in control. With regard to the design of production machines, there are five distinct areas of activity which will be explained below.

Area of activity I: Assistance and operating systems
The trend toward increasing technological complexity in production machines can be traced back in particular to the additional functions in these machines. Increasing functionality in the machines goes hand in hand with an increased number of control elements, which in many cases restrict the clarity of operation [3] and lead to higher cognitive demands during machine operation [4].
In addition, extra functionality increases the probability that the machine operators will only use some of the functions available to them in their daily work, and as a result the economic potential of the machines is not exploited in full [1]. While multi-touch operation with gesture control is by now the technical standard in smartphones and home entertainment devices, one that is accepted and valued by users, in machines, simple single touch operation is the standard technology [3]. Developments in the area of context-sensitive feedback [3] and augmented reality technologies to support training or complex operating, setup or maintenance procedures have so far been underutilized, meaning that the further development of assistance systems for production machines and consequently the design of the human-machine interface can be viewed as an area of activity for the Smart Factory.

Area of activity II: Changeability and self-configuration
The trend toward increasing variety in products and ranges, up to and including individualized products, means that it is necessary to design equipment, and in particular production machines, in such a way that they can be used across as broad a product spectrum as possible, or can easily be converted to new products or product variants. Wiendahl et al. [7] describe a system as changeable by reference to its modularity, compatibility, mobility, universality and scalability. Ergonomics can also be seen as an important enabler of change, as simple system reconfiguration also depends on the design of the human-technology interface (e.g. quick-clamp system to insert a module).
Self-configuration, also known as »plug and produce«, may be seen as the specific manifestation of the compatibility of a production system. By it is meant that modules – similar to the »plug and play« function of a computer or its peripherals – is recognized by the system controller and can configure itself without human intervention [8].

Area of activity III: Self-diagnosis and self-optimization
Production machines may be networked, just like workpiece carriers or products, into so-called cyber-physical systems. By recording environmental factors, their processing and communication among the system elements, conditions can be analyzed and

processes improved without human intervention. The aim of development is to design production machines in such a way that they can record and interpret deviations in order to optimize their settings independently [5].

Area of activity IV: Internet of things
With increasingly small embedded systems, it is possible to give products or workpiece carriers a »digital product memory«, through which they are clearly identifiable and locatable at any time. Information about their current status, production history and target state, including planned process steps yet to be carried out, can be stored in the products, so that it is possible to query individual products in real time about their status. Products can e.g. communicate wirelessly with each other and with equipment – such as production machines, conveyor and storage technology – and with humans, e.g. through »augmented reality« systems (see the assistance and operating systems area of activity).

Area of activity V: Transparent and customized production
The aim of area of activity V is to integrate customers and suppliers into the processing of orders to a large extent. For example, in this scenario the customer carries out product configuration online. The vendor's production planning system then automatically checks the purchase prices of individual suppliers and the availability of production capacities, including on the supplier side, and notifies the customer of the sale price and delivery deadline. After the order has been placed – thanks also to the CPS functions in the products – the customer can always check on the current status of the order online, and make changes to the order via the internet [9][6].

3. ERGONOMIC DESIGN OF GRAPHICAL CONTROL ELEMENTS ON PRODUCTION MACHINES

The ergonomics of production machines is of critical importance in the context of developments which are subsumed under the term »Industrie 4.0«. In accordance with the area of activity I - assistance and operating systems - there is a trend toward increasing technological complexity of machines and with it an increasing number of control elements. As a result, the demands on the usability of operating systems continue to increase. Icons as control elements in production machines should aid user operation, as well as conveying information independently of language [10]. Consequently the symbolic labeling of functions contributes significantly to usability, particularly to the intuitive operability of machines.
In the conducted investigation, the intuitive operability of production machines with respect to icons used was investigated. Recommendations for action were derived from the results of the investigation, which will lead to a user-friendly design of operating interfaces and higher work productivity, among other things [11][12].

Approach and method
The investigation as carried out is divided into three case studies. The case studies include laboratory and field investigations on five modern production machines (laser sintering machine, CNC universal lathe, plastic injection molding machine, laser processing machine, woodworking machine), each with a different operating concept (Table 1).

Table 1: Information on the production machines investigated

Case Study	Production machine	Year of manufacture	Operating system	Number of test subjects
1	Laser sintering machine EOS FORMIGA P100 and P110	2006/2011	Display with touchscreen	11
2	CNC universal lathe DMG MORI SEIKI CTX alpha 300	2013	Button operation and graphic display	10
	Plastic injection molding machine Arburg Allrounder 420 C	2008	Button operation and graphic display with touchscreen	10
	Laser processing machine Laservorm LVS-909F	2011	Button operation and graphic display	10
3	Woodworking machine	2013	Button operation and graphic display with touchscreen	11

The first case study was conducted as a laboratory and field investigation at a major manufacturer of industrial joining technology as well as in the laboratory for product development and design of the Ostwestfalen-Lippe University of Applied Science. In the second case study, usability tests were conducted in various laboratories at the Ostwestfalen-Lippe University of Applied Science. Case study 3 was conducted at a manufacturer of woodworking machines and two other production facilities in the timber industry.

The selected approach in all case studies included the conduct of usability tests in combination with video and speech recordings, the use of questionnaires and a final workshop in which measures were discussed and design recommendations extrapolated on the basis of the results of the analysis.

For the usability tests, test subjects were recruited from students and academic staff of various ages at the Ostwestfalen-Lippe University of Applied Sciences without any previous experience with the production machine in question. The test subjects received a short introduction to the production machine and were required to complete and comment on various tasks with minimal assistance from the investigator.

After all tasks had been concluded, a questionnaire – based on the Compendium of Ergonomics from the Federal Institute for Occupational Health and Safety [13] and the software questionnaire ISONORM 9241/110-S /ISONORM 9241/10 [14] – was completed on the operation of the machine, in which various aspects of the operation and design of the production machine were evaluated.

In addition to basic functions - such as switching the machine on and off - tasks on the production machinery included a selection of typical work tasks carried out by machine operators during normal use. Each usability test lasted approximately 45 minutes per test subject.

4. RESULTS OF THE INVESTIGATION

The evaluation of the recordings and videos from the usability tests show that the human-machine compatibility of the production machinery investigated in terms of the intuitiveness of the icons used could be improved.
In carrying out the tasks, so-called errors were frequently observed, the cause of which could be traced back to unsuitable representation of icons or their captions. Figure 1 shows the errors observed, the nature of the errors, and the identified causes. After that, a selection of examples of the observed errors is presented.

1. Icon not found

For example, on the laser sintering machine, difficulties were observed among the test subjects in loading the construction task (7 of 11 test subjects), as the icon representation was not perceived as comprehensible and was criticized [15]. On the CNC universal lathe, icon no. 0983 with the title "Program with machine function" (see [10], p. 44) was criticized by virtually all test subjects (9 of 10 test subjects) as not being self-explanatory, as it could only be found on the basis of its caption. On the woodworking machine, 7 of 11 test subjects could not find the icon to switch on the heating, as the abbreviated term "Auftragsei..." (German) could not be interpreted and the icon representation was not self-explanatory.

2. Operating error

On the CNC universal lathe, all test subjects used the "SELECT" button to select a program, despite the fact that this button was not relevant in this context. On the woodworking machine, six of the eight main function icons were either not recognized by the test subjects or were associated with other functions and selected accordingly.

3. Additional and superfluous actions

On the woodworking machine, for example, it was not clear to several test subjects whether a unit required for a particular process was switched on, as the yellow representation of the icon did not conform to the test subjects' expectations and was associated with an error. All 11 test subjects failed in the task of feeding in material for the process, as simply pressing the icon did not bring any response from the system or an instruction. Both mentioned examples led to uncertainty among the test subjects and a search for possible subsequent steps.

Overall, it was determined in the context of the whole study that self-designed icons appeared not to have been tested sufficiently or at all by the machine manufacturer during the development phase of the machine, and there were obvious weaknesses in the intuitiveness of individual icons. In addition, the results revealed that the use of standardized icons from DIN ISO 7000:2008 may be problematic, as the icon representations were not consistently perceived as intuitive by the test subjects. The errors set out in Figure 1 could significantly slow down operation, lead to operating errors, and cause uncertainty in the operator.

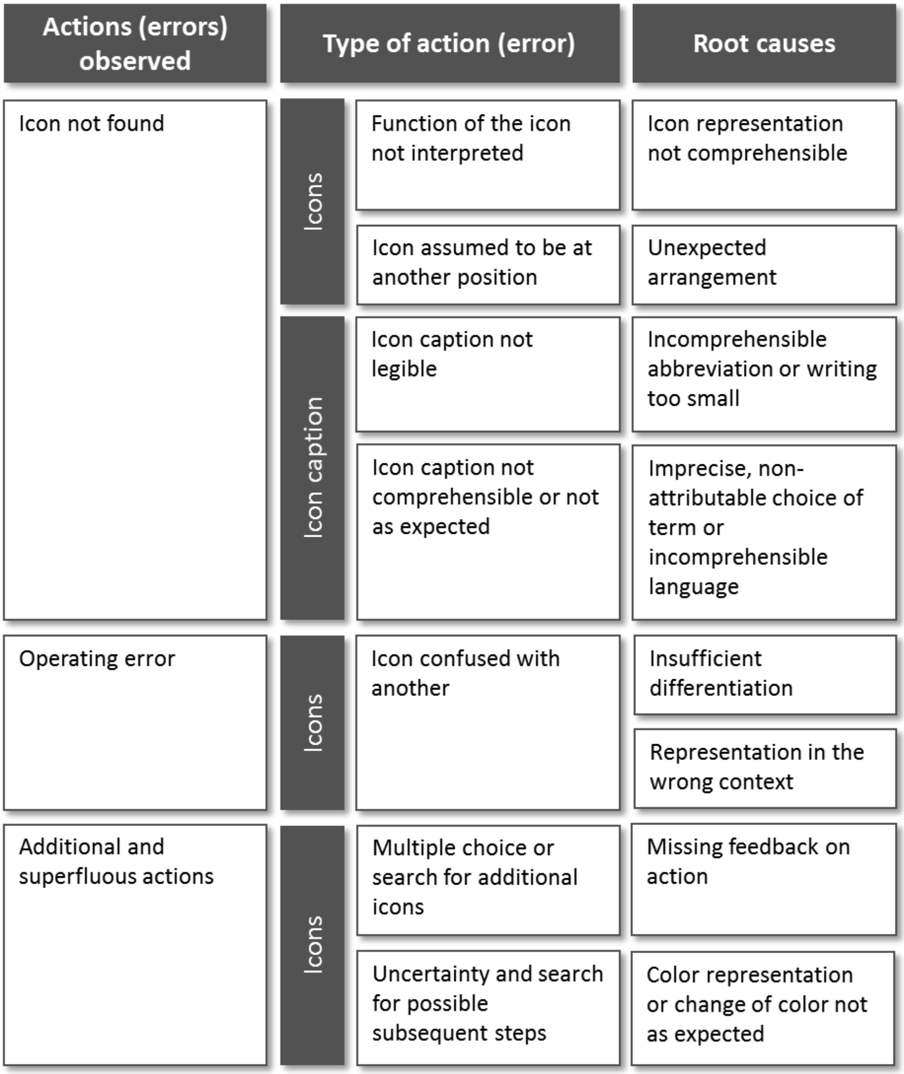

Figure 1: Errors observed and root causes

Requirements for the design of icons

Design recommendations for software ergonomics must be considered in the design of icons. These require, inter alia, that icons should be quickly and clearly identifiable, capable of being identified irrespective of language or culture, designed distinctively, and that standards are complied with (e.g. icon in the form of a diskette for the “Save” function). Feedback to actions is important for the user, to identify the current progress and to deduce further action to be taken [16]. An appropriate color scheme assists in triggering the correct action in the operator. Icon captions must be designed to be comprehensible and easily legible to provide additional assistance in identifying the icon. In addition, it should be noted that the intuitiveness of an icon can also be improved if it is only offered in a specific context [17]. With situation-based decision support, quick and reliable task processing can also be achieved [18]. Finally, it is recommended to test graphical operating elements in accordance with DIN EN ISO 9241-210:2011 during the development process of the machines.

5. CONCLUSION

Machine and plant construction is facing a technological change. This means on the one hand, the integration of an increasing number of functions in machines, and on the other hand, the networking of machines over the Internet. This development is also known in Germany by the term »Industrie 4.0«. In the course of these developments, the ergonomic design of production machines is of critical importance. One study on the use of icons as control elements showed that there is clear potential for improvement with regard to ergonomics. Since the design of production machines has a significant impact on the effectiveness and efficiency of operating, setup and maintenance processes, a greater attention to the design of machines and operating concepts should be directed by the machine manufacturer. It is recommended to test the ergonomic and intuitive design of production machines in accordance with DIN EN ISO 9241-210:2011 during the development process of the machines.

REFERENCES

[1] Hinrichsen, S.; Riediger, D. & Adrian, B.: Ergonomische Gestaltung von Produktionsmaschinen im Kontext der Industrie 4.0, *Betriebspraxis & Arbeitsforschung*, **Vol.** (2015) No. 224, pp. 24-29, ISSN 2191-6268

[2] Koller, F.; Beu, A.: Maschinenbedienung im Wandel, *IT&Production, Das Online-Magazin für erfolgreiche Produktion*, **Vol.** (2014) No. 12, ISSN 1439-7722. *Available from* http://www.it-production.com/index.php?seite=einzel_artikel_ansicht&id=61883 *Accessed:* 2015-11-30.

[3] Brecher, C.; Kolster, D. & Herfs, W.: Innovative Benutzerschnittstellen für die Bedienpanels von Werkzeugmaschinen, *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, **Vol.** (2011) No. 07-08, pp. 553-556, ISSN 0947-0085

[4] Levchuk, I.; Schäfer, A.; Lang, K.-H.; Gebhardt, H.j. & Klussmann, A.: Needs of ergonomic design at control units in production industries, *Work: A Journal of Prevention, Assessment and Rehabilitation*, **Vol.** (2012) No. 41, pp. 1594-1598, ISSN 1051-9815

[5] Kagermann, H.; Wahlster, W. & Helbig, J.: Deutschlands Zukunft als Produktionsstandort sichern - Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0. - Abschlussbericht des Arbeitskreises Industrie 4.0., *Available from* http://www.hightech-strategie.de/_files/industrie_4_0_umsetzungsempfehlungen.pdf *Accessed: 2013-03-17.*

[6] Hinrichsen, S.; Jasperneite, J.: Industrie 4.0 – Begriff, Stand der Umsetzung und kritische Würdigung, *Betriebspraxis & Arbeitsforschung*, **Vol.** (2013) No. 216, pp. 45-47, ISSN 2191-6268

[7] Wiendahl, H.-P.; Reichardt, J. & Nyhuis, P.: *Handbuch Fabrikplanung – Konzept, Gestaltung und Umsetzung wandlungsfähiger Produktionsstätten*, Hanser, ISBN 978-3446224773, München, (2009)

[8] Jasperneite, J.; Hinrichsen, S. & Niggemann, O.: „Plug-and-Produce“ für Fertigungssysteme, *Informatik Spektrum,* **Vol.** (2015) No. 38, pp. 183-190, ISSN 1432-122X

[9] Geisberger, E.; Broy, M.: Integrierte Forschungsagenda Cyber-Physical Systems, acatech Studie, *Available from* http://www.acatech.de/de/publikationen/empfehlungen/acatech/detail/artikel/acatech-studie-agendacps-integrierte-forschungsagenda-cyber-physical-systems.html *Accessed:* 2013-03-28.

[10]DIN ISO 7000:2008: Graphical symbols for use on equipment - Index and synopsis.

[11]Riediger, D.; Hinrichsen, S. & Schlee, A.: Ergonomische Gestaltung von grafischen Bedienelementen an Produktionsmaschinen, *Proceedings of »Verantwortung für die Arbeit der Zukunft«, Bericht zum 61. Kongress,* Gesellschaft für Arbeitswissenschaft e.V. (GfA) (Ed.), ISBN 978-3936804188, Karlsruhe (Germany), February 2015, GfA-Press, Dortmund (Germany), (2015)

[12]Riediger, D.; Hinrichsen, S. & Schlee, A.: Ergonomic Design of Graphical Control Elements on Production Machines, *Proceedings of »Production Engineering and Management«, 5th International Conference,* Villmer, F.-J.; Padoano, E. (Ed.), pp. 123-130, ISBN 978-3941645110, Triest (Italy), October 2015, Schriftenreihe Logistik, Lemgo, (2015)

[13]Adler, M.; Herrmann, H.-J.; Koldehoff, M.; Meuser, V.; Scheuer, S.; Müller-Arnecke, H.; Windel, A.; Bleyer, T.: *Ergonomiekompendium, Anwendung ergonomischer Regeln und Prüfung der Gebrauchstauglichkeit von Produkten*, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), ISBN 978-3882611182, Dortmund, (2010)

[14]Prümper, J.; Anft, M.: Die Evaluation von Software auf Grundlage des Entwurfs zur internationalen Ergonomie-Norm ISO 9241 Teil 10 als Beitrag zur partizipativen Systemgestaltung — ein Fallbeispiel, In *Software-Ergonomie ’93*, *Von der Benutzungsoberfläche zur Arbeitsgestaltung*, Rödiger, K.H. (Ed.), B. G. Teubner, ISBN 978-3322829726, Stuttgart, pp. 145-156.

[15]Riediger, D.; Hinrichsen, S. & Villmer, F.-J.: Ergonomische Gestaltung von Arbeitsprozessen in der additiven Fertigung, *Proceedings of »Gestaltung der Arbeitswelt der Zukunft«, Bericht zum 61. Kongress,* Gesellschaft für Arbeitswissenschaft e.V. (GfA) (Ed.), pp. 94-96. ISBN 978-3936804171, München (Germany), March 2014, GfA-Press, Dortmund (Germany), (2014)

[16]DAkks GmbH: *Leitfaden Usability*, Version 1.3, Deutsche Akkreditierungsstelle GmbH (DAkks), *Available from* http://www.dakks.de/sites/default/files/71_sd_2_007_leitfaden_usability_1.3_0.pdf *Accessed:* 2016-02-15.

[17]B Böhringer, J.; Bühler, P.; Schlaich, P. & Sinner, D.: *Kompendium der Mediengestaltung für Digital- und Printmedien, I. Konzeption und Gestaltung*, Springer Vieweg, ISBN 978-3642545801, Berlin, Heidelberg, (2014).

[18]Grandt, M.; Ley, D.: Unterstützung von Entscheidungsprozessen durch benutzerzentrierte Gestaltung von Führungssystemen, In *Ergonomie und Mensch-Maschine-Systeme*, Schmidt, L., Schlick, C.M. & Grosche, J. (Ed.), Springer, ISBN 978-3540783312, Berlin Heidelberg, (2008), pp. 79-102.

THE INVESTIGATION OF LED LIGHTING COMFORT AND PREFERENCE ON DIFFERENT AGE AND GENDER

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Abstract

Electric lighting has a wide range of effects in our daily life. In 1941, Kruithof revealed the range of comfortable lighting by combining of illuminance and color temperature. Despite Kruithof's finding have been frequently cited in many studies, there are some studies suggested that Kruithof's curve is not always useful. The problems are related to the establishment of lighting conditions and the lack of influence on different age and gender. With a vast growth in the amount of LED sources, this study aims to investigate LED lighting comfort and preference on different age and gender by using LED's characteristic of adjusting spectrum and analysis the influence caused by the combinations of illuminance and correlated color temperature.

Keywords: *lighting comfort, preference, LED, age, gender*

1. INTRODUCTION

Electric lighting has a wide range of effects in our daily life [1]. Numbers of studies showed that light and color are able to influence people's mood, both at physiological and psychological level [1-5]. In 1941, Kruithof revealed the range of comfortable lighting by combining of illuminance and color temperature [6]. It has a tendency that lower color temperature with higher illuminance gives a stifling and uncomfortable feeling, while higher color temperature with lower illuminance gives a gloomy and uncomfortable feeling, and excludes these two uncomfortable areas is defined as the comfortable area.
Despite Kruithof's finding have been frequently cited in many studies, there are some studies suggested that Kruithof's curve is not always useful [7-9]. One of the problems is related to the establishment of lighting conditions. It's hard to create a wide range of color temperature from 2000 K to 8000 K accurately with the lighting equipment at that time [7, 9]. Second, the demand of lighting changes with age increased, it means that lighting comfort will be different from age [2, 10-12]. For example, color discrimination decreases with age. Short-waves such as blue and green colors are most affected by the natural yellowing of the lens. Blue objects tend to be darker than they actually are. Also, as the amount of lighting that reaches the retina is reduced with increasing age, the older people needs three times the amount of light as the younger people to complete a visual task comfortably [11]. However, few studies investigate the lighting demand and

comfort for the older people [10]. With the proportion of the older people increasing in our society, how to create a comfortable lighting environment becomes an importance issue.

Nowadays, people are paying attention to the issue of energy shortage and environment pollution. Lighting-emitting diodes (LEDs) have become a new fashion in current lighting. Compare to traditional lighting device, LED has advantages such as non-mercury pollution, low power consumption, and long product life so that it is widely applied in working, living, and public environments. Also, LED is equipped with the characteristic of adjusting spectrum which could offer different kinds of combinations of illuminance and correlated color temperature (CCT). Due to this characteristic, the application of LED lighting is more flexible than other lighting resources. Despites the achievements that have been made previously, the effect of CCT and illuminance of LED lighting on people' biological and psychological level should be investigated, especially the influence of LED lighting on different age should be further tested. Therefore, this study aims to investigate LED lighting comfort and preference on different age and gender by using its characteristic of adjusting spectrum and analysis the influence caused by the combination of illuminance and CCT. Then, establish a database which could provide a reference for ergonomically lighting design for LED lighting comfort on different age and gender and help propose better lighting condition to satisfy people' psychological need.

2. TECHNICAL REQUIREMENTS

2.1. Experimental setting

In order to let participants have the real psychological perception, an experimental chamber (Figure 1) which was furnished like a small private room in the real lives was arranged for the study and the dimensions were 4.5 m (length) × 3.6 m (width) × 2.6 m (height). The suspended ceiling and walls were printed ivory which is the most common color that people always used and the flooring was covered with light coral cotton carpet which could absorb most of the lighting so that preventing the lighting reflection from interfering with the results. Apart from a chair, there isn't other furnish. Daylight penetration was controlled through dark roller curtain.

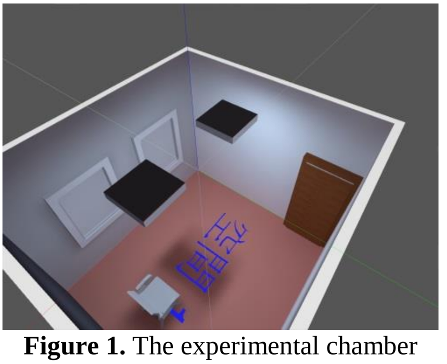


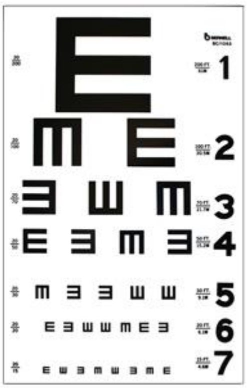
Figure 1. The experimental chamber

2.2. Lighting system

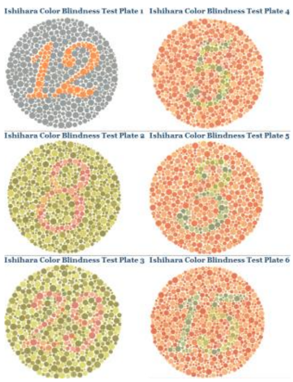
Two LED panels were mounted on the ceiling. The LED panel consists of 360 LED bulbs, which is mixed with red, green, blue, and yellow light colors. The light output of this LED panel, such as CCT and illuminance can be adjusted by a tablet PC. The range of illuminance was 0 lx to 1000 lx and the range of color temperature was 2700 K to 7000K. The system could be adjusted to maintain a constant illuminance of 200, 300, 400, 500, 600, 700, 800, 900, and 1000 lx on working surface while 2700, 3000, 3500, 4000, 4500, 5000, 5700, and 6500 K which suggested as the nominal CCT by American National Standards Institute (ANSI) could be created separately. A total of 72 combinations of illuminance and CCT were used in the experiment.

2.3. Visual inspection

A Tumbling E Eye Chart (Figure 2. a.) was being used to test visual acuity. The chart consists of 13 lines of letter "E". Each letter has different angle, and participants have to discriminate the gap of the letter in a row under the normal visual condition. Color vision was tested using Ishihara Color Test plates (Figure 2. b.) and Munsell 100-Hue Test (Figure 2. c.). Ishihara Color Test is to test whether participant has color-blindness, and participant need to read out the number on each plate. Munsell 100-Hue Test is widely used to test the ability of color discrimination. It total has 85 color discs arranged in four series. The discs will be random arranged first, and participants have to put the discs in an adequate order. An error score will be calculated to measure the degree of color-weakness.



a. Tumbling E Eye Chart



b. Ishihara Color Test plates

c. Munsell 100-Hue Test

Figure 2: The materials of visual inspection

2.4. Questionnaire

To evaluate the lighting comfort and preference, an adapted version of the questionnaire was used. This questionnaire collects the adjective related to lighting perception which were showed in table 1 [9, 13-14], and each adjective is evaluated by a bipolar scale from negative level to positive level. Participant has to response the answer by using a 7-point scale from -3 to 3, "-3" represents the strongly negative feeling and "3" represents the strongly positive feeling.

Table 1: Collected adjective which related to lighting perception

Flynn *et al., 1974.*	ugly/ beautiful small/large dislike/like simple/complex glare/non-glare confined/spacious dim/bright vague/distinct colorless/colorful subdued/lively cluttered/uncluttered	hazy/clear visual cool/visual warm faces obscure/faces clear pleasant/unpleasant private/public tense/relaxing subduing/stimulating frustrating/satisfying functional/non-functional special/ordinary stable/unstable
Lee *et al.*, 2014.	glare/non-glare unsatisfied/satisfied uncomfortable/comfortable dark/bright non-cozy/cozy	cold/warm unpleasant/pleasant tense/relax fidgety/ no fidgety cramped/spacious
Viénot *et al.*, 2009.	glare/non-glare dark/bright dull/cheerful uncomfortable/comfortable artificial color rendering/natural color rending	cold/warm crepuscular/clear tiring/relaxing unpleasant/pleasant

Resources: (Flynn *et al., 1974;* Lee *et al.,* 2014; Viénot *et al.,* 2009.)

2.5. Participants

A total 64 observers participated in the experiment representing four age groups: 8 males and 8 females aged 20-29 years, 8 males and 8 females aged 30-39 years, 8 males and 8 females aged 40-49 years, and 8 males and 8 females aged 50-65 years. All the observers had normal visual acuity and color vision. Before the experiment began, the participants were asked to remove shiny objects like rings and watches.

2.6. Procedure

Participants are instructed to sit the chair and informed the purpose of the study after they entered the experimental chamber. After finished the instruction, participants have to do acuity test, Ishihara Color Test plates and Munsell 100-Hue Test to ensure they have a normal visual. Then, participants will take a break with a mask and listen to soft music about 5 minutes in order to be clam down their emotion. After that, participants need to experience each lighting condition which is controlled by experimenter for 2 minutes after taking off the mask and fill in the questionnaire to evaluate the lighting condition. Participants have enough time to take a break after finished the questionnaire, then going to the next trial.

3. EXPECTED RESULT

This is a conducting study which anticipates to getting the different level of comfortable and preference by evaluating adjective of LED lighting on different age and gender. Due to the experimental design of this study is factorial full design, the results could get the comfortable area and preferred area under the combination of illuminance and CCT which is similar to the curve drew by Kruithof. In academic field, the result could be a new version of Kruithof's curve suitable for LED lighting. Also, provide a reference for ergonomically lighting design for LED lighting comfort on different age and gender and help propose better lighting condition to satisfy people' psychological need.

REFERENCES

[1] Veitch, J. A.: Psychological processes influencing lighting quality. *Journal of the Illuminating Engineering Society*, Vol. 30(2001) No. 1, pp.124-140.

[2] Gavriel Salvendy: *Handbook of Human Factors and Ergonomic, Third Edition*, John Wiley, ISBN: 9780471449171, (2006).

[3] Andre Kuijsters; Judith Redi; Borisde Ruyter; Ingrid Heynderickx: Lighting to Make You Feel Better: Improving the Mood of Elderly People with Affective Ambiences. *PLoS ONE*, Vol. 10(2015) No.7: e0132732.

[4] Chellappa S. L.; Steiner R.; Blattner P.; Oelhafen P.; Gotz T.; Cajochen C.: Non-visual effects of light on melatonin, alertness and cognitive performance: Can blue-enriched light keep us alert? *PLoS ONE*, Vol. 6(2011) No.1: e16429.

[5] B. M. T. Shamsul; C. C. Sia; Y. G. Ng; K. Karmegan: Effects of Light's Colour Temperatures on Visual Comfort Level, Task Performances, and Alertness among Students. *American Journal of Public Health Research*, Vol. 1(2013) No. 7, pp.159-165.

[6] Kruithof, A. A.: Tubular Luminescence Lamps for General Illumination, *Philips Technical Review*, Vol. 6(1941), pp.65-96.

[7] Katsuura T.: Physiological anthropology: Effects of artificial light environment on humans. *Oxford, UK: Encyclopedia of Life Support Systems (EOLSS)*. *Available from* http://www.eolss.net/sample-chapters/c03/e6-20a-05.pdf. *Accessed*: 2014-01.

[8] Oi, Naoyuki; Takahashi, Hironobu: Preferred combinations between illuminance and color temperature in several settings for daily living activities, *Proceedings of the 2nd International Symposium on Design of Artificial Environments*, pp. 214-215,(2007).

[9] Françoise Viénota; Marie-Lucie Durand and Elodie Mahler: Kruithof's rule revisited using LED illumination. *Journal of Modern Optics*, Vol. 56(2009) No. 13, pp.1433–1446.

[10] Wenting Cheng; Jiaqi Ju; Yaojie Sun and Yandan Lin: The Effect of LED Lighting on Color Discrimination and Preference of Elderly People. *Human Factors and Ergonomics in Manufacturing & Service Industries*, Vol. 22(2012) No. 3, pp. II-II.

[11] Marianne M. Sinoo; Joost van Hoof; Helianthe S. M. Kort: Light conditions for older adults in the nursing home Assessment of environmental illuminances and colour temperature. *Building and Environment*, Vol. 46(2011), pp.1917-1927.
[12] Shi-jhong, Li: *Lighting Design, First Edition*, Cyuan-Hua technical books limitedliability company, ISBN: 9572104993, Taipei, 1993.
[13] Ji-Hyun Lee; Jin Woo Moon and Sooyoung Kim: Analysis of Occupants' Visual Perception to Refine Indoor Lighting Environment for Office Tasks. *Energies*, Vol. 7(2014), pp. 4116-4139.
[14] John E. Flynn; Clyde Hendrick; Terry Spencer and Osyp Martyniuk: A guide to methodology procedures for measuring subjective impressions in lighting. *Illuminating Engineering Research Institute*, Project 92 (1979).

SEAT COMFORT ANALYSIS AT UNIVERSITY OF WEST HUNGARY BY BODY PRESSURE DISTRIBUTION SYSTEM

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Abstract

The main goal of this research was to raise awareness for prolonged sitting persons about the negative consequences of wrong seat. This was supported by a series of data acquired by examining the most prevalent chairs in the university's lecture halls from comfort and weight distribution point of view. For measurements the Tekscan's CONFORMAT pressure distribution measuring system was used, involving different chair types, ten subjects who seated in six different postures in the chairs. According to the results the body mass index has a great influence on the peak pressures and pressure distribution maps in most cases shows asymmetry both in pressure zones and peak values even in straight sitting position, the difference reaching sometimes a 20% value .The seat cushion can reduce up to 50% the peak pressure of the sitting bones' zone. Research data and analysis revealed also that beside the chair comfort a special attention should be paid also to a correct posture, because many of health complains can be linked to the latter.

Keywords: *chair comfort, pressure distribution, body postures, pressure map, ergonomics*

1. INTRODUCTION

Never seen developments in the informational technology sector during the last decades points to the fact that the seating time continuously increase and deskbound workers will be stacked to their chair even for more prolonged periods**.** However, the concepts of ideal sitting posture have a long history in the literature, for example in 1884 Staffel [1] wrote a standard for the sitting position that was quoted later by many other authors. [2] [3] [4] Seats with adjustable backrests and seat bottoms with rounded front edges were developed by Drescher to reduce pressure on the under-thigh region. [5] In a comprehensive work Akerbloom provided a review of sitting principles from the period 1853-1947. [6] The analysis of human–seat interface and understanding the effect of body weight distribution on seat comfort is beneficial for ergonomical and functional chair design. A balanced weight distribution on chair's seat, armrests and back is a key component on the usefulness of seating. According to Kiosak and Brienza compression or shear forces, or both developing during seating lead to discomfort. [7] [8] The importance of a high seating comfort is underlined by other studies arguing that prolonged seating represents a potential risk to spinal and paraspinal disorders. [9] Long hours of sitting in awkward postures might increase the risk of developing low back

pain and/or sciatica. [10] Porter and Gyi conducted an experiment to investigate observed optimum driving postures and positions and they developed guidelines for optimum postural comfort. [11] The relationships among Korean drivers' body dimensions, their driving postures and preferred seat adjustments was studied by Park et al. after collecting data concerning the preferred driving postures and adopted seat adjustment levels. [12] Hinz et al. investigated the characteristics of the contact areas between the seat cushion and the subject under static conditions and the effect of surface elasticity on pressure distribution. [13] The contribution of armrests in reducing weight on seat pan and mitigating stress on the spine was studied by Nag et al. [14]
This research intends to analyze the body pressure distribution of students with different body built using the most prevalent chairs in the university lecture halls and to determine the negative consequences of the wrong seat.

2. MATERIALS AND METHODS

Classrooms for students are comparable with the office environment of white collars. Both users category are sitting mostly in functional positions i.e. writing and reading at desks. Therefore the furnished environment must be developed taking into account these main functions, and optimization of several parameters is necessary. Between these parameters we find the seat dimensions and functions (seat and back angle, surfaces size, heights, cushions, forms) and the characteristics of desks as well (table top height and tilting angle).
At the University of West Hungary a student participates at three courses daily on the average, which means 3x2x45 minutes totally, in this way a student spends at least 270 minutes a day seating, almost a full day weekly. In this time period only the contact hours are included and the interval doesn't contain the participation in laboratories and homework completion. Having this long seating time the comfort of chairs is essential from many points of view. The main objectives of this research was to measure the body pressure distribution of students on different classroom chair types and analyze the pressure maps in order to evaluate the seating comfort. Beside the objective measurement technique, a less impartial questionnaire was prepared to evaluate the users' opinions about chair convenience. The survey asked the students to express their comfort feeling for the selected chairs and sitting postures and to rank the chairs in function of their subjective impressions. The comfort evaluation was weighted in function of the time period they spent in a class room furnished with a certain chair type.

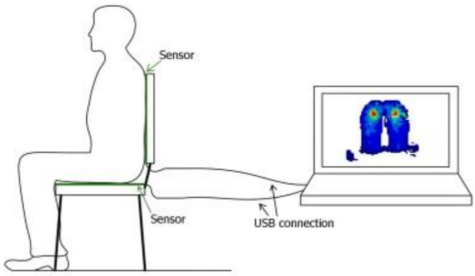


Figure 1: Measuring system

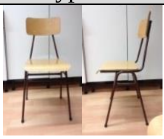
The measurements were made using the Tekscan's Body Pressure Measurement System (Conformat) with pressure sensitive foils size of 488 × 427 mm (Figure 1), containing 2016 pressure points with pressure range of 0-350 mm Hg, and accuracy of + / - 3.5 mmHg. The computerized data recorder provides a real-time picture of the pressure distribution. Before using the BPMS measuring system the pressure sensor foils were calibrated with the help of a vacuum pump. After calibration the pressure maps of different body built persons and seating positions were collected and analyzed with the software delivered with the system (BPMS Research 7.20) in the form of image (.FSX or .jpg) or short (0-200 s long) video files.
Ten persons (5 males and 5 females), four frequently used chair types were chosen and six typical body postures were defined (Table 1.) collecting 390 pressure maps altogether. The subjects were selected based on their body type and body mass index (BMI). Table 1. contains the basic characteristics of subjects:

Table 1. Characteristics of the measured subjects

User	1	2	3	4	5	6	7	8	9	10
Gender (female/male)	f	f	f	f	f	m	m	m	m	m
Age	21	21	21	22	21	22	23	23	22	21
Body weight (kg)	57	60	51	68	43	85	62	90	116	98
Height (cm)	165	168	165	160	151	192	182	197	216	186
BMI	20.94	21.26	18.73	26.56	18.86	23.06	18.72	23.19	24.86	28.33

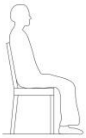
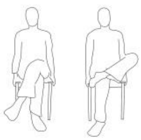
The high number of seating positions, the body built variation between subjects and the large number of pressure maps recorded were considered sufficient to drag reliable conclusions regarding to the chairs' comfort, dimensions correctness and to search for relationships between different factors.
The measured chairs are for generally use, classroom chairs, three types with conventional design with four legs and back, the third type upholstered and the forth with three legs and round seat used in laboratories (Table 2.).

Table 2. Chair types used for body distribution measurements

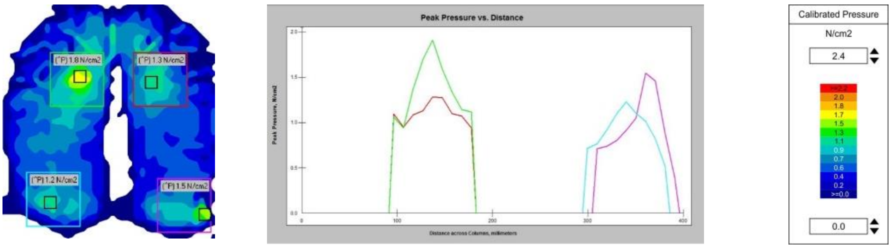
Type 01	Type 02	Type 03	Type 04
			
General chair, divided solid surface. Mildly hollow seat, high and arched backrest.	General chair with undivided solid surface, without upholstery, limber backrest.	Upholstered chair with low backrest.	Three-legged chair with circular seat. Edges are rounded.

The pressure maps were recorded in six different seating positions. Because of different chair structure the positions differ in the case of round seat chair as Table 3. shows. The straight seat is characterized by a normal seating position without back support and arms resting on thighs. Sitting position 12 differs from the straight seat just in leaning back only, the lean forward position is opposite to the previous one plus the arms rest on the table top. Forth position is related to the moments when the sitter decline to one side for example hanging on the phone which results in an unbalanced pressure on the seat and chair arms. The next posture is with crossed legs with a pulled up ankle in the case of male subjects and just crossed thighs for female subjects. The so called “floppy” posture is a kind of loose position with a crump back slightly back support and arms resting on thighs.

Table 3: Sitting position

Chair types 01-03					
Sitting position 11	Sitting position 12	Sitting position 13	Sitting position 14	Sitting position 15	Sitting position 16
					
Straight sitting position	Lean back sitting position	Lean forward sitting position	Lean side sitting position	Crossed leg sitting position	Floppy sitting position
Chair type 04					
Sitting position 21	Sitting position 22	Sitting position 23	Sitting position 24	Sitting position 25	Sitting position 26
Straight sitting position, legs on the stand	Straight sitting position, one leg on the stand, other on the floor	Straight sitting position, legs on the floor	Lean forward sitting position, leg on the floor	Straight sitting position, crossed legs	Floppy sitting position

In the case of laboratory chair the previous postures differ to some extent due to the higher height of the seat and cross bars fixed between legs. In the first posture the feet lean on the cross bars the back is straight, in the second position the feet rest on the floor, the third is characterized by one foot on the floor the second on the bar, in the case of the forth the feet are on the floor but the bust is leaning forward, in the fifth posture one legs is crossed the second rest on the bar, and the last is a "floppy" posture also.
After measuring the body pressure distributions and recording the pressure maps four equal pressure zones were defined for comparison purposes. The four zones were the left and right sitting bones' (ischial tuberosities) zone and the front contact zone between thighs and seats (Figure 2.) The zone size measured 9x9 cm of each and the peak contact pressure zone is revealed by the black squares placed in the pressure zones.



a.) b.) c.)

Figure 2: The selected pressure zones (a), average pressure distribution (b) and pressure legend (c)

Beside the exact pressure distribution measurements the subjective users' opinion about chair and posture comfort were recorded based on a questionnaire. The questions referred at overall chair comfort, functionality, usability, dimensions, postures and general feelings related to the chair use.

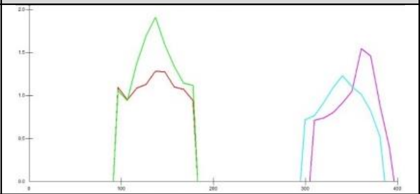
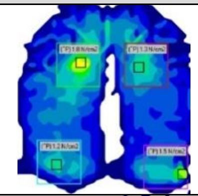
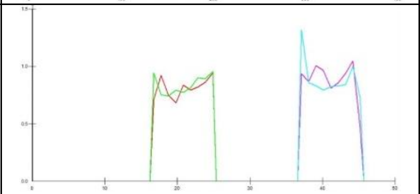
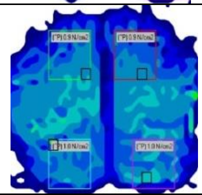
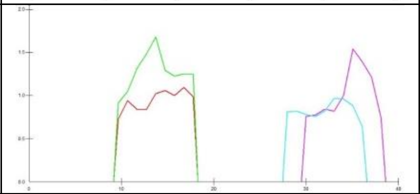
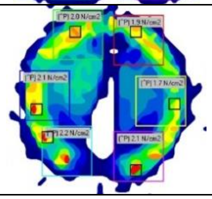
3. RESULTS

In this paper the body pressure distribution of four subjects measured in postures 11, 12, 13, and 16 for chairs 01-03 and postures 21, 22, 24 and 26 for the laboratory chair are presented.The selection criteria for subjects were height and body mass index, therefore the tallest and shortest subjects independently of gender were chosen, furthermore a female subject with high and male subject with low BMI were selected. The measured pressure distribution data were recorded in digital form for further analysis. On the pressure maps color coded patch field indicates the different pressures, the diagrams depict the average pressure distribution of the selected pressure zones. The measured pressure distribution values were compared with the users' subjective opinion recorded in a questionnaire.
From these comparisons it can be deduced that in cases where the user's comfort level was marked low, high differential pressure zones are located. The agreement was valid for both chair types and sitting postures. On the pressure maps with high discomfort zones peak pressures were observed which indicate that beside compression forces shear forces are present contributing to the user's low comfort.

The peak pressure in the sitting bone zones drops about 50% in the case of a normal body built person when a seat cushion is placed. However the decrease is just 38% when the body mass index is over 25. This is due to the fact that the overweight subjects have a larger contact surface area and therefore pressure distribution is more even. In this case the initial peak pressure in the aforementioned zone was lower with 20% compared to the peak pressure of a normal weight people.

Table 4. summarizes the straight sitting pressure distributions on three chair types for one of the female subjects with above average BMI index. In the first case the user evaluated the chair to be with a medium comfort, a slight compression was observed on the back and in the front of the seat. The pressure map and diagrams of the pressure zone underline the subject's subjective evaluation. In the second case the chair was considered more comfortable which can be confirmed by a more uniform pressure distribution map. This highlight the importance of the seat and back cushion. When the user seated on chair type 4 immediately remarked the discomfort of the round and hollow seat plate. The seat was considered too small and an inconvenient compression feeling was observed on the edge.

Table 4: Sitting pressure distributions

Sex: female Age: 22 Body mass: 68 kg Body height: 1610 mm BMI: 26,56		Pressure parameters (N/cm^2)	Pressure distribution
a	Seat pressure map and diagram for chair type 1, sitting position 11.		
b	Seat pressure map and diagram for chair type 3, sitting position 11.		
c	Seat pressure map and diagram for chair type 4, sitting position 21.		

The pressure maps recorded in different postures indicate high pressure zones near the edge as a result of the seat center's hollow form. These high pressures caused significant shear stress in the lower thigh soft tissues leading to a remarkable discomfort feeling. Similar conclusions can be deduced from the pressure maps recorded for the other subjects with moderate differences in function of the subject's body built.

4. CONCLUSION

Based on the recorded pressure maps it can be seen that the heavier person's pressure values were significantly smaller because of the larger surface contact area with the chair and the pressure distribution is more uniform compared with the thinner individuals' same values. Almost all subjects demonstrated a greater or lesser degree of asymmetry, even in the case of straight seat, which is a direct result of a bad posture. The asymmetry can reach 15-25%. The measured values were matched with the oral assessment of the subjects, in this way we had the opportunity to determine the weight distribution characteristics and pressure values that reach the comfort threshold of the subjects. For example, for the subject complaining about the bad back shape of chair type 1, we measured extremely high pressure values on back surface. In the case of chair type 3 many complained about the uncomfortable back which can be seen also from the high pressure zone around the spine. It can be deduced that sometimes the apparently high seating comfort (upholstered) could be shaded by a bad back. Those who considered chair type four with the worst comfort came to this conclusion because they exerted heavy loads on their thighs or considered too small the seat area. Research data and analysis revealed also that in addition to the comfort of the chair the environment is important too, because an improperly furnished room can reduce the performance of the audience. Taking into consideration facilities and use of a certain environment and measuring the ergonomic characteristics of the furniture we can appreciate the comfort level of them. Beside to a comfortable seat a special attention should be paid also to a correct posture, because many of health complains can be linked to the latter.

REFERENCES

[1] Staffel, F.: On the Hygiene of Sitting (in German), *Zbl. Allgemeine Gesundheitspflege* 3, (1884), pp.403-421

[2] Fick, R.: Spezielle gelenkund muskelmechanik, *Handbuch der Anatomie und Mechanik der Gelende*, Gustav Fisher, Jena, (1911), p. 688

[3] Strasser, H.: Die Rumghaltungen. *Lehrbuch der muskel und gelenkmechanic*, chapter VI. Vol.2., Springer, Berlin, (1913), p. 244-320

[4] Schede, F.: *Grundlagen der korperlichen eriziehung*, F. Enke, Stuttgart, (1935), p.154

[5] Drescher, E.W.: Arbeitssitz und arbeitplatz, *Reichsarbeitsblatt III*, (1929), p.159-175

[6] Akerbloom, B.: Standing and sitting posture, *AB Nordiska Bokhandein*, Stockholm, (1948)

[7] Brienza, D. M.; Chung, K.C.; Brubaker, C.E.; Wang, J.; Karg, T.E.; Lin, C.T.: A system for the analysis of seat support surfaces using surface shape control and simultaneous measurement of applied pressures, *IEEE Trans. Rehabil. Eng. 4*, (1996), pp. 103–113

[8] Kiosak, M.: A mechanical resting surface: its effect on pressure distribution, *Arch. Phys. Med. Rehabil.*, No 57, (1976), pp. 481–484, ISSN 0003-9993

[9] Corlett, E. N.: Are you sitting comfortably?, *Industrial Ergonomics 24*, International J., (1999), pp. 7-12, ISSN 0169-8141

[10] Lis, A. M.; Black, K. M.; Korn, H.; Nordin, M.: Association between sitting and occupational, *LBP*. *European Spine Journal*, No 16, (2007), pp. 283–298, ISSN 0940-6719
[11] Porter, J. M.; Gyi, D. E.: Exploring the optimum posture for driver comfort, *International Journal of Vehicle Design*, No 19 (3), (1998), pp. 255–266, ISSN 0143-3369
[12] Park, S. J.; Kim, C.; Kim, C. J.; Lee, J. W.: Comfortable driving postures for Koreans International, *Journal of Industrial Ergonomics, No* 26, (2000), pp. 489–497, ISSN 0169-8141
[13] Hinz, B.; Seidel, H.; Menzel, G.; Keitel, J.; Gericke, L: Laboratory study on pressure distributions at car seats—examination with groups of subjects characterized by a representative distribution of body height and weight, *Zeitschrift für Arbeitswissenschaft*, No 57, (2003), pp. 169–187, ISSN 0340-2444
[14] Nag, P. K.; Pal, S.; Kotadiya, S.M.; Nag, A.; Gosai, K.: Human–seat interface analysis of upper and lower body weight distribution, *International Journal of Industrial Ergonomics*, vol. 38, (2008), pp. 539–545, ISSN 0169-8141

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THE EFFICIENT IMPROVEMENT STRATEGIES OF ADVERSE EVENTS BY TOPSIS IN THE EMERGENCY DEPARTMENT

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Abstract

Human error is a major common factor in medical adverse events, and human error identification method (HEI) can be used along with other processes to analyze the important factors of human error accidents. However, an improvement strategy based on different criteria in terms of the error reducing time and cost is absent from the traditional HEI methodology. Fortunately, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method can be used to generate an improvement strategy for reducing human errors. Therefore, the goal of this study is to evaluate the human error factors in emergency department, and use fuzzy TOPSIS to help generate an efficient improvement strategy for error factors that can be used by decision makers to reduce adverse events in hospital. Based on the results of this study, the human error factor "Decision error" is the most efficient way to reduce emergency department adverse events.

Keywords*:* *Human Factors, Patient Safety, Human Errors, Adverse Events, TOPSIS*

1. INTRODUCTION

For more than ten years, patient safety has been an issue of serious concern and became an area of interest in many countries, along with increasing awareness of adverse events [1, 2, 3]. Adverse events are defined as unintended injuries that arise from medical management [2], and they might be responsible for 98,000 deaths and more than 1 million injuries per year in U.S. in 1999 [4]. Freund et al. [3] indicated that according to national survey in France almost 10,000 deaths per year could be related to medical errors. According to these studies and the fact that medical errors have high level of frequency, adverse events are considered as one of the major problems in patient safety.
Emergency departments (EDs) are very busy departments inside of medical institutions and are identified as departments where adverse events are highly likely to be attributable to errors [4, 5, 6, 7]. Fordyce et al. [5] investigated 1934 ED patients in the summer of 2001. 400 error reports were generated, and 346 errors were identified (approximately 18% of all investigated ED patients). Calder et al. [2] indicated that 6% of ED patients have experienced adverse events, and 71% of those were preventable [5]. If this estimation is true, then it can be expected that 400,000 to 1,100,000 ED adverse events happen in Taiwan every year.
EDs are considered to have particularly high risk of adverse events. Reasons include disrupted sleep, multiple interruptions, acute time constraints, high number of patients, and necessity for immediate major medical interventions without clear view of patients' medical history [3, 5, 7, 8]. Even at times of lower number of patients, the EDs are

prone to error. Hence, in order to increase the patient safety, the first step is to understand and analyze the causes of adverse events.

There are many methods that could be applied to analyze the causes of adverse events in EDs such as Root Cause Analysis (RCA), the Human Error Assessment and Reduction Technique (HEART), the Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACEr), and the Systematic Human Error Reduction and Prediction Approach (SHERPA). These methods are widely applied for analysis of factors which have caused accidents in different fields. However, an improvement strategy based on different criteria in terms of the influence and prevention of the adverse events is absent from the traditional error analysis methodology. Chiu & Hsieh [9] indicated that multi-criteria decision-making methods (MCDM) are not only utilized to make the decisions for companies, but also can be applied to determine the efficiency of improvement strategies for human error analysis. Thus, this study utilizes the investigation of human error analysis and MCDM.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a well-known MCDM method. It has been commonly used in solving decision-making problems. TOPSIS was proposed by Hwang and Yoon [10], and the basic idea is to consider how alternatives perform when multiple criteria are taken into account simultaneously (Bai et al., 2014). TOPSIS can be used along with other human error analysis processes to analyze the improvement strategies of human error accidents. Chiu & Hsieh [9] identified the human error factors in aviation maintenance tasks by Human Factors Analysis and Classification System (HFACS) and applied TOPSIS with four criteria to generate the efficient improvement strategies. The results show that the most efficient way of reducing human errors in aviation maintenance tasks is enhancement of maintenance capabilities.

HFACS was developed by Wiegmann & Shappell [11]. The idea was constructed from Reason's [12] organizationally based model of human errors. HFACS provides an organizational framework for accident analysis. It divides human error accidents into four categories, including organizational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts of operators. Category "Unsafe acts" represents the majority of accident research investigations. It refers to the behavior of medical staff which results directly in adverse events during medical procedures and form the active error in adverse events. "Preconditions for unsafe acts" involve the psychological precursors of the active failures within the category "Unsafe acts" and form the latent error in accidents. The category "Unsafe supervision" is also a latent error, which traces the causal chain of events producing the unsafe acts up to the level of the front-line supervisors. The category "Organizational influences" is a latent error category in accident analysis, involving the cause of faulty decisions at the management level that directly affect supervisories' practices. This is a preliminary study on application of TOPSIS and HFACS to analyze EDs adverse events, and only the subcategory of "Unsafe acts" in terms of "decision error", "skill-based error", "perceptual error", and "violation error" will be presented in the following contents.

The analysis of human errors and improvement strategies plays an important role in reducing and preventing adverse events in EDs. Therefore, the goal of this study is to analyze the human errors related to "Unsafe acts" and apply TOPSIS to generate an efficient improvement strategy for adverse events in EDs. It is expected that this study will provide a different perspective of error analysis in medical area and enhance the patient safety in EDs.

2. Method

2.1. The purcedure of human error analysis in ED

This is a retrospective study that focuses on adverse events in EDs, and there are two steps for selecting EDs adverse events. In the first step one physician who has worked in EDs for more than 20 years, and an expert from human factors and ergonomics area were recruited to identify the initial EDs adverse events based on six criteria. The criteria are integrated from the previous studies [2, 13, 14] including transferred to the intensive care unit or operation room, cardiopulmonary arrest occurred during the observation period in ED, death during diagnosis period in ED, the diagnoses of hospitalization are not consistent with discharge, returned to the ED in 72 hours, and returned and hospitalized within 7 days. In the second step from the pool of adverse events those which are not related to human errors have been removed, including false labor, vaginal spontaneous delivery, and Out-of- Hospital Cardiac Arrest.
The final pool of adverse events which was generated after the two steps described above were analyzed with help of three physicians, two nurses and one human factors and ergonomics expert. Physicians and nurses have more than 15 years working experience in ED in Taiwan. The human factors and ergonomics expert has more than 5 years working experience in National Tsing Hua University. Final pool of EDs adverse events were analyzed using the error factors including "decision error", "skill-based error", "perceptual error", and "violation error". During the period of analysis, experts can request to review and check detailed diagnosis contents of electronic medical records (EMR) for each ED adverse events to make their decision about category of human errors to which a specific error belongs. The occurrence rates of each error factors are calculated after the analysis process.

2.2 TOPSIS

TOPSIS was developed by Hwang and Yoon [10]. It is one of the classical methodologies for solving MCDM problems. The main objective of TOPSIS is to identify the positive ideal solution (PIS) and the negative ideal solution (NIS), and then to measure the distance of each alternative from the ideal solution to generate a ranking of the alternatives [15]. For instance, The PIS is that which maximizes the benefit criteria and minimizes the cost criteria, while the NIS maximizes the cost criteria and minimizes the benefit criteria. The selected alternative should be the one closest to the PIS and farthest away from the NIS. The analytic steps of TOPSIS are summarized as follows:
Step 1: Constructing the decision matrix
A group with k decision makers ($D_1, D_2, \ldots, D_k$), m alternatives ($A_1, A_2, \ldots, A_m$) and n criteria ($C_1, C_2, \ldots, C_n$) for a MCDM problem which is clearly expressed in a matrix format as:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_M \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{12} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \end{array}$$

where r_{mn} be the rating of alternative A_m with respect to criterion C_n.

Step 2. Aggregate the evaluation of decision makers

In this step, the decision makers' aggregate evaluations for determining the criteria weights is performed. Analytic hierarchy process (AHP) was utilized in this study to determine the weight of each criterion.

Step 3. Construct the normalized decision matrix

$$X = [x_{ij}]_{m\times n}$$

Assume that the decision matrix be. The decision matrix for m alternatives and n criteria can be normalized as:

$$S = [s_{ij}]_{m\times n}$$

where

$$s_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \qquad (1)$$

Step 4. Construct the weighted normalized decision matrix

In order to consider the different importance of each criterion, this study constructed the weighted normalized decision matrix. Let the weighted normalized decision matrix be

$$V = (v_{ij})_{m\times n}.$$

$$v_{ij} = s_{ij} \times W \qquad (2)$$

where i = 1, 2, …, m and j = 1, 2, …, n.

Step 5. Determine the PIS and NIS

The PIS and the NIS of this study can be defined as:

$$A^{+} = \{(max v_{ij} | j \in J), (min v_{ij} | j \in J^{'}) | i = 1,2 \dots, m\} = \{v_1^{*}, v_2^{*}, \dots, v_n^{*}\} \qquad (3)$$

$$A^{-} = \{(min v_{ij} | j \in J), (max v_{ij} | j \in J^{'}) | i = 1,2 \dots, m\} = \{v_1^{-}, v_2^{-}, \dots, v_n^{-}\} \qquad (4)$$

Step 6. Calculate the distance of each alternative from A^+ and A^- respectively

$$d^{+} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{*}\right)^2}, i = 1,2 \dots m; j = 1,2, \dots, n \qquad (5)$$

$$d^{-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-}\right)^2}, i = 1,2 \dots m; j = 1,2, \dots, n \qquad (6)$$

Step 7. Calculate the closeness coefficient

After step 6, this study calculated the closeness coefficient of each alternative using the formula bellow:

$$CC_i = \frac{d^-}{d^+ + d^-} \qquad (7)$$

Step 8. Rank the order of alternatives according to the closeness coefficient

According to the closeness coefficient of each alternative, this study determines the ranking order of all human error factors from the highest closeness coefficient to the lowest. The ranking order also represents the efficient improvement strategy for the ED adverse events.
There were three criteria in this study including influence, reproducibility, and preventability of ED adverse events, which are identified by the experts who participated in the study. After the human error analysis is completed, the experts need to evaluate the degree of these three criteria for each of the human error factors in the ED adverse events. After the evaluation is completed, TOPSIS method will be used for improvement strategy.

3. Results

3.1 Human error analysis

This study analyzed the EMR which occurred in the ED during 2012/1/1 to 2014/6/30. 840 EMR were selected based on the six criteria in the first selecting step. Of these 840 EMR, 46 were identified as ED adverse events which related to the purpose of this study.
Of these 46 ED adverse events, 69.8% were categorized as decision error, 59.2% were categorized as skill-based error, 28.6% were categorized as perceptual error, and 46.5% were categorized as violation error (Figure 1)

3.2 Improvement strategy

A five-step process was utilized to select the improvement strategy for ED adverse events based on the four subcategories of "Unsafe act". The process was as follows:
Step1: The criteria used to determine the improvement strategy for human error selection were identified with the assistance of the experts. There were three criteria in this study including influence, reproducibility, and preventability of ED adverse events. The experts determined the weight preference for each criterion and rated the alternatives based on the criteria.
Step 2: The experts (the decision makers, identified in section 2.1) need to evaluated the error factors (the subcategory of "Unsafe acts") based on the three criteria using 11 points scale (0 to 10, 0 means none and 10 means extremely high). The calculated weight of influence is 0.54, reproducibility is 0.16, and preventability is 0.31 based on the analytic hierarchy process (AHP).
Step 3: The TOPSIS methodology was used to rank the ED adverse events improvement strategy. The decision matrix was normalized using formula (1), and the weight of each criterion was multiplied with the normalized matrix form a weighted normalized decision matrix. After generating the matrix, the PIS and NIS were determined by following formula (3) and formula (4), respectively. In the next step, the distance of the criteria from the PIS and NIS was calculated using the formula in (5) and (6). In order to

rank the human error based on their closeness to the PIS and remoteness to the NIS, the closeness coefficient (CC) was calculated using formula (7). The weighted normalized decision matrix, the distance of each criterion to PIS and NIS, closeness coefficient, and ranks obtained by each criterion calculated in this study (Table 1 and 2), respectively.

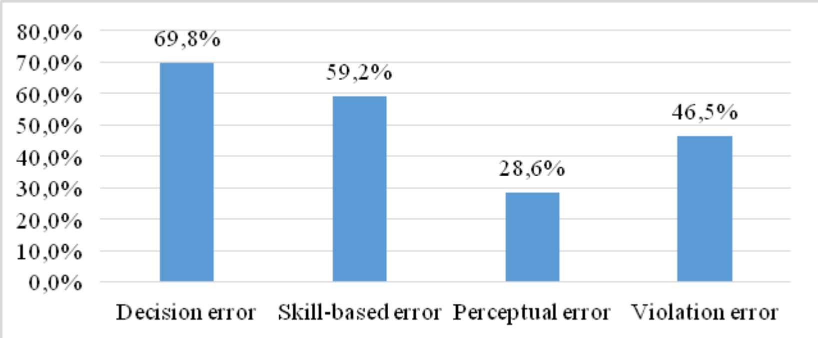

Figure 1: The occurrence rate of the subcategory of Unsafe acts

Table 1: The weighted normalized decision matrix

Unsafe act	Influence	Reproducibility	Preventability
Decision error	0.3417	0.0985	0.1930
Skill-based error	0.2931	0.0854	0.1718
Perceptual error	0.1615	0.0453	0.0909
Violation error	0.2401	0.0703	0.1450
PIS	0.3417	0.0985	0.1930
NIS	0.1615	0.0453	0.0909

Table 2: The distance, closeness coefficient, and ranks

Unsafe act	D^+	D^-	CC_i	Rank
Decision error	0	0.2139	1	1
Skill-based error	0.0546	0.1597	0.745331221	2
Perceptual error	0.2139	0	0	4
Violation error	0.1159	0.0987	0.459949141	3

D^+: The distance of the criteria from the PIS.
D^-: The distance of the criteria from the NIS.

Based on the results of the closeness coefficients (Table 2), the rank (improvement strategy) obtained for the four human error factors are summarized as follows:

- By TOPSIS method and under the category "Unsafe act":
  Decision error → Skill-based error → Violation error → Perceptual error

4. Discussion and conclusion

Based on the results of this study, the human error factor "Decision error" is the most efficient way to reduce ED adverse events. In ED, the medical staff need to diagnose the diseases immediately and execute relevant and simple treatment for the patients, and decision error might affect their professional diagnosis directly that could fail to provide support and assistance to patients. Thus, based on the three criteria in terms of influence, reproducibility, and preventability of ED adverse events, to decrease the influence of decision error is most efficient way on increasing patient safety in ED.

To analyze an improvement strategy is a decision-making problem, and more decision criteria can potentially make the results more objective. In this study, TOPSIS allowed the usage of three different criteria to assess improvement efficiency of four human error factors. From the perspective of reducing human errors, both Fordyce et al. [5] and Freund [3] provided the ED human error categories in their studies. However, they did not identify the most efficient way to reduce relevant human errors. This study applied TOPSIS after human error analysis to assess the error based on different criteria, and provided an improvement strategy for reducing adverse events in ED.

There are two limitations of this study. First, the improvement strategy found in this study is based on the ED adverse events, so the results might not be applicable to other departments. Second, previous studies indicated that human error could be divided into two types: active human errors and latent human errors [9, 12]. Active human errors result in accidents directly and their influence is immediate, such as error factors which are used in this study. Latent human errors cause accidents indirectly, such as resource management, organizational culture, and etc. However, this study uses four error factors to analyze ED adverse events, which belong to active human error. Latent errors factors were not involved and analyzed in this study, which could make this study incomplete on human error analysis. According to the limitations, the authors of this paper will continue efforts in analyzing human errors including active and latent error factors in ED adverse events with HFACS and investigate the improvement strategy in the future.

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REFERENCES

[1] Forster, A. J.; Asmis, T. R.; Clark, H. D.; Al Saied, G.; Code, C. C.; Caughey, S. C.; Baker, K.; Watters, J.; Worthington, J. & van Walraven, C.: Ottawa Hospital Patient Safety Study: incidence and timing of adverse events in patients admitted to a Canadian teaching hospital. *Canadian Medical Association Journal*, Vol. 170(2004) No 8, pp. 1235-1240.

[2] Calder, L. A.; Forster, A.; Nelson, M.; Leclair, J.; Perry, J.; Vaillancourt, C.; Hebert, G.; Cwinn, A. A.; Wells, G. & Stiell, I.: Adverse events among patients registered in high-acuity areas of the emergency department: a prospective cohort study. *Canadian Journal of Emergency Medicine*, Vol. 12(2010) No. 5, pp. 421-430.

[3] Freund, Y.; Goulet, H.; Bokobza, J.; Ghanem, A.; Carreira, S.; Madec, D.; Leroux, G.; Ray, P.; Boddaert, J.; Riou, B. & Hausfater, P.: Factors associated with adverse events resulting from medical errors in the emergency department: two work better than one, *The Journal of emergency medicine*, Vol. 45(2013) No. 2, pp.157-162.

[4] Kohn, L. T.; Corrigan, J. M. & Donaldson, M. S.: *To err is human: building a Safer Health System*, National Academies Press, ISBN: 0-309-51563-7, (1999).

[5] Fordyce, J.; Blank, F. S.; Pekow, P.; Smithline, H. A.; Ritter, G.; Gehlbach, S.; Benjamin, E. & Henneman, P. L.: Errors in a busy emergency department. *Annals of emergency medicine*, Vol. 42(2003) No. 3, pp. 324-333.
[6] Cowan, R. M. & Trzeciak, S.: Clinical review: emergency department overcrowding and the potential impact on the critically ill. *Critical care*, Vol. 9(2004), pp.291.
[7] Stang, A. S.; Wingert, A. S.; Hartling, L. & Plint, A. C.: Adverse events related to emergency department care: a systematic review. *PLoS One*, Vol. 8(2013) No. 9, e74214.
[8] Chisholm, C. D., Collison; E. K., Nelson; D. R. & Cordell, W. H.: Emergency Department Workplace Interruptions Are Emergency Physicians "Interrupt-driven" and "Multitasking"?. *Academic Emergency Medicine*, 7(2000) No. 11, pp. 1239-1243.
[9] Chiu, M. C. & Hsieh, M. C.: Latent human error analysis and efficient improvement strategies by fuzzy TOPSIS in aviation maintenance tasks. *Applied Ergonomics*, Vol. 54(2016), pp. 136-147.
[10] Hwang, C. L. & Yoon, K.: *Multiple attribute decision-making methods and application*, Springer-Verlag, ISBN: 978-3-54010558-9, New York, (1981).
[11] Wiegmann, D. A. & Shappell, S. A.:. Human error analysis of commercial aviation accidents: Application of the Human Factors Analysis and Classification System (HFACS). *Aviation, space, and environmental medicine*, Vol. 72(2001) No. 11, pp. 1006-1016.
[12] Reason, J.: *Human error*. Cambridge university press. (1990).
[13] Wolff, A. M. & Bourke, J.: Detecting and reducing adverse events in an Australian rural base hospital emergency department using medical record screening and review. *Emergency Medicine Journal*, Vol. 19(2002) No. 1, pp. 35-40.
[14] Hendrie, J.; Sammartino, L.; Silvapulle, M. J. & Braitberg, G.: Experience in adverse events detection in an emergency department: nature of events. *Emergency Medicine Australasia*, Vol. 19(2007) No. 1, pp. 9-15.
[15] Kannan, D.; de Sousa Jabbour, A. B. L. & Jabbour, C. J. C.: Selecting green suppliers based on GSCM practices: Using fuzzy TOPSIS applied to a Brazilian electronics company. *European Journal of Operational Research*, Vol. 233(2014) No. 2, pp. 432-447.

BIOMECHANICS AND ENERGY EXPENDITURE INDEX OF WALKING WITH DIFFERENT MODES OF LOAD CARRIAGE AMONG INDUSTRIAL WORKERS

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Abstract

Study was conducted with an aim to determine changes of human biomechanics and Energy Expenditure Index (EEI) of carrying load at different modes between young (n=10) and aged (n=10) workers. Qualisys Motion Capture System (Sweden), Kistler Force Plate (Switzerland) and Polar S810i HR monitor, Finland were used. Heart rate was measured at rest and during different modes of load carriage (20% of body weight) i.e. loads on head, shoulder and hand. Age of the young and aged workers was 26.1±2.64 yrs and 50.1±5.40 yrs respectively. Walking speed for young and aged subjects during head load were 4.5±0.21 and 3.9±0.63 km.hr^{-1}; shoulder load 4.6±0.39 and 3.6±0.83 km.hr^{-1} and hand load 4.7±0.29 and 3.2±0.53 km.hr^{-1} respectively. EEI values for young and aged subjects for head load were 0.63±0.11 and 0.85±027 beats.min^{-1}, during shoulder load 0.72±0.14 and 0.92±0.36 beats.min^{-1} and during hand load 0.72±0.13 and 1.13±0.30 beats.min^{-1} respectively. Results demonstrated a significant relationship between walking speed and EEI's of young and aged workers at different load conditions. Findings provide significant input for designing work and work rest cycle for industrial workforce.

Keywords: *biomechanics, Energy Expenditure Index, walking speed, load carriage*

1. INTRODUCTION

Human Locomotion is the process to stand upright and move about on two legs. The main three functions of lower limbs of human are to bear weight, provide means for locomotion and maintain equilibrium. The rhythmic alternating movements of the two lower limbs helps in the forward movement of the body and the manner in which it occurs i.e. how a person walks is what is known as gait.

There are three main phases of gait i) Stance phase (support) - begins when the heel of the forward limb makes contact with the ground and ends when the toe of the same limb leaves the ground. ii) Swing phase (no support) - begins when the foot is no longer in contact with the ground. The limb is free to move. iii) Double support - both limbs are in contact with the ground simultaneously. The activity that occurs between heel strike of one limb (reference limb) and the subsequent heel strike of that same limb is known as gait cycle.

Human movement with handling load and resultant energy expenditure play a significant role in industry for safety, health and efficiency of the workforce. It is evident that biomechanics of human movement changes with modes of load carriage in an industrial situation. Further, biomechanical load coupled with energy cost of work provides a significant input for design of a work system. Energy cost of work is derived from the rate of oxygen consumption directly or from the heart rate responses at work indirectly. Heart rate response has been found an easy assessment technique in industrial situation, since heart rate can be easily measured without using any sophisticated equipment. Physiological Cost Index (PCI) also known as Energy Expenditure Index (EEI) is used for measuring the energy cost of walking indirectly [9]. EEI is the difference of walking heart rate and resting heart rate divided by walking speed. There have been various studies using the Energy Expenditure Index to measure energy cost [1,5,6,8]. It is evident along with biomechanics of human movement, that there is change in EEI pattern with different modes of load carriage in industrial workers.

2. AIMS AND OBJECTIVES

Present study was carried out with following aims and objectives:

1. To capture and analyze the gait pattern of healthy workers (young and aged).
2. To investigate the changes associated with age in basic gait parameters like walking speed, stride width & length of healthy workers.
3. To determine changes of human biomechanics with selected modes of load carriage
4. To determine the Energy Expenditure Index (EEI) of carrying load at different modes between young and aged workers
5. To compare the basic gait parameters and EEI of young and aged workers.

3. MATERIALS AND METHODS

3.1 Participants

Volunteers for the study were selected from an industrial site in Mumbai, the western region of India. The volunteers were selected by using purposive sampling method. While selecting volunteers, care was taken that none of them had musculoskeletal disorders or restriction on movement. The sample size of the study was 20 that included 10 young workers of age range 22 to 28 years and 10 aged workers of age range 46 to 58 years.

3.2 Instrumentation

Biomechanics was studied by using Qualisys Motion Capture System (Sweden). For tracing the subject's movements, an array of six high speed cameras (type: 'Oqus') by the company 'Qualisys' was used. Kistler (Switzerland) force plates (2 Nos) were used along with the Qualisys system. This system altogether captures motion data along with the force data. In the study, it was used to collect kinematic data of gait. Weighing scale, flexible measuring tape and anthropometric kit were used to measure the physical dimensions of the volunteers. Polar S810i Heart Rate Monitor, Finland was used to measure heart rate after exertion of activity. Written consent was obtained and then a screening examination was conducted to ensure each volunteer was free of lower extremity musculoskeletal problems.

3.3 Data collection procedure

Thirty six reflective markers were placed on specific locations of each volunteer's legs and pelvic region. The defining markers, which enabled Visual 3D to reconstruct the digital skeleton of the volunteers, included the following anatomical positions: ASIS (Anterior Superior Iliac Spine), PSIS (Posterior Superior Iliac Spine), greater trochanters, thigh, shanks, lateral and medial side of knee joint line, lateral and medial malleolus, heel marker was placed on the posterior side of the calcaneus of both the legs and two markers were placed on the first and fifth metatarsal bone of both the legs. After the static trial, heel, knee and hip markers were not needed so were removed during the motion trial.

The OQUS cameras and the Qualisys Motion Capture System, Sweden were used to film the volunteers walking along a 50 meter rectangular walkway. Each volunteer first walked along the walkway at their self-selected speed without any load. This was used to establish a baseline and then, in random order, they walked along the walkway while carrying 20% of body mass of individual volunteers [3] load on head, across one shoulder and hand (frontal plane). Each volunteer followed the same protocol for the testing conditions. The volunteers were allowed to walk on both the force plates (Kistler, Switzerland). Force plate-1 and force plate-2 were stepped by left foot and right foot respectively. The volunteers were asked to walk for 15 minutes during which the activity was recorded by the OQUS infrared digital cameras and was considered for analysis. Resting and peak heart rates were also noted for each activity.

Four different modes of walking were selected. Those are:

i. Carrying (20% of body mass in kg) load on head
ii. Carrying (20% of body mass in kg) load across one shoulder
iii. Carrying (20% of body mass in kg) load on hand on frontal plane (hand load)

3.4 Data-Processing

To record the motion and force plate data the software Qualisys Track Manager was used and was analyzed by Qualisys Visual 3D software (professional version). The gait parameters and Energy Expenditure Index were generated for each of the volunteers and comparison was made between young and aged workers with different modes of load carriage.

3.5 Analysis

To ensure that the cameras and force plates recorded properly from both sides of the y-axis (defined as the direction of walking), the test subject entered the analyze-space from positive y-direction half of the trials, while the other half from the negative y-direction. The reflective markers were used to define the different anatomical points on the test subject's body. It was ensured that the cameras and force plates recorded properly all the three coordinate axis. In order to test the comparability of the force plates, half the trails were done stepping with the subject's left foot on force plate-1 and second half of the trails the subject stepped with his right foot on force plate-1 while traversing the same pathway in reverse direction.

The data collected was analyzed by using standard statistical tools. It was tabulated and appropriate result and discussion was prepared.

4. RESULTS AND DISCUSSIONS

The young group comprised of 10 healthy industrial workers of age range from 22–28 years (26.1±2.64 years). None of the subjects had any history of neurological or orthopedic disorders likely to affect their mobility. The aged industrial workers comprised of 10 healthy volunteers in the age range of 46–58 years (50.1±5.40). Volunteers were excluded from the study if they had any health problem like arthritis, diabetic feet or Parkinson's disease.

Table 1. Demographic parameters of the subjects

Groups	**Age (years)**	**Height (m)**	**Weight (kg)**	**BMI (kg/ m^2)**	**Q angle (^{0})**
Young Workers	26.1±2.64	1.7±0.06	64.7±6.49	23.28±2.29	12.0±1.33
Aged Workers	50.1±5.40	1.7.±0.089	63.1±7.78	22.4±2.59	15.9±0.99

Mean±SD

In Table-1 the demographic details of the workers have been presented. The mean age of young group was 26.1±2.64 years and the aged group was 50.1±5.40 years. The mean height and weight were 1.7±0.06 m and 64.7±6.49 kg for the young group and 1.7.±0.09 m and 63.1±7.78 kg for the aged group respectively. The Body Mass Index and resting heart rate of both the groups were 23.28±2.29 kg/m^2 and 74.1±3.44 beats/min and 22.4±2.59 kg/m^2 and 86.2±9.07 beats/min respectively. Higher Q angle in aged group indicated posture related instability among aged workers in comparison to young group.
In Table-2, changes in the basic gait parameters like walking speed, stride length and width have been shown for both young and aged workers in different load conditions.

Table 2. Biomechanical parameters with modes of load carriage

Parameter	Stride length (m)		Speed (km/h)		Stride width (m)	
	Young Workers	Aged Workers	Young Workers	Aged Workers	Young Workers	Aged Workers
Head Load	1.36±0.09	1.11±0.04	4.89±0.21	3.89±0.63	0.10±0.01	0.45±0.44
Shoulder Load	1.32±0.08	1.10±0.03	4.6±0.39	3.59±0.83	0.12±0.01	0.49±0.09
Hand Load	1.35±0.23	1.06±0.03	4.45±0.29	3.23±0.53	0.13±0.01	0.55±0.54

Mean±SD

Walking speed for both the young and aged workers was maximum while carrying load on head and minimum speed while carrying load in hand. Aged workers found it difficult to carry load in hand and shoulder compared to younger workers. Comparison of stride width shows that it increases from head load to shoulder load to hand load in both the young and aged workers. Since, load on hand creates a moment arm anterior to spine and shifts the Centre of Gravity outside the body, hence, to counteract shifting of Centre of Gravity, there is increase of Base of Support (stride width). Decrease in speed and increase in stride width is a sustained effort to maintain the stability while carrying load [4]. Maximum stride width was maintained while carrying hand loads for both the groups. Wide-based gait is considered indicative of imbalance [2]. So, hand load caused maximum imbalance as speed decreased and stride width increased which indicated as adaptability for the workers to carry on their work and it had more adverse impact on elderly workers.

Stride length of young groups found to be maximum while carrying load on hand. The minimum stride length was found while carrying load on head for both the groups. The stride length was found maximum for aged workers while carrying load on head and it was found minimum for them while carrying load on hand. Overall stride length was found to be greater among younger workers compared to aged workers. Rose et al [7] shows similar result, in which young adults showed a greater increase than did the aged subjects. While the changes in gait characteristics were relatively small for the young subjects, the older population was affected to a greater extent thereby demonstrating a greater sensitivity to load magnitude in a load carriage task.

In Table-3, the heart rate (pre-work and post-work), heart rate cost, energy expenditure indices in different load conditions of both young and aged workers has been presented. Table-4 showed oxygen consumption (VO_2) and the energy cost of work (in different load conditions) of both the young and aged groups.

Table 3. Heart rate responses with modes of load carriage

Parameter	Pre-load heart rate (beats/min)		Post-load (beats/min)		HR Cost (beats/min)		EEI (beats/meter)	
	Young Workers	Aged Workers	Young Workers	Aged Workers	Young Workers	Aged Workers	Young Workers	Aged Workers
Head Load	64.3 ±7.38	83.7 ±7.99	111.1 ±10.89	136.9 ±6.08	46.8 ±7.58	53.2 ±12.43	0.63 ±0.11	0.85 ±0.27
Shoulder Load	71.9 ±4.75	82.3 ±5.86	126.7 ±8.60	137.3 ±10.84	54.8 ±7.19	55.0 ±11.61	0.72 ±0.14	0.92 ±0.36
Hand Load	74.1 ±3.45	82.3 ±5.87	129.5 ±7.99	145.7 ±8.00	55.4 ±8.09	63.4 ±8.59	0.72 ±0.13	1.13 ±0.30

Mean±SD

The changes in the above mentioned physiological parameters signify the impact of age and different modes of carrying load on industrial workers while carrying out their daily job of manual handling of heavy loads.

There is a gradual increase in heart rate cost and EEI from head load to shoulder load and hand load in both the young and aged workers (Table 3). Both the groups found to have increased heart rate and VO_2 during hand load followed by shoulder load compared to head load condition. Also, response of energy cost shows that values are higher in shoulder and hand load in comparison to head load.

Table 4. Oxygen consumption and energy cost with modes of load carriage

Parameter	VO2 (ml/kg/min)		Energy cost work (kJ/min)	
	Young Workers	Aged Workers	Young Workers	Aged Workers
Head Load	18.71±3.05	25.93±1.70	17.72±2.86	20.06± 6.65
Shoulder Load	23.08±2.41	26.04±3.03	20.80±3.30	19.10± 6.25
Hand Load	23.9±2.24	23.9±2.24	21.11±3.95	22.15±5.57

Mean±SD

Energy expenditure indices (EEI) and energy cost based on heart rate were used to compare the economy of walking at various load conditions by young and aged workers. During walking with shoulder load and hand load, EEI values were high, indicating poor economy of walking for both the groups, but elderly workers found it more difficult to maintain a low EEI compared to younger groups in all the load conditions. Compared to other load conditions both the groups maintained lower value of EEI during head load.

5. CONCLUSIONS

All the above findings can help to provide objective information evaluate the influence on gait function with increase in age and different loaded gait intervention. Carrying load on head has been found to be the most comfortable way of carrying out manual handling of loads for both the age group. Minimizing all those biomechanical changes seems a rational design goal for the industrial workers doing manual handling of load.

REFERENCES

[1] Butler, P.; Engelbrecht, M.; Major, R. E.; Tait, J. H.; Stallard, J. & Patrick, J. H: Physiological cost index of walking for normal children and its use as an indicator of physical handicap, *Developmental Medicine & Child Neurology*, **Vol 26** (1984) 5., pp. 607-612, ISSN: 0012-1622.

[2] Fredericson, M. & Yoon, K.: Physical examination and patellofemoral pain syndrome, *American Journal of Physical and Medical Rehabilitation*, **Vol 85** (2006) 3., pp. 234-243, ISSN: 0894-9115.

[3] Kinoshita, H.: Effects of different loads and carrying systems on selected biomechanics parameters describing walking gait, *Ergonomics*, **Vol 28** (1985) 9., pp. 1347-1362, ISSN: 0014-0139.

[4] Maki, B. E.: Gait changes in older adults: predictors of falls or indicators of fear?, *Journal of American Geriatrics Society*, **Vol 45** (1997) 3., pp. 313-320, ISSN: 0002-8614.

[5] Mossberg, K. A.; Linton, K. A. & Friske, K.: Ankle-foot orthoses: Effect on energy expenditure of gait in spastic diplegic children, *Archives of physical medicine and rehabilitation*, **Vol 71** (1990) 7., pp. 490-494, ISSN: 0003-9993.

[6] Mukherjee, G. & Samanta, A.: Physiological response to the ambulatory performance of hand-rim and arm-crank propulsion systems, *Journal of rehabilitation research and development*, **Vol 38** (2001) 4., pp. 391-399. ISSN: 0748-7711.

[7] Rose, J.; Gamble, J. G.; Burgos, A.; Medeiros, J. & Haskell, W. L.: Energy expenditure index of walking for normal children and for children with cerebral palsy, *Developmental Medicine & Child Neurology*, **Vol 32** (1990) 4., pp. 333-340, ISSN: 0012-1622.

[8] Shkuratova, N.; Morris, M. E. & Huxham F.: Effects of Age on Balance Control during Walking, *Archives of Physical Medicine and Rehabilitation*, **Vol 85** (2004) 4., pp. 582-588, ISSN: 0003-9993.

[9] Suzuki, T.; Sonoda, S.; Saitoh, E.; Murata, M.; Uno, A.; Shimizu, Y. & Kotake, T.: Development of a novel type of shoe to improve the efficiency of knee-ankle-foot orthoses with a medial single hip joint (Primewalk orthoses): a novel type of shoe for Primewalk orthosis, *Prosthetics and orthotics international*, **Vol 29** (2005) 3., pp. 303-311. ISSN: 0309-3646.

ASSESSMENT OF SPINE STABILITY AFTER AN EIGHT-HOUR OFFICE WORK PERIOD

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Abstract

Low back pain is a common symptom among office workers. Several mechanisms, through which prolonged sitting can contribute to the development of back pain, have been identified. The aim of this study was to test acute effects of an eight-hour office work on sensory-motor functions underlying spine stability. 17 healthy office workers participated in the study. Kinesthetic sense of the trunk, anticipatory postural adaptations and postural reflex reactions were tested before and after an eight-hour office work in real life environment. There was a tendency toward impaired kinesthetic sense ($p = .079$) and changes in postural trunk functions ($p < .05$) after an eight-hour office work. The detected (tendency of) changes in postural trunk functions suggest impairment in elements responsible for stability of the spine. Office workers should be informed about postural recommendations during sitting, benefits of active breaks and should avoid demanding exertions immediately after prolonged periods of sitting.

Keywords: *sitting, low back pain, ligaments, postural trunk functions, kinesthesia*

1. INTRODUCTION

Spinal stability is a well-known concept among clinicians and researchers. It is believed to play an important role in the development and persistence of non-specific low back pain (LBP). From the engineering point of view, stability is the ability of the system to successfully resist mechanical disturbances [1]. If the system is not stable, its mechanical efficiency is compromised and the system is prone to premature overuse. An instable spinal segment is characterized with unfavorable trajectory of joint surface movement, which causes overloads on specific tissues and consequently (micro) damages of the tissue. Spinal stability is a complex, dynamical, multi-factorial and temporally variable index [2]. Panjabi [3] has divided stabilizing system of the spine into three interdepended subsystems – passive (skeletal and connective elements), active (muscles) and control (nervous system). The latter has to precisely control activation of trunk muscles in order to achieve continuous spinal stability and to assure a base for coordinated movements of the body segments. For this aim, trunk muscles act predominantly in co-contraction activation patterns [4]. When sudden expected or unexpected mechanical perturbations on the trunk occurs, anticipatory postural adaptations (APAs) and postural reflex reactions (PRRs), respectively, are needed for spinal stability maintenance [5]. Central nervous system has the ability to anticipate consequence of the expected mechanical perturbation and to activate trunk muscles accordingly (typically before the perturbation occurs), so the effect of perturbation and the need for further muscle activation corrections are diminished [6]. In case of unexpected mechanical perturbations, PRRs occur. Proprioceptors in different (para)spinal tissues detect a mechanical perturbation applied to the trunk and send afferent information to the central nervous system which sends demands for muscle activation [7].

All tree subsystems of the spine are interdependent. Non-optimal functioning of one subsystem cause an effect on the other two subsystems and on spinal stability [3]. The control subsystem detects deficits and attempts to compensate for them with changes in the active subsystem. Stability of the spine can therefore be achieved although one system is compromised acutely or chronically. However, consequences of chronically modified muscle activity has unfavorable effects, typically resulting in increased loading of spinal structures. Several sensory-motor changes have been reported in patients with LBP: (i) decreased strength and endurance of trunk and/or hip muscles [8], (ii) increased level of co-contraction [9], (iii) changes in trunk muscle recruitment pattern [10], (iv) delays in APAs [11] and (v) in PRRs [12], (vi) impaired kinesthetic sense of the trunk [13] etc. Whether those changes are a cause or a consequence of LBP is not fully understood. Many clinicians and researches believe that micro damages of viscoelastic spinal tissues (ligaments, capsules and fascia) are a source of non-specific LBP. Those tissues are rich with proprioceptors and if a tissue is damaged, sensory information is compromised. That can result in impairments of sensory-motor control of the lumbo-pelvic region of the body. Impairments in sensory-motor control increase the risk of future micro damage of the viscoelastic tissues. LBP patients can therefore be caught in a vicious circle, which results in chronic pain.

Kinesthetic sense of the trunk and PRRs are also acutely changed in healthy individuals after relatively short periods of lumbo-pelvic flexion [14, 15]. The effect of flexion on APPs has not been well researched yet. In flexion positions, viscoelastic tissues of the spine are stretched. That changes their mechanical and biological characteristics and micro damage could also occur [2]. Due to the changes in viscoelastic tissues, sensory-motor control of the lumbo-pelvic region is compromised. People often slouch their backs in everyday activities, which can be in some cases a risk factor for LBP development. A very common everyday activity during which people slouch their backs is sitting. A modern human spend 6 to 10 hours per day in a sitting position [16]. There are many different ways of sitting, but people most often sit with their spines semi-flexed. Sitting has also become a prevailing working position. Office workers sit up to 80 % of their work time [17]. One of real life environment study has shown, that office workers sit almost 30 % of the sitting time with their lumbar spine near full flexion [18]. That could have negative effects on their spinal structures, sensory-motor functions and spinal stability. LBP is a common symptom among office workers and several deleterious mechanisms have been identified. The aim of our study was to test APAs, PRRs and kinesthetic sense of the trunk prior and after an eight-hour office work in real life environment. Impairments in those sensory-motor functions of the trunk could challenge spinal stability and increase the risk for LBP development and persistence.

2. METHODS

2.1 Participants

The interested office workers of Slovenian logistic company participated in the study. Only those who were free from clinically important LBP (VAS < 3) during the last 12 months were included in further analysis. 17 healthy office workers (9 male, 8 female) participated: age 42.2 ± 9.4 years, body height 176 ± 8 cm, and body mass 76.5 ± 14.5 kg. The participants` time of employment at the current workplace was 7.8 ± 4.7 years.

2.2 Study design

Each participant was tested two times in the same day - prior (before 7 am) and after (after 15 pm) his/her working time. Participants underwent a short warm up prior to both testing sessions. Each testing session lasted about one hour and several measurements were carried out. In this report we are focusing on the following datasets: (i) kinesthetic sense of the trunk measured as an error of active repositioning, (ii) trunk muscles` responses to expected trunk perturbation (quick arm flexion), i.e. APPs, and (iii) trunk muscles responses of unexpected trunk perturbation, i.e. PRRs.

2.3 Measurement devices

All measurements were carried out using a custom developed diagnostic system (TNC system by S2P, Science to Practice, Ltd., Ljubljana, Slovenia). Among other sub-components the TNC system includes: (i) axial inertial measurement units (IMU) for reposition error measurements, (ii) unit for quick arm rise with electromyogram for APPs measurement and (iii) unit for sudden arm loading with electromyogram for PRRs measurement. EMG signals were 1500-times amplified and captured via analog-digital card (NI USB-6343, National Instruments Inc., Texas, USA) with the frequency of 4000 Hz. Signal acquisition and processing was done by a custom built software (Labview, National Instruments Inc., Texas, USA).

2.4 Measurement procedure

Kinesthetic sense of the trunk was measured with the active repositioning test (Figure 1a). One IMU on the skin over the sacrum (S1), the second one over the spinal segment L1/Th12, and third one over the processus spinousus of C7. While performing the test, the participant wore a non-transparent mask to exclude vision. The starting position was a normal upright posture. Researcher than guided the participant to a mid-range trunk flexion (i.e. forward bend), and stopped the participant with the verbal notice “stop and remember this referent position (2-3 s); and return back to the upright position”. Immediately after that, the participant was asked to reproduce the previous reference position on his/her own – as precisely as possible. Three such pairs of guided and self-reproduced trunk flexions were performed by the subject.

a. b. c.

Figure 1: The tests: a) kinesthetic sense of the trunk, b) anticipatory postural adaptations and c) postural reflexive reactions.

APAs were measured during the quick arm rise in standing position (Figure 1b). We measured bilateral muscle responses of thoracic part of erector spinae, lumbar multifidus, obliquus externus and internus abdominis, and right deltoideus muscle. The participant stood relaxed with feet parallel at the hips` width and holding a stick (300 g) in his/her hands positioned relaxed in front of the hips. The participant was asked to quickly rise his/her hands (90° shoulders flexion) following a sound signal that appeared at random timing (8 to 12 s). Two sets of 10 repetitions (1-min rest between sets) were performed [19].
PRRs of the same muscles were measured using sudden unexpected loading applied to the participant`s hands (Figure 1c). Participant stood relaxed with feet parallel at the hips width and 90° flexion in elbows, hands facing up and slightly touching the stick. The mechanism randomly (every 8 to 12 s) released the stick which fell into the participant`s hands. An 8-kg (~ 9.1 % body mass) stick for men and 5-kg (~ 7.8 % body mass) for women was used. Two sets of 10 repetitions (1-min rest between sets) were performed [19].

2.5 Evaluation of data and statistical analysis

For repositioning error evaluation, we calculated spatial orientation of the IMUs and angels between them, using Madgwick filter. Data from reference and repositioned posture were compared and the repositioning error was calculated. An average of all the tree repetition-pairs was taken to further statistical analysis.
In case of APAs` and PRRs` analysis, the EMG signals were filtered (Butterworth band-pass, 3 to 500 Hz, level 2, zero phase shift) and smoothed (flowing window root-mean-square, 20-ms window), followed by a linear envelope calculation (Butterworth 10 Hz low-pass filter, level 2, zero phase shift). The onset of muscle activation was determined using a custom developed algorithm [20] with the criterion of two standard deviations change in EMG activity (reference 50-ms window prior to the arm movement). Latencies of APAs were calculated as the time difference between the onset of the deltoid muscle`s activation and the onset of the individual trunk muscle`s activation, respectively. The latencies of PRRs were calculated in reference to the time instant of the load release. Additionally, we calculated the average an EMG amplitude in the 50-

ms window from the muscle`s activation onset. Averages and standard deviations of all 20 repetitions were taken to further statistical analysis.

Descriptive statistics were calculated (mean, standard deviation). Normality was tested using Shapiro-Wilk test. Pairwise two-tailed t-test was applied to test differences between pre and post work values. Statistical significance was set at $p < .05$.

3. RESULTS

LBP is a common symptom among office workers. Many mechanisms through which prolonged sitting could cause or importantly contribute to LBP have been suggested. In this study, we focused on acute effects of the eight-hour office work on some elements involved in spinal stability. Whereas direct measure of spinal stability is not possible, many indirect measures have been introduced. Some of those measures are kinesthetic sense, APAs and PRRs of the trunk.

Results from the repositioning test showed no statistically significant difference ($p > .05$) of kinesthetic sense of the trunk after the eight-hour office work. Although there was a tendency of minor exceedance of reference position in the pre-work testing, the post-work testing showed a slight undershooting of the reference position (t= 1.770 and 1.923; p = 0.102 and 0.079; ES = 0.207 and 0.236; for lumbar and lumbo-thoracic part of the trunk, respectively). Dolan and Green [14] have shown significant repositioning error immediately after 5 min of slouched sitting, while Hendershot and co-workers [21] reported that postural control of the lumbo-pelvic region (while sitting on an unstable surface) returns to baseline values after only 10 min of rest. In our study the repositioning error test was performed at least 20 min after the participant finished his/her office work. We believe that kinesthetic sense has already improved to some point in that time. Deterioration of kinesthetic sense after a period of lumbo-pelvic flexion has been attributed to a viscoelastic tissue stretch. It is possible that participants have good postural habits while sitting, so there is no/small lumbo-pelvic flexion during their sitting. However, we did not monitor sitting habits of participants.

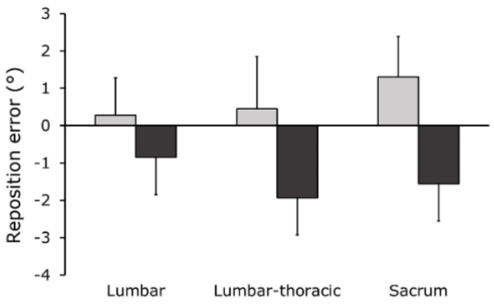
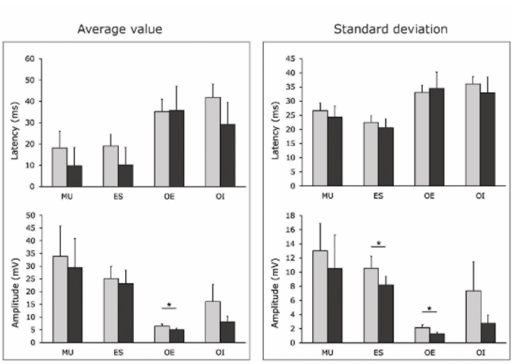


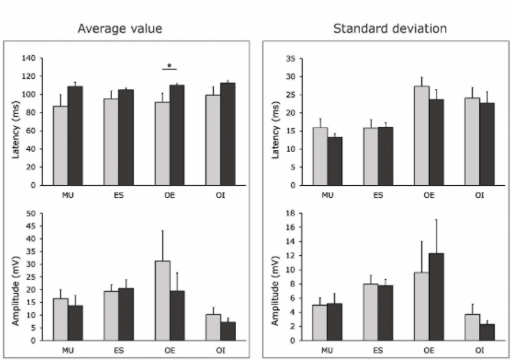
Figure 2: Results (mean, standard errors) of the kinesthetic sense of the trunk before and after the eight-hour office work. The light colored columns represent results before and the dark colored columns represent results after the eight-hour office work.

We detected some changes in EMG amplitudes in APPs and EMG latency in PRRs after the office work. A statistically significant decrease in rectus abdominis EMG amplitude was observed (t = 3.024; p = 0.011; ES = 0.433) while a trend of the same change was seen in the multifidus muscle (t = 2.131; p = 0.054; ES = 0.275). Significantly lower was also the intra-participant` (i.e. inter-trial) variability of EMG amplitudes in erector spinae and obliquus externus abdominis muscles (t = 2.231 and 2.725; p = 0.046 and 0.018; ES = 0.293 and 0.382, respectively). In case of PRRs the obliquus externus abdominis increased its latency after the eight-hour work (t = -2.336; p = 0.039; ES = 0.332); the change of ~ 20 % (i.e. 19 ms) compared to the pre-work values.

Sanchez-Zuriaga and co-workers [15] have shown delays in latency of PRRs in erector spinae muscles (p < .001) after one hour of 70 % full lumbo-pelvic flexion in sitting position. Delays were attributed to decreased sensitivity of proprioceptors in viscoelastic tissues due to viscoelastic stretch in lumbo-pelvic flexion. Our results showed delays in all the measured muscles (from 10 to 22 ms), but statistical significance was found only in case of the obliquus externus muscle. Cholewicki and co-workers [22] have shown that an increase of the PRR`s latency of only 14 ms can increases the risk for future LBP development. In spinal stability maintenance, proper activation (co-contraction) of all trunk muscles is required. Acute delays in trunk muscle latencies in PRRs after the eight-hour office work may therefore represent a risk factor for LBP development.



a.



b.

Figure 3: Results (mean, standard error) of: a) anticipatory postural adaptations and b) postural reflex reactions of the trunk before and after the eight-hour office work. The light colored columns represent results before and the dark colored columns represent results after the eight-hour office work; muscles: MU – multifidus; ES – erector spinae; OE – obliquues externus abdominis; OI – obliquus internus abdominis; * - p < .05.

Effects of lumbo-pelvic flexion on APPs have not been well researched yet. We have found only one study which shows no effect of a 10-min exposure to full flexion [23]. However, our results showed lower EMG amplitude and intra-participant`s variation of EMG amplitudes after the eight-hour office work. Acute changes in APPs could be adaptations to altered demands of spinal stability maintenance. Whether those changes are beneficial or harmful is not known yet. Lower EMG amplitudes in APPs in combination with shorter latencies are also seen as an adaptation to muscle fatigue [24]. The decrease in variability in APPs` latencies have been shown in those with LBP [25] and it was suggested that stereotypic patterns of activity brings unfavorable loads on spinal structures.

4. CONCLUSION

The detected (tendency of) changes in postural trunk functions suggest impairments in the elements responsible for stability of the spine. Office workers should avoid slouched sitting and take regular active breaks. When sensory-motor control of the spine is compromised there is an increased risk for spinal injury. Therefore, avoiding of demanding exertions immediately after prolonged period of semi-slouched sitting is suggested.

REFERENCES

[1] Reeves, N.P., Narendra, K.S. & Cholewicki, J.: Spine stability: the six blind men and the elephant, *Clin Biomech (Bristol, Avon)*, **22** (2007) 3, pp. 266-74, ISSN 0268-0033

[2] Solomonow, M.: Time dependent spine stability: the wise old man and the six blind elephants, *Clin Biomech (Bristol, Avon)*, **26** (2011) 3, pp. 219-28, ISSN 1879-1271

[3] Panjabi, M.M.: The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement, *J Spinal Disord*, **5** (1992) 4, pp. 383-9, ISSN 0895-0385

[4] Bergmark, A.: Stability of the lumbar spine. A study in mechanical engineering, *Acta Orthop Scand Suppl*, **230** (1989), pp. 1-54, ISSN 0300-8827

[5] Brown, S.H. & McGill, S.M.: The intrinsic stiffness of the in vivo lumbar spine in response to quick releases: implications for reflexive requirements, *J Electromyogr Kinesiol*, **19** (2009) 5, pp. 727-36, ISSN 1873-5711

[6] De Wolf, S., Slijper, H., & Latash, M.L., Anticipatory postural adjustments during self-paced and reaction-time movements, *Exp Brain Res*, **121** (1998) 1, pp. 7-19, ISSN 0014-4819

[7] Kandel, E.; Schwartz J.; Jessell T.: *Principles of neural science, 4 ed.*, McGraw-Hill, ISBN 0-8385-7701-6, United States of America, (2000)

[8] Steele, J., Bruce-Low, S. & Smith, D.: A reappraisal of the deconditioning hypothesis in low back pain: review of evidence from a triumvirate of research methods on specific lumbar extensor deconditioning, *Curr Med Res Opin*, **30** (2014) 5, pp. 865-911, ISSN 1473-4877

[9] van Dieen, J.H., Cholewicki, J. & Radebold, A.: Trunk muscle recruitment patterns in patients with low back pain enhance the stability of the lumbar spine, *Spine (Phila Pa 1976)*, **28** (2003) 8, pp. 834-41, ISSN 1528-1159

[10] Hammill, R.R., Beazell, J.R. & Hart, J.M.: Neuromuscular consequences of low back pain and core dysfunction, *Clin Sports Med*, **27** (2008) 3, pp. 449-62, ISSN 1556-228X
[11] Hodges, P.W. & Richardson, C.A.: Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds, *Arch Phys Med Rehabil*, **80** (1999) 9, pp. 1005-12, ISSN 0003-9993
[12] Radebold, A., et al.: Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain, *Spine (Phila Pa 1976)*, **26** (2001) 7, pp. 724-30, ISSN 0362-2436
[13] Noh, K.H., Oh, J.S. & Yoo, W.G.: Comparison of lumbar repositioning error according to different lumbar angles in a flexion pattern (FP) subgroup of patients with non-specific chronic low back pain, *J Phys Ther Sci*, **27** (2015) 1, pp. 293-4, ISSN 0915-5287
[14] Dolan, K.J. & Green, A.: Lumbar spine reposition sense: the effect of a 'slouched' posture, *Man Ther*, **11** (2006) 3, pp. 202-7, ISSN 1356-689X
[15] Sanchez-Zuriaga, D., Adams, M.A. & Dolan, P.: Is activation of the back muscles impaired by creep or muscle fatigue?, *Spine (Phila Pa 1976)*, **35** (2010) 5, pp. 517-25, ISSN 1528-1159
[16] Bauman, A., et al.: The descriptive epidemiology of sitting. A 20-country comparison using the International Physical Activity Questionnaire (IPAQ), *Am J Prev Med*, **41** (2011) 2, pp. 228-35, ISSN 1873-2607
[17] Alkhajah, T.A., et al.: Sit-stand workstations: a pilot intervention to reduce office sitting time, *Am J Prev Med*, **43** (2012) 3, pp. 298-303, ISSN 1873-2607
[18] Morl, F. & Bradl, I.: Lumbar posture and muscular activity while sitting during office work, *J Electromyogr Kinesiol*, **23** (2013) 2, pp. 362-8, ISSN 1873-5711
[19] Voglar, M. & Sarabon, N.: Reflex delays of the trunk muscles in response to postural perturbations: A reliability study, *Journal of Biomechanics*, **47** (2014) 11, pp. 2807-2812, ISSN 1873-2380
[20] Panjan, A.: *Methods for automatic processing of electromyography signals of human trunk muscles: Doctoral dissertation*, University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies, Koper, (2015).
[21] Hendershot, B.D., et al.: Evidence for an exposure-response relationship between trunk flexion and impairments in trunk postural control, *J Biomech*, **46** (2013) 14, pp. 2554-7, ISSN 1873-2380
[22] Cholewicki, J., et al.: Delayed trunk muscle reflex responses increase the risk of low back injuries, *Spine (Phila Pa 1976)*, **30** (2005) 23, pp. 2614-20, ISSN 1528-1159
[23] Lehman, G.J., Story, S. & Mabee, R.: Influence of static lumbar flexion on the trunk muscles' response to sudden arm movements, *Chiropr Osteopat*, **13** (2005), pp. 23, ISSN 1746-1340
[24] Vuillerme, N., Nougier, V. & Teasdale, N.: Effects of lower limbs muscular fatigue on anticipatory postural adjustments during arm motions in humans, *J Sports Med Phys Fitness*, **42** (2002) 3, pp. 289-94, ISSN 0022-4707
[25] Jacobs, J.V. Henry S.M. & Nagle, K.J.: People with chronic low back pain exhibit decreased variability in the timing of their anticipatory postural adjustments, *Behav Neurosci*, **123** (2009) 2, pp. 455-8, ISSN 0735-7044

INVESTIGATION OF NOISE LEVEL IN THE PROCESS OF WATER BOTTLING

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Abstract:

Noise affects the human body and causes physical and mental disorders, and there are risks of hearing impairment. This paper deals with the noise level of the water bottling machine at three workplaces equipped with computer-controlled machines. Upon analyzing the measurement results it was found that the equivalent noise level was different at various work places. At the first workplace it amounted to 82.1 dB(A), at the second workplace it amounted 83.1 dB(A),which requires the use of personal protective equipment. At the third workplace the equivalent noise level amounted to 78.3 dB(A) and lay within the limits of permissible noise level for such an activity.

Keywords: *noise level, workload, workplace*

1. INTRODUCTION

The water bottling process is an automated system controlled and monitored by the operator in standing posture whereby he uses the upper limbs to control the control panel. This kind of work requires a certain degree of concentration and concentrated power of vision, whereby it is desirable that the control panel is located within the normal field of view.

To accomplish the task efficiently and to achieve a certain degree of productivity, favorable working conditions are to be provided, including pleasant temperature and relative humidity, minimum air flow, adequate lighting, and a space without excessive noise and vibrations. Unfavorable working conditions cause workload and worker fatigue, deterioration of health and reduces labor productivity [1].

With regard to the type of activity and required concentration while monitoring automated machines equivalent noise level during water bottling should not exceed 80 dB(A) according to the Regulations on Noise Protection at the Workplace [2]. Nose depending on the intensity and duration can disable voice communication, reduce work concentration and lead to the deterioration of worker health.

2. NOISE

Noise is any sound that interferes with human work or rest. It can be divided according to the mode of propagation, source or ways of penetration. According to the mode of propagation it is divided into sound and structure. According to its source it is divided into internal and external noise, whereas according to the frequency range it is divided into infrasound (<20 Hz), sound (20-20,000 Hz) and ultrasound (>20,000 Hz). According to its mode of action it can be either continuous or discontinuous [3, 4].
Effect of noise on human beings is harmful in many ways. It damages their health directly or indirectly, it causes fatigue, reduces capacity for work, and interferes with understanding each other, rest and sleep. Therefore, the usual division of harmful effects of noise on people is as follows [5-7]:
- The effect of noise on the sense of hearing (aural or auditory effects) which directly damages the organ of hearing and thus hearing;
- The effect of noise with consequences on the whole organism (extra-aural or non-auditory effects) expressed in the influence on organs and body systems (nervous system, circulatory system, digestive system) and the influence on human functioning and performance (mental work, concentration, attention, perception of acoustic signals, oral understanding each other, rest and sleep).

Harmful effects on worker health depend on the level of sound intensity dB(A), sound frequency (Hz), exposure duration (hours/day), form of sound (continuous, discontinuous, pulse) and individual sensitivity.
According to Regulations on Noise Protection at the Workplace [2, 8] minimum requirements of protection from noise are established whereby permissible exposure levels (daily and weekly) and peak values of the C-evaluated sound pressure are prescribed as follows:

a) Limit value of exposure ($L_{ex, 8h}$ = 87 dB (A) and p_{max} = 200 Pa ($L_{p, peak}$ = 140 dB (A)
b) Upper warning limit of exposure ($L_{ex, 8h}$ = 85 dB (A) and p_{max} = 140 Pa ($L_{p, peak}$ = 137 dB (A)
a) Lower warning limit of exposure ($L_{ex,8h}$=80 dB(A) i p_{max}=112 Pa ($L_{p,peak}$=135 dB(A)

At the limit value (a) noise reduction due to the use of personal protective equipment for hearing protection is taken into account, while at the upper warning value (b) and at the lower warning limit (c) this effect should not be taken into account. It is required that under no circumstances the worker should be exposed to a noise level of 87 dB(A), including the effect of personal protection. If exposure is equal to or greater than the upper warning limit, workers should wear appropriate personal protective equipment. Above the lower warning limit workers shall be provided with personal protective equipment with a recommendation for use. Personal protective equipment for hearing protection consists of earplugs and earmuffs and plastic material. In order to reduce harmful effects which can be caused by noise, it is necessary to take measurements to determine noise levels at individual workplaces and to decide which measures shall be applied to reduce the risk for worker health.

3. EXPERIMENTAL PART

An investigation of noise levels was carried out in a manufacturing plant at three selected machines in the technological process of water bottling during 10 days. The technological process of water bottling consists of bottle blowing, water bottle filling and bottle labelling. Subsequently, the finished product is packed in six-bottle packs. Depending on the volume the following bottles are used: 0.3 l, 0.5 l, 1 l and 1.5 l. Packs are then palletized, stored in the storehouse and delivered to customers' orders. The water bottling process is located on the ground-floor. The space is air conditioned, the fluorescent tubes arranged on the ceiling and the windows for natural light provide lighting (Fig. 1).

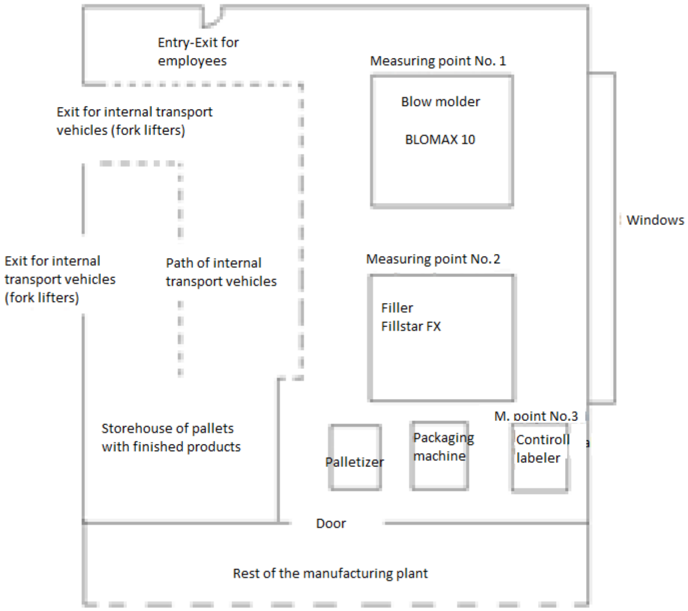
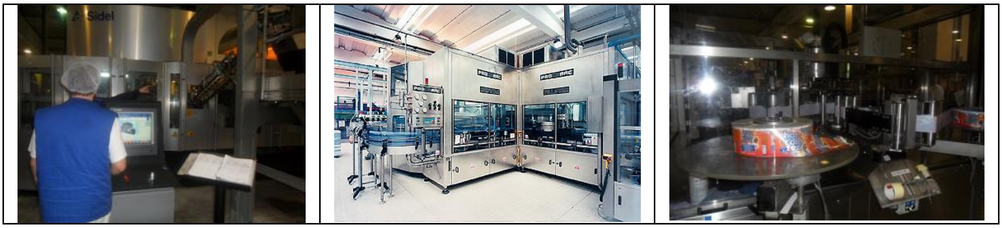


Figure 1: Representation of the manufacturing process with marked measuring points

In order to measure noise, three machines constituting a technological unit located next to each other were selected. The measuring points of noise are as follows:

- Blow molding machine (BLOMAX 10) manufactures bottles of 0.3 l to 3.0 l, and its production capacity amounts to 1,800 bottles/h. The machine is fully automated and is computer controlled (Fig. 2a) – RM1.
- Bottle filling machine (FILLSTAR FX) consists of sterilizer, rinser and filler. The production capacity amounts to 1,800 bottles/h. The machine is automated and is computer controlled (Fig. 2b) – RM2.
- Labeling machine (CONTIROLL labeler) is also automated.

The labeling speed is 50 mmin^{-1}, and the labeling width ranges from 8 to 128 mm (Fig. 2c) – RM3.



a. b. c.

Figure 2: Processing machines a) Blow molder, b) Bottle filler, c) Labeler

3.1. Measuring equipment and procedures

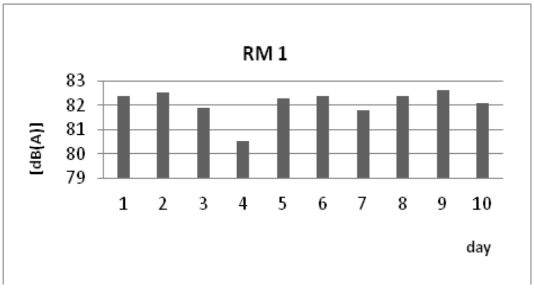
The UNITEST Sound Level Meter 93411 was used to measure noise level (Fig. 3).

Figure 3: Sound level meter

Measurements were carried out at three selected workplaces every 3 hours in one shift (8 hours) during 10 working days. Thus, a total of 30 measurements were obtained per workplace. During measurements the measurement microphone was directed towards the ear height of the operator.

4. RESULTS AND DISCUSSION

During measurements, all machines in the manufacturing plant were in operation. Upon analyzing the equivalent noise level on RM1 (blow molder BLOMAX 10) it was found that per day it ranged from 80.5 dB(A) to 82.6 dB(A), whereby the mean exposure of workers to noise amounted to 82.1 dB(A) (Fig. 4).



Figures 4: Measured values of noise level on RM1 (blow molder BLOMAX 10) per days

Upon analyzing the equivalent noise level on RM2 (filler FILLSTAR FX) it was found that per day it ranged from 82.5 dB(A) to 83.8 dB(A), whereby the mean exposure of workers to noise amounted to 83.1 dB(A) (Fig. 5).

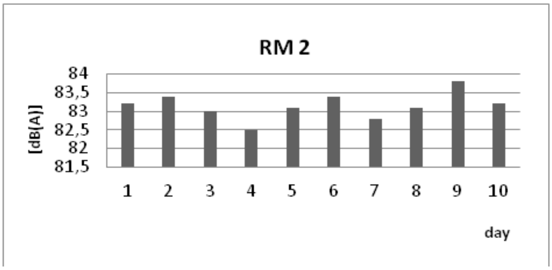
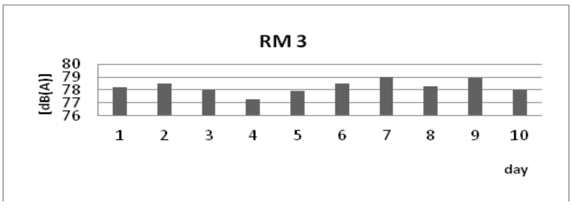


Figure 5: Measured values of noise level on RM2 (filler FILLSTAR FX) per days

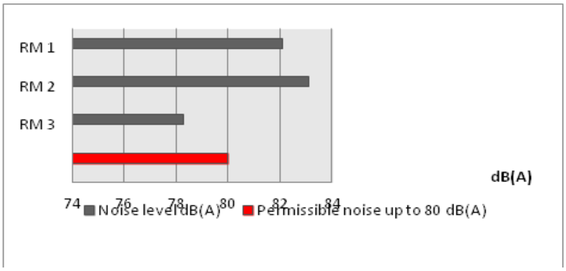
Upon analyzing the equivalent noise level on RM3 (CONTIROLL LABELER) it was found that per day it ranged from 77.3 dB(A) to 78.9 dB(A), whereby the mean exposure of workers to noise amounted to 78.3 dB(A) (Fig. 6).



Figures 6: Measured values of noise level on RM3 (CONTIROLL labeler) per days

According to the Regulations on Noise Protection at the Workplace tasks in the water bottling process can be classified as tasks requiring mostly routine physical work whereby accuracy and auditory environment tracking with the maximum permissible noise levels of 80 dB(A) are permitted. According to the current and applicable

regulations a level of noise over 80 dB(A) requires special measures to protect hearing impairment.
In this study it was found out that noise exceeded the limit noise level on two machines (blow molder BLOMAX 10 and filler FILLSTAR FX), while it did not exceed the limit noise level on one machine (CONTIROLL labeler) (Fig. 7).



Figures 7: Measured and permissible of noise level per workplace

5. CONCLUSION

As a result of investigating the noise level at three workplaces in the real production process of water bottling it was found that that the mean equivalent noise level for RM1 (blow molder BLOMAX 10) amounted to 82.09 dB(A), for RM2 (filler FILLSTAR FX) amounted to 83.1 dB(A), and for RM3 (CONTIROLL labeler) amounted to 78.3 dB(A). Based on the results of the measurements it was found that the noise at RM1 and RM 2 was above the permissible value because it was higher than the permissible 80 dB(A). The mean value of noise level on RM3 amounted to 78.3 dB(A) and lay within the permissible value.
To reduce the exposure of workers to noise at RM1 and RM2, it is necessary to use personal protective equipment such as ear plugs.

REFERENCES

[1] Mijović, B.: Applied ergonomics, Karlovac University of Applied Sciences, ISBN 978-953-7343-23-1, Karlovac, (2008)
[2] Rules on the protection of workers from exposure to noise at work, N.N., br. 46/08
[3] Kirin, S., Lauš, K.: The study noise levels in the technological process of sewing, *Safety*, **Vol. 53** (2011) No.3, pp.243-250, ISSN 0350-6886
[4] Mijović, B. et.al.: Contribution to the research of noise in the clothing industry, *Safety*, **Vol. 43** (2001), No.3, pp. 199-208, ISSN 0350-6886
[5] Horvat, J., Regent, A.: Personal protective equipment, Polytechnic of Rijeka, ISBN 978-953-6911-43-1, Rijeka, 2009
[6] Varžić, D.: The use of personal hearing protection equipment, *Safety*, **Vol. 52** (2010) No.3, pp.263-274, ISSN 0350-6886
[7] Poplašen, D.: Hearing impairment caused by noise, *Safety*, **Vol. 56** (2014) No.1, pp.67-69, ISSN 0350-6886
[8] Učur, M.: Rules on the protection of workers from exposure to noise at work, *Safety*, **Vol. 51** (2009) No.1, pp.31-36, ISSN0350-6886

DEMOGRAPHIC CHANGE AND ITS IMPLICATIONS FOR ERGONOMIC STANDARDIZATION

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Abstract

Companies in different industries are facing the same challenge: demographic change. This leads to a need for action in the field of industrial engineering. At the same time, many of the ergonomic standards were written many years ago, when demographic change was not really an issue. The aim of this paper is to investigate the status quo of standards, which should cover the specific requirements of older workforce. Therefore a three step approach was conducted: First, the changes, which humans go through when they get older, are elaborated based on an extensive literature review. Based on that, age-critical factors that should be covered in ergonomic standards are derived. Second existing standards that cover workplace design were collated and finally the need for action within these standards was elaborated. The paper closes with eight steps, which should together enable ergonomic standards with respect to demographic change.

Keywords: *Demographic Change, Ergonomic Standardization*

1. INTRODUCTION

The topic of an on average increasingly older workforce in high cost countries is currently the focus of public discussions. On the one hand retirement plans reach their limits because ever more people retire and less young people follow up to pay for them. On the other side also industry suffers because of a lack of skilled workforce for the ever more complex tasks that have to be carried out in production. Looking at the employment situation of older people, it is apparent that it is much more difficult for them to find employment. The situation is particularly problematic for the age group 50+. In February 2015 an increase in registered unemployed persons by 14.6% was reached in this age group compared to last year, which means that at this time more than a quarter (26.2%) of all unemployed people were 50 years old or older. It can be assumed that demographic change and the associated general aging of the population represents a major challenge in the future for a variety of industries. As a result due to this fact there will be an increasing need for action in the future in the design of work tasks and workplaces in order to keep older people longer in working life. Therefore industrial standardization of work tasks and workplaces and in general of the work environment have to play a major role, as older workforce has different needs, abilities and disabilities than young workforce. Therefore in this paper first the changes of human workforce with increasing age are systematically compiled and the implications on industrial standardization are drawn. After reviewing the current consideration of older workforce in specifically chosen standards that refer to the system "industrial workplace" the need for action within those standards is described.

2. CHANGES OF WORKFORCE WITH INCREASING AGE

Generally it is assumed that the elderly people are less physically powerful than their younger counterparts. These assumptions justify to partially outdated theories. Recent findings show that chronological age is not a sufficient criterion for evaluating the performance of an employee, but on the contrary, individual factors such as education, physical fitness and psychosocial values and settings are crucial for the performance.

The performance or work performance of people is made up of many factors. It is described as the capability of workforce to provide a certain performance over a longer period of time without suffering from health damages. Therefore each specific person as well as the environmental circumstances of this person are considered and identified as dependent factors of the performance of workforce. [1] Ilmarinen summarizes these factors in his "house of workableness" that is illustrated in Figure 1:

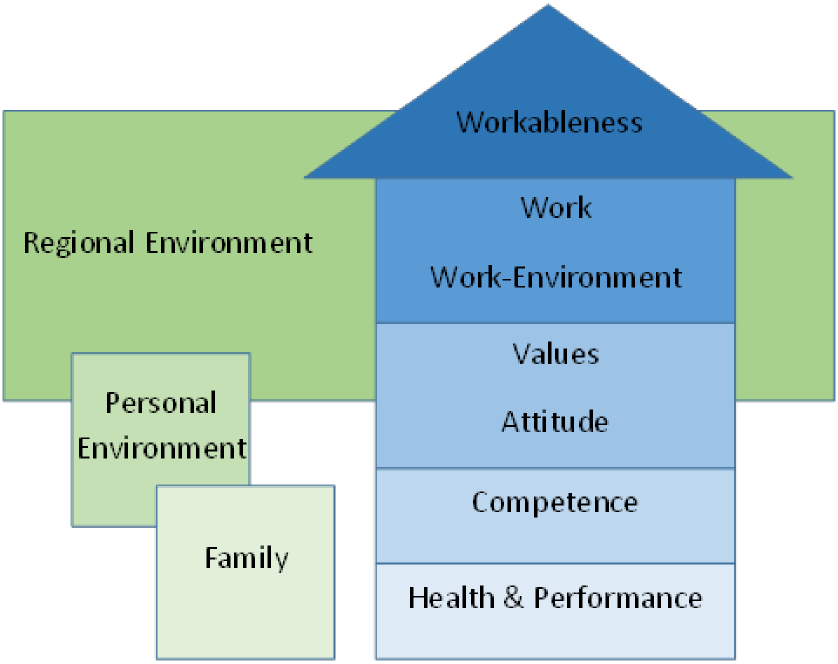

Figure 1: House of Workableness [2]

The foundation of the house of workableness is built by the health and performance of the individual that are supported by his or her social structure (community, personal environment and family). Starting from there, professional and social skills have to be present and expanded which are transformed into work within the work environment by the personal values and attitudes such as motivation. The working environment is finally determined by the design of the physical, psychosocial and organizational exposures of the worker. [3] The roof of the house represents the personal workableness of a person which is given only if all the other factors are kept in a balanced ratio [2]. Thus, the working capacity is no more a detached single factor but seen as a combination of the identified work requirements and the individual functional capacity [2].

When talking about older workforce, these factors have to be taken into account, as many of them change with increasing age. In general Bruggmann (Table 1) has identified different personal factors that change when a person gets older.

Table 1: Changes in Performance of Human Workers with increasing Age [4]

Increasing	Constant	Decreasing
Ability to cooperate	Performance- and target-orientation	Physical capabilities
Ability to judge	System-thinking	Mental flexibility
Ability to communicate	Creativity	Speed of taking up and processing information
Considerateness	Decision-making ability	Short term memory
Awareness for quality	Physical and psychological endurance	Readiness to assume risk
Reliability	Ability to concentrate	Promotion orientation
Conscientiousness		Readiness to learn and further educate oneself
Conflict ability		
Life- and job-experience, job-relevant knowledge		
Positive work attitude		
Balance and stability		
Fear of change		

Out of these mainly qualitative changes of human behavior and capabilities direct influences on the work-abilities of older workforce can be deviated. Structured into physical, psychological & social, cognitive & mental and sensory changes Figure 2 shows summarized the relevant changes of human workforce that should be considered in the design of workplaces, work tasks and work environments [5-22].

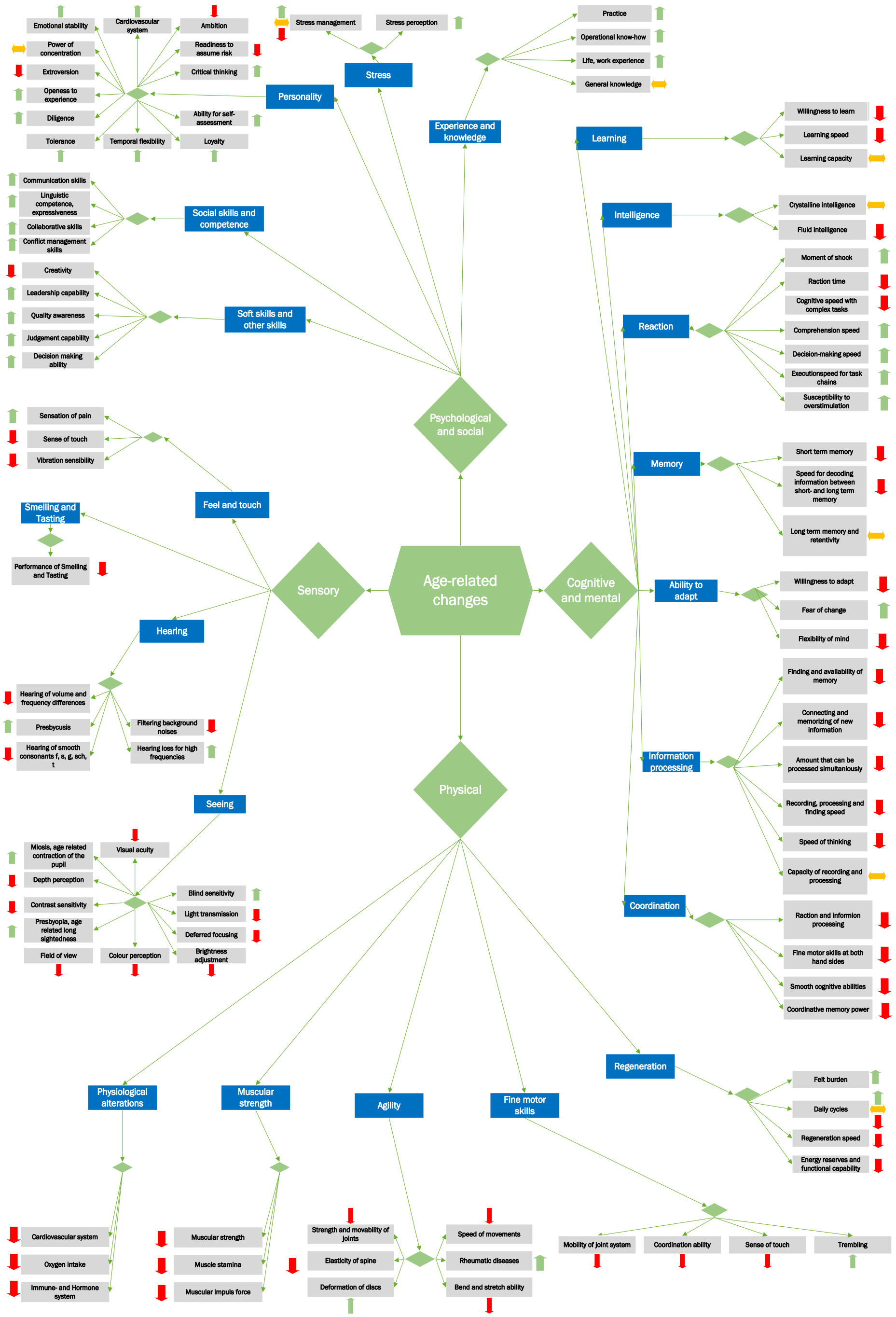

Figure 2: Summary of relevant changes of workforce with increasing age

The arrows besides the changing characteristics indicate the direction of change. Green arrows indicate an increase or improvement of the specific characteristic, red arrows indicate a decrease or worsening and orange arrows define characteristics that stay on the same level with increasing age. In order to be able to set up workplaces in an appropriate way for elderly people, these changes should be considered to a certain extent in industrial standardisation. Not only could companies increase their labour productivity because of the elderly-tailored workplaces, some of the changing characteristics with increasing age could also lead to hazardous situations if not considered. As an example the decrease of the field of view should be mentioned that could cause injuries of an older worker if critical and endangering zones or parts are not placed according to the limitations of this worker. It has to be mentioned, that especially the limited physical and sensory abilities of older workers could lead to incidents and injuries. Furthermore it should be stated at this point that the changes of worker's characteristics with increasing age can only be defined for the majority of elderly people and do not have to be true for all older workers.

3. STATUS QUO OF INDUSTRIAL STANDARDISATION

In order to identify the most relevant industrial standards for investigating the proper treatment of the specific needs of older workforce in workplace- and work process-design, the REFA work system was used as a basis. The REFA work system defines the coexistence of all relevant elements at a workplace that are the worker him or her-self, the operating means, the work environment and the organisation of work. We added working-time and pauses as a fifth factor as the day-time of work and also the duration of work are very critical with increasing age and therefore should be considered independently from the other factors. Together with the identified personal changes of ageing workforce critical factors are derived that concretize the relevant aspects of industrial standardisation for work place design in accordance to the specific needs of older workforce. These critical factors are [2, 3, 23-28]:

1. Organisation of work:
Within the organisation of work it has to be considered that monotone work tasks that require a steady concentration and very complex, abstract and totally new work tasks should be prevented from being given to elderly workers. Furthermore high workloads with time- and/or performance-pressure as well as a highly takt-bounded and other-directed pace of work, interruptions and disturbances should be permitted much more for older workforce. Gratification risks are also a major concern for the organisation of work for elderly workforce.

2. Work environment:
Especially the decreasing visual capacity and the vulnerability to environmental conditions like illuminance or climate have to be considered more in detail. This means that labels and warnings for example have to be written in a proper contrast and size. Furthermore the increased sensibility to noise and vibrations as well as to the exposition to hazardous gases and electromagnetic fields should be considered in standardisation.

3. Operating means:
High requirements regarding the reaction- and movement-capabilities as well as fine motor skills and none-ergonomic design of operating means should be avoided. Furthermore selective and sub-divided attention and increased requirements regarding the manual precision of operating machines or tools are critical.

4. Worker:
Heavy loads to be carried, pulled or pushed as well as continued physical aerobic work with high necessary forces and sudden load-peaks should be completely avoided. Also constrained postures, longer static muscle-work and one-sided strain are much more critical to older workers. Moreover individual operating ranges and different body-forms are more important to be considered in work-place design for older workforce as their ability to adapt to non-optimal work and body postures decreases heavily.

5. Working- and break-time
Because of the changed bio-rhythm and the with age increasing inability to adapt to changing working times especially shift work over night has to be avoided. Proper breaks to guarantee recovery are of great importance. Also the possibility of flexible work- and break-times should receive greater attention.

With these factors industrial standards were screened in order to determine whether the specific characteristics of elderly workforce are treated well enough or if there is space for improvement. The relevant standards were identified via a web search on the Austrian Standards Institute. From over 31.000 standards that are valid in Austria 100 standards were selected that cover the field of industrial workplaces and contain aspects that could be critical in accordance to the above defined critical factors of elderly workforce. After the extensive review of the selected standards 77% of these standards were classified as standards with high or at least medium need for action in terms of elderly workforce. Therefore only 23% of the reviewed standards considered the specific characteristics of older workforce in a sufficient way.

4. NEED FOR ACTION IN INDUSTRIAL STANDARDISATION

For the 77% of the standards that were identified as not sufficient in covering the needs of older workforce specific indications for necessary changes were developed. In general critical values like required action-spaces, ergonomic heights or sizes of emergency buttons and warnings were checked if they correlate with the specific needs of elderly workers. All in all eight points were identified that, if implemented properly in standardization for industrial work-places, would improve industrial standardization with regard to the coverage of elderly workforce.

1. There are some standards that cover the specific needs of older workforce very well. However, if the content of those standards would be included in other standards or if those standards that do not cover the topic of elderly workforce would at least include references to proper standards a huge improvement would be possible.
2. As the topic of demographic change is increasingly of importance, we suggest a specific standard that exclusively covers ergonomic aspects for the design of work-places for elderly workforce. In comparison ORN CEN ISO/TR 22411 or the ISO GUIDE 71 / CEN CENELEC Guide 6 could serve as a guideline for this standard.
3. Furthermore a specific management-standard for the corporate management of older workforce like the management standard EN ISO 9001 would help both, companies and employees to master the challenge of demographic change.

4. As mentioned above, the working- and break-times are of increasing importance with ongoing age of workers. Therefore these topics should also be covered in a separate standard.
5. In the sense of ÖNORM EN ISO 15537 further standards should be established that cover all anthropometric aspects that are relevant with increasing age of workforce (body postures, noise or thermic environment).
6. Many of the critical values like those for the exposure of workers to vibrations are not defined in accordance to workers at different ages. Therefore we suggest further research in order to generate specific critical values for workers at different groups of age.
7. Within the standards of corporate health care older workforce is not treated individually. This should be changed, as elderly workers have other needs than their younger colleagues.
8. A lot of the disabilities that elderly workforce brings with it could be eliminated with the application of modern technological assistance systems. The application of and the collaboration with such systems like collaborative robots, driverless transportation systems or wearables should also be covered within a separate standard.

Within the company-interviews it was shown that companies have invented their own strategies to deal with older workers in production. Most of the companies transfer older workers to other workplaces where they are able to perform the required tasks. This habit also leads to the fact that workers that perform certain work very well since a long time but are not able to continue that work due to their physical inabilities are moved to other workplaces and take all their experience with them. Modern assistance systems would help at this point to keep workers for a longer time at their workplaces.

5. CONCLUSION

It was shown in this paper that industrial standardisation does not cover the topic of elderly workforce in an appropriate way. When looking at the demographic situation in most of the European countries there is definitely a need for improvement. Also the specific critical values for physical stress or environmental influences of workers many times are not explored specifically for elderly workers. This makes further research necessary in order to deeply understand how the human body changes with increasing age and how it reacts to different situations at industrial workplaces. Moreover the exploration of different technological and methodical innovations in the fields of assistance systems will be of increasing interest in research in the future as thereby many disabilities of older workers could be eliminated. Somehow industry will have to deal with the application of older workforce in the future. Industrial standardisation has to set the organisational basis and can be a first countermeasure to demographic change for companies, even if the current issues of the necessary application of elderly workforce might not be justified from an economic point of view. However, simply replacing older workers with less expensive younger workers will not work any longer, as the demographic change continues to change the working landscape.

REFERENCES

[1] Jaeger C.: *Being and staying productive*, in: Institute of applied work science (ed.): Productivity in the firm, Springer, Berlin Heidelberg, S. 27-39, (2015) (Original paper/book in German language)

[2] Ilmarinen J.; Tempel J.: *Working ability 2010 – What can we do so that you stay healthy?*, Hamburg, (2002) (Original paper/book in German language)

[3] Grabbe J.; Götz R.: Work- and employment-ability – *Basis for innovative and competitive capability*, in Klaffke M. (2014): Generational-Management: Concepts, instruments, good-practice approaches, Springer Fachmedien Wiesbaden (2014)

[4] Bruggmann M.: *The experience of older employees as a resource*, Deutscher Universitäts-Verlag Wiesbaden, (2000) (Original paper/book in German language)

[5] Riedel S.; Gillmeister F.; Kinne J.: *Effects of age-related changes of operating personnel on the safe use of hand machines*, in: Federal Institute for Occupational Safety and Health (Eds.): Research Project F 2118, Dortmund Berlin Dresden 2012. (*Available from* https://www.baua.de/de/Publikationen/Fachbeitraege/F2118.pdf?__blob=publicationFile&v=3 *Accessed* 2015-07-20) (Original paper/book in German language)

[6] Biermann H.; Weißmantel H.: *Rule catalog SENSI devices: user-friendly and accessible through the right design*, Institute of electro-mechanic constructions, Darmstadt 1997. (*Available from* http://www.emk.tu-darmstadt.de/~weissmantel/sensi/sensi.html, *Accessed 2015-07-20*) (Original paper/book in German language)

[7] Rensing L.; Rippe V.: *Aging - Cellular and molecular bases, physical changes and diseases, therapies*, Springer Berlin Heidelberg (2012) (Original paper/book in German language)

[8] Rinnerhofer S.: *Physical performance and measured energy consumption at different professional activities typical development of standard values*, Dissertation University of Graz 2012. (*Available from* http://unipub.uni-graz.at/obvugrhs/content/titleinfo/225109 *Accessed* 2015-07-21) (Original paper/book in German language)

[9] Schlick C.; Bruder R.; Luczak H.: *Industrial Engineering*, Springer Berlin Heidelberg, (2010) (Original paper/book in German language)

[10] Münch M.; Cajochen C.; Wirz-Justice A.: *Sleep and circadian rhythm aged*, in: Journal of Gerontology and Geriatrics, Volume 38, Supplement 1. Steinkopf Publishing Company, (2005) (Original paper/book in German language)

[11] Hecht K.: *Mature age and emotional stress*, In: Urologist [B], Springer Publishing Company, S. 338-343, (2001) (Original paper/book in German language)

[12] Zulley J.: *Chronobiology of aging*, Scientific Journal of the Humboldt University of Berlin. Series Medicine 41, 2, S. 86-94, (1992) (Original paper/book in German language)

[13] Kruse A.; Lehr U.; Rott C.: *Gerontology - an interdisciplinary science*, Bayrischer Monatsspiegel Verlagsgesellschaft mbH, Munich, (1987) (Original paper/book in German language)
[14] Prasch M.: *Integration of staff with changed performance in variant serial mounting*, Herbert Utz Publishing Company GmbH, Munich, (2010) (Original paper/book in German language)
[15] Winkler R.: *Older people as a resource for the economy and society of tomorrow*, In: Clemens W.; Höpflinger F.; Winkler R. (Eds.): Work in later stages of life-dead ends, perspectives, visions. Haupt Publishing Company Bern, S.84-104, (2005) (Original paper/book in German language)
[16] Ilmarinen J.: *Towards a Longer Work life! Ageing and the Quality of Work life in the European Union*, Finnish Institute of Occupational Health, Ministry of Social Affairs and Health, and Juhani Ilmarinen, (2006)
[17] Sakris J.: *Workplace health promotion for older employees. The application of salutogenetic principles in business*, Diplomica Publishing Company GmbH Hamburg, (2014) (Original paper/book in German language)
[18] Bijedic T.: *Developing entrepreneurial personality in the context of entrepreneurship education. Didactic teaching-learning design and empirical analysis for secondary education*, Rainer Hampp Publishing Company Munich Mering, (2013) (Original paper/book in German language)
[19] Holz M., Da-Cruz P.: *Demographic changes in company-challenge for strategic workforce planning*, Business Management Publishing Co. Dr. Th. Gabler | GWV Fachverlage GmbH Wiesbaden, (2007) (Original paper/book in German language)
[20] Blumberger, W.; Sepp, R.; Affenzeller, S.: *"Work - age - recognition"*, IBE-Research Report, 2 Vol., Linz, (2004) (Original paper/book in German language)
[21] Lohmann-Haislah A.: *Stress Report Germany 2012, Mental requirements, resources and being*, Federal Institute for Occupational Safety and Health, Dortmund Berlin Dresden, (2012) (Original paper/book in German language)
[22] Ritz A.; Thom N.: *Talent management, identify talent, develop skills, get achievers*, Gaber Publishing Company Springer Fachmedien Wiesbaden GmbH, (2011)
[23] Bullinger H.; Volkholk V.; Betzl K.; Köching A.; Risch W.: *Age and employment of the future*, Springer Publishing Company Berlin Heidelberg GmbH, (1993) (Original paper/book in German language)
[24] Brandenburg U.; Domschke P.: *The future looks old: challenges of demographic change for personnel management,* (1. Edition.), Gabler Publishing Company Wiesbaden, (2007) (Original paper/book in German language)
[25] Schlick C.; Bruder R.; Luczak H. (Eds.): *Industrial Engineering*, Springer Berlin Heidelberg, (2010) (Original paper/book in German language)
[26] Richter G., Bode S., Köper B.: *Demographic changes in working life,* Federal Institute for Occupational Safety and Health (Eds.), Dortmund, (2012) (Available from: www.baua.de/de/Publikationen/Fachbeiträge/Artikel30.html. Accessed: 28.7.2015) (Original paper/book in German language)

[27] Weger G.: *Age(ing) diversity in operation.* in: Age (ing) diversity in operation, strategies and actions for sustainable corporate policy in small and medium enterprises, workspace Gender and Diversity in Organizations. University of Economics Vienna (Eds), 1. Edition, S. 22-29, (2006) (Original paper/book in German language)

[28] Sandrock S.: *Ageing-appropriate work design - a building block for obtaining the performance*, in: Operating Practice & Work Sciences, No. 221, S. 42-45, (2014) (Original paper/book in German language)

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DEVELOPMENT OF A METHODOLOGY FOR IDENTIFYING ERGONOMIC RISKS IN THE WORKPLACE

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Abstract

This paper presents a new methodology for identifying and managing ergonomic risks and improving working conditions in the workplace. The method is mainly focused on physical ergonomics, which deals with the anatomy, anthropometrics, physiology and biomechanics (working positions, material handling, repetitive movements, muscle bone dysfunction, physical demands of the work, health and safety) and allows companies to transfer knowledge throughout the enterprise as well as from external sources. A simple tool has been designed that companies can use to redesign or improve work processes and work organization. The method presented is based on the classification and visualization of typical working positions that cause muscular and skeletal disorders. On the basis of detecting these situations, the methodology evaluates ergonomic risk, which will be illustrated in practical examples.

Keywords*:* *ergonomic risk, work place, working position, safety at work, health*

1. INTRODUCTION

In literature, many different definitions of ergonomics can be found; here is one that is very well formed: *Ergonomics is a science field where an interdisciplinary research of influence of techniques, technology and environment on people in combination with ergonomic principles is needed to optimally harmonize the relation between human - workplace - product and environment with work humanization objective [1]*.
Ergonomics as one of the most important elements of work science links several science fields, which are bound by a common goal: a successful (economical), humane and safe work. The workplace where the work is done is adapted to the people that are carrying out the work. To form such a workplace that leads to a successful, safe and humane work several things are required [2]:

- Thorough knowledge of people and their ability to carry out their work, which requires cooperation between psycho-phisiologists, doctors of work medicine, anthropologists and biomechanic specialists.
- Knowledge of workplace design and work methods, which requires cooperation between developers, technologists, designers, engineers and production.
- A normal environment, consistency of operation must be ensured and with help of safety engineers a safe operation enabled, that causes no injuries at work and minimizes any risks.

- The workplace must be designed in such a way that is adapted to the person carrying out the work in a given moment.

It is recognized that ergonomics in a business environment improve the operational performance (production and product efficiency or the quality of services), productivity and create wellbeing of employees in the workplace. For improving the business performance organizations have to create an environment, which facilitates operational performance and addresses the employees' wellbeing (health, safety) [3]. Considering ergonomics principles in designing workplaces and the adaptation of tasks to the physical and mental abilities of workers contributes to the creation of such an environment which can contribute to a better climate which fosters success and wellbeing at the same time [4].

When designing jobs and products the aggregated information on processes, tools, machines, subjects of work, tasks and operators must be taken into account, limitations, which are often conflicting, must be met and a design must be generated, which will be acceptable for all parties involved [5]. The successful optimization of products is only possible if ergonomic aspects are systematically embedded into the product life cycle and if an Ergonomic evaluation is carried out of prototype solution variants [6]. Many good examples of applying the ergonomics principles can be found: for example in the process of designing and ergonomically evaluating variants of hand tools [7] or in designing the handle tailor made to the human hand [8].

In a two years period, a group of researchers has taken a look at larger production plant and examined to what extent ergonomics measures for increasing operational performance and wellbeing of employees influence the incidence of diseases, injuries and pain. Based on measurements and evaluations they have recognized the number of injuries and diseases recorded was smaller if the organization applied ergonomics principles for facilitating the employees' efficiency and wellbeing [4].

A holistic ergonomics access in companies supports human factors and the increasing diversity of employees; as such it contributes to the company's economic performance. It is recognised that ergonomics measures reduce absenteeism or absence from work (less workrelated injuries and diseases) and raise the satisfaction and efficiency of employees. Taking this into consideration intensive campaigns oriented towards decision makers in organisations/companies must be promoted and supported [9]**.**

Thus the present human factors can be used engineers, psychologists or ergonomist to achieve better results or can expand their cooperation [10].

2. METHODOLOGY DEVELOPMENT

2.1. Methodology basics

Nowadays, researchers often come to the conclusion that the most common chronic diseases in Europe are the so-called musculoskeletal diseases and disorders, that affect up to one quarter of the population. They represent 60% of the causes of early retirement and sick leave from work. Due to the low mortality, they don't call enough attention to healthcare policy providers and general population. EU views and standpoints in terms of health and safety at work:

- the status of health-related absenteeism and the incidence and consequences of work injuries and occupational diseases reflect the status of individual employer;
- investing in occupational health and safety means investing in higher productivity, better motivation and thus the quality of life;
- due to the pace of changes in terms of occupational health and safety the company policy must encourage greater concern for the health of workers and thus reduce the number and consequences of work injuries and occupational diseases.

Because of the increasing pace in production processes (as a cause of product diversification, new technologies, new materials, new organizational forms, procedures, etc.) monitoring changes in specific workplaces in the field of disease risks is nearly impossible. The requirements which nowadays practically every employer must face include increasing productivity while minimizing the cost for manpower and equipment. This means that work and workplace design is limited to minimal legal requirements in terms of safety at work, thus minimizing the risk for work-related accidents. The risks of occupational diseases often aren't taken into account; the reason is that all design processes are seen primarily in the short term and the consequences for the people are often ignored. The task of workplace and work design in terms of ergonomics is often (if at all) left to safety and work experts, that can't cope with rapid changes in work processes and also often don't have the knowledge of musculoskeletal disorders risk recognition and management.

Another equally important element, that needs to be taken into account when ensuring health of the working population is the fact that the retirement age in the pension legislation changed and, according to experts forecasts, will continue to change. This means that companies will be forced to include activities and methods for occupational health risk identification and management while designing work processes. Workplaces and work processes will have to be designed in a way that will ensure normal work and productivity achievement also for older workers.

All said points out that ergonomic workplace design requires taking a specific person, his ability, disposition and willingness to work, the environment, equipment, tools and devices, material, product, logistical processes and accessibility into account. In short, a health-friendly workplace design and organization is needed.

Current practice indicates the type of models, tools and practices for workplace design, aimed at healthy employees, in order for them not to become disabled. However, since nowadays the trend in number of sick leave and occupational disease in the industrial or administrative work environment is increasing, our goal is to establish principles and norms for a worker-friendly workplace and work in work process. We will use the developed concept to carry out training for leading and professional workers, who will use the knowledge gained in work system design in their environment.

Thus, it is necessary to design the work in such a way that it is adaptable to each worker, while the ergonomic principles as the base for humane workplace design is divided into many areas of scientific disciplines.

The effects of workplace design can be evaluated with economic parameters since appropriate measures can achieve efficiency and reduced fatigue of people with disabilities, and hence positive economical outcomes.

Designing an optimal production process requires both: a designed workplace that enables the employee to perform work efficiently with minimum costs and at normal fatigue. This means that the workplace must be designed to suit the worker's ability and suffice the ergonomic and economic principles.

2.2. The methodology for identifying ergonomic risk in the workplace

In practice, an ergonomic project in the workplace is carried out in the following order:

1. Workplace choice e.g. type of work for the analysis
2. Collecting work data
3. Analysis and evaluation of gathered data
4. Project completion: a list of measures and implementation of improvements

2.2.1. Selecting a workplace

There are several ways how to identify an "appropriate candidate" (work operation) for the study:

- Researching medical history. If the workplace historically often caused injuries or (occupational) diseases, it could represent a valid candidate for the study.
- Employees interview. If the worker finds a specific part of operation and/or an entire operation "difficult" or "fatiguing" (why?), that operation is very likely a valid candidate.
- A visual evaluation of work operations in the production and search for non-neutral postures, high forces and frequencies and/or any combination of the mentioned parameters could reveal a valid candidate for the study.
- An ideal selection could be found using all of the possibilities mentioned above.

2.2.2. Collecting data about the operation

At this stage, data such as is gathered:

- Work operation general data
- After careful observation, the complete operation is devided into smaller parts that shall be called work segments
- Operation video documentation (for easier detailed analysis)
- Operation photo documentation
- Interview with the employees
- Collection of medical history data for this workplace

- Taking measurements in the workplace (equipment, workplace, product and tools dimensions, positions, weights, force needed)

2.2.3. Data analysis and evaluation

After all (or most) necessary information has been collected in the working place and work, the following analysis can be carried out:

A) QUANTITATIVE ERGONOMIC ANALYSIS (QEA)

The methodology of this analysis is based on 4 factors that represent a risk in ergonomics: posture, force, duration and frequency. The assessment can be completed either for an individual work segment or for the complete work operation; we asses four mentioned factors for nine bodily areas: R/L hands, R/L elbows, R/L shoulder, back, legs and neck we call risk levels. In this manner, we create a 9 by 4 matrix with the possibility 0 (false) or 1 (true). For each risk factor, a strict limit (threshold) is determined, that defines when the risk factor takes the value 0 and when the value 1. The risk for a specific bodily part is then calculated by summing up the 0 and 1 values. This means that the summed up values or ergonomic risk for each body part in the analysis may take a value in an interval between 0 and 4.

B) WORKPLACE ERGONOMIC ANALYSIS

The result of QEA analysis tells us the ergonomic risks for each bodily part, but it doesn't give a numeric estimation for the ergonomic risk of the workplace (total risk). It is true that we could sum the nine risks to get a new value, but by this way we wouldn't take the following factors into account:

- higher risk levels (3 and 4 for example) have a greater significance in the total risk
- to calculate the total risk for a workplace, the exposure of a specific employee to the workplace has to be taken into account (40 hours without rotation, for example)
- in addition to the four risk factors found in QEA, additional risks have to be taken into consideration, e.g. risks that cause stress to the blood flow - low temperatures, vibrations, sharp edge contact, gloves problem etc.

Table 1: QEA scaling up

QEA	Scaled value
0	0
1	1
2	3
3	5
4	10

Table 2: Exposure factor

Weekly exposure	Factor
> 40 hrs	0
20-40 hrs	1
4-19 hrs	0,80
< 4 hrs	0,40

Workplace ergonomic analysis takes all the above points into account and first scales up the output of QEA (Table 1).
The weighted values are summed together, and for each risk referred to in point B a value of 2 is added. The sum is then multiplied by the exposure factor from table 2; the final value is the total risk for the workplace.

2.2.4. Project completion

After the evaluation is complete, we have all the risks (for each bodily part) calculated and identified (posture, force, duration, frequency or additional). Some interdisciplinary brainstorming in a form of workshop is needed to make a list of measures. Often, we have to follow certain guidelines, for example:

- ANTHROPOMETRY to determine the dimensions, heights, etc.;
- NIOSH (National Institute for Occupational Safety and Health, USA) revised equations [11];
- 2D Static Strength Biomechanical Calculator [12];
- "Snook and Ciriello" tables for lift/lower, push/pull and carrying tasks[13]

3. RESULTS – A PRACTICAL EXAMPLE

We chose "OPEL gear shift housing control and cleaning" as a exemplary workplace to test out the methodology (Fig. 1). We video documented the operation in the production in order to make the analysis easier, as pointed out in 2.2.2. We carried out the measurements of workplace dimensions and forces needed to complete the work (where possible). The job was completed when a list of measures and an example of a micro layout (Fig. 2) was done.

Figure 1: Workplace video documentation

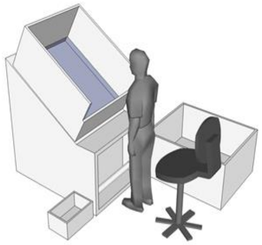

Figure 2: Micro layout suggestion

Using the methodology, we calculated the ergonomic risks first. Risk levels for individual bodily parts were evaluated with scores from 0 to 4 and weighted according to table 1; the results can be found in table 3 below:

Table 3: Risk levels

Hands		**Elbows**		**Shoulders**		**Neck**	**Back**	**Legs**
L	**R**	**L**	**R**	**L**	**R**			
2	3	2	2	1	1	3	2	0
3	5	3	3	1	1	5	3	0

Next, the workplace ergonomic analysis for the operation was completed. All the weighted values were summed together (the result being 24). Because of two risks that cause stress to the blood flow (contact of both knees with desk edge), 4 was added to the sum (each additional present risk adds a value of 2) which gave us a value of **28**. This number quantifies the ergonomic risk for this specific workplace. In table 4 we can read out that this number represents a medium risk, threat or priority for this workplace in an ergonomic sense.

Table 4: Workplace risk/threat/priority

RESULT ANALYSIS	
Result	Risk/threat/priority
0 – 9	low
10 – 29	medium
30 – 49	high
50+	very high

After completing the analysis, a list of measures was made:

- A fixed (or variable) lift and tilt of the table towards the worker or
- A rotary panel/table for the container so the worker can turn the container if one side is empty
- A container that opens in the middle: easier product access (causes less ergonomic risks)
- Change from a sitting position into a sit-stand position: less getting up
- Micro-layout change (see Figure 2 - includes the measures above)
- Mandatory job rotation: forces the workers to use different muscle groups.

4. CONCLUSION

Ergonomics as a scientific discipline tries to increase effectiveness by designing workplaces or adapting work, and by eliminating processes without added value as well as threats which increase the risk of developing illnesses and injuries of employees [3]. The application of ergonomics principles in a business environment can ensure a direct benefit for employees and organizations by easing physical and psychological burdens, reducing the risk of developing occupational diseases and injuries, and increases work efficiency [2]. Based on an EU directive, institutions in individual member states demand a risk and threats assessment for individual jobs. Ergonomics is a recognized discipline used to assess whether work, equipment and environment match the required performance of persons involved [9].

The shown process of workplace risk analysis has confirmed the effectiveness of the developed methodology. It also shows the usefulness of the obtained results while making the list of measures or improvement possibilities and hence work risk reduction. Long-term use of the developed methodology in the company has proven to be an effective tool for reducing work injuries, dysfunctions and costly absenteeism. It can be stated with great certainty that an ergonomically designed workplace affects the well-being of employees, increases the satisfaction and motivation, which leads to better productivity.

REFERENCES

[1] Polajnar, A.; Verhovnik, V.: *Work- and Workplaces design – Handbook*, University of Maribor, ISBN 86-435-0305-3, Maribor, (2007), *(Original book in Slovenian language)*

[2] Sanders, M.S., McCormick, E.J.: *Human Factors In Engineering and Design*, McGraw- Hill Education, 7th Edition, ISBN 987-0070549012, NY (1993)

[3] Wickens, C.; Lee, J.; Liu, Y.; Becker, S.E.G.: *An Introduction to Human Factors Engineering*, Upper Saddle River, ISBN 978-8120343719, NY: Pearson/Prentice Hall, (2004)

[4] Hoffmeister, K.; Gibbons, A.; Schwatka, N. & Rosecrance, J.: Ergonomics Climate Assessment: A measure of operational performance and employee well-being, *Applied Ergonomics*, **Vol.** (2015) 50, pp 160–169, ISSN 0003-6870

[5] Feyen, R.; Liu, Y.; Chaffin, D.; Jimmerson, G. & Joseph, B.: Computer-aided ergonomics: a case study of incorporating ergonomics analyses into workplace design, *Applied Ergonomics*, **Vol.** (2000) 31, pp 291–300, ISSN 0003-6870

[6] Haubner, P.J.: Ergonomics in industrial products design, *Ergonomics*, **Vol.** (1990) 33(4), pp 477–485, ISSN 0014-0139

[7] Lin, K.-C. & Wu, C.-F.: Practicing universal design to actual hand tool design process, *Applied Ergonomics*, **Vol.** (2015) 50, pp. 8-18, ISSN 0003-6870

[8] Harih, G.; Borovinsek, M.; Ren, Z. & Dolsak, B.: Optimal products' hand-handle interface parameter identification, *International Journal of Simulation Modelling*, **Vol.** (2015) 14(3), pp 404–415, ISSN 1726-4529

[9] Mcatamny, L. & Corlett, E.N.: Ergonomic workplace assessment in a health care context, *Ergonomics*, **Vol.** (1992) 35(9), pp 965–978, ISSN 0014-0139

[10] Kleiner, B.M.: Macroergonomics: Work System Analysis and Design, *Human Factors.* **Vol.** (2008) 50(3), pp 461–467, ISSN 0018-7208

[11] Thomas R. Waters; Vern P. Anderson; David K. Wall: Evaluation of the Revised NIOSH Lifting Equation, *SPINE*, **Vol.** (1999) 24(4), pp 386-395, ISSN 0362-2436

[12] Don B. Chafin: Primary Prevention of Low Back Pain Through the Application of Biomechanics in Manual Materials Handling Tasks, *Giornale Italiano di Medicina del Lavoro ed Ergonomia*, **Vol.** (2005) 27 (1), pp 40-50, ISSN 0391-9889

[13] Snook S.H.; Ciriello V.M.; The design of manual handling tasks: revised tables of maximum acceptable weights and forces, *Ergonomics*, **Vol.** (1991) 34(9), pp 1197-1213, ISSN 0014-0139.

EFFECTS OF DIFFERENT REST PERIODS AND LOAD WEIGHTS ON UPPER LIMB MUSCLE FATIGUE RECOVERY FOR A HAND TRANSFER TASK

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Abstract

An experiment was conducted to collect the biomechanical behavior of upper limbs in the laboratory where EMG system and heart rate monitor were performed. Twelve young male subjects were recruited to perform the tasks performed with different rest periods and object loads. The rest periods consisted of 0.25, 0.5, 1, and 1.5 times of work time of 9 min and the object loads included 1 and 2 kg in this study. The Viewlog software developed in this laboratory was used to calculate %MVC (Maximum Voluntary Contraction, MVC) from electrographic signals of tested muscles to explore the recovery status. The heart rate was recorded every 15 seconds during the experiment. The EMG results showed the middle deltoid presented significant difference among different rest periods. It is observed that the recovery status of the middle deltoid showed significant effects. However, the EMG results obtained from biceps and triceps brachii showed no significantly different in this study.

Keywords: *work/rest, muscle fatigue, upper limb, EMG*

1. INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) are one of the main focuses in the area of occupational disease prevention. Many preventive strategies of WMSDs including engineering control and administrative management were suggested in the literature. However, relatively few attentions were paid on work and rest arrangement issues during repetitive handling tasks of upper limbs. Most of these studies published were discussed on the static (isometric) exertions (e.g., Kroemer and Grandjean, 1997; Sanders and McCromick, 1993; Rohmert, 1973; Milner, 1986; Rose et al., 1992; Bystrom and Fransson-Hall, 1994). Few studies were examined for dynamic tasks such as Shin and Kim (2007) and Sbriccoli et al. (2007). Shin and Kim (2007) explored the trunk muscle fatigue during dynamic lifting and lowering as recovery time changes. Sbriccoli et al. (2007) also discussed low back disorders about the work to rest duration ratios exceeding unity situation. To prevent the WMSDs an experiment was conducted to explore the behavior of upper limbs during repetitive handling tasks with different work and rest periods and load weights in this study.

2. METHOD

2.1. Subjects

Twelve young male subjects were recruited as paid volunteers in this study. Their mean age was 24.3 years (SD 1.1 yr), mean body height 172.0 cm (SD 4.9 cm), and mean body weight 66.6 kg (SD 10.1 kg). All subjects were free of known musculoskeletal injuries and described themselves as right-handed. A written consent was obtained from the subjects after they were given a clear explanation of the objectives and procedures of the experiment.

2.2. Apparatus

Surface electromyography (sEMG) is often used to obtain myoelectrical signals from active muscles to determine local muscle fatigue. Four selected muscles of the right upper limb in the experiment were the middle deltoid, anterior deltoid, biceps brachii, triceps brachii. The raw sEMG signals were amplified with gain of 5000, low pass filtered at 500 Hz, and digitized at a rate of 1000 Hz.

2.3. Experimental Design

The surface electromyographic measurement system and the environmental setting parameters were calibrated before the experiment. The anthropometric data were measured after the subject was given a clear explanation of the experiment objectives and procedures. Surface electrodes were then attached to four muscles of the upper limb. At the start of the experiment the maximum voluntary contraction (MVC) of each tested muscle was measured. The subject was instructed to be seated and remain in upright posture as the work surface was kept at the subject's elbow height. The moving speed was 30 times/min. Four different rest periods (0.25, 0.5, 1, and 1.5 times of work time of 9 min) and 2 object loads handled (1 and 2 kg) formed 8 experimental conditions. Each subject had to complete 8 conditions in the experiment. The order of the 8 conditions was randomized. The Viewlog software developed was used to calculate %MVC of electromyographic signals to explore the upper limb muscle fatigue recovery. The experimental setting was shown in Figure 1.

3. RESULTS

Figure 2 shows the electromyogram recordings of four monitored muscles. The sEMG results obtained from biceps brachii, middle deltoid, and anterior deltoid for the rest period of 0.25 times work time had the significantly different muscle fatigue recovery ($p < 0.05$) when compared with the other three rest periods (Table 1). More than 90% of the muscle recovery could be obtained for the rest period of 0.5 times work time. The sEMG results significantly affected the middle deltoid fatigue recovery when the object load changed. The heart rate decreased when R/W value increased, ranging from 83.90 to 77.78 bpm. Table 2 shows the result of Duncan's new multiple range test for mean heart rate in each experimental condition (α=.05). It can be found that the heart rate between the rest period of 0.25 and 1.5 times work time showed significantly different.

Figure 1: The experimental setting

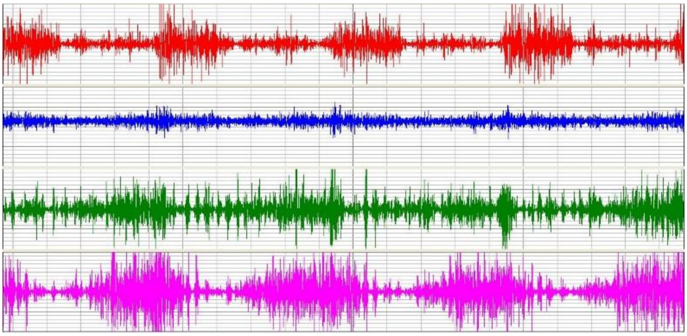

Figure 2: Recordings of the sEMG for 4 monitored subject muscles.

Table 1: Duncan's new multiple range test for mean %MVC in each experimental condition by tested muscle. (α=.05).

Tested muscle	R/W	Mean	Group	Tested muscle	R/W	Mean	Group	Tested muscle	R/W	Mean	Group
biceps brachii	0.25	0.88	A	middle deltoid	0.25	0.89	A	anterior deltoid	0.25	0.84	A
	0.5	0.95	B		0.5	0.93	B		0.5	0.89	B
	1	0.97	B		1	0.93	B		1	0.92	B
	1.5	0.97	B		1.5	0.95	B		1.5	0.94	B

R/W: ratio of the rest time to work time; Means with the same letter are not significantly different.

Table 2: Duncan's new multiple range test for mean heart rate in each experimental condition. (α=.05).

R/W	Mean	Group*
0.25	83.90	A
0.5	81.86	AB
1.5	79.91	AB
1	77.78	B

*Means with the same letter are not significantly different.

4. CONCLUSION

The study results found that the tested muscle fatigue increased when the handling loads increased and the rest period changed might significantly affect the tested muscle recovery in this study. It was suggested that the rest period should be taken at 0.5 times of the working time and the recovery might reach between 87.3% and 98.6%. If the rest was allowed only with shorter time (0.25 times of work time), it was found more than 83.9% recovery could be reached.

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REFERENCES

[1] Bystrom, S. & Fransson-Hall, C.: Acceptability of intermittent handgrip contractions based on physiological response, *Human Factors*, Vol. 36 (1994) pp.158-171.

[2] Kroemer, K.H.E., & Grandjean, E.: *Fitting the task to the human: a textbook of occupational ergonomics*, 5th ed., Taylor and Francis, Inc., Bristol, PA, USA, (1997)

[3] Kuijer, P.P.F.M., Visser, B. & Kemper, H.C.G.: Job rotation as a factor in reducing physical workload at a refuse collecting department, *Ergonomics*, Vol. 42 (1999) No. 9, pp.1167-1178.

[4] Milner, N.P.: Modeling fatigue and recovery in static postural exercise, *Clinical Biomechanics*, Vol. 1 (1986) No. 1, pp.29.

[5] Rohmert, W.: Problems in determining rest allowances. Part 1: use of modern methods to evaluate stress and strain in static muscular work, *Applied Ergonomics* Vol.4 (1973) pp.91-95.

[6] Rose, L., Ericsson, M., Glimskar, B., Nordgren, B. & Ortengren, R.: Ergo-index: development of a model to determine pause needs after fatigue and pain reactions during work, In: Mattila, M., & Karwowski, W. (Eds.), Computer Applications in Ergonomics, Occupational Safety and Health, 461-468, Elsevier Science Publishers B.V., North-Holland, (1992)

[7] Sanders, M.S., & McCromick, E.J.: *Human Factors in Engineering and Design*, 7th ed., McGraw-Hill, (1993)

[8] Sbriccoli, P., Solomonow, M., Zhou, M. & Lu, Y.: Work to rest durations ratios exceeding unity are a risk factor for low back disorder; a feline model, *Journal of Electromyography and Kinesiology*, Vol. 17 (2007), pp. 142-152.

[9] Shin, H.J., & Kim, J.Y.: Measurement of trunk muscle fatigue during dynamic lifting and lowering as recovery time changes, *International Journal of Industrial Ergonomics* Vol. 37 (2007), pp. 545-551.

ERGONOMIC RISK ASSESSMENT AT WORK-SITE: A CASE STUDY IN A FACTORY

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Abstract

This study shows an example of ergonomic risk assessment for workers in an automobile parts factory in Taiwan. The Key Indicator Method, developed by the Federal Institute for Occupational Safety and Health (BAuA) and the Committee of the German states for Occupational Safety and Health (LASI), was employed to determine their risk of suffering musculoskeletal disorders. Two workers performing parts cleaning were selected. They were interviewed and videos were taped when they were performing their tasks. Based on the results of the Lifting, Holding, and Carrying (LHC) of KIM, the physical overload is highly likely to occur with probable first worker and redesign of the workplace is necessary. The LHC & Push/Pull (PP) analyses results for the second worker indicate increased exposure of musculoskeletal disorders. Recommendations of work redesign were discussed.

Keywords: *musculoskeletal disorders, survey, job assessment, job redesign, parts handling*

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are common at workplaces. Workers exposed to risky working conditions & environments are suffering risk of MSDs. The risky conditions or environments include heavy, repetitive and forceful work, adoption of awkward and uncomfortable postures, carrying of excessive loads, vibration, low temperature, and so on [1-5]. These conditions impose stress on muscles and joints, affecting the soft tissues in body parts including the neck, shoulder, elbow, hand, wrist, fingers and back. Chronic MSDs are very likely to develop cumulatively in a period of time and most of them can lead to permanent disability. The MSDs are found in workplaces in including industries in manufacturing, dining, agricultural, health care, construction, and so on[6].
A workplace safety & health survey in Taiwan [7] found that 58.7% of the employees participated in the study reported pains or discomfort in at least one of the body parts within 12 months. Shoulder (37.7%), neck (28.3%), and low back (30.5%) were the top three body parts complained most by the subjects. Lee et al. [8] had investigated 386 employees in six companies. Most subjects reported that prolonged use of computer (92%), wrist/hand repetitive movement (84.2%) and prolonged sitting (87%) were

required. Self-reported discomforts in shoulder (78.9%), neck (70%) and low back (62.7%) were common. They concluded that the MSDs are correlated with work environment and ergonomic factors significantly. Similar results have been reported in the literature [9-10].

The so-called 'ergonomic risk factor' for a workstation or for a worker may be assessed via direct observation and measurements. Many methods, techniques, and tools have been developed for such purposes. The "Key Indicator Methods" (KIM), developed by the Federal Institute for Occupational Safety and Health (BAuA) and the Committee of the German states for Occupational Safety and Health (LASI), were one of those methods developed to assess ergonomic risks at workplaces [11]. Two different KIM Worksheets, one for Lifting, Holding, Carrying of loads (KIM-LHC) and one for Pulling and Pushing of loads (KIM-PP), are available. In addition, the Manual Handling Operations (KIM-MHO) has also been developed to analyze manual tasks. The KIM determines the risk of musculoskeletal disorders based on the load handling, exposure time, posture, and working conditions. A risk score may be calculated by adding the ratings of the load handling, posture, and working condition and then multiplied by rating of time. The levels of risk may then be determined as low (total score less than 10), median, (score between 10 and 25), median-high, (score between 25 and 50), and high (score is equal to or greater than 50). A high risk condition requires immediate intervention for improvements of job design [12]. The job characteristics such as posture, force exertion, frequency, and duration are assessed by means of the KIM and a score is calculated to indicate the risk for MSDs. The objective of this study was to assess the ergonomic risk for workers in an automobile parts factory.

2. METHODS

A field study in an automobile parts factory was conducted. The research personnel visited the factory in a one-day trip and had a panel discussion with the safety & health manager of the factory to discuss the work stations or jobs with employee complains of musculoskeletal discomfort. Two of the work stations were selected for direct observation & measures.

2.1. Work station 1

The first workstation selected was a parts cleaning station. In this station, the worker picked up two parts from the container on the left hand side using both left and right hands (see Figure 1: a) and put both parts into the machine by inserting the parts into a slot. He pushed the clicks to fix the parts, then, pushed the power button to start cleaning. The worker picked up two parts (see Figure 1:b), which had been cleaned in the previous run, on the table and twisting almost 180 degree to put these parts in a carton (see Figure 1: c). Each of the parts has a mass of 6.2 kg. The operation of the worker was videotaped to analyze for a time study.

As the parts cleaning involved manual handling tasks, the KIM LHC was employed.

a.

b.

c.

Figure 1: Parts cleaning: a. pick up parts, b. loading & unloading, and c.

2.2. Work station 2

In work station 2, the worker also perform parts cleaning. The layout of the work station is shown in Figure 2. The parts processed in this station were relative small as compared with that in work sattion 1. Each of the parts has a mass of 1.19 kg. The opeartion of this work station follows the steps in the folowing:

1. Pick up parts, two at a time, using both hands from the container on the left botton connerin Figure 2. Four trips were make to collect a total of 7 parts to put in steel basket A.
2. Wiping the grease on the gloves and waiting
3. Push basket A forward and the basket was then moving forward on the conveyor into the cleaning machine on the top of Figure 2; pulled the loaded basket (13.71 kg) just finished cleaning from the conveyor to position B.
4. Pick up parts, two at a time, from steel basket B and put into the plastic container on the workbench. The worker pick up 7 parts in four picks.
5. Pull the empty basket (5.38 kg) from B to A.
6. Repeat 1 to 4
7. When there were 14 parts in the plastic container, wrap the parts using the plastic linen
8. Lifting the container (18.29 kg) and carrying it to the pallet (C) on the button in Figure 2. Put down the container.

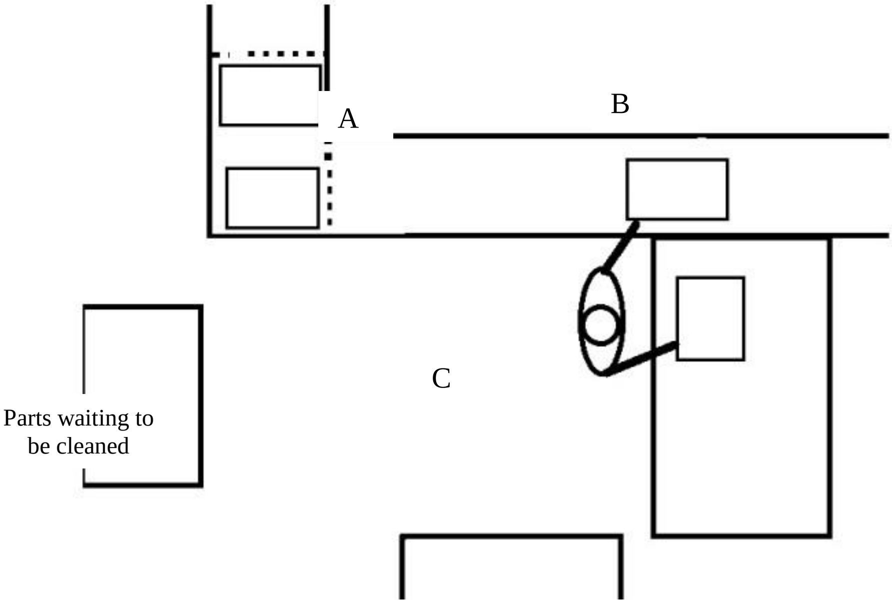

Figure 2: Layout of workstation 2

a. b.

Figure 3: a. parts in the steel basket, b. finished in the plastic container

The tasks in this work station involved manual handling tasks and pulling. Video was also taken for the tasks. The KIM LHC and PP were adopted.

3. RESULTS

3.1 Work Station 1

The analysis results of the video of the worker performing the parts cleaning tasks indicate that the cycle time for this cleaning operation was approximately 32 sec. In other words, the frequency was 1.875 per minute. In each cycle, the worker performed three materials handling tasks: picking up parts from the container on the left and insert them into the slots in the cleaning machine, picking up parts on the table in front and putting them into the carton in the back, and picking up the parts just finished washing and putting them on the front table. The frequency of the materials handling tasks was, therefore, 1.875×3=5.63 per minute. In each handling, two parts were handled. The weight of each handling was 6.2 kg/piece×2piece =12.4 kg. The total number of handlings was, therefore, 2700 (5.63×60 minutes×8hr). This handling number could be overestimated as the worker needed to do minor tasks occasionally. There were also personal and other allowances. Taking an allowance of 40%, the number of handling was still as high as 1,620 (2700×0.6). The KIM LHC results for this worker are shown in Table 1.

Table 1: KIM LHC results for work station 1 (based on video data)

	condition	Rating point
Handling per day	1,620≥1000	10
Weight handled	12.4 kg > 10kg (male)	2
Posture	Waist bending/twisting	4
Working condition		0
KIM LHC score		10×(2+4+0)=60

According to the site manager, two workers worked in the same work station. The workers completed three cartons (270 pieces per carton) of the parts daily. Each part needed to be handled three times. The daily handling for each worker was, then, 1,215 (270 piece/carton×3carton/2workers×3times/piece). The frequency of part handling was 2.53 per minute (1,215/480). The weight for each handling was 6.2 kg. Table 2 shows the KIM LHC results based on the interview data with the site-manager.

Table 2: KIM LHC results for work station 1 (based on interview with site-manager)

	condition	Rating point
Handling per day	1,215≥1,000	10
Weight handled	6.2 kg <10 kg (male)	1
Posture	Waist bending/twisting	4
Working condition		0
KIM LHC score		10*(1+4+0)= 50

As the KIM LHC results indicate high risk conditions, ergonomic interventions are required to reduce the ergonomic risk for this workstation. It was recommended that the both the parts waiting to be cleaned and the pallet (C) be supported by height-adjustable platforms so that the worker does not need to bend his waist when picking up parts or lowering the finished parts. The cartoon for the finished parts be redesigned to housing half of the amount of the parts so that the workers does not need to bend his waist when putting the parts in the cartoon.

3.2 Work Station 2

Based on the video tape analysis, the cycle time for this work station was approximately 250 seconds. In each cycle, the operation involved one handling (lifting & lowering) of finished parts (18.29 kg), one pushing and one pulling of loaded steel basket (13.71 kg), one pulling of empty steel basket (5.38 kg), and 28 picking up work piece (1.19 kg). There were 80 cycles in each day (480/4.16). Therefore, the daily operation involved 80 handling (lifting & lowering) of finished parts (18.29 kg), 80 pushing and 80 pulling of loaded steel basket (13.71 kg), 80 pulling of empty steel basket (5.38 kg), and 2,240 (80*28) picking up work piece (1.19 kg). The KIM LHC results for handling of the finished parts and the work piece were shown in Table 3 and 4, respectively. The KIM PP for push/pull of the loaded basket and the empty basket were shown in Table 5 and 6, respectively.

Table 3: KIM LHC results for finished parts handling

	condition	Rating point
Handling per day	40<80<200	4
Weight handled	10<18.29kg <20 kg (male)	2
Posture	bending waist sometimes	2
Working condition	Good	0
KIM LHC score		4*(2+2+0)= 16

Table 4: KIM LHC results for work piece handling

	Condition	Rating point
Handling per day	2,240≥1000	10
Weight handled	1.19 <10 kg (male)	1
Posture	bending waist sometimes	2
Working condition		0
KIM LHC score		10*(1+2+0)= 30

Table 5: KIM PP results for loaded basket

	Condition	Rating point
Handling per day	40<160<200	4
Sliding load	13.71 kg × 0.1<10 kg	1
Speed & accuracy	Slow, low	1
Posture	Good	1
Working condition	Good	0
KIM PP score		4*(1+1+1+0)= 12

Assuming the COF between the bottom of the basket and the surface on the workbench was 0.1

Table 6: KIM PP results for empty basket

	Condition	Rating point
Handling per day	40<80<200	4
Sliding load	5.38 kg × 0.1<10 kg	1
Speed & accuracy	Slow, low	1
Posture	Good	1
Working condition	Good	0
KIM PP score		4*(1+1+1+0)= 12

Assuming the COF between the bottom of the basket and the surface on the workbench was 0.1

As the KIM LHC and KIM PP results indicate medium risk conditions, job design improvements are not urgent. However, we still recommended that the both the parts waiting to be cleaned and the pallet (C) be supported by height-adjustable platforms so that the worker does not need to bend his waist when picking up parts or lowering the finished parts. In addition, the automatic conveying system is recommended so that the worker does not need to pull the basket from B to A.

4. CONCLUSION

The limitation of the study was that there were only two subjects in this study. Nonetheless, the cases discussed in this paper provide examples of conducting ergonomic assessment of manual tasks in real scenarios and work conditions. Both workstations discussed were characterized by their manual operations. The ergonomic risk levels were, however, different. Ergonomic interventions were proposed.

REFERENCES

[1] Armstrong TJ, Radwin RG. Repetitive trauma disorders: job evaluation and design, *Human Factors*, **Vol.** 28 (1986) 3, 325-336.
[2] Chaffin, DB, Andersson, GBJ, *Occupational Biomechanics*, John Wiley & Sons, New York. (1984)
[3] Putz-Ansderson V, *Cumulative trauma disorders: a manual for musculoskeletal diseases of the upper limbs*, Taylor & Francis, London. (1988)
[4] Ayoub, MM, Mital A, *Manual Materials Handling*, Taylor & Francis, London. (1989)
[5] Ayoub, MM, Bethea, NJ, Deivanayagum, S, Asfour, SS, Bakken, GM, Liles, D, Mital A, Sherif, M, Determination and modeling of lifting capacity, final report, NIOSH (5R01-OH-00545-02) (1978)
[6] Schneider, S, Susi, P. Ergonomics and construction: a review of potential hazard in new construction, *Am Ind Hyg J*, **Vol.** 55(1994) No.7, 635-649.
[7] Institute for Occupational Safety & Health (IOSH), A survey of workplace safety & health, technical report, IOSH99-M306. (2010)(in Chinese)
[8] Lee, Yu-Hsuan, Weng, Jui-Hsuan, Hsu, Ya-Yuarn, Wang, Tzyy-Jiuan, Relationship between the Work Environment and Perceived Body Discomforts, *Institute of Occupational Safety & Health Journal*, **Vol.** 21(2007)No. 4, 432-441.
[9] Li, K.W., Cheng, YC, Chen, CY, Yeh, WY, Self-report musculoskeletal symptoms and biomechanical task analysis for photographers, *Institute of Occupational Safety & Health Journal*, **Vol.** 10(2002) No.1, 12–21.
[10] Li, K.W., Hsu, YW, Prevalence of musculoskeletal symptoms for employees in Hsin-Chu Science Park, *Institute of Occupational Safety & Health Journal*, **Vol.** 6 (1998) No.4, 21-34.
[11] Klussmann, A., Steinberg, U., Liebers, F., Gebhardt, H., Rieger, MA. The Key Indicator Method for Manual Handling Operations (KIM-MHO) - evaluation of a new method for the assessment of working conditions within a cross-sectional study, *BMC Musculoskeletal Disorders*, (2010), 11:272; http://www.biomedcentral.com/1471-2474/11/272
[12] Steinberg, U., Caffier, G., Liebers, F., Assessment of manual material handling physiological and psychophysiological measures. International Journal of based on

key indicators - German guidelines. In: Karwowski, W. (Ed.), *Handbooks of Standards in Ergonomics and Human Factors,* Lawrence Erlbaum Associates, Mahwah, N.J., (2006), pp. 383-392.

ANALYSIS OF KINEMATIC CHARACTERISTICS USING MULTIPLE RGB-D SENSORS

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Abstract

We concern the problem of fully automated analysis of kinematic characteristics. Markerbased systems suffer from widely known shortcomings, such as errors due to broken marker trajectories, long setup times, and the inability to capture the motion of actors in normal clothing, and the necessary of frequent manual intervention. In this paper, we present a markless method for capturing the motion of a human from multi-view RGB-D sensors.
In the offline stage, firstly a human surface model is constructed by dynamic fusion of the point cloud created by RGB-D sensors, secondly the articulated template model is built by a automatic rigging algorithm. In the online stage, body-parts are detected from depth images, skeleton pose are tracked by fitting the surface to the silhouettes from and point cloud from multi-view RGB-D sensors. We further propose a novel optimization scheme for skeleton-based pose estimation that exploits the skeleton's tree structure to split the optimization problem into a local one and a lower dimensional global one.
We show on various sequences that our approach can capture the 3D motion of humans accurately even in the case of rapid movements and large scale deformations. Kinematic characteristics such as working space, occupied space are also calculated automatically.

Keywords*:* *kinematic characteristics analysis, markerless motion capture, RGB-D sensor, human factors, biomechanics*

1. INTRODUCTION

RGB-D sensors capture color image and depth image simultaneously in real-time, which are widely used in computer vision related domain such as markerless motion capture. In this research, we proposed a novel RGB-D sensor based markerless motion capture method for ergonomics analysis, including human pose estimation, motion parameter calculation and working space evaluation.

2. RELATED WORK

Nowadays, motion capture is an essential acquisition technology with many applications in computer vision and computer graphics, such as sports science, biomechanics, or character animation for games and movies. Marker-based systems can in principle capture such motions of subjects, but they suffer from widely known shortcomings, such as: errors due to broken marker trajectories, long setup times.

Further on, in occlusion case, frequent manual intervention is necessary. Markerless multi-view motion capturing algorithms overcome some of these limitations [1].

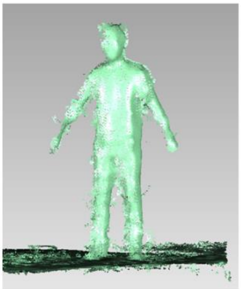
In this paper, we propose a markerless motion capture method for analysis of kinematic characteristics.

3. OVERVIEW

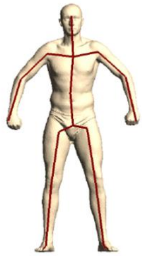
The performance of a human is captured by synchronized but non-calibrated RGB-D cameras. Similar to [1], we acquire for each person a rigged 3d shape model comprising a bone skeleton, a triangle mesh surface model, and skinning weights for each vertex, which connect the mesh to the skeleton. The mesh surface of each person can be generated using a laser scanner or a Kinect sensor. In our experiments, we use laser scans of the actors, each rigged with a skeleton with 39 degrees of freedom. Such a skeleton partitions the whole body into 15 body parts where the highest skinning weight of a vertex determines its unique association to a body part.
Multiple cameras in different view angle capture color and depth images of the subject. These depth images are transformed to point clouds. They are registered to the same coordinate system. For each time, foreground silhouettes and point clouds are extracted by background subtraction.
As in [1], we aim at estimating the skeleton configuration (pose), consisting of the global rigid transformation of the torso and the joint angles of the skeleton. Non-articulated surface deformations (shape) that cannot be approximated by skeleton driven deformation are not considered in this paper.
Based on the estimated pose, we calculate the motion parameters. Kinematic characteristics such as working space, occupied space are also calculated automatically.
An outline of the processing pipeline is as follows. Starting with the estimated skeleton from the previous frame, the skeleton pose is optimized as described in Section 6 such that the projection of the deformed surface fits the image data in a globally optimal way. The estimated skeleton pose serves as initialization for the next frame to be tracked.

4. BODY MODELING

Body modeling includes two aspects, mesh model building and automatic rigging. The 3D mesh surface model of each person can be generated using a laser scanner or a Kinect 2.0 sensor. KinectFusion [2] is a popular method to model the human body but the precision is limited. In our experiments, we use laser scanner AMETEK CREAFORM to build the triangle mesh model (STL format), see Fig.1, a.
Normally, animating an articulated 3D character currently requires manual rigging to specify its internal skeletal structure and to define how the input motion deforms its surface. We use Pinocchio [3] for animating characters automatically. Given a static character mesh and a generic skeleton, our method adapts the skeleton to the character and attaches it to the surface, allowing skeletal motion data to animate the character.
After rigging, the surface model can be deformed by the pose of the skeleton model (Fig 1, b).



a.



b.

Figure 1: Example images captured from RGB-D sensors:

5. MULTI-VIEW IMAGE CAPTURE

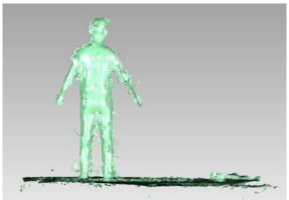
Each RGB-D sensor captures color images and depth images simultaneously. 3D point cloud is calculated from depth image.

Multiple RGB-D sensors were mounted surrounding the working area. Point clouds from multi-view are registrated by iterative closest point (ICP) procedure to get an integrated point cloud. Foreground silhouettes and point clouds are extracted by background subtraction.

Based on the Foreground point clouds, we further create a composite depth image by project the integrated point cloud to some special viewpoint. The composited depth image will be used in the following body-part detection procedure.

a.

b.



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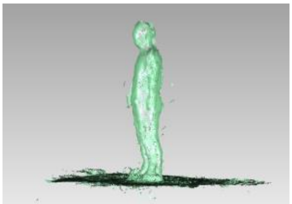
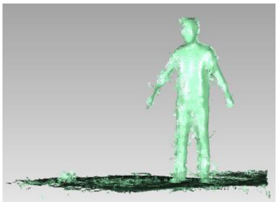


d.



e.

Figure 2: Example images captured from RGB-D sensors: a. color image, b. depth image, c.~e. point clouds in different view.

6. MARKERLESS MOTION CAPTURE

The proposed markerless motion capture procedure uses foreground silhouettes and foreground point clouds to estimate the human pose.

6.1. Body-Parts Detection

Based on the composite depth image calculated above, we use the real-time human body part recognition method [4] to detect body-parts and generate the body joints hypothesis. The method of [4] can quickly and accurately predict 3D positions of body joints from a single depth image, using no temporal information. It takes an object recognition approach, designing an intermediate body parts representation that maps the difficult pose estimation problem into a simpler per-pixel classification problem. Microsoft's large and highly varied training dataset allows the classifier to estimate body parts invariant to pose, body shape, clothing ,etc. Finally it generates confidence-scored 3D proposals of several body joints by reprojecting the classification result and finding local modes.

The detection procedure mainly serves as initialization step for pose tracking, it also serve as re-initialization step when pose tracking is failed or is falling into local minimum.

6.2. Pose Tracking

Pose tracking or pose refinement is the process of pose optimization. The practice in the literature is using iterative closest point (ICP) method. In this paper, we use point clouds as well as silhouettes to build the energy function.

On the one hand, the optimization is to minimize the chamfer distance between the transformed model silhouette and the foreground silhouette. We call it model-image alignment or silhouette matching. On the other hand, the optimization should also minimize the point-to-point distance between the transformed model surface points and the foreground point cloud. We call it model-point registration or point registration.

7. KINEMATIC CHARACTERISTICS ANALYSIS

The human body pose is obtained through the motion capture method above, including the global rigid transformation of the torso and the joint angles of the skeleton.

Through further calculation, we can get the kinematics parameters and ergonomics parameters: working space, reachable domain, occupying space, and so on.

8. EXPERIMENTS

We use laser scanner AMETEK CREAFORM to build the triangle mesh model, and use Orbbec Astra camera as our RGB-D sensor (Figure 8). We recorded 7 test sequences consisting of over 1500 frames. The data was recorded with 3 cameras at a resolution of 640*480 pixels and at a framerate of 15fps. The initial segmentations were generated by background subtraction.

The sequences consist of a wide range of different motions, including dancing, fighting, and jumping. The motions were performed by 5 different persons wearing casual clothing. We also recorded an evaluation sequence where one of the performers was simultaneously tracked by a marker-based motion capture system, yielding ground-truth data for a quantitative evaluation.

Figure 3: a. Orbbec Astra camera, b. AMETEK CREAFORM laser scanner

The program was developed in Microsoft Visual Studio using C++, runs on a Windows 7 Notebook with 8G RAM.

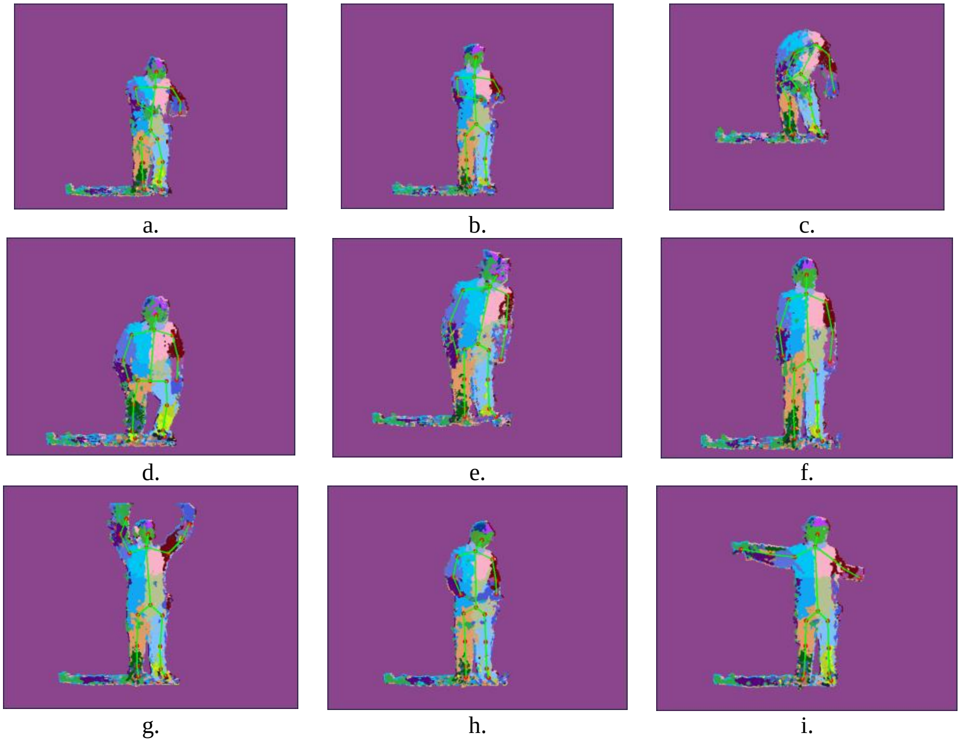


Figure 4: Body joints detection results and skeleton show.

Table 1: Joints definition and their positions in intermediate pose

	Body Joints	X(mm)	Y(mm)	Z(mm)
1.	Head	58.5105	364.5650	2567
2.	Neck	47.9537	220.5870	2735
3.	Right shoulder	-167.5840	200.1690	2655
4.	Left shoulder	240.1190	206.5020	2739
5.	Right elbow	-140.6520	32.8189	2674
6.	Left elbow	298.7000	51.9478	2469
7.	Right wrist	105.2000	-227.933	10000
8.	Left wrist	278.0370	-61.3316	2332
9.	Torso	-4.7761	-262.6840	2724
10.	Right hip	-109.2850	-351.6140	2710
11.	Left hip	72.0357	-360.1790	2739
12.	Right knee	-94.0137	-611.0900	2681
13.	Left knee	133.6810	-615.8880	2723
14.	Right ankle	-92.1114	-848.3950	2765
15.	Left ankle	94.7099	-872.3280	2843
16.	Right foot	-78.9702	-952.5780	2815
17.	Left foot	140.5540	-968.8210	2863

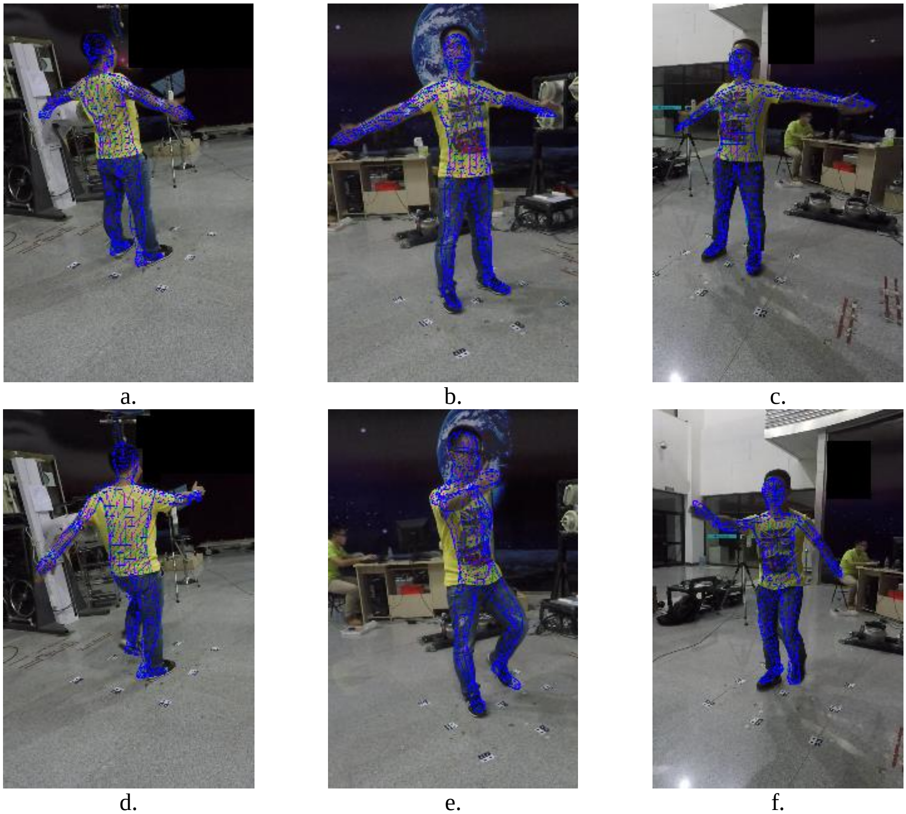


Figure 5: Tracking results superimposed in color images show high accuracy of pose estimation.

In the proposed motion capture method, pose estimation is only depended on depth images. Color images are not used for pose estimation; they are used for pose verification and result replay show. This is more intuitive than the use of depth images.

Results show
A. space target positioning error: less than 5mm;
B. length measurement error: less than 1cm;
C. human body 3D model reconstruction error: less than 1cm;
D. operating space measurement error: less than 5cm;
E. angle measurement error: less than 5 degrees;
F. measurement error of each joint point of the human body, the centroid of each segment, and the position of the feature points: less than 2.5cm.

9. CONCLUSION

In this paper, we proposed a RGB-D sensor based markerless motion capture method, and we use this method for ergonomics analysis, including human pose estimation, motion parameter calculation and working space evaluation.
We validated the feasibility of using RGB-D camera to carry out the scheme of mark

free motion capture. Due to the influence of marker inconsistency, the results of markerless motion are more consistency. With the use of the reconstructed 3D model for motion capture, and the accuracy is higher than that of general human body model.

Robust pose estimation and tracking can be achieved, which can capture the whole set of human body position and attitude parameters.

To our knowledge, this is the first system to fully-automatically perform ergonomics analysis using multiple RGB-D sensors.

REFERENCES

[1] Gall, J., Stoll, C., De Aguiar, E., & Theobalt, C. (2009). Motion capture using joint skeleton tracking and surface estimation. IEEE Conf on Computer Vision & Pattern Recognition (pp.1746-1753). IEEE.

[2] Izadi, S., Kim, D., Hilliges, O., Molyneaux, D., Newcombe, R., & Kohli, P., et al. (2011). KinectFusion: real-time 3D reconstruction and interaction using a moving depth camera. ACM Symposium on User Interface Software and Technology, Santa Barbara, Ca, Usa, October (pp.559-568).

[3] Baran, I.and Popovic, J. (2007). Automatic rigging and animation of 3d characters. Acm Transactions on Graphics, 26(3), 72.

[4] Shotton, J., Fitzgibbon, A., Cook, M., Sharp, T., Finocchio, M., & Moore, R., et al. (2011). Real-time human pose recognition in parts from single depth images. Postgraduate Medical Journal, 56(1), 1297-1304.

A STUDY ON THE INTERFACE DESIGN OF HEAD-UP DISPLAY FOR IN-VEHICLE NAVIGATION SYSTEMS

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Abstract

With the progress of technology, the global positioning system (GPS) of in-vehicle navigation systems (IVNSs) can be integrated with communication, entertainment and personal service on intelligent products. However, the INVSs may not reach users' requirements and will increase users' burden. To help designers provide appropriate interfaces with drivers, this research developed an experimental analysis of head-up display interface to help identify an optimum interface of INVS information and images for a GPS display. The development included data collection, analysis and identification of experimental parameters, construction of a vehicle interior environment, experimental design and back-propagation neural network simulation. It is expected that the results can help build a proper graphical user interface in the INVS for user awareness and present an appropriate mode of electronic display on windshield of vehicles.

Keywords*: Human-Computer Interaction, Graphical User Interface, Head-up Display, In-Vehicle Navigation System, Back-Propagation Neural Network*

1. INTRODUCTION

With the technological development of computers, communication, consumer electronics and related products, the global positioning system (GPS) of in-vehicle navigation systems (IVNS) can be integrated with communication, information, entertainment and personal service on intelligent products [1]. Recently, people choose a vehicle not only considering basic functions and safety but also focusing on comfortable, convenient, efficiency, and exterior factors. This change makes companies introduce some peripheral products, such as event data recorder, portable or build-in navigation device (PND) and portable or build in television to satisfy users' requirements [2]. However, the in-vehicle navigation systems may not reach users' requirements although nowadays they offer more various functions. In fact, too many additional functions and information will increase users' burden [1]. Therefore, the human-computer interaction interface in the in-vehicle navigation systems should be designed and developed based on users' cognitive behavior to present the contents with the most comprehensible way [3-4]. In general, most global positioning systems (GPS) are either externally or internally connected under the lower right display of the driver and the visual field varies depending on the size of screen and the maker [5]. This kind of design and arrangement makes the driver unable to see the monitor clearly in a relatively short time. Some auto makers used new techniques of head-up display (HUD) to upgrade driving efficiency and safety. In view of currently marketed HUDs, the GPS representation has three shortcomings: (1) existing IVNSs have different layer designs on quantity of functional items and menu selection that cannot be adapted to suit individual operation, (2) current IVNSs provide users with a variety of functions that will increase search time and cause mental burden for drivers and (3) the IVNS developer usually designs the operational interface based on his or her own subjective opinion that may not meet the user requirements. To help auto maker designers provide appropriate interface information with drivers, the objective of this research is to apply the concept of back-propagation neural network simulation in the experimental analysis of head-up display interface to help identify an optimum presentation of in-vehicle navigation information and images.

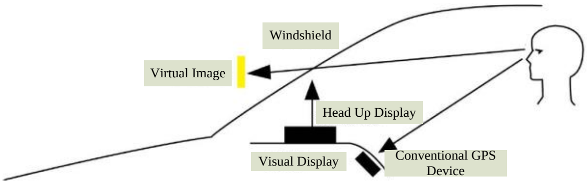
2. HEAD-UP DISPLAY

The head-up display is a humanized design that can efficiently assist the driver to reduce the response time when driving and prevent great movement of head on looking at the display from occurring accidents [6]. The advantage of using a head-up display is primarily because the position of image projection is fallen into the same visual field of the driver that help simultaneously look at driving and road situation [7]. Current head-up displays set up the projecting position at the left front of the windshield. To avoid reflection or reflective images, a black and semitransparent reflective membrane or tinted window film is stuck on the window of projecting area, and a dark nap type of pad is laid on top of the visual display panel. Note that the projecting information shares a relatively small area of driver's viewing field and the images are transparent to allow the driver to perceive the outside scenery [4]. In general, current marketed head-up displays possess a variety of functions including rotational speed, speed per hour, time in hours and minutes, water temperature, speeding warning, average gas consumption and instant gas consumption. Some vehicles also equip with simple GPS functions such as current road situation and driving direction [8]. Figure 1 illustrated a representation of head-up display for IVNS in vehicles. In fact, the GPS information is more important for the driver than those of other head-up display functions. It is because the GPS information helps the driver make decisions on driving at the right direction and avoiding accidents. Therefore, the representative way and functions of the GPS play an important role in the head-up display interface design. Based on the preliminary investigation of the current head-up display development, an appropriate and suitable GPS interface for the head-up display is still worth of continuous research. It is noted that current technology has successfully connected the IVNS with a rear-mirror, it will also be possible to connect the GPS of INVS with the windshield in the near future.

3. DEVELOPMENT PROCEDURE

There are four stages for the research development: (1) identification of experimental parameters, (2) conduction of experimental design, (3) back-propagation neural network

a.



b.

Figure 1: Current head-up display representation: a. a head-up display example, and b. conceptual representation of a head-up display

simulation and (4) representation of an optimum interface design. In the first stage, characteristics of existing vehicles with head-up display for IVNS were collected including specific structural parameter values, types of interface modes and functions for head-up display representation. The research built graphic images for these interface functions and designed a questionnaire based on these interface functions. The questionnaire was distributed to the experienced users. The research then categorized the tested users into specific groups. Each group will have its respective functional interface. In stage 2, the categorized groups of experimental display interface modes were defined and the software Adobe Illustrator CS4 was used to build simulation images. The environmental layout for the experiments was also setup in stage 2. Having finished the necessary setting, the research selected tested subjects and proceeded to the cognitive experiments. The steps for the cognitive experiments were also determined in Stage 2. As to the Stage 3, the research used the collected data obtained from Stage 2 to perform the back-propagation neural network training. Note that the back-propagation neural network training is primarily used to help search for a more precise location for the GPS presentation. According to the characteristics of the parameters and values of the experimental data, a three-layer back-propagation neural network with multiple-input neurons is selected. The software MATLAB 7.0 is used in the training simulation to help determine the optimum head-up display interface for the IVNS. The projector-style navigation interface for different ethnic groups and its projection position is then identified and recommended. Finally, in Stage 4, the research used the computer software Adobe Illustrator CS4 to develop the recommended head-up display IVNS interface mode for a specific group of users.

4. IDENTIFICATION OF EXPERIMENTAL PARAMETERS

To help identify important interface parameters for experiments, the research collected three brands (BMW, Audi and Lexus) and a total of 16 existing vehicles with a head-up display IVNS and measured the corresponding structural parameters. These parameters include (1) θ(in degree): angle between windshield and horizontal line, (2) L1 (in mm): horizontal distance between projection point and top of seat back, (3) L2 (in mm): vertical distance between projection point and buttock, (4) L3 (in mm): vertical distance between top of vehicle and buttock, (5) L4 (in mm): seat width and (6) L5 (in mm): seat length as illustrated in Figure 2. Considering a popular type of vehicles, the research chose 5 types of four-door vehicles as targeted products and calculated their average values of the above parameters as illustrated in Table 1. The research also collected

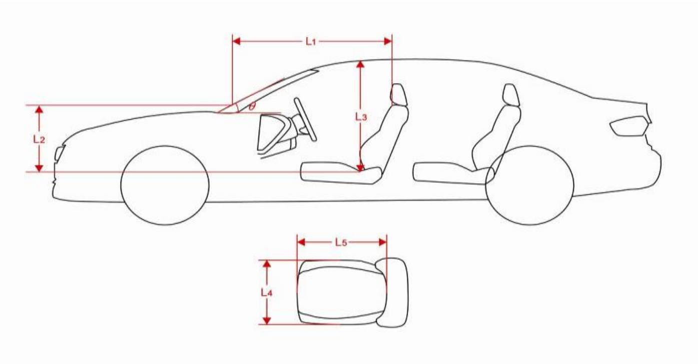


Figure 2: Measurement of vehicle structural parameters

Table 1: Averaged values for five four-door vehicles of structural parameters

Parameter	θ	L1	L2	L3	L4	L5
Value	31.2º	934	627	964	536	544

eight types of head-up display IVNS interface modes associated with their functions, as illustrated in Figure 3. Based on the collected interface modes shown in Figure 3, the research identified eight specific functions for head-up displaying: road image representation, route indication, speed, gas consumption, distance, warning, time and road name, as illustrated in Table 2. These functions are displayed in numerical symbols, text information, graphic images or null indication. The research rebuilt graphic images for all functions illustrated in Table 2 and designed a questionnaire of user preferences regarding these interface functions. A total of 250 subjects took the questionnaire and 217 subjects were effective. After a K-Means clustering analysis has been conducted with the assistance of the SPSS 14 statistical software, the research categorized five interface functional groups corresponding to the user preferences. Figure 4 illustrated a head-up display of user interface for group 1.

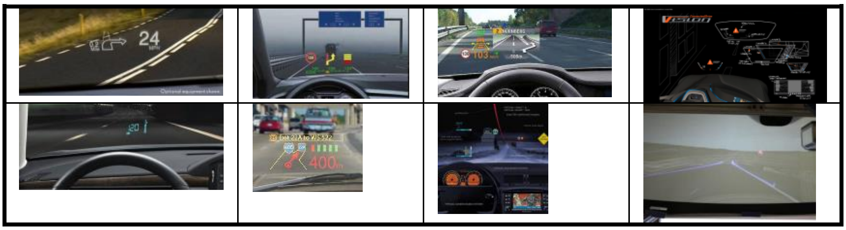


Figure 3: Eight types of existing head-up displays

5. CONDUCTION OF EXPERIMENTAL DESIGN

To help explore an optimum head-up display IVNS interface mode, the research constructed a vehicle interior environment for experiments. The surroundings of the vehicle interior were arranged as close as a real vehicle so that the noise factors for tested subjects can be reduced to the minimum. The experimental materials included:

Table 2: Identification of interface functions for GPS head-up display of IVNSs

Function	Characteristic 1	Characteristic 2	Characteristic 3	Characteristic 4	Characteristic 5
Road Image Representation	Third-angle Projection/2D	First-angle Projection/2D	First-angle Projection/3D	No Marks	NA
Route Indication	Solid Arrow	Hollow Arrow	Upper Curve	Two Side Curves	No Marks
Speed	Numerical Display	Linear Moving-Display	Curvy Moving-Display	No Marks	NA
Gas Consumption	Discrete Bar	Long Bar	Curvy Moving-Display	No marks	NA
Distance	Numerical Display (with Unit)	Vertical Bar (Triangle Indicator)	Vertical Bar (Car Image Indicator)	Horizontal Bar (Triangle Indicator)	No Marks
Warning	Text	Graphic Display	No Marks	NA	NA
Time	Numerical Display	Graphic Display	No Marks	NA	NA
Road Name	Text	No Marks	NA	NA	NA

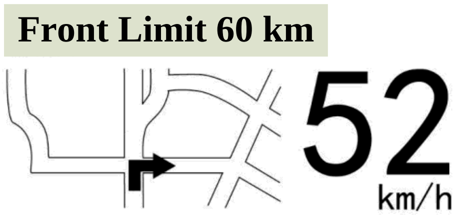


Figure 4: An interface mode for group 1 users

windshield, fixture framework for windshield, projector, car seat, computer and related accessories. The relative position for these materials are adjusted based on the parameter values shown in Table 1. Figure 5 illustrated an environmental layout for the experiment. As to the user interface of the IVNS operational experiments, the research used the representative sample of each categorized interface functional group as a system interface for the tester simulated operation. Note that the functional images for each group of interface mode include road, indicative symbol, speed, fuel consumption, distance, warning signal, time and road name. The research used the computer assisted graphics software Adobe Illustrator CS4 to develop all interface functions of GPS and built in the projection system so that the whole representation can be suitable for the interface operation of testers. The projection system is developed by Microsoft Power Point 2003 and the tester operational interface is projected on the experimental windshield. To conduct the experimental design, the research designed a six-step procedure for the GPS simulation of the IVNS. They are: (1) explanation of experimental process including introduction of head-up display of IVNS, example of current head-up display, experiment procedure and questionnaire, (2) selection of functional element images for GPS user interface including selection one representational sample from five interface functional groups and 37 GPS interface functional images, (3) GPS operational interface simulation, (4) experiment of operational simulation on determining preferred GPS operational interface, (5) storage

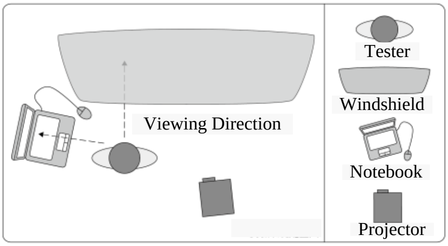


Figure 5: Experiment layout

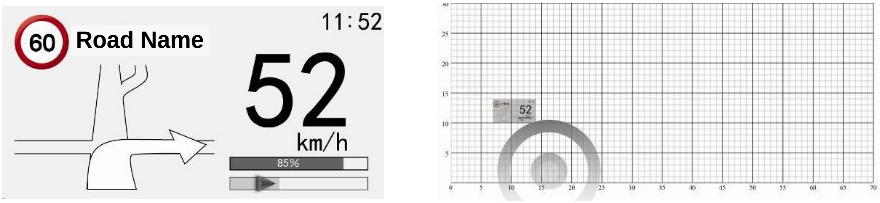
operational simulation on determining preferred GPS operational interface, (5) storage of the preferred GPS operational interface and (6) questionnaire survey and completion of the experiment. In this experiment, 30 tested subjects completed the questionnaire and their experimental data including personal characteristics and GPS functional image preferences were stored in the system for the training of back-propagation neural network simulation.

6. BACK-PROPAGATION NEURAL NETWORK SIMULATION

According to the conduction of experimental design for the head-up display IVNS, the research collected experimental data about GPS interface functions. These data were forwarded to the process of back propagation neural network simulation to search for the optimum head-up display interface representation mode. To implement the training of back-propagation neural network simulation, the personal characteristics of the tested subjects are used as input values and the corresponding GPS functional image preferences are considered as output values [9-10]. The above data will be used as the initial inputs and the desired output in the neural network training. In this research, the neuron model selected for the experiments is a 10–26–54 type of network, which means that there are ten input signals in the input layer, twenty-six actual outputs of neurons in the hidden layer, and fifty-four actual outputs of neurons in the output layer. The initial input values include: (1) ages between 25 and 34, (2)college graduated, (3) single, (4) occupation, (5) monthly income between NTD$30000 and NTD$50000, (6) driving experience between 2 and 5 years, (7) PND user, (8) outdoor experienced traveler, (9) know about HUD and way of operation and (10) be willing to use HUD. As to the output values, they are: (1) 26 items for road image representation and route indication, (2) 6 items for speed and gas consumption (3) 10 items for distance and 14 items for warning, time, road name and projection coordinates. The procedure for the training includes: (1) normalize the input data of tested subject information and GPS user interface parameters, (2) transform the input data into the MATLAB matrix format, (3) select a suitable type of neuron model and specify the training function, adaption function, performance function, number of layers, number of neurons, and transfer function and (4) feed the matrix data in the back-propagation neural network system and implement the training [9-11]. After finished the training of back-propagation neural network simulation, the derived output values are forwarded to a normalization process that the data are transformed into functional parameter values. These parameter values will be considered as an optimum IVNS user interface mode of the head-up display.

7. REPRESENTATION OF AN OPTIMUM INTERFACE DESIGN

The functional parameter values of the IVNS of head-up display obtained from the back-propagation neural network simulation that are recommended for a specific group of users include: (1) first-angle projection/3D with an area 60mm x 140mm for road image representation, (2) hollow arrow for route indication, (3) numerical display with an area 50mm x 50mm for speed, (4) long bar with an area 30mm x 80mm for gas consumption, (5) horizontal bar and triangle indicator with an area 20mm x 80mm for Distance, (6) graphic display with an area 40mm x 40mm for warning, (6) numerical display with an area 30mm x 80mm for time, (7) text with an area 30mm x 80mm for road name and (8) start coordinates (7, 10) and end coordinates (14, 14) with units in millimeters (mm). Based on the above data, the research used the computer software Adobe Illustrator CS4 to build the images and positions for the recommended head-up display IVNS interface mode [12]. After a back and forth review and modification, the final representation of an optimum interface design of a head-up display IVNS for a specific group of users is illustrated in Figure 6.



a. b.

Figure 6: A recommended head-up display alternative: a. image representation, and b. located position

8. CONCLUSION

IVNS products have become popular and the number of functional items in current IVNSs has increased gradually. Their differences have also become more apparent, which make it difficult for the user to choose. Therefore, the designer is responsible for developing a friendly IVNS to meet user requirements. Due to the progress of technological applications in IVNS, the head-up display on the vehicle windshield could be the coming generation for the GPS of IVNS. The research proposed a procedure to explore an optimum head-up display interface mode for IVNS that integrated several approaches, such as a usability scenario model, clustering analysis, experimental design, back-propagation neural network simulation and graphics design. The recommended interface mode was then represented. It is expected that through the implementation of this research, the following results can be obtained: (1) a proper connection between the factors of graphical user interface in the IVNS and user awareness and (2) an appropriate mode of electronic information display on windshield of vehicles. In addition, this research will provide referencing information and research process with designers to help establish users' awareness on the graphical user interface and the information transmission mode of IVNSs to make human-computer interaction be more humanized and intelligent.

ACKNOWLEDGEMENT

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REFERENCES

[1] Lin, M.-C.; Lin, Y.-H.; Lin, C.-C. & Lin, J.-Y.: A study on the interface design of a functional menu and icons for in-vehicle navigation systems, *Lecture Notes in Computer Science,* **Vol.8522** (2014), pp.261-272, ISSN 0302-9743

[2] Amditis, A.; Pagle, K.; Joshi, S. & Bekiaris, E.: Driver vehicle environment monitoring for on-board driver support systems: lessons learned from design and implementation, *Applied Ergonomics*, **Vol.41** (2009) No.2, pp.225-235, ISSN 0003-6870

[3] Chan, W. L. & Chan, H. S.: Spatial S–R compatibility of visual and auditory signals: implications for human–machine interface design, *Displays*, **Vol.26** (2005) No.3, pp.109-119, ISSN 0141-9382

[4] Cui, Y.; Oulasvirta, A. & Ma, L.: Event perception in mobile interaction: toward better navigation history design on mobile devices, *I. J. Human-Computer Interaction*, **Vol.27** (2011) No.5, pp.413–435, ISSN 1071-5819

[5] Lin, C.-T.; Wu, H.-C.& Chien, T.-Y.: Effects of e-map format and sub-windows on driving performance and glance behavior when using an in-vehicle navigation system, *I. J. Industrial Ergonomics*, **Vol.40** (2010), pp.330–336, ISSN 0169-8141

[6] Charissis, V.; Arafat, S.; Chan, W. & Christomanos, C.: Driving simulator for head up display evaluation: driver's response time on accident simulation cases, Proceedings of *DSC'06 Asisa/Pacific Driving Simulation Conference*, pp.1-8, ISBN 9782857826859, Tsukuba, May, 2006, Tokyo, Japan, (2006)

[7] Charissis, V. & Papanastasiou, S.: Human-machine collaboration through vehicle head up display interface, *Cognition*, *Technology & Work*, **Vol.12** (2010) No.1, pp.517-527, ISSN 1435-5558

[8] Jung, E. C.: Methodology for context-sensitive system design by mapping internal contexts into visualization mechanisms, *Design Studies*, Vol.31 (2010), pp.26–45, ISSN 0142-694x

[9] Hagan, M. T.; Demuth, H. B. & Beale, M.: *Neural Network Design*, PWS Publishing Company, ISBN 9812404856, Boston, MA, (1996)

[10] Negnevitsky, M.: *Artificial Intelligence: A Guide to Intelligent Systems*, Pearson Education Limited, ISBN 0201711591, Harlow, England, (2002)

[11] Jung, J.-R. & Yum, B.-J.: Artificial neural network based approach for dynamic parameter design, *Expert Systems with Applications*, **Vol.38** (2011), pp.504-510, ISSN 0957-4174

[12] PreiBner, O.: Design of graphic displays for driver information and communication systems, *Computer Aided Animation*, GmbH, AAAI Technical Report, SS-00-04 (2000)

INFLUENCE OF TASK AND DURATION ON LOWER LEG CIRCUMFERENCE AND SUBJECTIVE DISCOMFORT DURING SQUATTING/KNEELING TASK

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Abstract

Many occupations require workers to squat or kneel for prolonged periods, which can cause both discomfort and pain. This study examines the effects of different task type, working duration, and working posture on squatting/kneeling discomfort in the laboratory. Ten paid subjects (5 males and 5 females) with no history of problems of the lower extremities were enrolled in this study. They performed two tasks (paving stone and painting the wall), using three working postures (squatting, kneeling on one leg, and kneeling on both legs) on a hard floor for two working duration (15+15 min and 30 min) in a laboratory setting. Analytical results demonstrate that working postures and working duration significantly affected muscle activation, circumferential thigh measurements, and subjective ratings for leg discomfort. Working duration significantly affected heart rate. We conclude that different working postures and prolonged working duration influence worker lower extremity discomfort. These analytical findings suggest that common ergonomic interventions, such as providing the squatting/kneeling aids on which workers squat or kneel might somewhat alleviate leg edema. Nevertheless, prolonged squatting or kneeling for even 15 minutes without rest showed negative effects and should be avoided when possible.

Keywords*: squatting/kneeling task, musculoskeletal fatigue, lower leg circumference*

1. INTRODUCTION

Working in the construction industry typically requires awkward postures, heavy lifting, and considerable exertion. Many workers performing such tasks complain of discomfort in their upper extremities and lower back over the course of a workday [1-4]. Awkward posture means a considerable deviation from the neutral position of one, or a combination of joints. These postures typically include reaching behind, twisting, working overhead, wrist bending, kneeling, stooping, forward and backward bending, and squatting [5]. Several studies identify that there is a relationship between awkward postures and pain, and symptoms and injuries in the musculoskeletal system [6-9]. Meerding *et al*. [10] reported that 59% of construction workers had musculoskeletal complaints, and 41% experienced low back pain in the preceding 6 months. Goldsheyder *et al*. [11] identified a high prevalence of 82% for musculoskeletal disorders among stone masons. The one-week prevalence of lower back and knee complaints among Dutch pavers was 42% and 22%, respectively, in 2005 [12]. Epidemiologic studies indicate that prolonged kneeling increases the risk of osteoarthrosis of the knee [13]. However, issues regarding the health status of constructional workers during tasks that are squatting or kneeling in relatively long-lasting have seldom received public attention, as so is in Taiwan. The primary objective of this study is to determine the task demands and loads on the physiology and lower extremities under different task type, working duration, and working posture combinations, and to associate these demands with the strength of subjects. This study will provide evidence that supports ergonomic recommendations to promote workplace health by alleviating pain or fatigue of the physiology and lower extremities while performing squatting or kneeling task in construction.

2. MATERIALS AND METHODS

2.1 Subjects

Ten college students, 5 males and 5 females, were recruited and paid for their participation. Subject age range was 19–22 (mean, 20.9). Average height was 170.3±6.7 cm and average weight was 60.8±5.9 kg. All subjects were in good health and had no history of musculoskeletal and cardiovascular problems. All were right-handed and no subject had experience to work squatting or kneeling for prolonged periods. Before participation, subjects were informed of study objectives, and all chose to participate voluntarily.

2.2 Apparatus

A surface EMG (sEMG) system was used to measure muscle activity via surface electrodes [14]. Four sEMG sensors were positioned based on the specific muscle location. These bipolar surface electrodes were attached bilaterally over the right and left vastus lateralis and gastrocnemius muscle groups of subjects to record muscular activities. The sampling rating was 1,000Hz per channel and data were analyzed using Viewlog software [14]. The subject’s skin was abraded or shaved and cleaned with an alcohol pad when necessary. A series of calibrations were then performed to obtain individual baselines for maximal voluntary contraction (MVC) of each muscle group. The recorded sEMG data were subsequently utilized to normalize sEMG signals recorded during task performance by expressing these signals as a percentage of MVC (%MVC). All maximum contractions were performed three times, and the highest 1-s mean force was utilized. To identify variations in lower extremity circumference, a Gulick tape measure was used. To decrease error caused by traction and tension compression of soft tissues, this tape measure does not generate tension, and has a tension meter at one end, ensuring that each measurement is under the same pressure on the test area.

2.3 Experimental design

The experiment had a three-factor design with repeated measures analysis of variance (ANOVA). Task type (two levels), working posture (three levels), and working duration (two levels) were fixed factors. Subjects were the random factor. Two different task types were used: paving stone and painting the wall. Three working postures were tested, squatting, kneeling on one leg, and kneeling on both legs on a hard floor. The experiments were performed in the laboratory, and the forces, lower extremity circumference, and heart rate were measured. During the experiment, each subject performed 12 trials (two different task types with all three working postures in the two working durations). Task order was randomized across subjects. To present experimental data clearly, Table 1 lists the 12 experimental tasks in a fixed order. Dependent variables were muscle activity (%MVC) measured from the sEMG for each of the four muscle groups, variations in lower extremity circumference, heart rate, and subject-perceived exertion to quantify perceived muscular exertion for body segments. Subjective ratings of perceived exertion responses were on a fifteen-point Borg-RPE scale, ranging from 6 for "No exertion at all" to 20 for "Maximal exertion."

Table 1 Twelve experimental tasks used in this study

Experimental tasks	Task type	Working posture	Working duration
Task 1	painting	squatting	30 min
Task 2	paving	squatting	30 min
Task 3	painting	squatting	15+15 min
Task 4	paving	squatting	15+15 min
Task 5	painting	kneeling on both legs	30 min
Task 6	paving	kneeling on both legs	30 min
Task 7	painting	kneeling on both legs	15+15 min
Task 8	paving	kneeling on both legs	15+15 min
Task 9	painting	kneeling on one leg	30 min
Task 10	paving	kneeling on one leg	30 min
Task 11	painting	kneeling on one leg	15+15 min
Task 12	paving	kneeling on one leg	15+15 min

2.4 Experimental procedure

Prior to the experimental sessions, all subjects were informed of the study's purpose, procedures, and physical risks and informed consent forms were voluntarily signed. Experimentally significant anthropometric data were obtained, including body height, and weight. After anthropometric measurements were taken, the sEMG sensors were attached using double-sided tape collars. The sensors were then zeroed while a subject was in a relaxed standing position. Resting and set muscular activity measures were then recorded, such that sEMG data could be normalized during analysis. As mentioned, each subject participated in 12 experimental sessions. Subjects adopted a natural and comfortable stance to perform tasks and were allowed to work at their own pace. Each session lasted approximately 30 min, and each subject performed no more than three trials on the same day. Subjects were given a 5-min break at minimum between trials to minimize muscle fatigue. This break was measured using a stopwatch. After each trial was completed, subjects then filled out a subjective rating of perceived exertion questionnaire. No subject practiced before the experiment. The order in which each subject performed each of the 12 trials was randomized.

2.5 Data analysis

All analyses used SPSS v 11.5.0 [15]. First, descriptive statistical analysis was conducted for all variables. Next, repeated-measures ANOVA was applied to each dependent variable to test whether it significantly affected any measure. *Post hoc* multiple-range tests were conducted to compare variable values when a factor was statistically significant at the $\alpha=0.05$ level.

3. RESULTS AND DISCUSSION

Table 2 presents means of %MVC under all treatment conditions. Mean exertion force (%MVC) of the right vastus lateralis (26.8 % MVC) and left vastus lateralis (26.7 % MVC) was significantly higher than that of the right gastrocnemius (23.1% MVC) and left gastrocnemius (23.0% MVC). Table 3 presents mean heart rate, lower extremity circumference (thigh and shank), and subjective rating of perceived exertion responses in experimental tasks. Each subject rated perceived exertion at the end of each trial. Average difference between before and after experimental task was 7.2 beats per min, subject-perceived exertion increased over time from 7.6 to 10.4. Table 3 also showed that the thigh circumference (0.71 cm) had the greater average changes after the test period, while the shank circumference (0.37 cm) had the lower average changes. To identify factors impacting muscle loads, muscle activation levels of the four muscles were subjected to a three-factor design with repeated measures ANOVA (Table 4). The ANOVA results of sEMG measurements demonstrate that the main effects of the task type, working posture, and working duration on the vastus lateralis were significant ($p<0.01$). Working posture, and working duration had a significant effect on gastrocnemius ($p<0.01$). Working posture, and working duration also had a significant effect on thigh circumference ($p<0.01$) and Borg-RPE ($p<0.01$), respectively. Working duration had a significant effect on heart rate ($F = 7.93$, $p<0.01$). The interactive effect between task type and working duration significantly influenced muscle activities of the vastus lateralis ($F = 12.70$, $p<0.01$) and gastrocnemius ($F = 28.12$, $p<0.01$), but not lower extremity circumference, heart rate, and Borg-RPE. The interactive effect between the working posture and working duration significantly impacted the vastus lateralis ($F = 5.38$, $p<0.05$), gastrocnemius ($F = 3.54$, $p<0.05$), heart rate ($F = 62.10$, $p<0.01$), and Borg-RPE ($F = 9.55$, $p<0.01$), while no interactive effects existed on lower extremity circumference.
Although the lower extremity discomfort mechanisms remain unclear, forceful exertion, repetition, and static muscle load are significant risk factors for cumulative trauma disorders. In a study by Fennigkoh *et al*. [16], a job requiring high force was defined as

that requiring with >30% MVC, whereas a job requiring low force was defined as that requiring <10% MVC. In this study, muscular activity (*i.e.*, %MVC) increased over time from 14.5% MVC to 38.1% MVC during testing periods, ranging from an average of 23.0% MVC for the left gastrocnemius 26.8% MVC for the right vastus lateralis (Table 2); thus, kneeling or squatting task was categorized as medium to high force. However, as the experiment task involved kneeling/squatting plus repetitive motion, this may have generated a highly static muscle load, resulting in fatigue, regardless of whether a subject's muscular activity was <30% MVC. Furthermore, the muscular activity of vastus lateralis was higher than that of the gastrocnemius muscle (Table 2). Increased vastus lateralis activity is in agreement with thigh circumference (Table 3), the consistent findings in objective response parameter suggest that a future study is required to describe accurately the work performed and ways of measuring these parameters while performing a kneeling or squatting task.

Table 2 Mean of Relative EMG signal activity (%MVC) in experimental tasks

Experimental tasks	Right Vastus	Left Vastus	Right Gastrocnemius	Left Gastrocnemius
Task 1	38.1	38.1	37.4	36.3
Task 2	35.0	34.9	26.2	26.3
Task 3	21.9	22.1	16.3	15.6
Task 4	25.2	24.5	17.7	17.5
Task 5	24.7	23.2	22.4	22.2
Task 6	34.3	35.7	31.3	31.4
Task 7	21.9	21.4	20.7	21.0
Task 8	26.0	26.4	21.4	21.2
Task 9	25.4	25.7	23.7	24.3
Task 10	24.7	24.7	25.8	26.5
Task 11	19.6	19.4	15.8	14.5
Task 12	24.3	24.6	18.9	19.2
Average	26.8	26.7	23.1	23.0

Table 3 Mean heart rate, lower extremity circumference, and subjective rating of perceived exertion responses in experimental tasks

Experimental tasks	HR (pre)	HR (post)	HR (△)	Borg-RPE	Thigh (△)	Shank (△)
Task 1	74.5	83.4	8.9	10.4	1.15	0.33
Task 2	74.3	83.6	9.3	9.8	1.45	0.57
Task 3	74.2	79.1	4.9	8.0	0.61	0.24
Task 4	74.5	79.7	5.2	8.0	0.70	0.21
Task 5	73.8	83.6	9.8	9.9	0.92	0.43
Task 6	74.2	83.9	9.7	9.7	0.67	0.49
Task 7	73.8	78.7	4.9	7.9	0.65	0.43
Task 8	74.0	78.1	4.1	7.6	0.58	0.45
Task 9	74.2	83.4	9.2	8.8	0.53	0.38
Task 10	73.1	83.6	10.5	9.1	0.53	0.33
Task 11	74.0	79.0	5.0	7.9	0.42	0.16
Task 12	73.8	79.0	5.2	8.0	0.31	0.43
Average	74.0	81.3	7.2	8.8	0.71	0.37

Δ: the average difference between before and after experimental tasks.

Table 4 ANOVA of relative EMG, lower extremity circumference, heart rate, and subjective ratings of perceived exertion

Performance measures	Task type	Working posture	Working duration	Task x posture	Task x duration	Posture x duration
EMG						
Vastus	13.04**	56.32**	16.78**	1.61	12.70**	5.38**
Gastrocnemius	2.85	75.30**	59.01**	1.28	28.12**	3.54*
Circumference						
Thigh	0.44	13.06**	15.97**	0.93	0.05	3.06
Shank	1.39	1.14	1.50	0.09	0.01	0.45
Heart rate	0.52	0.20	7.93**	0.44	0.03	62.10**
Borg-RPE	0.30	7.48**	195.89**	2.96	0.08	9.55**

*p<0.05, **p<0.01.

4. CONCLUSIONS

This study demonstrates that working posture and working duration affect muscular activities, thigh circumference, and subject-perceived exertion while performing squatting/kneeling tasks. Additionally, different task type also affected vastus lateralis muscular activities—paving generated the higher muscle load and painting the smaller. These muscle loads may increase risk for musculoskeletal disorders. These analytical findings suggest that common ergonomic interventions, such as providing the squatting/kneeling aids on which workers squat or kneel might somewhat alleviate leg edema. Nevertheless, prolonged squatting or kneeling for even 15 minutes without rest showed negative effects and should be avoided when possible.

REFERENCES

[1] Buchholz, B.; Paquet, V.; Punnett, L.; Lee, D. & Moir, S.: PATH : A work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work, *Ergonomics,*Vol. 27, 1996, pp. 177-187.

[2] Jeong, B.Y.: Occupational deaths and injuries in the construction industry, *Appl. Ergon.,* Vol. 29, 1998, pp. 355-360.

[3] Hoozemans, M.J.M.; Van der Beek, A.J.; Frings-Dresen, M.H.W. & Van der Molen, H.F.: Evaluation of methods to assess push/pull forces in a construction task, *Appl. Ergon.*, Vol. 32, 2001, pp. 509-516.

[4] Davis, K.G.; Kotowski, S.E.; Albers, J. & Marras, W.S.: Investigating reduced bag weight as an effective risk mediator for mason tenders, *Appl. Ergon.*, Vol. 41, 2010, pp. 822-831.

[5] Pinzke, S. & Kopp, L.: Marker-less systems for tracking working postures-results from two experiments, *Appl. Ergon.*, Vol. 32, 2001, pp. 461-471.

[6] Grandjean, E. & Hünting, W.: Ergonomics of posture-review of various problems of standing and sitting posture, *Appl. Ergon.*, Vol. 8, 1977, pp. 135-140.

[7] Corlett, E. N. & Manenica, I.: The effects and measurement of working postures, *Appl. Ergon.*, Vol. 11, 1980, pp. 7-16.

[8] Westgaard, R.H. & Aarås, A.: Postural muscle strain as a causal factor in the development of musculo-skeletal illnesses, *Appl. Ergon.*, Vol. 15, 1984, pp. 162-174.

[9] Haslegrave, C.M.: What do we mean by a working posture?, *Ergonomics*, Vol. 37, 1994, pp. 781-799.

[10] Meerding, W.J.; Ijzelenberg, W.; Koopmanschap, M.A.; Severens, J.L. & Burdorf, A.: Health problems lead to considerable productivity loss at work among workers with high physical load jobs, *J. Clin. Epidemiol.*, Vol. 58, 2005, pp. 517-523.

[11] Goldsheyder, D.; Nordin, W.; Weiner, S.S. & Hiebert, R.: Musculoskeletal symptom survey among mason tenders, *Am. J. Ind. Med.*, Vol. 42, 2002, pp. 384-396.

[12] Van der Molen,H.F.; Sluiter, J.K. & Frings-Dresen, M.H.W.: Evaluation covenant reducing physical work demands among carpenters, bricklayers and pavers, Coronel Institute of Occupational Health, Amsterdam, 2005.

[13] Bierma-Zeinstra, S.M.A. & Koes, B.W.: Risk factors and prognostic factors for hip and knee osteoarthritis, *Nat. Clin. Pract. Rheumatol*, Vol. 3, 2007, pp. 78-85.

[14] Liu, Y.P.; Chen, H.C. & Chen, C.Y.: Multi-transducer data logger for worksite measurement of physical workload, J. Med. Biol. Eng., Vol. 26, 2006, pp. 21-28.

[15] SPSS Institute, Inc: *SPSS user's guide, Release 11.5.0* , 2002.

[16] Fennigkoh, L.; Garg, A. & Hart, B.: Mediating effects of wrist reaction torque on grip force production, *Int. J. Ind. Ergon.*, Vol. 23, 1999, pp. 293-306.

QUALITATIVE ANALYSIS OF USABILITY RELATED HUMAN ERRORS IN A COLLABORATIVE VR ENVIRONMENT

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Abstract

The aim of the article is to describe the nature of usability issues in a new virtual environment designed for collaboration through an information-based task. The virtual environment models a collaborative problem space of scheduling a two-day trip for students in a tourist office. Usability issues are analyzed within the framework of James Reason's where errors observed are interpreted as rule-based mistakes, i.e. the false application of rules from the physical world in the virtual reality. The issues observed qualitatively on video recordings reveal that these rule-based errors of usability in the 3D cave are related to the lack of feedback.

Keywords: *3D VR environment, collaboration, usability, rule-based errors*

1. INTRODUCTION

Information-rich collaborative tasks can greatly benefit from tangible representations of information that the collaborators can easily share. Two historians collaboratively studying multiple documents at the same time can more easily and efficiently work together when they are both present in a shared physical space with print documents than using collaborative technologies. However, sharing a physical space is often difficult and expensive when collaborators are distantly located. We set out to address this problem by developing a collaborative immersive 3D space with shared digital representations of documents.

We chose immersive 3D environments over 2D solutions for several reasons. First and foremost, we feel that 3D immersive environments can best replicate and improve on the advantages of shared physical spaces. Second, immersive 3D environments allow large amount of information to be displayed. 2D displays can also create high-density information displays, however, we assumed that 3D immersive environments would make it easier for users to browse, manipulate, interpret and use the information. Third, a shared virtual space where both users are represented through avatars can help the users create common ground and would bring emotional commonality.

We developed the space in the VirCA virtual collaboration arena (www.virca.hu). "VirCA is a loosely coupled modular; 3D Internet based interactive virtual environment for collaborative manipulation of robots and other hardware or software equipment." (www.virca.hu) The core environment was developed by the Cognitive Informatics Research Group of the Computer and Automation Research Institute of the Hungarian

Academy of Sciences. The main goals of the system are to allow researchers to rapidly develop knowledge sharing environments. The project presented in this paper used the environment to create a space for collaborative information-intensive tasks. Presence of the partner (even if virtual) means a difference in quality when engaged in a cooperative task. The study of collaborative task execution in virtual space compared to real life was one of the goals of the NeuroCogSpace project. VirCA is designed (among other features) to support collaborative work in virtual environments. The size of the CAVE environment was 3x3 meters. (Figure 1.)

Figure 1: CAVE environment. A triangle shaped desk was placed 230 centimeters from the main wall, in the middle of the space. Participants were seated on the left side of the table.

While immersive 3D environments have their challenges for users, such as disorientation and fatigue, they also afford interaction patterns that are similar to shared physical spaces and thus they have the potential to support collaborative information tasks. [1] User interaction methods and information displays possess more flexible characteristics than physical spaces. In addition to physically moving and organizing information items, users can take advantage of digital capabilities, such as full text search, digital annotations, different access levels for different users, exporting and importing digital formats, and so on.

Another advantage of such spaces is that the number of documents or information items is theoretically limitless. The flexibility of the virtual environment allows users to browse, view, move, group, and annotate a large number of documents. While this is a great opportunity for users, designers should create the environments carefully to make interaction natural and address the challenges of disorientation and fatigue for users of 3D immersive spaces.

Figure 2: The VirCa virtual reality cave: The schedule can be seen on the left; posters are scattered on the walls, two notepads can be found down right from the schedule, and two avatars of the participants are in the foreground

Shared virtual reality systems offer remote collaboration to geographically dispersed collaborators. Not only hearing, but also seeing another person (or at least an avatar representing that person) will create a higher sense of presence, interpersonal trust and perceived communication quality [2]. The more realistic an environment is, the more effective the spatial search is [3], [4]. Such collaborative virtual reality environments have been developed for various purposes. Among others, immersive 3D virtual environments can afford shared viewing and manipulation of digital representations of documents in a common virtual space. An example of these systems closest to our focus is VR VIBE [5], a collaborative virtual reality system in which users can browse and search web content in a 3D immersive space, while at the same time seeing other users in the space using the same information is also possible. While our study did not locate studies on collaborative information seeking tasks in immersive virtual reality, Raja and colleagues [6] found that immersive environments support individual information visualization tasks. The VirCa virtual space used in this study is similar to VR VIBE in, for example, its purpose and setup, however, VirCa supports only the interpretation and use of information. Three important elements of our space are: (1) physical representation of information on posters; (2) user actions to manage those posters; (3) a schedule table on what the selected posters can be placed in order to fulfill the program of the two-day trip. Typical actions necessary for the interpretation of information are: reading, structuring and organizing, highlighting, commenting, placing information objects, and creating new content. The virtual environment presented here is a modified version of the previously used VirCa (Virtual Collaboration Arena) environment [7]–[11]. The modifications in a framework of iterative design and innovation [12] are focused on issues related to writing or typing. A shared text input field used in the previous version of VirCa was replaced the empty schedule table representing the output area due to several usability problems reported and found in analyses. Furthermore, typing as an activity was found to be immersion breaking [8] during the task, thus we limited its usage to note taking.

2. THEORETICAL BACKGROUND

James Reason in his 1990 book [13] distinguishes three performance levels where errors can occur: skill-based, rule-based, and knowledge-based levels. (Figure 3.) In the following, the possibilities of the interpretation of the three error types in the VirCa used for the experiment are examined.

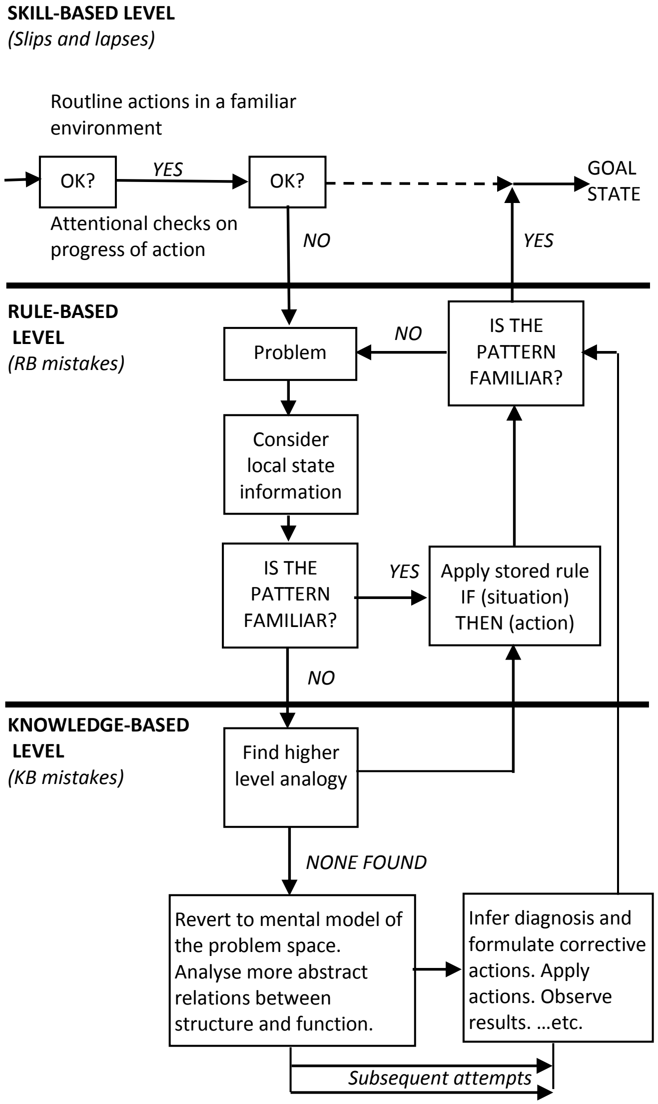

Figure 3: The model of mistakes on different performance levels by James Reason [13, p. 64] that serves as a theoretical frame of the analysis of errors in this study.

New stimuli, novel task, some inner pressure to complete it fine, and the fact that the participants are being observed by the experiments make the errors on skill-based level (slips and lapses) less likely to occur. The mentioned components force the attention to be focused on the task which gives no opportunity to slips and lapses related to automatic reactions to happen.

Knowledge-based mistakes are more likely to be related to problems affecting the whole task completion. In the case analyzed here, the usability problems are not complex enough to be knowledge-based mistakes. If there is a knowledge related issue in the usability of the 3D cave, the participants are allowed to ask the experimenter, so they do not invent a false mental model of the situation. However, knowledge-based mistakes do exist in the 3D cave, but on the level of the whole scheduling task: a typical example for that is when the participants misunderstand the instruction of the task (e.g. what program points have to be included in the schedule compulsorily, etc.) and they complete it with errors regarding the instruction. Those kinds of mistakes are not usability errors, thus we focus on them in another analysis in the future.

Rule-based mistakes are the types of errors describing the usability issues in the framework of James Reason's. In these kind of errors the participants apply rules that sometimes in the real word fit the problem. In this case of the 3D virtual environment the mentioned rules are not always effective. The application of a rule in the cave that does not work for the problem leads to a rule-based mistake. In this level the usability problems can be described as applications of unfitting rules that lead to problems.

In this paper an example of a usability error interpreted in the framework of Reason for human errors is presented.

A working definition has been established for the scope of analysis presented in this paper: usability errors in this analysis are distinguished from the errors in the quality of the task completion. Usability errors are not connected to the content of the task, e.g. the scheduling itself but they are related to the 3D environment and to its usage only. It is indicated by an expression of intention to interact with the environment that is failed right after.

3. RESEARCH TASK

Arriving to an unknown place itself a task. Maintaining orientation, coping and functioning in a new environment requires effort from the user. In a 3D environment this could be detected as disorientation and fatigue [3]. People has far more experience in real life environments than in VR. The rules of a VR depend on the given program therefore they have infinite variations and can be ambiguous. Those rules are not as obvious as in real life this can be understand by the question of one of the participant when he asked if he could put objects into the trashcan. If we want to avoid pitfalls and create a user-friendly virtual environment we have to analyze the environment without preconceptions to apprehend the behavior. To detect the process of coping with a new environment we choose to measure visual attention.

The task replicates the process of creating an interesting holiday plan for other tourists visiting Budapest. In the virtual tourist office, there are posters and a map available for the participants to create a feasible schedule for two days. Optionally, one is able to type, but only direct graphical manipulation is required to complete the task. The exact instructions are:

"Create a holiday plan for two days for a foreign tourist group who are around your age. Make sure to include in your plan a trip to a bath and a pub. Also, both days should end at a club. Suggest places for lunch and dinner for both days; they receive breakfast at their hotel. Try to fill both days with classic tourist attractions. Create a plan that is varied, yet manageable. Display the final plan in the table located on the front wall."

4. PARTICIPANTS AND METHOD

21 pairs of university students participated in the experiment with an average age of 22.58 years. The students were recruited from two universities in Budapest, Hungary in December 2013. In the qualitative phase of analysis we observed the video recordings of the 21 cooperative tasks recorded in the VirCa environment. We searched for issues where an intention of a participant is expressed (verbally or non-verbally) and then this intention is failed to be satisfied (what can be expressed also verbally or non-verbally).
The coding scheme of the usability errors was:

1) The coder identify the intention to a specified act that either declared verbally or non-verbally
2) Sequences of acts appear and the intention identified previously is still not satisfied thus it is repeated or declared as a problem.
3) Registration:
    1) time stamp
    2) short description
    3) error type
       (categories were: hand usage, putting down, seizure, false seizure, problems with the notes)
    1) physical object involved participant who committed the error (involved physical agents were: Hands, Map, Notepad, Poster, Schedule, Wall)

5. RESULTS

In our research, we explored and analyzed 188 usability error. As you can see in Table 1. only the 32% of the usability errors were verbalized, and participants hardly ever asked for help.

Table 1: Verbalizing usability errors and ask for help frequencies and percent

Verbalizing		
	Frequency	Percent
YES	60	31,9
NO	128	68,1
TOTAL	188	100

Ask for help		
	Frequency	Percent
YES	182	96,8
NO	6	3,2
TOTAL	188	100

The most common usability error observed in the videos was an error in the seizure of posters or other objects.

Trying to grab a poster to replace it participants often moved the hand through it which hinders to seize the poster. Therefore, the users felt the poster to be transparent: it was not solid and stopping the hand when a participant had reached it. It can be seen on Fig. 4 and 5: a participant is preparing the movement towards the poster and finally they move the hand through it. That unrealistic possibility confused the participants and they expressed their surprise verbally (e.g. “Oh, I can reach through it.”). This pattern appeared repeatedly in the recordings of the same pair and across most of the pairs of participants generally. The lack of boundaries (as a tactual feedback) made the movements less precise and contributed to frustration. Participants could not feel that they have reached (touched) the poster.

6. CONCLUSION

As a general conclusion it can be stated that the virtual reality cave provided a supportive environment for the collaborative information seeking task. The usability errors appeared here were identified as rule-based mistakes which are described by the inadequate application of a rule in the virtual environment. The rules (e.g. touching the poster that gives a feedback: it is not penetrable) applied and failed here are based on non-visual (tactual, postural, or combined) feedback [15]. Trying to seize a poster and reaching through it is caused by the lack of tactual feedback from touching the poster that should trigger the stopping of the movement. The sitting position of the participants also contributes to the mentioned rule-based usability errors by disabling the possibility of postural feedback and hinders them from building a better spatial model of the cave by exploring it. A possible solution for these overgeneralized rule-based usability errors could be an overall metaphor used generally in the cave environment for interacting with the physical agents and using the interface. This can be based either on computers (scrolling and clicking) or on real world movements, but it has to be an overall fitting metaphor of any usability situations to solve. Helping the users also some replacements for tactual and postural feedback should be considered to be implemented in the cave environment. That would lead to a mutual interaction with the objects, similarly to the concept of the body language of objects [15].
In our further researches we are aiming to quantify the role of the rule-based usability mistakes in the collaborative task. The main focus is going to be on the features that affect the time and the quality of the task completion in the VirCa virtual reality cave.

7. ACKNOWLEDGMENT

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REFERENCES

[1] Sebrechts, M.: Visualizing information in virtual space: Prospects and pitfalls, In *Knowledge and Information Visualization*, Springer Berlin Heidelberg, ISBN: 978-3-540-26921-2 (2005), pp. 136–166.
[2] Bente, G.; Rüggenberg, S.; Krämer, N. C.; and Eschenburg, F.: Avatar-Mediated Networking: Increasing Social Presence and Interpersonal Trust in Net-Based Collaborations, *Human Communication Research*, **Vol**. (2008) 34, no. 2, pp. 287–318, doi: 10.1111/j.1468-2958.2008.00322.x
[3] Meijer F.; Geudeke, B. L. and Van Den Broek E. L.: Navigating through Virtual Environments: Visual Realism Improves Spatial Cognition *CYBERPSYCHOLOGY & BEHAVIOR*, vol. (2009) 12, no. 5, pp. 517–521, doi: 10.1089/cpb.2009.0053.

[4] Pausch, R.; Proffitt, D. and Williams, G.: Quantifying immersion in virtual reality, *in Proceedings of the 24th annual conference on Computer graphics and interactive techniques*, 1997, pp. 13–18. ISBN:0-89791-896-7, ACM Press/Addison-Wesley Publishing Co., New York, NY, USA (1997)

[5] Benford, S.; Greenhalgh, C.; Rodden, T.; and Pycock, J.: Collaborative virtual environments *Communications of the ACM*, vol. 44, no. 7, pp. 79–85, 2001.

[6] Raja, D.; Bowman, D.; Lucas, J.; and North, C.: Exploring the benefits of immersion in abstract information visualization, *in Proc. Of IPT (Immersive Projection Technology)*, (2004) Springer Cham Heidelberg New York Dordrecht London ISSN 1865-0929

[7] Hámornik, B. P.; Köles, M.; Komlódi, A.; and Hercegfi, K.: Studying the Features of Collaboration in the VirCa Immersive 3D Environment, *in Proceedings of Measuring Behaviour (*2014) Wageningen, The Netherlands, August 27-29, (http://www.measuringbehavior.org/files/2014/Proceedings/Hamornik,%20B.P.%20-%20MB2014.pdf)

[8] Hámornik, B. P.; Köles, M.; Komlódi, A.; and Hercegfi, K. and Izsó, L.: Features of Collaboration in the VirCA Immersive 3D Environment, *in Advances in Cognitive Engineering and Neuroergonomics - Proceedings of AHFE 2014*, (2014) Advances in Human Factors and Ergonomics, Krakow, Poland, 2014 Jul 19-23. AHFE International, pp. 131-139. (ISBN:1495121011)

[9] Vámos, A., I. Fülöp, B. Reskó, and P. Baranyi,: Collaboration in virtual reality of intelligent agents, Acta Electrotechnica et Informatica, vol. (**2010**) 10, no. 2, pp. 21–27.

[10] Galambos, P.; Csapo, A.; Zentay, P.; Fulop, I.; Haidegger, T.; Baranyi, P. and Rudas, I.: Design, programming and orchestration of heterogeneous manufacturing systems through VR-powered remote collaboration, *Robotics and Computer-Integrated Manufacturing*, vol. (2014) 33. pp. 68-77.

[11] Baranyi, P. and Galambos, P.: VirCA as Virtual Intelligent Space for RT-Middleware, in *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, 2011, pp. 140–145.

[12] Tóvölgyi, S.: The effect of 'EFQM Framework for Innovation' on competitiveness in the education sector, *Periodica Polytechnica Social and Management Sciences*, vol. (**2009**) 17, no. 2, pp. 97.

[13] Reason, J.: Human error. Cambridge: Cambridge University Press, 1990. ISBN: 9780521314190

[14] Tan, D. S.; Gergle, D.; Scupelli, P. and Pausch, R.: Physically large displays improve performance on spatial tasks, *ACM Transactions on Computer-Human Interaction*, vol. (**2006**) 13, no. 1, pp. 71–99.

[15] Sonneveld M. H.; and Schifferstein, H. N. J.: The tactual experience of objects, in *Product Experience*, Oxford, UK: Elsevier Inc., 2008, pp. 41–67. ISBN-9780080450896

THE HUMAN RELIABILITY FOR PUMPIMG PROCESSES IN A CHEMICAL SHIP

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Abstract

This study aim is to detect the potential human factors and calculate human reliability within the process of pumping chemicals from a ship to the tanks on earth. The used tools were the Hierarchical Task Analysis (HTA), systematic human error reduction and prediction approach (SHERPA) and human error assessment and reduction technique (HEART) and questionnaire to investigate the 45 workers. The results showed the 7 parts of the whole job: arrivals, loading preparation, pre-loading, loading, pro-loading, leaving preparation, and departures; and the most high error rate activities were action (49%) and check (44%); the workers' knowledge and attitude had relationship; and HEART pointed that human reliability of the processes. The results of HTA and the SHERPA indicate that the potential human factors play a quiet huge proportion in this process. To promoting the human reliability, the suggestions are the program design could be improved and the workers need re-training.

Keywords: *Human reliability, Human factors, ship, chemicals safety*

1. INTRODUCTION

The international trade way in Taiwan depends on air and marine transportation. Marine transportation is the main way to ship chemicals, like petroleum, gasoline, natural gas, and methylbenzene. The GHS stipulate some rules for these chemicals transportation and their physics and chemical characters. The transportation process needs staffs to operate many kinds of interfaces. These interfaces, like human-software and human-hardware, have some potential disadvantages. The human factors about these disadvantages are action error, management oversight, and misjudgment, improper use of protective equipment, and error of machine operation, safety inspection insecurity before work, error of process operation. Most of these factors refer to un-safety motion or behavior.

Chemical industry is an important industry in Taiwan. It plays an important role in other industries and daily use for transportation, refine, and distribution. There are many kinds of complex and dangers chemical substances, like raw material, finished and half-finished products. These toxicity, corrosiveness, inflammable, exponible substances could cause explosion and fire during transportation and using. Careless and manipulate fault during operation in chemical industry would cause serious accident. According to the previous serious accidents analysis, we could determine some prevention and protection ways to decrease the risk of accident happens and financial loss [1].

The port of unloading in southern petroleum company is this study's object. Its main products are gasoline, natural gas, and inflaming materials. These would cause

accidents easily when staffs load and unload cargos inappropriately. This study's aim is to use reliability methods to analysis human error mode of loading and unloading process in southern petroleum company and utilize these results to determine the staffs' reliability and un-safety behaviors. Furthermore is to establish database for long-term tracking and to calculate failure rate or reliability analysis. These would be contributive to improve the process's safety and quality. This study use field survey, job analysis, motion analysis, questionnaire survey, and error analysis to determine error type and failure action level, and calculate its failure rate. These would be help to improve human error in chemical industry and its human reliability mode's validation.
The subjects in this study were staffs and sailors who worked in the port of unloading in southern petroleum company. Their major work was to transport chemicals, like gasoline, natural gas, and alkenes. This study's aim is to determine the potential human error risks during their work and be help to plan the best process.

2. TECHNICAL REQUTS

2.1. Methods

The used tools were the Hierarchical Task Analysis (HTA), systematic human error reduction and prediction approach (SHERPA) and human error assessment and reduction technique (HEART) and questionnaire to investigate the 45 workers.
Hierarchical Task Analysis, HTA: HTA [2] is the most used method in industrial safety, and be used to analyze the workers action.HTA can completely describes the whole work activity. It can be used in many ways, and not only confined in ergonomic. For example, it also is used in the nuclear emergency system. HTA aimed at the structure of operate and to develop the useful hypothesis to solve the efficiency problem. Systematic Human Error Reduction and Pre-diction Approach, SHERPA: SHERPA is including the error mode and the behavior mode, and it can stratum type operating analysis and, classify the operation [3]. It can find the potential human errors or design errors. Due to the references, the precision of forecast the error in SHERPA is the most accurately of the identification human error way.

Analysis steps:
(1) Hierarchical Task Analysis, HTA
Analyze every action step. We collected the in-formation by interviewed the workers, observed the operation activity.
(2) Task classification
Classified the operation as "Action" "Retrieval"" Check" "Selection" and "Communication" after analyzed the operation.
(3) Human error identification
After classified the operation, we analyzed the possible error of every act, and described the error actions, and classified the possible error actions by using SHERPA.
(4) Consequence analysis
Based on the document to pretend and describe the consequence of all the possible error actions.
SHEL model
It is developed from the traditional system "human-machine-environment". It can find out the relation-ship between the workers and another interface, for example: human-

hardware interface. After that, we can modify the interface to decrease the weak point of the action.

The case of the study: The study sit is the part of the petrochemical business and also is the biggest import and export port of the south part of Taiwan. The workers including the ship pilots and dock workers are totally forty workers. The study performed by operate observation, and questionnaire

2.2. Results

The basic data showed the workers age, work age and education on Table 1. The education level shows 2 (5%) participate have been graduated from 4 years institute & university (Table1 1).

The result from the HTA (Figure 1), Separated the Oil tank up & down load process into seven parts: 1. Ship into the dock, 2. Preloading process, 3. Preloading process action, 4. Start loading, 5. Loading complete, 6. Pre-pare to leave and 7. Ships leave away the dock.

Table 1: The age, work age and education of workers

	Mean	SD
Age	49.5	9.1
Working time (Year)	19.6	12
	Number	**Percentage (%)**
Gender		
Male	40	100
female	0	0
Education level		
Junior high	0	0
Senior high	25	62.5%
College (2-3 years after high school)	13	32.5%
Institute & university (4 years after high school)	2	5.0%

The result from SHERPA showed the error code and distribution on the Table 2 and also showed the Figure 2. On table 3 shows the error model distribution of SHERPA, and the error code classified to “A” for action error, “C” for checking error, “R” for retrieval error, “I” for communication error, and action error and checking error took the large percentage of the error model (Table3).

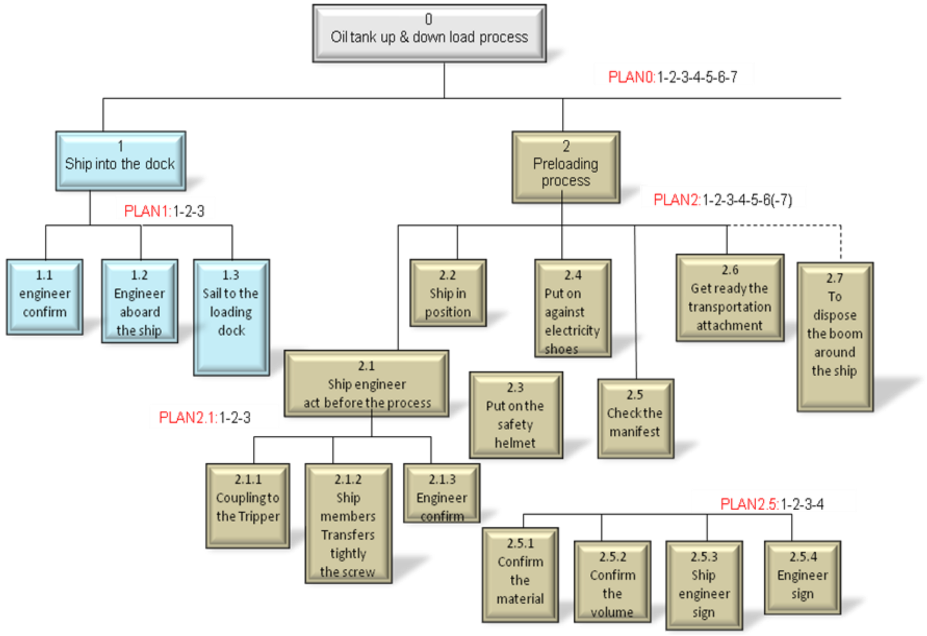

Table 2: error distribution of HERPA

The error code of the workers	Number of error	percentage
A4.act too low or too much	55	8.6%
A6.right action on the wrong event	10	1.6%
A7 wrong action on the right event	34	5.2%
A8 action omit	127	19.8%
A9 uncompleted action	56	8.7%
A10.wrong action on the wrong event	31	4.8%
C1 check omit	200	31.1%
C2 uncompleted check	80	12.4%
R1.miss information	23	3.6%
I1.information not pass	27	4.2%
Total	643	100%

Table 3: error model distribution of SHERPA

Error model code	number	percentage
Action Errors	313	49%
Checking Errors	280	44%
Selection Errors	23	3%
Retrieval Errors	27	4%
Communication Errors	0	0%
Total	643	100%

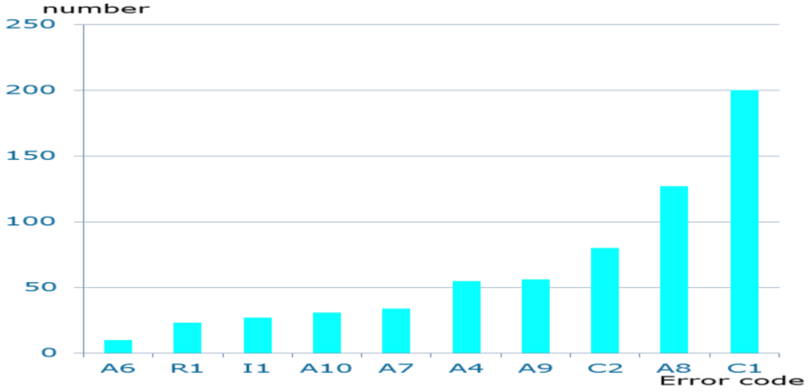

Figure 2: The numbers of the error type by HERPA

The result from SHEL model showed: The knowledge of the SOP helped the workers to do the correct action and the attitude of the workers led the negative relation in the operation. The organization helps the workers to get the knowledge, but it got negative relation to direct the workers operation. The hardware showed the negative relation to the workers. The behavior of some foreign ship members led the negative relate to the workers to accomplish the operation.

3. CONCLUSION

In the whole operation, it must be done by all kind of worker at the dock, including the ship pilot and the dock workers. To make sure the safety and prevent accident events and increase the human reliability there are some points have be noticed. At first the supervisor should remind the operator the correct action and, retrain the workers on a regular. And the hardware at the dock should be checked regularly of the applied and, some of the hardware should be upgrade to decrease the weak points.

Due to the international business, the operation must be done with foreign members, but when the members don't follow the rule should be the biggest problem in the operation. Our company should let the foreign company know the members done here to administer their members

4. ACKONOWLEDGE

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REFERENCES

[1] Yu-Hern Chang, Chung-Hsing Yeh （2010） Human performance interfaces in air traffic control *Applied Ergonomics* 41 (2010) 123–129.
[2] Annett, J. (2004). Hierarchical task analysis. In: Diaper, D., Stanton,N.A. (Eds.), The Handbook of Task Analysis for Human–Computer Interaction. Lawrence Erlbaum Associates, Mahwah, NJ, pp. 67–82.
[3] Bertolini, M. (2007). "Assessment of human reliability factors: A fuzzy cognitive maps approach." *International Journal of Industrial Ergonomics* **37**(5): 405-413.
[4] Christensen, J. M., Topmiller, D. A., & Gill, R. T. (1988). Human factors definitions revisited. Human Factors Society Bulletin, 31, 7-8.
[5] Lasala, K. P. (1998), Human Performance Reliability：A Historical Perspective, *IEEE Transactions on Reliability*, Vol. 47, No. 3, pp. 365-371.
[6] Ruckart, P. Z. and P. A. Burgess (2007). "Human error and time of occurrence in hazardous material events in mining and manufacturing." *Journal of Hazardous Materials* **142**(3): 747-753.
[7] B. Kirwan, S. Scannalit and L. Robinson (1996) a case study of a human reliability assessment for an existing nuclear power plant *Applied Ergonomics* Vol.27. No. 5. pp. 211~302. 1996.
[8] C. Baber and N.A. Stanton (1996), Human error identification techniques applied to public technology: predictions compared with observed use, *Journal of Apply Ergonomics, Vol*. 27, No. 2, and pp119-131.

EVALUATION OF ISOLATION EFFECTIVENESS DURING THE USE OF GLOVES IN JACKHAMMER OPERATING

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Abstract

The main purpose of this study was to measure the vibration in the dominant hand on subjects wearing four anti-vibration gloves in different force application scenarios using jackhammers. This study included 15 participants using 4 types of glove, two different force applications, and two griping techniques. The minimum vibration using the jackhammer was observed when lightly pushing and lightly griping while wearing gelfoam anti-vibration gloves. The maximum vibration was observed wearing cotton gloves and by pushing with a larger force while heavily griping the jackhammer. The study showed that, without impacting worker safety, lightly pushing and lightly griping while wearing gelfoam anti-vibration gloves offered the greatest reduction in vibratory force on the shoulder area joints. Therefore, the worker should apply the minimum necessary force the task demands.

Keywords*:* *Industrial hygiene, Occupational health, Hand-arm vibration, Anti-vibration gloves, Griping force*

1. INTRODUCTION

"Vibration" (or oscillation), we have associated with it every day, such as travel by vehicle, motorcycle, train or plane, etc., The vibration of vehicle body affect the whole human body, and symptoms include dizziness and uncomfortable. The local vibration, also known as hand-arm vibration, such as labor hands clenched hand power equipment, such as operating an electric drill, crushers, grinders, saws and etc. The shock wave is transmitted through the handle into the operator's hand arm system. Prolonged intensive exposure to vibration generated by powered hand tools may cause hand–arm vibration syndrome(HAVS) [1,2].The HAVS causes changes in sensory perception which can lead to permanent numbness of fingers, muscle weakness and, in some cases, bouts of white finger. It is caused by working with vibrating tools. When the symptoms occur, it is difficult to treat and rehabilitate. Although the relationship between such disorders and physical characteristics of vibration (frequency, magnitude and direction) is not yet known, it is generally agreed that onset of these disorders can be reduced through a reduction in magnitude of vibration transmitted to the hand. As an attempt to reduce the vibration transmitted to the hands, gloves are commonly used to protect hands from injury while operating a powered hand tool. Cotton and resilient materials gloves are two of the most common types of gloves used on industry. The results of gloves influencing the hand-transmitted vibration reported in published reports are varied. When operating a pneumatic chipping hammer, Goel and Rim [3] indicated that the use of leather, Poron padded and Sorbothane padded gloves, all reduce hand transmitted vibration as compared with the barehanded condition. On the other hand, the report of Gurram et al. [4] revealed that the gloves do not yield an effective attenuation of hand-transmitted vibration caused by hand-held powered tools. Upon recognizing the lack of uniformity in the measurement and assessment methods, the International Standard Organization (ISO) has established a laboratory test method to assess the anti-vibration performance of gloves [5]. The standardized test method requires the measurements under specific posture (forearm horizontal and parallel with the direction of vibration), and constant static grip (30±5N) and feed (50±8N) forces. The recommended test method, however, cannot predict the vibration isolation performance of gloves when used with a specific tool, since the vibration spectra of various hand-held power tools differ considerably from those of the idealized M- and H-spectra [6, 7]. It has been reported that variations in the arm posture and the gripping force affect the glove transmissibility only marginally [8], while the effects of feed force variations have not been reported. Owing to the dependency of the transmitted vibration on the handgrip and feed forces, the current study was conducted under controlled levels of both grip and push forces while operating jackhammers. Electric jackhammers that combines a hammer directly with a chisel, are usually used to break up rock, pavement, and concrete in industry.

2. MATERIALS AND METHODS

Owing to the complex nature of tool vibration and coupled hand-handle-glove system dynamics, the assessment methodology based upon either field or laboratory measurements would require repetitive measurements involving representative human subjects and test conditions under specific tool vibration spectra. Fifteen male student subjects from a local university participated in this experiment. None of the subjects had experience in using electric jackhammers, and none had a history of musculoskeletal injury in the dominant hand. Four types of gloves that are commonly used in industry were selected for evaluation and are shown in Fig.1. Three of the selected gloves were marketed as anti-vibration (AV) gloves. The other one was a cotton glove, which is often used to avoid bruising and abrading. Various sizes of each glove model were purchased in order to provide the best fitting gloves for each study participant.

To measure the griping force, the force sensor and data acquisition system manufactured by DATAQ Instruments (USA) was used. Thin film force sensors that have a 10 mm diameter pressure area were glued on tool handle. A spring scale with a sensitivity range of 0-36kg was fixed under jackhammer to control the push force. Tri-axial accelerations of hand-transmitted vibration were also measured by using the transducer with accelerometer (SEN026) having a sensitivity of 1 mV/(m/s^2). The accelerometer was attached on the adaptor which was held between tested glove and palm of the dominant hand. Measuring all three axes of vibration simultaneously, the IHVM 100 (Larson Davis Co., USA) automatically calculates the vector sum from the three channels of measured data. The instruments used in current study were shown in Fig. 2.

A balanced factorial experiment design, as employed in this study, contains three independent factors: glove (cotton, neoprene, natural rubber, gelfoam), grip force (1kg, 5kg), and push force (5kg, 15kg). Each subject was asked to perform tasks with sixteen different conditions: 4 gloves × 2 griping force × 2 pushing force. The experimental order was randomized, except wearing glove by the order of cotton, neoprene, natural rubber, and gelfoam. In each experiment, the subject was asked to trigger jackhammer and vertically push it down on the iron plate for duration of 30 seconds. After completing each experimental task, the subject rested for 5 min. The next glove or force levels were assigned for the subsequent tasks.

3. RESULTS

After statistical analysis software ANOVA for independent samples t-test, Table 1 summarizes the ANOVA results and reflects the significant effect of the independent variables (glove, grip force, and push force) on the dependent variables (hand-transmitted vibrations). The results showed that the use of various gloves had significant influence on hand-transmitted vibration in the sum of the 3-axes. The results shown indicate that when the vibration exposure due to handle acceleration with the cotton glove is considerably larger than that with the other gloves ($p<0.001$) under all four operating conditions. The isolation effectiveness of natural rubber glove is a little bit better than that of neoprene glove, but does not reach statistical significant difference. From above statistical results, the order of four kinds of glove in isolation performance from bottom to top is, cotton glove, neoprene glove, natural rubber glove, gelfoam glove, Except natural rubber gloves and neoprene gloves are no significant differences ($p>0.05$), all others comparisons show significant differences under four grip and push conditions.
As shown in Table 2, the statistical analysis of average sum of the three-axis vibration acceleration for four operation scenarios shows that there are no significant differences between two kinds of combinations, (1) light grip - heavy push and heavy grip - light push, (2) light grip - heavy push and heavy grip - heavy push; the other four kinds of combinations all achieve significant differences.
The results conform to Lu et al. [9] noted that the more force applied on tool handle, the more amount of vibration transmitted to the hand. Ho et al. [10] indicated that wearing proper gloves result in significant lower vibration exposure and the material damping capability results in Neoprene-SBR material is best among all tested materials. Japanese researchers, Sibat & Maed [11], who compared the use of general cotton gloves with foam damping gloves, indicated the damping capacity of anti-vibration glove was better than other types of cotton gloves, and the results of current study are also consistent with the findings of several studies.

a. b. c. d.

Figure 1: Picture of tested gloves: a. cotton; b. neoprene; c. natural rubber; d. gelfoam

a.

b.

c.

d.

e.

Figure 2: Picture of instruments: a. spring scale; b. data acquisition; c. film sensor; d. vibration monitor IHVM 100; e. measurement set-up

Table 1: Vibration and statistical results

		Cotton		Neoprene		Rubber		Gelfoam	
		Light grip	Heavy grip	Light grip	Heavy grip	Light grip	Heavy grip	Light grip	Heavy grip
Cotton	Light push	61.2 ±5.3	64.9 ±5.3	p<0.001*	p<0.001*	p<0.001*	p<0.001*	p<0.001*	p<0.001*
	Heavy push	68.1 ±5.7	70.5 ±6.2	p<0.001*	p<0.001*	p<0.001*	p<0.001*	p<0.001*	p<0.001*
Neoprene	Light push			43.1 ±3.5	47.1 ±6.5	p=0.585	p=0.261	p<0.001*	p<0.001*
	Heavy push			52.2 ±3.8	53.2 ±4.4	p=0.497	p=0.660	p<0.001*	p<0.001*
Rubber	Light push					43.9 ±3.5	49.3 ±3.9	p<0.001*	p<0.001*
	Heavy push					50.9 ±6.1	54.0 ±6.4	p<0.001*	p<0.001*
Gelfoam	Light push							32.0 ±4.2	35.8 ±4.8
	Heavy push							36.3 ±5.1	40.2 ±3.0

Table 2: Force combinations and vibration intensity correlation statistics

Force combinations	Vibration intensity	Significance
light grip - light push	45.0±11.3	
light grip - heavy push	51.9±12.5	.002*
light grip - light push	45.0±11.3	
grip grip - light push	49.3±11.6	.044*
light grip - light push	45.0±11.3	
heavy grip - heavy push	54.5±12.0	.000*
light grip - heavy push	51.9±12.5	
heavy grip - light push	49.3±11.6	.243
light grip - heavy push	51.9±12.5	
heavy grip - heavy push	54.5±12.0	.242
heavy grip - light push	49.3±11.6	
heavy grip - heavy push	54.5±12.0	.017*

4. CONCLUSION

The results of this investigation lead to the following conclusions: this study found that the reductions of vibration exposure due to AV gloves were more than those of the non-AV gloves (cotton glove). However, there was no substantial difference (<10%) between neoprene and natural rubber gloves. This suggests that the replacement of some regular work gloves (cotton) used at some workplaces with appropriately selected AV gloves greatly reduce the vibration exposure while operating a tool or machine. In addition, the gelfoam glove is the best among the tested gloves to isolate vibration. Without affecting the safety of operations, lightly griping and pushing operation of hand-arm provides vibration exposure reduction the best. In conclusion, wearing a gelfoam glove and applying a light force is recommended when using a jackhammer.

REFERENCES

[1] Griffin, M.J.: *Handbook of Human Vibration*, Academic Press, London, 1990.
[2] Pelmear, P.L. & Wasserman, D.E.: *Hand– Arm Vibration: A Comprehensive Guide for Occupational Health Professionals*, seconded, OEM Press, Beverly Farms, MA, 1998.
[3] Goel, V.K. & Rim, K.: Role of gloves in reducing vibration: an analysis for pneumatic chipping hammer. *American Industrial Hygiene Association Journal*, 48 (1987), 9-14.

[4] Gurram, R., Rakheja, S. & Gouw, G.J.: Vibration transmission characteristics of the human hand-arm and gloves. *International Journal of Industrial Ergonomics*, 13(1994), 217-234.
[5] ISO 10819, 1996. Mechanical vibration and shock －Hand-arm vibration －Method for the measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand. International Organization for Standardization, Geneva, Switzerland.
[6] Paddan, G.S. & Griffin, M.J.: Individual variability in the transmission of vibration through gloves. *Contemporary Ergonomics*, Taylor and Francis, London, 320–325, 1997.
[7] Griffin, M.J.: Evaluating the effectiveness of gloves in reducing hazards hand-transmitted vibration. *Occupational and Environment Medicine*, 55(1998), 340–348.
[8] Paddan, G.S.: Effect of grip force and arm posture on the transmission of vibration through gloves. *Proceedings of the UK Informal Group Meeting on Human Responses to Vibration*, September, MIRA, UK, 1996.
[9] Lu, S.Y., Chen, H.C. & Liu, Y.P.: Evaluation and reduction of hand-arm vibration on the use of air-driven tools in assembling, *Annual report of labor safety and health research*, Institute of Labor, Occupational Safety and Health, Taiwan, ROC, 2005.
[10]Ho, S.T. & Yu, H.S.: A study of europhysiological measurements and various function tests on workers occupationally exposed to vibration, *Int. Arch. Occup. Environ. Health*, 58(1986), 259-268.
[11]Shibat, N. & Maed, S.: Vibration-isolating Performance of Cotton Work Gloves Based on Newly Issued JIS T8114, *Industrial Health*, 46(2008), 477–483.

THE DIGITAL MICROSCOPY IN ORGAN TRANSPLANTATION: ERGONOMICS OF THE TELE-PATHOLOGICAL EVALUATION OF THE UTERUS GRAFT

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Abstract

The article searches the Ergonomics of Digital Microscopy (DM) based on virtual slide, in Telemedicine Systems (TS) for Tele-Pathological (TPE) and Tele-Cytological Evaluation (TCE) of the Uterus Graft (UG) in the Uterus Transplant (UT). Simulation of DM on TS for pre-grafting TCE and post-grafting TPE of UG on a total of 208 human (UG) tissues Digital Microscopic Images (DMI) by 2 specialists, for inflammatory and neoplastic lesions on four different Electronic Spaces (ES), is experimentally applied. Analysis showed that the DM on TS in UT is elaborated best on the ES of a Desktop, followed by a Lap-Top and a Tablet ($p<.001$).The DM on TS for TPE and TCE of UG in UT seems feasible while ergonomics depend on the type of the applied ES and on the mode of projection of DMI.

Keywords: *Uterus Transplant, Tele-Pathology, Tele-Cytology, Digital Microscopy, Virtual Slides.*

1. INTRODUCTION

Uterine transplant is used to treat uterine infertility. This is a common problem, there are thousands of women who need scientific assistance because of congenital absence of the uterus (Mayer-Rokitansky syndrome), surgical resection, or damage from abortions or infections. In several parts of the world, there is no realistic option for these women if they wish to have children [1].

A group from the University of Gothenburg led by Professors Brannstrom and Olausson has performed a clinical trial in 2013 for nine living donor related uterus transplants (UT) [1]. Since then the group announced the birth of two babies from two recipients respectively. On the other hand, considering that not only living donor related donation but also deceased donor donation may be a possible scenario of the future in UT and taking into consideration that Professor P. Friend referred that a high percentage of solid organs (8-14%) arrive at the recipient hospitals and are defined as injured or improper transplantation [2,3], ergonomics of Digital Microscopy (DM) in Telemedicine Systems (TS) for remote post-grafting Tele-Pathological (TPE) and pre-grafting Tele-Cytological (TCE) evaluation of the uterine graft (UG) in (UT), are examined.
Actually the (DM) adds significant information about the grafts (G) and enhances personalized medicine in Organ Transplantation (OT) leading to a significant change in their management [4]. Thus, DM may improve outcomes in the remote evaluation of the quality of the solid organs preventing damaged or diseased organs from being sent from the donor hospital (DH) to the recipient hospital (RH) and consequently reducing the possibility that diseased or damaged grafts arrive at the recipient hospital for implantation [3]. In technological terms, this is realized first by the replacement of the current fax and telephone based communication mode among coordinators, the coming - to the DN-grafting team and the -based in the RH- transplant team, with telemedicine systems (TS), integrated with Tele-pathology applying the Virtual Slide (VS) system [4].
Regarding UT in the procurement phase in the DH, the examined ergonomics of DM follows the already published clinical, technological and methodological principles. In clinical terms and referring to the proposed technology and methodology for remote evaluation of the quality of the UG, all criteria for who can donate a uterus should remain the same as other types of organ donations apart from some special testing, including Pap tests and Human Papilloma Virus test.
Other criteria include donors who are between the ages of 16 and 45, with no history of pelvic inflammatory disease, cervical dysplasia, endometriosis, ovarian cancer, or any other anatomical abnormalities. However, in case the donor is a living one the aforementioned detailed assessment is considered her past medical history, while in case of a deceased donor which include brain-dead, heart beating, multi-organ donors who in the future may be considered acceptable in UT, the aforementioned remote assessment is considered as a set of examinations.
However, in the present article we will focus only on the ergonomics of the remote evaluation of the graft from an uterus donor, referring to the remote: a. Histologic evaluation of the UG in case of a diagnosed lesion on it, after grafting and b. Cytological evaluation of the donor vaginal smear (Pap-test) before grafting, for diagnosis of inflammatory and/or cancerous diseases of the UG.

2. TECHNICAL REQUIREMENTS

A new architecture in the procurement phase of UT from a living or a deceased donor need to be built over tele-communication networks based on TS and be integrated with VS systems for digitalization and remote recognition of diseases of the UG on a microscopic level applying TPE and TCE, after and before grafting respetively in the DH. Also the donors' data have to be saved in the electronic medical record and be shared with the necessary digital images among the donor hospital, the coming grafting team and the transplant team. This has been proved to contribute significantly in the pre-grafting and the post-grafting remote evaluation of the grafts and in the pre-transplant preoperative planning [2,3,4,5,6].

In technological terms this includes a systematic and integrated communication method for determining appropriate assessment, intervention and a detailed, remote, personalized UG evaluation in the sequence of the coordination process by indicated histologic examination of the diseased or damaged lesions of the UG [3,4,5]. In addition and applying conclusions about the impact of DM (TPE) in the remote, personalized evaluation of the UG after grafting, it is examined the ergonomic impact of DM in the evaluation of the UG before grafting, by the remote evaluation of the Pap-test of the vagina of the living donor or of the one after brain death (DBD), applying Tele-Cytology (TCE).

By experimental simulation, we analyzed the value of the electronic space of TS in terms of the ergonomics of DM pre-grafting TCE and for post-grafting TPE of UG in deceased donor transplant scenarios, which in fact corresponded to the ergonomics of digital microscopy for TCE and TPE in UT by applying VS for digitalization of UG lesion sample tissue and vaginal Pap-smear stained anatomic sections for remote diagnosis of microscopic inflammatory or neoplastic lesions. Experimentation included: a. Development of an OTE-TS similar Experimental Telemedicine System (Exp.-TS), b.Integration of TS with the VS based microscopic TCE and TPE of UG applying DM. (Table I) [2,4,5,6,7], c. Simulation of TPE and TCE.

Table 1: Comparison of the Modules between the OTE-TS and the Exp.-TS.

MODULES	OTE-TS	Exp.-TS
a. Medical record process	+	+
b. Examinations results.	+	+
c. Capture scanning and imaging.	+	+
d. DICOM and PACS vision.	+	+
e. Real-time tele-conference	+	+
f. Chat and whiteboard facilities	+	+
g. Application sharing.	+	+
h. Tele-secretary facilities.	+	+
j. Tele-Mentoring facilities	+	+
k. Telecommunication net	ISDN based	Internet based
i. Virtual Slide integration	-	+

I. By simulating TPE of the UG diseased tissues by DM on TS for remote microscopic evaluation of the quality of the UG based on digital images taken by VS from uterus lesions of deceased simulating donors in UT, we found that the methodology and the design is feasible for the grafting and the implantation team to mutually and remotely evaluate UG tissues after retrieval and decide whether UG are worth being sent to the recipient hospital for implantation [11].Additionally it is proved that the electronic space of a Desktop seems to be the best option for remote microscopic visualization while the Exp.-TS seems comparable irrelatively to the disease. Microscopic visualization on the electronic space of tablets and mobile-phones, have high possibility to mislead examiners [11,12].

Simulation of the pre-grafting TCE and post-grafting TPE of the simulating UG for microscopic diagnosis of inflammatory or neoplastic lesions. DM on TS for TCE of UG between the Grafting Team in the Donor Hospital (DH) and the Transplant Team in the Recipient Hospital (RH) over integrated four different Electronic Spaces after digitalization of the anatomic sections by Virtual Slide: The pathologist locating in the RH accessed the donor's microscopic graft images captured by the VS (green image on the top in left) in the DH standard (yellow box and red/blue box in left behind the red wall). After remote microscopic TCE and TPE of the UG and notification of it in the electronic medical record of the donor, indications may be reset (Figure 1).

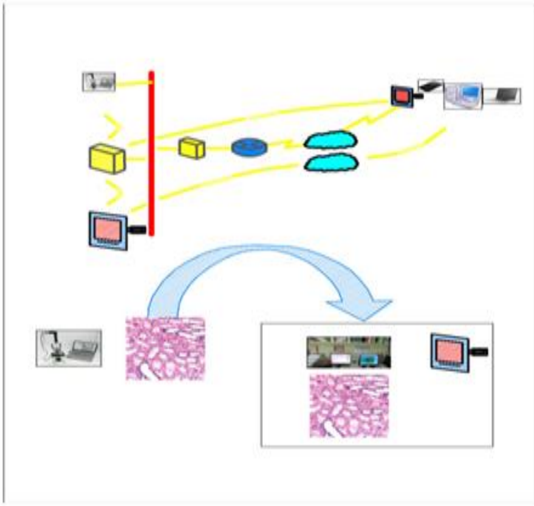

Figure 1: Simulation of the pre-grafting TCE and post-grafting TPE of the simulating UG for microscopic diagnosis of inflammatory or neoplastic lesions. DM on TS for TCE of UG between the Grafting Team in the Donor Hospital (DH) and the Transplant Team in the Recipient Hospital (RH) over integrated four different Electronic Spaces after digitalization of the anatomic sections by Virtual Slide: The pathologist locating in the RH accessed the donor's microscopic graft images captured by the VS (green image on the top in left) in the DH standard (yellow box and red/blue box in left behind the red wall).

Simulation of TPE of UG for microscopic inflammatory or neoplastic lesions, by two specialists based on the examination of two sets of digital microscopic images (N1=188 digital microscopic images in total that had been digitalized in the VS system stored in a way that contributed DICOM). Each set contained both normal and pathologic uterine tissue images respectively (inflammatory and/or neoplastic graft pathologies). The first examiner was the standard, and the diagnoses of the second were compared to those of the first for each digital microscopic image after projection, magnification and scrolling (microscopic virtual benching) on the electronic space of: A:the Desktop, B:the Exp.-TS, C:a Tablet and D:a Mobile phone (Figure 1.). The statistical analysis based on the answers of the second specialist examiner a. matched with the standard ones and b. based on his satisfaction level (ranging from the minimum -3,-2,-1, to the maximum

1,2,3 level) regarding the size of four suggested electronic spaces including the Exp.-TS. (A=Desktop, B=Exp.-TS, C=Tablet, D=Mobile Phone).

Analysis of TPE simulating data using SPSS (version 19.0) and applying the Wilcoxon-signed rank test for the comparison among the size of the four suggested TS electronic spaces (A,B,C,D) and the classification of answers of the examiner (ranged for each graft tissue microscopic digital photo: -3,-2,-1,0,1,2,3) showed that the examiner could define the microscopic inflammatory or neoplastic lesions on the electronic space of the four used TS, while comparisons of his answers analysis about the ability to diagnose accurately the diseased lesions of UG tissues on the electronic space among four TS (A,B,C,D) showed the following results (Table 2.).

Table 2: Simulated VS based TPE of the UG after retrieval based on the size of the four electronic spaces (A=Desktop, B=Exp.-TS, C=Tablet, D=Mobile Phone).

Lesion	N1	A vs B	A vs C	A vs D	B vs C	B vs D	C vs D	
A. Inflammation	94	<.001	<.001	<.001	<.001	<.001	<.001	P
B. Neoplasm	94	.002	<.001	<.001	<.001	<.001	<.001	p

Results proved that the ES of a mobile-phone (D) has the least ability to drive to the right microscopic remote diagnosis about the inflammatory and neoplastic lesions of UG in comparison to a Desktop (A) to the Exp.-TS (B) and to a Tablet (C). Also, the ES of a Tablet (C) has a significantly lower ability to drive to an accurate diagnosis in comparison to a Desktop (A) and to the Exp.-TS (B). The electronic space of the Exp.-TS (B) has significantly lower possibility to drive to the right diagnosis about inflammatory and neoplastic diseases of the UG tissue, in comparison to the Desktop (A).

II. On the other hand simulation of the pre-grafting TCE of the Pap-test of the vagina of the UG for remote microscopic examination of inflammatory and/or neoplastic lesions, by two specialists based on the examination of two sets of digital microscopic images digitalized in the VS system (N2=20 digital microscopic images in total stored in a way that contributed DICOM). Each set contained both normal and pathologic uterine tissue images respectively (inflammatory or pre-neoplastic graft pathologies).

The first spercialist cytologist examiner was the standard, and the diagnoses of the second one compared to those of the first examiner for each digital microscopic image after projection, magnification and scrolling (microscopic virtual benching) on the electronic space of: A:a Desktop, B:the Exp.-TS, C:a Tablet and of D:a Mobile phone (Figure 1.). The statistical analysis based on the answers of the second specialist examiner a. matched with the standard ones and b. based on his satisfaction level (ranging from the minimum -3,-2,-1, to the maximum 1,2,3) regarding the size of four suggested electronic spaces including the Exp.-TS. (A=Desktop, B=Exp.-TS, C=Tablet, D=Mobile Phone).

Analysis of TCE of the Pap-test simulating data using SPSS (version 19.0) and applying the Wilcoxon-signed rank test for the comparison among the size of the four suggested TS electronic spaces (A,B,C,D) and the classification of answers of the examiner (ranged for each graft tissue microscopic digital photo: -3,-2,-1,0,1,2,3) showed that the examiner could define the microscopic inflammatory or neoplastic lesions on the electronic space of the four used TS, while comparisons of his answers analysis about the ability to diagnose accurately the diseased lesions of UG tissues on the electronic space among four TS (A,B,C,D) showed an anexpected limitation in reliabiltiy (Table 3.). In fact the diagnosis was not possible to 5 out of the 20 examined digital pre-

grafting Pap-spear stained anatomic sections of the examined VS based UG digital images (Reliability of 75%).
The analysis of the rest 15 well diagnosed digital anatomic sections showed that the TCE of the UG depends also on the size of ES and on the type of the disease (inflammatory or pre-neoplastic) (Table 3.). Actually, in this case and taking into consideration the low reliability of the VS digitalization for TCE, the impact of the mobile phone (D) has the least ability to drive to the right remote microscopic diagnosis about inflammatory or pre-neoplastic lesions of UG vaginal Pap-smear in comparison to a Desktop (A), to the Exp.-TS (B) and to a Tablet (C) both in inflammatory and in pre-neoplastic lesions.
Also, the ES of a Tablet (C) has a significantly lower ability to drive to an accurate diagnosis in comparison to a Desktop (A) ($p<.001$) and to the Exp.-TS (B) ($p=.002$) (table 3.). Hence, only in the remote examination of inflammatory lesions the tablet (C) has a significantly lower possibility to drive to the right diagnosis in comparison to the Desktop (A).

Table 3: Simulated VS based TCE of the Pap-test of the vagina of the UG before retrieval based on the size of the four electronic spaces. (A=Desktop, B=Exp.-TS, C=Tablet, D=Mobile Phone).

Lesion	N2	**A vs B**	**A vs C**	**A vs D**	**B vs C**	**B vs D**	**C vs D**	
A. Inflammation	15	<.564	<.102	<.011	<.083	<.011	<.0017	P
B. Neoplasm	5	.046	<.001	<.001	<.008	<.002	<.001	p

It is a common place that if human factors engineering is not considered in the design of TS, the user needs and their existing problems are rarely identified and hence not properly addressed. Unfortunately, when this occurs, many computer systems in healthcare do not solve the problem or do not address the error in a usable manner. At best, the computer does nothing to eliminate errors. At worst, it introduces insidious new problems [8,9,10].
By simulating TPE by DM on TS for remote microscopic evaluation of the quality of the UG based on digital images taken by VS from deceased donors in UT, we found that the methodology and the design is feasible for the grafting and the implantation team to mutually and remotely evaluate neoplastic or inflammatory lesions found on UG tissues after retrieval and decide whether these particular UG are worth being sent to the recipient hospital for implantation [11].
Additionally it is proved that the ES of a Desktop seems to be the best option for remote microscopic visualization while the Exp.-TS and the Tablets seem comparable irrelatively to the disease or damage. However the microscopic visualization on the electronic space of mobile-phones, have high possibility to mislead examiners [11,12].
On the other hand simulation of the pre-grafting TCE of the Pap-test of the examined UG for microscopic inflammatory or neoplastic lesions, showed that DM on TS for TCE of UG based on automatic VS digitalization, is feasible with a low reliability of the level of 75% which is considered unacceptable for such a demanding process and prospective service [13].
It is a common place in ergonomics that explanations of errors rarely penetrate the true underlying causes [13,14,15] and the solutions have only a limited effect. For example, some usual solutions would be to increase the training of personnel or to introduce higher technology. However in this revolutionary and high standard process the fact that even highly trained professionals made mistakes during TCE of the donors’ UG, on the

high level of 25% of the samples of the examined Pap-test was taken seriously into consideration [16,17].

In addition we examined the low reliability of the VS digitalization based TCE of the vagina's Pap-test of the donors UG process, more as technological issue than a training problem of the examiners, given that they are considered of the highest level of cytologists in Greece. That is why a priority was given to change the visualization standards in pre-grafting TCE of UG so as to improve outcomes and built a reliable integrated service on TS for the remote pre-grafting and post-grafting evaluation of the UG for decision support and planning.

Thus, by shifting from VS based digitalization of the anatomic sections for microscopic remote visualization which realized the static tele-pathology requirements and methodology to the real-time one for TCE, by a trial on 22/10/2015 which simulated TCE in UT between ''Aretaieion'' University Hospital and ''Agios Savvas'' Anticancer Hospital, of Athens, we managed to up-grade diagnostic reliability of TCE in the pre-grafting remote evaluation of Pap-smear based anatomic sections of the UG vagina for about 25% i.e. a high reliability to the accepted level of 100% [13,16,17].

Among the limitations of the study is that analysis is based on a simulating experimental model and that is why new clinical simulation research protocols for TCE integrated with TPE of the UG in UT are being developed.

Regarding the future projects, our research in the ergonomics of TCE and TPE of the UG in UT has paved the path for further applications in other medical fields with high significance in UT and in the public health as well. Regarding organ transplantation TCE and TPE has been successfully applied on solid grafts from deceased and living donors. Thus, the proposed remote evaluation of the UG, is currently investigated with UT simulation experimental models, referring to the ergonomics of both living and deceased UG donors. In addition and in accordance with the aforementioned ergonomic findings, TCE of the vaginal smear may become the methodology of choice to increase the low number of women who undertake Pap-test for prevention of vaginal cancer in third world countries [17].

3. CONCLUSION

The simulating VS based TPE with DM of UG lesion tissues after retrieval, seems feasible and highly reliable, although dependable on the size of the ES of the applied TS for remote diagnosis and prevention of diseased or damaged UG from being sent from the DH to the RH and for post-grafting and pre-transplant planning. However, VS based visualization for pre-grafting TCE of UG for pre-grafting planning on TS, differs significantly compared to the referred TPE. TCE of the Pap-smear of the vagina of the UG is feasible, while VS digitalization for pre-grafting remote evaluation showed low reliability. DM on TS for remote pre-grafting TCE and post-grafting TPE of the donor's UG in UT seems feasible while ergonomics depend on the size of ES and on the type of the remotely examined digital microscopic images (static or dynamic).

REFERENCES

[1]Brännström, M.; Johannesson, L.; Bokström, H.; et al.: Livebirth after uterus transplantation, *Lancet,* **385.** (2015) 9968., 607.

[2]Friend, P.: Organization of organ retrieval-bitter lessons and ambitious plans, Available from http://vincentbourquin.files.wordpress.com/2010/11/friend-Hammersmith-11-10-10.pdf Accessed: 2012-07/17.

[3]Graham, AR; Bhattacharyya, AK; Scott, KM; et al.: Virtual slide tele-pathology for an academic teaching hospital surgical pathology quality assurance program, *Hum Pathol*. ,**40**. (2009) 8., 1129.

[4]Pantanowitz, L.; Valenstein, PN; Evans, AJ; et al.: Review of the current state of whole slide imaging in pathology, *J Pathol Inform*, **2** (2011) 36, 10.4103/2153-3539.83746

[5]Mammas,C. S.; Economou, G.P.; Arkadopoulos, N.; G. Kostopanagiotou, G.; et.al.: ELMP for TS in the coordination process as a method to optimize quality in organ transplantations, *Proceedings of the 16th Congress of the Hellenic Society of Organ Transplantation* , HSOT, Thessaloniki, 2011, 24.

[6]Mammas, CS; Mandellos, G.; Economou, G.P.; Lymberopoulos, D.: Structuring Expert-Leaded Medical Protocols for Telemedicine Systems, *Proceedings of the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, IEEE Constantinople, (2001), 3529-32.

[7]Karavatselou, E.; Economou, G.P.; Chassomeris, C.; Daneli, V.; Lymperopoulos, D.: OTE-TS-A new value-added telematics service for telemedicine applications, *IEEE Transactions on information technologies in biomedicine*, **5.** (2011) 3., 210-24.

[8]Morgan, R.H: Computer network security for the radiology enterprise Computer network, *Radiology* **220.** (2001) 2.,303.

[9]Furness, P.N.; Bamford, W.M.: Tele-pathology, *Curr Diag Pathol*, **7** (2001) 4., 281.

[10]Coiera, E.: *Guide to medical informatics*, *The Internet and Telemedicine CHM*, NY, (2007).

[11] Fónyad L.†; Krenács T.†; Nagy P.;† et al.:Validation of diagnostic accuracy using digital slides in routine histopathology, *Diagnostic Pathology*, **7** (2012) 1., 35.

[12] Ghaznavi, F.; Evans, A.; Madabhushi, A.; Feldman, M.: Digital imaging in pathology: whole-slide imaging and beyond, *Annual Review of Pathology: Mechanisms of Disease* **8.** (2013), 331.

[13] Romero, G.; William, L.; Andrew, C.: Digital Pathology Consultations—a New Era in Digital Imaging, Challenges and Practical Applications, *Journal of Digital Imaging*, **26.** (2013) 4., 667.

[14] Kothari, S.; Phan, H.; Stokes, T. H.; Wang, M. D.: Pathology imaging informatics for quantitative analysis of whole-slide images, *Journal of the American Medical Informatics Association* **20.** (2013) 6., 1099.

[15] Allen, T.C: Digital pathology and federalism, *Archives of pathology & laboratory medicine* **138.** (2014) 2., 162.

[16] Glassy, E.:Rebooting the pathology journal: learning in the age of digital pathology, *Archives of Pathology & Laboratory Medicine* **138** (2014) 6.,728.

[17] Mammas, CS.: The remote evaluation of pap-test applying tele-cytology in the context of uterus graft remote evaluation and in the remote prevention of vaginal cancer, Available from http://www.lib.uoa.gr/fileadmin/user_upload/I.K.Y_Papanikolaou.pdf, Accessed: 2015-04/11.

RETURN OF EXPERIENCE ABOUT THE INTEGRATION OF THE HUMAN FACTOR IN ENGINEERING PROJECTS. CONDITIONS FOR THE SUCCESS AND RESULTS EXAMPLES

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Abstract

The need for human factors specialists is now deeply rooted in most design processes. In order to achieve reliable, high-performance devices compatible with the Human Factors requirements, it is necessary to deploy the specific HFE methods, and cross the design criteria between the different specialists involved in the project.
We develop in this presentation what appears today fundamental to the success of project management from the point of view of Human Factor contributions. These principles will be shown through various steps and deliverables during project management. They will be illustrated with documentary extracts. We will take examples from a refurbishing project of a turbine producing nuclear energy, from the design of a full scale simulator for the supervision of a nuclear reactor, and from the renovation of a metallurgical plant.
We will take examples of results obtained in these various stages, showing how they are supported by the knowledge of the operating activity, how they meet the cost requirements, deadlines, the performance of the systems designed. we will develop several specific points about the forecast of the future working situation, by mock ups and simulations. The success conditions for the cooperation between HFE specialists and technical specialists are highlighted in this presentation.

Keywords*: Human Factors Engineering, project management; return of experience, cooperation Human Factor Specialists/other specialists*

1. INTRODUCTION

The Ergotec Team is composed of practitioners. We support many projects, carrying the human factors criteria in multi-skilled project teams. We don’t do research, but we use the developments realized by researchers, about the functioning of humans at work and the methods linked. The need for human factors specialists is now deeply rooted in most design processes.
In order to achieve reliable, high-performance devices compatible with the Human Factors requirements, it is necessary to deploy the specific HFE methods, and cross the design criteria between the different specialists involved in the project.
The HFE methods follow the well known steering ways, where different specialists are involved in the design team, in a funnel principle, detailed below [5].

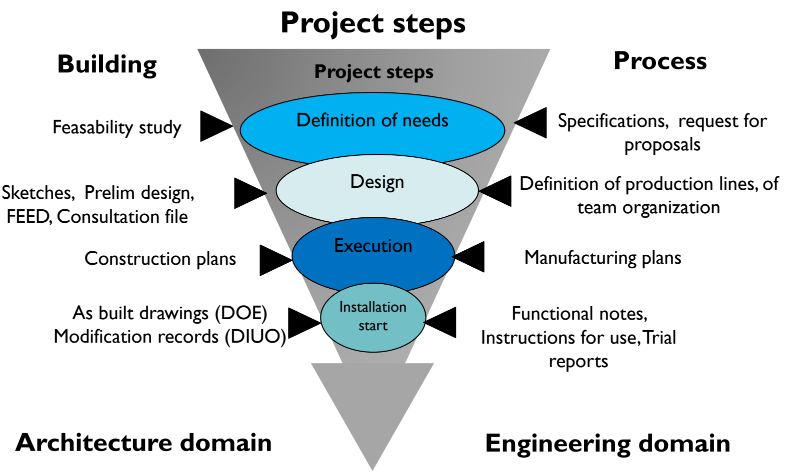

Figure 1: Project steps

The steering logic is detailed in several documents [1]; [2]:

- **Phase 1:** Definition of the needs: based on specifications and requests for proposals, the feasibility if the project is studied. The objectives for the human factors are defined in accordance with the operating experience feedbacks. A note heading "Operational experience" is recorded.
- **Phase 2:** Design: the definition of production lines and of team organization lead to the design of the project with sketches, preliminary design, FEED and contribution files. This phase contains the project organization, the work analysis in reference situations and the first evaluation of the design principles (current situation and synthesis of input data and hypotheses, technical specification of need, studies of preliminary definition and then detailed design, studies of safety, studies of support for the exploitation and for the maintenance, general layout followed by precise layout). Human factors deliverables as: FH integration plan, critical activity analysis, notes helping the owner's choice, notes of identification and follow-up of the FH requirements, are produced.
- **Phase 3:** Execution: realized with the combination of manufacturing and construction plans. The content of this part refers to: plans and documents done by different specialists, simulations or tests in real situations, evaluation of the design, reception and acceptance of the equipment. Notes as "Analyze and follow up of the trials" and "Contract holder document analysis" are produced.
- **Phase 4:** Integration and start of the equipment: functional notes, instructions for use and trial reports used with built drawings (DOE) and modification record (DIUP) allowed the project to be started. The final trials for the equipment (including FH trials) are realized and "analysis and follow up of the trials" note is produced.
- **Phase 5:** Use and exploitation: based on actual operational experience an "Operational experience" note is recorded.

An important success factor is linked to the team consistency and particularly to the concurrent engineering [4] method. But this is still not enough [3].

We develop in this presentation what appears today fundamental to the success of project management from the point of view of Human Factor contributions. These principles will be shown through various steps and deliverables during project management. They will be illustrated with documentary extracts. We will take examples from a refurbishing project of a turbine producing nuclear energy, from the design of a full scale simulator for the supervision of a nuclear reactor, and from the renovation of a metallurgical plant.

2. STEERING METHODS FOR MANAGING HFE IN LARGE PROJECTS

We don't discuss the whole project methodology in this communication; we preferred to focus on the points leading to the success in a project. To give a general overview of a large project in which we were involved, here is below a representation of a project and its steps.

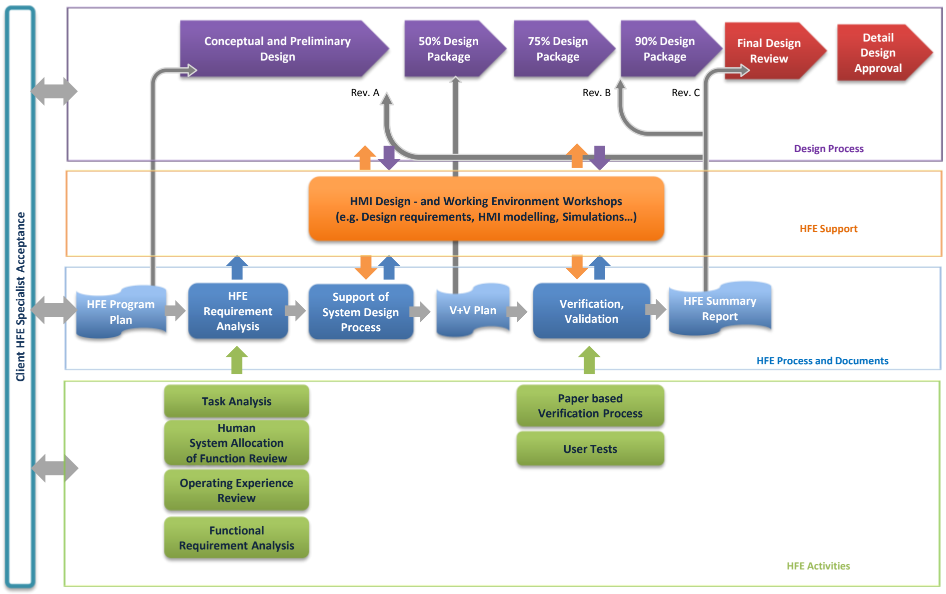

Figure 2: Overview of full project steps

The steps as well as the important points are summarized in the following table.

Table 1: Steps and steering methods for managing HFE in projects

Step/project deliverable	Condition for success / results
Before starting the project, the HFEPP (Human Factor Engineering Project Plan). This is the action plan that shows the overall organization of the project, the integration of the HFE specialist into the technical team, the methods and deliverables. It also determines the HFE HFEPP deliverables all along the project	The HFEPP must be keyed to the project deadlines and to other specialists' requirements. Indeed, it is useless to produce specifications related to HFE when other experts have frozen their design. Before starting, milestones are always approximate. Throughout the advancement, it is necessary to review these milestones and synchronize the productions of all specialists
When starting the project, the HFE training. It serves to share with the entire design team the ins and outs of the HFE approach. This is an expectation described in the methods for the Human Factor (Ex. NUREG) ; it is the first thing to do in the team, at the start up of the work	HFE remains a strange subject for technical specialists. Training, even a short session, if practical, with examples, will enlighten the whole design team on what the field of human factor can bring them. Additionally, they will understand the HFE specialists' information needs. It is a strong prerequisite for the proper subsequent operation of the team. At the same time, the HFE team will identify the information needs of other specialists, as well as their representation of the project (what the outcome should be)
Before design, The OPEX. It gathers information about the current experience of maintenance and production. The methods are documentation analysis, interviews with the future users, and observations of their work	Knowledge of work practices is crucial to the development of specifications. It can be data collected in the target situation, or reference situations. The importance of this OPEX is due to the fact that labor situations always have a hidden side; No one can foresee everything about what happens in working situations, and the certainty is that operators adapt to what they encounter. Knowledge of these adaptations can both accelerate the design process and increase the relevance of this design. These analyses are also an opportunity to establish the participation of operators through user groups. The mobilization of operators is one of the important points in the project's success
Throughout the design, the task analysis. It consists in a description of what operators will do during the different steps of the future task. This task analysis supports the assessments using the HFE guidelines	The knowledge of the different operations, step by step, allows to identify precisely what the operator or team has to do, the means to be used, the associated risks. The OPEX information is injected into this formalization, and the HFE guidelines are used to foresee the effects of changes and innovations

Step/project deliverable	Condition for success / results
The HFEVVP is done in parallel to the previous work. It shows how the design choices are validated, by two main methods : the use of the field guidelines at the beginning, then by user testing	Throughout the specifications, we must demonstrate that they are compliant with human functioning, and if there are risks, we must expose them and show what countermeasures will be implemented. For this, the first stage is the "paper" proof. The second stage is carried by the user testing. The test protocols have to be designed, carried out, and their results analyzed. The two-step organization saves time and energy: the documentary-based demonstration makes at least some of the weaknesses in the design obvious and leads to efficient mitigations. Before the user testing, a set of deviations have already been eliminated. This ensures minimal feasibility tests at the time they are performed. Then, the tests are the final way of demonstration. The success or failure for established tests are plotted, the sessions are recorded with the agreement of the participants Etc…
The HFE workgroup report gathers the results of user testing	Most often, for these tests, we have to create mock ups, because the equipment is not at the manufacturing stage yet, and there is usually no prototype. Here is required the most rigorous methods; it determines the usability of the results. These results still show aspects of the design to be changed; after prioritizing the points, the project team must provide feasible solutions. At this stage, the constraint is related to the significant progress of the project: leeway is reduced. But there are always solutions, technical, organizational or procedural
At the end of the project, the HFESR gathers all the HFE steps and results. It includes detailed specifications, mitigations, standards compliance.	This document leads the overall design for the owner. Throughout the project progression, successive versions are provided to the owner, who can then express his point of view, manage the design on the basis of his knowledge of the system and his expectations.

During the presentation, we will take examples of results obtained in these various stages, showing how they are supported by the knowledge of the operating activity, how they meet the cost requirements, deadlines, the performance of the systems designed.

2.1. Example 1: Task analysis documentation

The picture below shows an extract of a task analysis, for maintenance operators. This kind of result supports the design analysis for new equipment and systems

Task description	Steps	Means	Physical/Cognitive/ Communication Requirements	Potential issues	Consequences	Comments
Prepare the maintenance	Prejob briefing Prepare the tools, documentation Get the key to open the panel doors	Meeting between operating staff and maintenance staff	Knowledge of all the means that have to be prepared	Hazards and protective means not identified	Depends on the maintenance task and impact on the process	
Get the parts if necessary	Get the part reference and pick it from the store	Order slip	Legibility of part references	Wrong reference	Wrong part	
Secure the operation	Lock out the component Lock out the power supply	Key and lock for the lock out/tag out OMM	N/A	N/A	N/A	The actions to be done will be listed in the OMM

Figure 3: Example for a task analysis representation

2.2. Example 2: Recommendations documentation

The picture below shows an extract of some recommendations. This documentation allows the tracking of the different issues all along the project.

Reference	Identified point	HFE requirement
HFER-001	A crouching posture is required to access the fans of the excitation room: i.e. there is not enough space to work (between the ceiling and the fan)	Facilitate the access for the fan replacement and maintenance
HFER-002	The risk of dropping tools in the cabinet during Fan & motor replacement (space, access): the removal of the fan leaves a hole in which tools/components can fall (screwdriver, screws around 10 mm diameter), inside the cabinet. The technicians are not authorised to go inside the cabinet and grab them so they have to wait for a shut-down.	The new fans and other equipment should be installed taking in account the risk of dropping tools inside the cabinet for MM technicians : facilitate mechanical components removal from outside the cabinets and stop components falling inside the cabinet
HFER-003	Lighting above the fan is inadequate	Ensure the lighting is adequate next to the fan
HFER-004	Bolts access with torque wrench at the back of cubicles	Improve access for torque wrench at the back of cubicles
HFER-005	Bus access at the bottom of cubicles	Improve access to buses
HFER-006	DC bars access on top of the cubicle (too high)	Improve access to DC bars
HFER-007	Lighting for checks and maintenance in cabinets	Provide adequate lighting inside the cabinets

Figure 4: Example for the recommendations and their traceability

2.3. Example 3: mitigation on an Human Machine Interface

The picture below shows a mockup of an HMI. It has been amended to keep the principles of the HFE process only

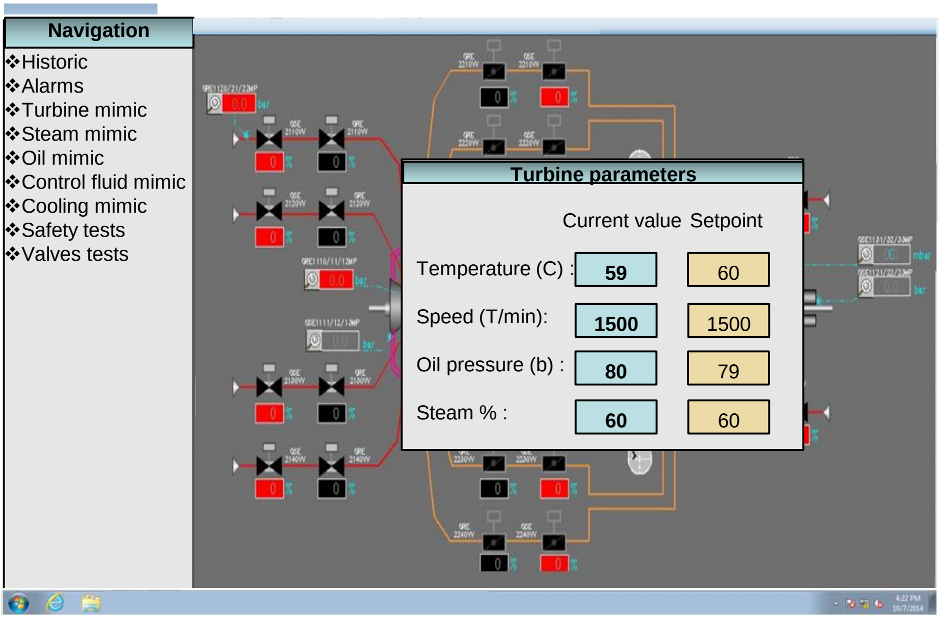

Figure 5: Example for the realization of a mockup

The HFE identified problem was that the parameter setting was very short. The user clics on the area, types the value, key “Enter”, and it’s done. It could directly impact the turbine speed with a wrong value, and huge risks.
We all saw this kind of problem during our experience; it has become a commonplace. Finding a solution with the technical team is less a commonplace. It has to be included in a rigorous process.

3. CONCLUSION

In conclusion, we will underline the need to train young practitioners on methods of project management in engineering. Specifically, a set of Human Factor specialists now uses very well articulated steering methods with those of technical engineering . These methods are very efficient, and were assembled from national and international repositories.
If graduates have good knowledge and methodologies about human functioning, they lack preparation for this integration in large projects. This level of knowledge is currently communicated through practice, between specialists working on the same project. The need for Human Factors Specialists becomes stronger, and our suggestion is to integrate the HFE project managing domain in university training programs. As far as we know, this has not been yet developed.

REFERENCES

[1] J. M. O'Hara, J. C. Higgins, S. A. Fleger, P. A. Pieringer, *Human Factors Engineering Program Review Model,* Office of Nuclear Regulatory Research, Nureg-711 rev 3; 2012

[2] J. C. Higgin, J. M. O'Hara, P. M. Lewis, J. J. Persensky, J. P. Bongarra, S. E., Cooper, G. W. Parry, *Guidance for the Review of Changes to Human Actions*, Division of Inspection Program Management Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, NUREG 1764, 2004

[3] Flore Barcellini, Laurent Van Belleghem, François Daniellou, *Les projets de conception comme opportunité de développement des activités,* In Falzon, P. (coord.) Ergonomie constructive. Paris PUF, 2013

[4] Pierre Leclair, Pascale Bossard, Claude Chanchevrier ; INGENIERIE CONCOURANTE. De la technique au social ; Ed Economica ; 1997

[5] INRS- ED 950 - ; Conception des lieux et des situations de travail- Santé et sécurité : démarches, méthodes et connaissances techniques- 2006

QUALITY OF LIFE OF NURSES WORKING IN INDIAN HOSPITALS

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Abstract

Healthcare is one of India's largest and rapidly expanding sectors, in terms of revenue generation and employment. Yet, health caregivers like nurses are themselves stressed from their occupation. Very little is known about the impact of physical, psychological, social relationships and environmental domain on quality of life (QoL) amongst nurses in India. A cross-sectional study to assess the location-wise, designation-wise, age-wise ward-wise comparison of QoL of nurses working in private hospitals was done. 650 female participants were interviewed on a one to one basis. QoL was evaluated using WHOQoL-BREF Questionnaire. Among various domains of QoL, highest mean score (68.14) was found for the 'social relationship' domain. The lowest score was found in the 'environmental' domain (61.7). Nurses from non-metro cities were found to have an inferior QoL and low monthly income compared to nurses from metro cities. Staff nurses had an inferior QoL than nursing in-charges. Total QoL score was comparable among nurses from different wards, however, ICU nurses scored highest in social relationship domain. The findings revealed that nurses working in Indian private hospitals have moderate levels of QoL.

Keywords: *quality of life, nurses*

1. INTRODUCTION

As the Indian economy heads towards a double-digit growth, women have surpassed men in terms of employment growth rate with a 3.35 % rise in employment between 2000 and 2010 as against a fall of about 8 % in case of men according to a study by the Associated Chambers of Commerce and Industry (ASSOCHAM) - Women Employment Growth Rate and Gender Budgeting (Indo-Asian News Service, 2007).
Statistics from scientific studies reveal that women bear the brunt of duties associated with childcare and eldercare and are responsible for the majority of the household chores (The National Union of Public and General Employees)[12]. It is therefore not surprising that much of the findings include widespread and well-expressed concerns for the double burden of women at work and at home [1], [8]. However, there is a general perception that women's occupational health issues are understudied, despite the enormous magnitude of the problem, especially in the developing countries where such issues are perhaps more prevalent [25].
Stressful conditions at workplace and family may lead to detrimental changes at physical, psychological, and social levels. These changes may precipitate health related problems like depression, anxiety, sleep disorders, and stress [7]. Subsequent studies have shown an association between stress and quality of life (QoL) [3], [21].

It is noteworthy that a substantial fraction of the working women are involved in the healthcare industry, which is a challenging and demanding domain in the current scenario. Healthcare is one of India's largest and rapidly expanding sectors, in terms of revenue and employment. According to Technopark Advisors, India Healthcare Trends (2008), healthcare, which is now a US$ 35 billion industry in India, is expected to reach over US$ 150 billion by 2017. In India, hospitals and nursing homes contribute 49% of the Indian healthcare delivery. According to a report of National Health profile (2013), more than 1.5 million healthcare workers are engaged in this sector (including auxiliary midwives and general nurse midwives), and their numbers have increased from a modest 1650 in 1951 to the present level, that is about 100 times increase in number of nursing employees.

Doctors and nurses are an extremely important part of healthcare team [5], [6]. In India, nursing is traditionally thought of as a female profession, therefore, is mostly pursued by women. Nurses perform wide range of activities, and are usually responsible for implementation of the care plan the doctor sets up for the patient. They are trained for variety of the skills ranging from administering medication and monitoring side effects, caring for patients continuously, 24 hours a day, to help the patients to do what they would do for themselves if they could. Nurses also coordinate the work of all the team members and sees that the patient caring plan is carried out effectively. The occupational stress in hospital environments, particularly intensive care units (ICUs) and emergency departments has been increasingly discussed considering its negative impact on quality of life of healthcare workers. For instance, Cavalheiro *et al.* (2008) found that ICU and hospice nurses differed in terms of frequency and sources of job stress from medical and surgical nurses. Their findings indicated that death and dying situations were the most stressful to the former groups, with work overload and staffing situations proving the most stressful to medical and surgical nurses [9].

Working in shifts has become very common and essential to fulfill the job demand of nurses. Shift work refers to work patterns that extend beyond the conventional 8-hour work day and that potentially disrupt workers' normal biological and/or social diurnal rhythms [15].

Stress research among nurses has revealed that the job stress in the nursing profession has been a persistent global problem for many years now. The variety of the roles that are being carried out by the nurses along with their odd working hours (in shifts) lead to the higher levels of perceived stress which has been found to be associated with decreased job satisfaction, increased psychological and physical complaints [11]. However, consolidated research data in the Indian context seems to be lacking.

With the average life expectancy of Indian women having increased during the last decade (from 63.13 to 71.9 [from 2000 to 2007]) (Central Intelligence Agency, World Fact book, 2009), women nowadays get to live a substantial part of their lives after menopause. With the advancement of the age and during menopause, women experience number of biological changes and their long and short term effects. Women go through a lot of anxiety, tension, worry, emotional suppression, and a lot of physical and mental stress, before and during menopause, even if they are aware of its eventuality. Due to these changes during and after menopause, post-menopausal women are characterized by several features that make them susceptible to risk of obesity, diabetes, hypertension, sympathetic activation and cardiovascular diseases and mood disorders [19], [13], [4]. It has been documented that with the commencement of menopause, apart from the above mentioned inconveniences, females suffer more from musculoskeletal and rheumatic complaints than men [24], [20]. In this way for

perimenopausal and post-menopausal women menopause may count up stress effects and MSDs due to work.
With this background, it is apparent that occupational stress, burnout not only affects individual but it involves his efficiency, dissatisfaction and absenteeism, in turn causes an influence on the productivity and economy of organization. It is therefore important and justified to provide all significant measures that may ameliorate QoL for all women of healthcare sector expecting a prolonged life. Therefore, this study was taken up to determine the QoL of nurses working in hospitals of India. The study was undertaken with the following aims: (i) To ascertain effects of age and experience on QoL amongst nurses and nursing-in charges of hospitals (ii) To determine effect of location (metro/non-metro) of hospital QoL amongst nurses in India (iii) Ward-wise comparison of the QoL amongst Indian nurses.

1.1. Quality of Life (QoL)

The World Health Organization defines QoL as the "individual's perception of his / her position in life in the context of the culture and value systems in which the person lives and in relation to the goals, expectations, standards and concerns". The group working on the WHOQoL instrument saw QoL as 'a broad ranging concept affected in a complex way by the person's physical health, psychological state, level of independence, social relationships and their relationship to salient features of their environment' (WHOQoL group, 1995).
QoL is an organizing concept, a construct that can be used as a guide to its users [23]. QoL is computed from different angles in the various scientific disciplines, most of all in philosophy, psychology, medicine, sociology and economics [22], [23], [2]. In the philosophical parlance one can choose to understand the term 'QoL', as a pure "term of value" [2]. QoL, from a philosophical standpoint is said to be the "good life" or broaches on existential questions. In simple words, it can be explained in the way that a person's QoL is high if and only if he / she has a good life, and if the QoL is low then the person has a bad life. A high QoL does not imply a higher moral life style or a more aesthetically attractive life but indicates that the person in question feels good and lives a life which is good for her and finds the life worth living. In psychology, QoL is related to mental states which recently have gone over to being described in terms of psychological well-being [14]. In sociology, QoL is included as part of concept of welfare and in economics science, QoL is connected to the GDP product e.g. in order to measure the distribution of a population's prosperity [14]. In medical science, QoL and objective and/or subjective health are connected, which is expressed as "health-related QoL" (HRQoL) [23].

2. METHODOLOGY

2.1. Study design

The present research work was a cross-sectional study. Random sampling of population was undertaken to remove any bias. Participants responded to the survey and interviewed on a one to one basis. Data was collected during different days and shifts over a 7-month period, all the volunteers from nine hospitals were asked to respond to a set of the questionnaires, according to a schedule that was prepared through coordination between researchers and hospital supervisors. These hospitals were selected from metro and non-metro cities to check if location of the hospitals has any impact on these variables.

2.2. Selection of organizations for study

Four hospitals from Mumbai (metro city) and five hospitals from Indore, Bhopal, Sagar (non-metro cities) have been selected for the study. The study examined the extent to which different factors influenced QoL of nurses in these nine hospitals. Total 1020 sets of structured questionnaires were distributed out of which 820 sets were obtained of which 650 completed sets were used for statistical analysis. On an average, respondents took 30 minutes to complete set of questionnaire. Sample collected was assembled according to classification of wards in the hospitals: (i) Medical/Surgical (ii) Intensive Care Unit (ICU) (iii) Pediatric (iv) Other.

2.3. Sampling of the respondents

Convenient sampling method was used to select 650 nurses as respondents of the study. The eligibility criterions for participants were the following: (i) Every volunteer must have been working as a nurse/nursing-in charge in her current job for at least 1 year (ii) All volunteers were non-smokers to be included in the study (iii) They were not under any medication, including vitamins, antioxidants or mineral supplements, contraceptive pills or hormone replacement therapy. After understanding all the procedure involved in the study the consent was given by all volunteers by signing a 'singed informed consent'. The sample was categorized using following criteria: (A) Designation wise: Nurses and Nursing-in charges (B) Age wise: <35 and ≥ 35 (C) City wise: Metro (Mumbai) and Non-metro (Indore, Bhopal, Sagar) (D) Ward-wise.

2.4. Procedure and Measures

The volunteers were briefed about the procedures involved and instructed about the manner in which the questionnaire was required to be filled up. The volunteers were encouraged to ask questions about the testing prior to giving their consent. The corporal data involving the stature and the body weight was assessed by a stadiometer (Holtain) and a portable weighing machine (Avery, India), respectively. The decimal age was calculated from the date of birth of the volunteers. The body mass index was computed using standard equations (ACSM Manual, 2008). The QoL was computed using the World Health Organization's "QoL Questionnaire" (WHOQoL-BREF). The validated version of the World Health Organization QoL-Brief Version (WHOQoL-BREF) is a 26-item version of the 100-item instrument of the World Health Organization QoL (WHOQoL- 100) that was developed to provide a short form QoL assessment concerned with the meaning of different aspects of life to the respondents, and how satisfactory or otherwise their experiences have been with these factors. It is a self-reported questionnaire containing four domains namely physical health (7 items), psychological status (6 items), social relationships (3 items) and environmental conditions (8 items). Domain scores in this questionnaire were scaled in the positive direction, i.e. a higher score denotes a higher QoL. Reliability coefficient for 24 items was found to be 0.86. Cronbach's alpha for 'physical' domain was 0.7, 'psychological' domain was 0.62, 'social relationship' domain was 0.54 and 'environmental' domain was 0.74. The scale has been found to have good validity and validity has also been determined in Indian population.

3. RESULTS

Data has been analyzed using SPSS Statistics 20 software. The level of significance was set at 0.05.Descriptive statistics was used to calculate mean and standard deviation of all demographic variables used in the study. All of the study participants were female with mean age 26.73 and mean BMI 20.93. Ninety-nine percent of respondents were graduate and one percent were postgraduates (Tables 1 and 2).

Table 1. Demographic details of sample (N=650)

Demographic detail	Minimum	Maximum	Mean	Std. Deviation (±)
Decimal Age (Years)	20.01	61.49	26.73	6.96
Height (cm)	139.70	170.18	156.8	6.26
Weight (Kg)	34.00	80.00	51.37	8.36
BMI (Kg/m^2)	13.66	35.09	20.93	3.28
Income (INR)	4,000	35,000	10,210.51	4,086.47
Work Experience (Years)	1.0	33.0	4.4	3.8
Working Hours	48	72	51.58	8.56

Table 2. Demographic details of sample

Demographic detail	Classification	N=650 n (%)
Marital Status	Married	183 (28.2)
	Unmarried	467 (71.8)
Qualification	Graduate	643 (98.9)
	Postgraduate	7 (1.1)

Table 3. QoL score of respondents

Domains	Mean (SD)
Physical health domain	65.95 (12.76)
Psychological domain	66.28 (12.92)
Social relationship domain	68.14 (14.47)
Environmental	61.68 (14.13)
Total QoL	261.75 (42.98)

3.1. Quality of life score of the respondents

The mean scores in the four domains of QoL of the volunteers were determined using WHOQoL-BREF questionnaire (Table 3). As to the WHOQoL-BREF questionnaire, of the 26 questions answered by each nurse, only 24 items were necessary for the QoL assessment. These 24 questions were grouped into four domains and the results were synthesized, by applying equations that determine the raw scores (RS), which were further transformed into transformed scores (TS). The maximum and minimum values of the RS possible to be determined in each domain were as follows: domain I – physical, which may have a RS between 7 and 35; domain II – psychological, between 6 and 30; domain III – social, may vary between 5 and 15; and finally, domain IV – environment that may vary between 8 and 40. In reference to the TS, these suffered no

variation in possibly identifiable values; the TS 4-20 remained between 4 and 20 for all domains and the TS 0-100 remained between 0 and 100.
As to QoL, the ‘social relationship’ domain obtained the highest score, while the ‘environmental’ domain had the lowest score (Table 3). The score in each domain was further categorized using percentile method, wherein a score of 25 percentile or below was considered as ‘poor’; one between 25 percentile and 75 percentile was considered as ‘medium’; that of 75 percentile or above was taken as ‘high’ [17]. Highest mean score (68.14) among all QoL domains was found to be for ‘social relationship’ domain. 4% of the respondent had ‘poor’ category of QoL for ‘environmental domain’, highest percent (78%) of respondents fell under “medium” category for ‘environmental’ domain and highest percent (41%) of respondents fell under “good” category for ‘psychological’ domain (Table 4).

Table 4. QoL rating of respondents

	Poor (%)	**Medium (%)**	**Good (%)**
Physical health domain	0	71	29
Psychological domain	0	70	30
Social domain	1	58	41
Environmental	4	78	18
Total QoL	0	82	18

3.2. Comparison of QoL of nurses among different locations

A comparison of QoL amongst nurses from metro cities and nurses from non-metro cities revealed that mean scores for ‘physical health’ domain, ‘social relationship’ domain, ‘environmental domain’ and overall QoL were significantly ($p<0.01$) higher in nurses from metro cities than that of nurses from non-metro cities (Table 5). Monthly income of nurses from metro cities was found to be significantly higher than that of their non-metro counterparts.

Table 5. Mean (± SD) of domains of QoL amongst the two groups

City	**n**	**Domain I Physical health**	**Domain II Psychological**	**Domain III Social relationships**	**Domain IV Environmental**	**Total QoL**	**Monthly Income (INR)**
Metro	356	68.82±13.43	66.40±12.66	69.53±13.95	63.89±13.07	268.26±42.52	11,037.72± 2947.14
Non-metro	294	62.47±11.49	62.47±11.49	66.28±14.91	59.01±14.91	253.88±42.29	9,208.84± 4962.60
p-value		0.000	0.783	0.004	0.000	0.000	0.000

3.3 Comparison of QoL between staff nurses and nursing in-charges

Independent t-test for the QoL scores of two groups depicted that nursing in-charges scored significantly higher in total QoL and ‘environmental’ domain (<0.05 and p=0.001 respectively) when compared with staff nurses, whereas no significant difference was found in other domains (Table 6).

Table 6. Mean (± SD) of domains of QoL amongst staff nurses and nursing in-**charges**

Designation	N	Domain I Physical health	Domain II Psychological	Domain III Social relationships	Domain IV Environmental	Total QoL
Staff nurse	607	65.75±12.82	66.28±13.01	67.81±14.43	61.21±14.27	260.83±43.25
Nursing in-charge	43	68.77±11.61	66.16±11.72	71.51±14.86	68.32±9.87	274.77±37.10
p-value		0.134	0.953	0.105	0.001	0.040

3.4. Comparison of QoL among different age groups

Nurses scored better in 'environmental' domain with advancement of age (Table 7). Two tailed t-test for QoL between age groups (<35, ≥35) showed that significant difference between these age groups was found only for 'environmental' domain. The 'environmental' domain score was significantly higher (p<0.04) in nurses of age group '>35 years' than in nurses of age group '<35 years'. Though not significant, higher score for total QoL was also found in women '≥35 years' age group (Table 7).

Table 7. Means (SD) of scores of QoL domains of nurses in two age groups

Age groups	N	Domain I Physical health	Domain II Psychological	Domain III Social relationships	Domain IV Environmental	Total QoL
<35	531	65.63±12.66	66.34±13.04	67.79±14.36	61.29±14.25	260.81±43.04
≥35	119	68.49±13.29	65.75±11.98	70.13±15.25	64.79±12.81	269.18±38.93
pvalue		0.07	0.71	0.19	0.04	0.11

3.5. Comparison of QoL among different wards

One-way ANOVA depicted that a significance difference (p<0.05) was found between wards for 'social relationship' domain (Table 8). Surprisingly, mean score for social relationship domain was found to be highest in ICU ward and minimum score was found in pediatric ward. Fischer's LSD post hoc test revealed that social relationship domain score was significantly higher in ICU than pediatric ward (Table 8). There was no significance difference between wards for psychological and environmental domain.

Table 8. Means (SD) of scores of QoL domains of nurses from different wards

SN	Wards	n	Domain I Physical health	Domain II Psychological	Domain III Social relationships	Domain IV Environmental	Total QoL
1	**Medical /Surgical**	418	65.62±12.53	65.58±12.89	67.4±14.78	61.67±13.71	260.28±42.8
2	**Pediatric**	32	66.56±10.45	67.03±12	65.5±14.03	62.63±13.60	261.72±37.44
3	**ICU**	105	67.76±17.89	68.41±12.35	72.43±12.14	62.04±14.42	270.64±40.15
4	**Other**	95	65.19±13.80	66.71±13.86	66.96±14.92	61.96±7.64	258.45±47.70

4. DISCUSSION

In the present study concerning QoL, the 'social relationship' domain scored highest which evaluates personal relationships, social support, and sexual activity facets.

Lowest score was found in the 'environmental' domain. Environmental domain measures influence of factors like financial resources, freedom, physical safety and security, health and social care: accessibility and quality, home environment, opportunities for acquiring new information and skills, participation in and opportunities for recreation / leisure activities, physical environment (pollution / noise / traffic / climate) transport. Poor score of environmental domain may be because of low opportunities for recreation and leisure activities and high level of exposure to many contagious diseases in hospital. These findings were similar as finding of the study by [18], on nursing technician and nursing assistant, wherein 'environmental' domain scored lowest and 'social relationship' domain obtained highest score.

An attempt was made to compare the QoL of nurses from metro and non-metro cities. The study revealed a significantly higher score for total QoL in nurses from metro cities than their non-metro counterparts [16]. Nurses from metro cities had better QoL in terms of 'physical health, 'social relationship' and 'environmental' facets. The higher score of these facets of QoL in nurses from metro cities may be related to the fact that the hospitals in these cities are large private enterprises with a qualified modern structure, that offers its employees some benefits, such as a healthcare plan, transportation service, refresher courses, daycare center for employees' children, and salaries equivalent to or higher than those of hospitals at non-metro cities. These findings could not be compared with other studies due to absence of literature pertaining to location-wise comparison of QoL among nurses.

Nursing in-charges scored significantly higher for total QoL and 'environmental' domain of QoL than staff nurses. As stated earlier environmental domain measures influence of factors like financial resources, freedom, physical safety and security, health and social care: accessibility and quality, home environment, opportunities for acquiring new information and skills, participation in and opportunities for recreation / leisure activities, physical environment (pollution / noise / traffic / climate) transport. Poor score of environmental domain in staff nurses may be because of lesser opportunities for recreation, leisure activities and acquiring new information; moreover, staff nurses have to work on shifts while in-charges are absolved from shift work which may give them more time for family and leisure activities.

Age-wise comparison of QoL amongst nurses indicated that nurses scored better in 'environmental' domain with advancement of age. As stated earlier, this domain measures influence of factors like financial resources, freedom, physical safety and security, health and social care: accessibility and quality, home environment, opportunities for acquiring new information and skills, participation in and opportunities for recreation / leisure activities, physical environment (pollution / noise / traffic / climate) transport. The possible reason for higher score with advancement of age might be better financial support, better knowledge, experience and skills.

During ward-wise comparison of QoL oncology ward had highest score for 'physical health' domain. Physical health domain measures the impact of one's health state on the activities of daily living, dependence on medicinal substances and medical aids, energy and fatigue, mobility, pain and discomfort, sleep and rest, work capacity. Higher score of oncology ward in this domain might be because these wards particularly had lesser patients which may cause lesser workload for nurses working in this ward which may contribute to better health of these nurses. Interestingly, ICU nurses obtained highest score for 'social relationship' domain, which measures personal relationships, social support, and sexual activity facets. That means these ICU nurses were doing well in these facets. These findings could not be corroborated with other studies because no study has been done to compare QoL amongst nurses belonging to different wards. Overall, the total QoL score was comparable for nurses from different wards, which might be because of more or less similar job role of nurses in different wards.

5. CONCLUSION

The study attempted to quantify and determine QoL of Indian nurses. Location-wise, designation-wise, ward-wise and age-wise comparison of these variables was done to further elucidate the effect of these factors. Nurses from non-metro cities were found to have an inferior QoL than nurses from metro cities. Furthermore, the non-metro nurses' monthly income was also found to be comparatively less as compared to nurses of the metro cities. Staff nurses had worse QoL than nursing in-charges. Total QoL score was comparable among nurses from different wards, however, ICU nurses scored highest in social relationship domain.

REFERENCES

[1] Artazcoz L., Borrell C., Benach J., Cortes I., Rohlfs I. (2004). Women, family demands and health: the importance of employment status and socio-economic position. *SocSci Med..*, 59, 263–274.

[2] Bowling A. (2005). Measuring health-A review of quality of life measurement scales. 3 ed. Berkshire: Open University Press.

[3] Cavalheiro A. M., Moura Junior D. F., & Lopes A. C. (2008). Stress in nurses working in intensive care units. *Revista Latino-Americana de Enfermagem*, 16(1), 29-35.

[4] Chedraui P., Aguirre W., L. Hidalgo L., ayad L. (2007). Assessing menopausal symptoms among healthy middle aged women with the Menopause Rating Scale. *Maturitas*, 57, 271-278.

[5] Das, S. K., Patyal, V. S., & Mukhopadhyay, S. (2016). Development and validation of a Re-Modified Work-Style Short Form Questionnaire for assessment of stress in medical practitioners working in Indian hospitals. *Theoretical Issues in Ergonomics Science*, 1-15.

[6] Das, S. K., Mukhopadhyay, S., & Koilakuntla, M. (2015). Analytic Hierarchy Process to Rate Risk Factors Associated with WMSDs in General Physicians. *Journal of Health Management*, *17*(2), 241-247.

[7] D'Souza R.M., Strazdins L., Lim L.L., Broom D.H., Rodgers B. (2003). Work and health in a contemporary society: demands, control, and insecurity. *J Epidemiol Community Health*, 57, 849-54.

[8] Kane P. Women and Occupational Health.Issues and Policy Paper Prepared for the Global Commission on Women's Health. http://www.who.int/occupational_health/publications/ en/oehwomenandoh.pdf (3 September 2015, date last accessed).

[9] Kirkcaldy, B.D., & Martin, T. (2000). Job stress and satisfaction among nurses: Individual differences. *Stress Medicine*, 16, 77-89.

[10] Konstantinos N., & Christina O. (2008). Factors influencing stress and job satisfaction of nurses working in psychiatric units: a research review. *Health Sci J*, *2*(4), 183-95.

[11] Knutsson, A. (2003). Health disorders of shift workers. *Occupational Medicine*, 53(2), 103-108.

[12] NUPGE (2009).The stress of balancing personal life with work life. Retrieved on April 2, 2016 from http://www.nupge.ca/womensurvey.

[13] Krajewska K., Krajewska-Kułak, E., Heineman L., Adraniotis J., Chadzopulu A., Theodosopoyloy E. et al. (2007).Comparative analysis of quality of life women in menopause period in Poland, Greece and Belorussia using MRS Scale. Preliminary report. *Advanced Medical Science*, 52, 140-3.

[14] Lindstrom B. (1992). Quality-of-life- a model for evaluating health for all-conceptual considerations and policy implications. *Sozial-und Praventinmedizin*, 37, 301-306.

[15] Ohlander J., Keskin M. C., Stork J., & Radon K. (2014). 0170 Shift work and hypertension: prevalence and analysis of disease pathways in German car manufacturing workers. *Occupational and environmental medicine*, *71*, A81-A81.

[16] Pathak, V., Chakraborty, T., & Mukhopadhyay, S. (2014). Comparison of quality of life and organizational stress among nurses from metro and non-metro Indian cities. *Research*, 1, 727.

[17] Pareek U. (2001).Training Instruments for Human Resource Development, Tata MacGraw-Hill Publishing Company Ltd., New Delhi, pp. 13.

[18] Rios K.A., Barbosa D.A., Belasco A.G. (2010). Evaluation of quality of life and depression in nursing technicians and nursing assistants. *Rev Lat Am Enfermagem*., 18, 413-420.

[19] Sievert L.L. and Susan K. (2005). Goode-Null Musculoskeletal pain among women of menopausal age in Puebla, Mexico. *Journal of Cross-Cultural Gerontology*, 20, 127-140.

[20] Treaster D. E., & Burr D. (2004). Gender differences in prevalence of upper extremity musculoskeletal disorders. *Ergonomics*, 47(5), 495-526.

[21] Valenzuela S.S., Andrades B.L. (2007). Quality of life associated factors in Chileans hospitals nurses. *Rev Lat Am Enfermagem.*, 15, 480-486.

[22] Ventegodt S, Merrick J, Andersen N. (2003). Quality of life theory I. The IQOL theory: An integrative theory of the global quality of life concept. *Scientific World Journal*, 13, 1030–40.

[23] Wallander J.L., Schmitt M., Koot H.M. (2001). Quality of Life measurement in children and adolescents: Issues, instruments, and applications. *Journal of Clinical Psychology*, 57, 571-585.

[24] Wijnhoven H. A., De Vet H. C., & Picavet H. S. J. (2006). Prevalence of musculoskeletal disorders is systematically higher in women than in men. *The Clinical journal of pain*, 22(8), 717-724.

[25] WHO (World Health Organization). (2003). Diet, Nutrition and the Prevention of Chronic Diseases. Report of a joint WHO/FAO expert consultation. Technical Report Series No. 916.Geneva: World Health Organization.

A POTENTIAL NEW USE FOR CLOTHING TO ENHANCE LOCOMOTIVE ABILITY THROUGH HAPTIC SENSORY INPUT

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Abstract

This study investigated the effect of haptic sensory input through contacted cloth on locomotive ability. 17 healthy men performed tandem gait test with their eyes closed for 4m under two different conditions: (1) wearing only half-tights (HT), and (2) wearing a fluttering cloth wrapped around the waist extending to the lower leg (FC). Participants performed 2 trials with a 3 min rest period. The 1st trial was the HT condition, while the 2nd trial was the FC (n = 9) or HT (control-group, n =8) condition. Although gait speed and double support phase significantly improved in the FC condition than in the HT condition, it did not significantly change in the control-group. These results suggest that fluttering cloth can provide a haptic sensory cue for postural control mechanisms, possibly owing to enhanced perception through sensory interaction with the environment. Therefore, locomotive ability might improve depending on the shape of the garment.

Keywords*:* *Light touch, Gait Speed, Tandem gait test, Double support phase, Garment*

1. INTRODUCTION

Independent mobility is an important factor affecting quality of life. One aspect of independent mobility is balance control during locomotion and how it is necessary to decrease the incidence of falls. Some researchers have observed that providing additional haptic sensory input through the hand or finger increases postural stability during standing [1-4]. Jeka and Lackner [1, 2] showed that a light touch with the tip of the index finger on a surface at waist height (producing insufficient force (<1 N) to have any appreciable mechanical effect on stability) resulted in decreased postural sway during the Romberg stance (tandem) with the eyes closed. This “light touch effect” has also been observed and reported for light finger contact with an unstable object. Riley et al. [3] reported that a light touch to a cloth curtain decreased postural sway. It has also been found that lightly touching a finger to the upper part of the own thighs significantly decreases postural sway during standing [4]. These findings indicate that lightly touching an object during quiet standing primarily provides information about the relative movement of the body segments. It helps an individual sense the movements of the trunk, arms, and thighs, relative to each other.

The association between postural stability and light touch is of particular interest to researchers. However, it is unusual for an individual to stand and lightly touch an object while performing daily activities. Hageman et al. [5] reported that although static balance does not decrease in the elderly until remarkable functional declines occur, dynamic balance decreases much earlier. Riemann et al. [6] and Sell [7] suggested a shift away from static balance testing toward dynamic balance testing as it may be more functional and more applicable to healthy, physically active individuals. Certainly, from the view point of applying light touch effects to daily activities, lightly touching a cane increases dynamic balance control, as evaluated by the functional reach test [8]. However, both dynamic balance testing and balance control during walking or locomotion activities are also important in preventing falls and fall-related injuries [9, 10]. Therefore, the study of light touch effects is of particular importance because of it might influence on balance control during walking or locomotive activity. Furthermore, the study should be of concern regarding the ability to develop light touch effects for useful applications during daily activity.
In the case of lightly touching an object, it is likely to impede the performance of certain types of human movement. For instance, it would be difficult to walk while touching something. However, a previous study found that passive haptic input to the leg also reduced postural sway [11]. If haptic input through clothing can also provide a light touch effect, it could be used to improve human movement. Furthermore, this finding would be useful for the development of a garment that can be worn while performing daily activities. This study investigated the effect of contact while wearing clothing on balance control during locomotive ability.

2. METHOD

2.1. Participants

Data were obtained from 17 healthy men (age 22 ± 4 years) with no current or previous medical history of neural, muscular, or skeletal disorders. The participants were randomly assigned to a control group (CON, n = 8) or the clothes-wearing (WC, n = 9) group. Before initiating the study, all participants were informed of the purpose of the study and informed consent was obtained from each of them. Further, this study was approved by Human Ethics Committee of Graduate School of Human Development and Environment, Kobe University.

2.2. Experimental Setup

To evaluate locomotive ability, participants were asked to perform the tandem (heel-to-toe) gait (Figure 1). The participants were instructed to remove footwear, step with one foot onto the edge of a Walkway board and maintain a tandem stance with the other foot on a floor. The Walkway board was 75 mm wide, 15 mm high, and 4 m long with a firm surface. The experimenter then instructed the participant to close their eyes, and begin a tandem gait (with the heel of one foot directly in front of the toe of the other) along the board. When the participant was close to reaching the end of the board, the experimenter instructed them to finish (stop) walking. During the board walking, the participant was asked to avoid contact between the fingers/palms and their body (trunk, legs, etc.), but they were allowed to swing their arms for balance recovery.

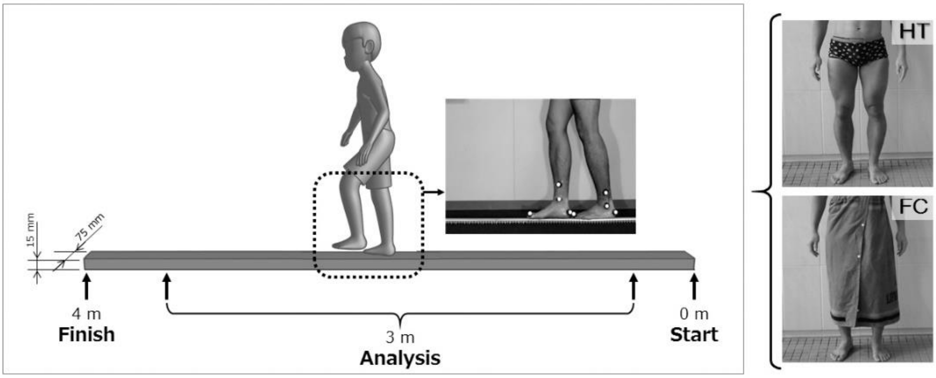

Figure 1: Schematic diagram of the experimental setup

The tandem gait task was performed under two different conditions: wearing only half- or short tights (HT), and wearing half- or short-tights and a fluttering cloth wrapped around the waist extending to the lower leg (FC).
To acquire kinematic gait data, a manual-tracking system was employed. The infrared marker-tracking system avoided capturing the markers by the use of the fluttering cloth wrapped around the waist during the FC condition. Data were collected using a digital camera (AW100, Nikon, Japan) at a frame rate of 120 fps. Analysis (calculating a double-stance phase, which is described later) was implemented with the motion-analysis software Kinovea (ver 0.8.15, French). Kinematic data were recognized from 4 reflective markers on each foot. Markers were fixed on the following anthropometric landmarks: the toe (placed in the center of the hallux nail bed), the heel, (shifted a little to the inside or outside from a line bisecting the posterior aspect of the heel to avoid impeding the tandem (heel-to-toe) gait task), the ankle (in the center of the medial or lateral malleolus), and the shank (over the lower 1/3 of tibia or fibula).

2.3. Procedures

To assess kinematic parameters, 3 m in the middle portion of each task was selected for analysis.
Gait time: Gait time was defined as the duration between one toe marker of one foot passing the 0.5 m point (start point of analysis) and another toe marker reaching 3.5 m (the end point of analysis).
Double-support phase (DSP): DSP was defined as the duration both feet were in contact with the board, which was defined as the time that one toe or heel was in contact with the board and the other toe or heel was off the board during the analysis section. The DSP of a certain trial was the overall average of all analysis sections of that trial. If the participant’s step(s) contacted the outside of the walking board (misstep), that step was not included in calculating DSP.
Visual-Analogue Scale (VAS): Subjective walking sensation was measured by using the visual-analogue scale, which is a 100 mm horizontal line. The degree of difficulty for the walking sensation was marked within the range of 0 mm (quite easy to walk) to 100 mm (difficult to keep standing upright) by the participant. VAS was measured immediately after each trial.

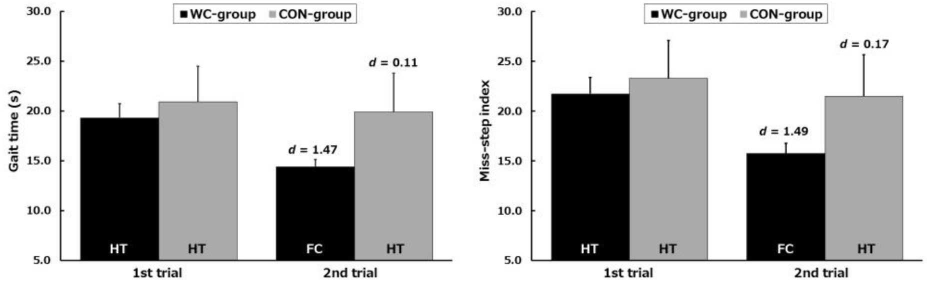

Figure 2: Change in gait time (left: gait time, right: misstep index)
ANOVA results: (gait time) group: N. S.; trial: $P < 0.01$; interaction: $P = 0.03$. (MSI) group: N. S.; trial: $P < 0.01$; interaction: $P = 0.05$

Evaluation of misstep(s): If the participant's step(s) contacted outside the walking board during the analysis section in each task, it was calculated in the misstep index (MSI). This was calculated as:

$$MSI = gait\ time + number of\ misstep(s)$$

2.4. Protocol

Before the experiment, a practice session took place to allow participants to become familiar with the tandem gait task. This lasted approximately 5 to 10 min under the HT condition.
Each participant was asked to perform the tandem gait task 2 times with a 3 min rest period. Under the HT condition, all participants performed the tandem gait task as their first trial. In the second trial, participants in the CON group were instructed to perform the tandem gait task under the HT-condition again. Participants in the WC group were instructed to perform the tandem gait task under the FC condition. The participants were allowed to reject a trial that they deemed as a "failure trial" or "not satisfactory". This was allowed 2 times for each trial.

2.5. Statistical analysis

Statistical analysis was performed using a two-way repeated-measures analysis of variance (ANOVA), which was used to compare trials and groups. To investigate the effect of walking sensation on locomotive ability, the relationship between the difference in VAS and the difference in gait time or MSI in each group was evaluated by regression analysis. These analyses were performed using J-STAT (ver. 12.5) software. The level of statistical significance was established at 5% or less. In addition to the significance testing, effect sizes were calculated for changing tasks, using Cohen's *d*. Data are presented as mean ± standard deviation (SEM) unless otherwise stated.

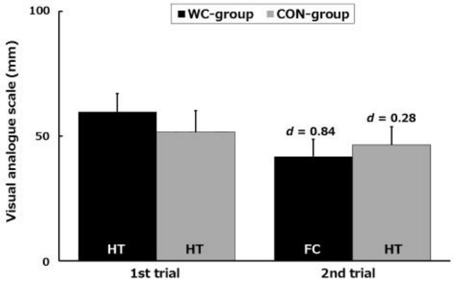

Figure 3: Change in subjective walking sensation
ANOVA result: group: N.S., trial: $P < 0.02$, interaction: $P = 0.17$

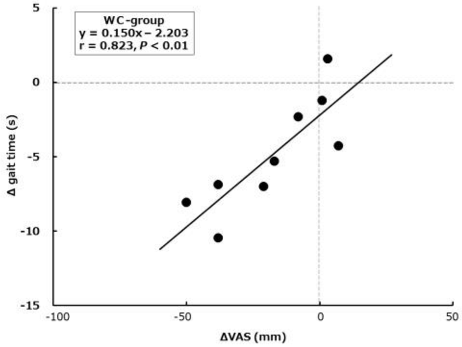

Figure 4: Relationship between change in gait time and change in walking sensation in WC group

3. RESULTS

Regarding gait time parameters, figure 2 shows the change in gait time (left) and MSI (right) in each group. ANOVA revealed a significant effect of trials on gait time and MSI. Although the effect of groups on these parameters was not significant, there was a significant interaction between trials and groups. Furthermore, although effect sizes of the 2nd trial compared to the 1st trial in the CON group were small (gait time, $d = 0.11$; MSI, $d = 0.17$), this effect size was large in the WC group (gait time, $d = 1.47$; MSI, $d = 1.49$). ANOVA revealed a significant effect of trials on DSP ($P < 0.01$). Although the effect of groups on DSP was not significant, there was a significant interaction between trials and groups (CON group, 0.90 ± 0.20 s to 0.98 ± 0.26 s; WC group, 0.87 ± 0.10 s to 0.64 ± 0.06 s, $P = 0.05$). Furthermore, although the effect size of DSP of the 2nd trial compared to 1st trial in the CON group was small ($d = 0.35$), the effect size was large in the WC group ($d = 2.30$). Therefore, although the improvement of gait performances was induced by the clothed condition, it was greater when the participants wore a fluttering cloth wrapped around the waist extending to the lower leg.
Although ANOVA revealed a significant effect of trials on walking sensation (through VAS scores), there was no significant effect of groups and their interaction (Figure 3). However, the effect size of VAS scores of the 2nd trial compared to 1st trial in the WC group was large ($d = 0.84$), even though a medium sized effect was seen in the CON group ($d = 0.28$). Therefore, although the subjective gait sensation (with a difficulty of 'easy to walk') was improved in the clothed condition, it was greater when the participants wore a fluttering cloth wrapped around the waist extending to the lower leg. Furthermore, a relationship between the change in gait time and change in VAS was significant in the WC group (Figure 4). Although a significant relationship between the change in MSI and VAS in the WC group was observed ($r = 0.74$), these were not significant in the CON group. Therefore, if participants felt it was easier to walk when wearing a fluttering cloth, this was accompanied by improvement of actual gait performance.

4. DISCUSSION

The present study revealed that balance control during locomotion, as evaluated by tandem gait performance, improved more in the FC condition than in the HT condition. Therefore, it is suggested that wearing a fluttering cloth can provide a haptic sensory cue to enhance perception through sensory interaction between the environment and the individual's body position, which contributes to better balance control during locomotion.

A passive haptic stimulus applied to the skin of the leg (which was a small piece of Velcro® attached to a flexible mount that was applied to three different sites on the leg) significantly reduces body sway during standing, even if healthy young individuals [11]. In the present study, tandem gait time was greatly decreased when the participants wore a fluttering cloth. Since base of support became narrower during the tandem gait task, more careful balance control was required during the task compared to other gait tests. Especially, the increasing of DSP during normal and fast gait has the capacity to influence and decrease gait ability (i.e. gait speed) even in young individuals [12]. In the present study, DSP was also greatly decreased by wearing clothing. Therefore, the present results suggest that an improvement in tandem gait performance is influenced by an improvement in balance control through passive haptic input by wearing a fluttering cloth. Furthermore, it suggests a potential new use for clothing (or garments) to enhance balance control during locomotion by utilizing the light touch effects.

Regarding light touch effects on upright stance, a previous study observed that co-activation of agonist and antagonist muscles was decreased when utilizing light touching [4]. Another study suggested that this co-activation with light touch during standing might influence anticipatory postural adjustments (APAs) [13]. Increased co-activation of agonist and antagonist muscles can increase postural stiffness. However, some researchers have found unfavorable effects of co-activation on the motion of postural control, reporting that excessive muscular co-activation increases the rigidity of postural control [14, 15]. Rigidity of postural control induced by greater muscle co-activation reduces the degrees of freedom during postural control [16]. Therefore, such a stabilization strategy was observed during threatening conditions (i.e. the platform height is low or high and toes are positioned at or away from the edge) in healthy, normal individuals while standing [17, 18]. Haptic sensory input through touching provides information about the relative changes in one's own body segments and allows one to stand or move more easily compared with the no touching condition. Thus, in the present study, if participants felt it was easier to walk by contact through the fluttering cloth, their gait performance improved more (Figure 4). Therefore, this result suggests the possibility that wearing a fluttering cloth improves locomotive ability by decreasing co-activation of the muscles.

5. CONCLUSION

This study investigated the effect of haptic sensory input through clothing on locomotive ability. Locomotive ability, as evaluated by tandem gait performance, improved more in the FC condition than in the HT condition. This result suggests that wearing a fluttering cloth can provide a haptic sensory cue to enhance perception through sensory interaction between the environment and individual's body position.

Therefore, balance control during locomotion might improve depending on the shape of the garment.

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REFERENCES

[1] Jeka, J.J.& Lackner, J.R.: Fingertip contact influences human postural control, *Exp. Brain Res.*, **Vol. 100** (1994), pp. 495-502, ISSN 0014-4819

[2] Jeka, J.J. & Lackner, J.R.: The role of haptic cues from rough and slippery surfaces in human postural control, *Exp. Brain Res.*, **Vol. 103** (1995), pp. 267-276, ISSN 0014-4819

[3] Riley, MA., Stoffregen, T.A., Grocki, M.J., & M.T. Turvey, Postural stabilization for the control of touching, *Hum. Mov. Sci.,* **Vol. 18** (1999), pp. 795-817, ISSN 0167-9457

[4] Oshita, K., & Yano, S.: Effects of light finger touch to the upper legs on postural sway and muscle activity during quiet standing, *Conf. Proc. IEEE Eng. Med. Biol. Soc.* **Vol. 2013** (2013), pp. 7459-7562, ISSN 1557-170X

[5] Hageman, P.A., Leibowitz, J.M., & Blanke, D.: Age and gender effects on postural control measures, *Arch. Phys. Med. Rehabil.*, **Vol. 76** (1995), pp. 961–965, ISSN 0003-9993

[6] Riemann, B.L., Caggiano, N.A., & Lephart, S.M.: Examination of a clinical method of assessing postural control during a functional performance task, *J. Sport. Rehab.*, **Vol. 8** (1999), pp. 171-183, ISSN 1056-6716

[7] Sell, T.C.: An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults, *Phys. Ther. Sport.*, **Vol. 13** (2011), pp. 80-86, ISSN 1466-853X

[8] Oshita, K, & Yano, S.: The Effect of Lightly gripping a cane on the dynamic balance control, *Open Biomed. Eng. J.*, **Vol. 9** (2015), pp. 146-150, ISSN 1874-1207

[9] Campbell, A.J., Borrie, M.J., & Spears, G.F.: Risk factors for falls in a community-based prospective study of people 70 years and older, *J. Gerontol.*, **Vol. 44** (1989), pp. M112–M117, ISSN 0022-1422

[10] Granata, K.P. & Lockhart, T.E.: Dynamic stability differences in fall-prone and healthy adults, *J. Electromyogr. Kinesiol.*, **Vol. 18** (2008), pp. 172-178, ISSN 1050-6411

[11] Menz, H.B., Lord, S.R., & Fitzpatrick, R.C.: A tactile stimulus applied to the leg improves postural stability in young, old and neuropathic subjects, *Neurosci. Lett.*, **Vol. 406** (2006), pp. 23-26, ISSN 0304-3940

[12] Ferrandez, A.M., Pailhous, J., & Durup, M.: Slowness in elderly gait, *Exp. Aging Res.*, **Vol. 16** (1990), pp. 79-89, ISSN 0014-4819.

[13] Slijper, H., & Latash, M.: The effects of instability and additional hand support on anticipatory postural adjustments in leg, trunk, and arm muscles during standing, *Exp. Brain Res.*, **Vol. 135** (2000), pp. 81-93, ISSN 0014-4819.

[14] Tang, P.F., & Woollacott, M.H.: Inefficient postural responses to unexpected slips during walking in older adults, *J. Gerontol. A Biol. Sci. Med. Sci.*, **Vol. 53** (1998), pp. M471-M480, ISSN 1079-5006

[15] Wu, G.: Age-related differences in Tai Chi gait kinematics and leg muscle electromyography: a pilot study, *Arch. Phys. Med. Rehabil.*, **Vol. 89** (2008), pp. 351-357, ISSN 0003-9993

[16] Tucker, M.G., Kavanagh, J.J., Barrett, R.S., & Morrison, S.: Age-related differences in postural reaction time and coordination during voluntary sway movements, *Hum. Mov. Sci.*, **Vol. 27** (2008), pp. 728-737, ISSN 0167-9457

[17] Carpenter, M.G., Frank, J.S., & Silcher, C.P.: Surface height effects on postural control: a hypothesis for a stiffness strategy for stance, *J. Vestib. Res.* **Vol. 9** (1999), pp. 277-286, ISSN 0957-4271

[18] Carpenter, M.G., Frank, J.S., Silcher, C.P., and Peysar, G.W.: The influence of postural threat on the control of upright stance, *Exp. Brain Res.* **Vol. 138** (2001), pp. 210-218, ISSN 0014-4819.

AUDITORY DISTRACTION AND HOSPITAL NURSES' COGNITIVE PERFORMANCE: AN OBSERVATIONAL CASE

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Abstract

A hospital ward corridor is used for professional communication, informal contact and concentrated tasks. The corridor acoustics should facilitate communication yet not compromise nursing tasks. Interruptions of nursing tasks are an important aspect in the onset of medication errors and other care omissions. Whereas most findings in the literature are based on visible disruptions of the care process, auditory distraction has not received much attention. Although psychoacoustic studies have thoroughly investigated the effect of (ir)relevant speech on various cognitive tasks, the relation to 'cognitive stacking' that is typical for hospital care has not been addressed. An observational study is conducted to investigate the auditory environment in a hospital ward and its possible effects on nursing performance. A follow up literature study is performed to support the findings. The preliminary results lead to the hypothesis that auditory distractions have a considerable influence on nursing tasks in hospital wards.

Keywords: *nursing, healthcare, acoustics, irrelevant speech, performance*

1. INTRODUCTION

The influence of the auditory environment in hospitals on patient satisfaction, outcomes and sleep quality has been a topic of research since the early twentieth century. The results of these studies contribute to the awareness of the beneficiary effects of a hospital with a quiet indoor environment even though a complete understanding of the influence of the auditory environment in hospitals has not yet been achieved. The present work is part of a larger study aiming to contribute to that understanding by focusing on the influence on hospital nurses' cognitive performance.

It is evident that the individual performance of a nurse is correlated with patient outcomes; correct medication administration, diagnosis and communication are directly linked to a patient's well-being. Therefore, one reason for addressing the influence of the auditory environment on hospital nurses is that the environmental characteristics inside a hospital should allow a professional to be in, or even contribute to obtaining, the most suitable state of mind for providing good patient care. A second and equally important reason originates from an ergonomics point of view, in which it is central to create healthy and comfortable environmental conditions for the working population.

Looking into the literature on the sound environment in hospitals and its effect on healthcare staff, most studies focus on the high noise levels that are continuously present in intensive care units and during (orthopedic) surgery [1]. The role of the sound environment in general nursing wards has gone unremarked, perhaps due to the absence of extreme sound levels in these areas. From research on the effects of noise and sound in office buildings though, it can be learned that it is not always the absolute sound *intensity* that is a reason for complaint or task impairment. For people working in an environment in which they are surrounded by speech, it is suggested that increased speech intelligibility is correlated with a decrement in task performance [2]. A review by Szalma and Hancock [3] revealed that the effect of sound on task performance is dependent on the type of sound, its duration, the schedule of exposure (e.g., intermittent or continuous), the type of task and the performance measure to assess it (e.g., speed or accuracy). The limited knowledge on the typical auditory environment in hospital wards and its influence on nursing staff have motivated this observational study, aimed at constructing a hypothesis on the influence of the sound environment in a hospital ward on nurses' performance. In addition to gaining insight in the role of the auditory environment in hospital wards, the knowledge can, in a more advanced stage of this research, contribute to understanding the cognitive impact of sound.

2. METHODOLOGY

A three-day observational study and a follow-up literature study have been performed. The decision was made to start the observations open-minded without focusing on predetermined aspects of the environment or specific activities of the nurse. This is in line with a grounded theory approach [4]. A qualitative analysis of the observation data is compared to findings from literature to construct a first hypothesis on the role of the auditory environment in nursing performance. Follow up observations and interviews will be planned based on this first hypothesis.

2.1. Observations

The observations were conducted in June 2015 in a Dutch top clinical hospital to gather data on nursing activities and the physical environment in the ward. Throughout a day-, evening-, and night shift a nurse was shadowed (a different nurse each shift) at a combined urological and cardiovascular ward. The ward was chosen based on the willingness and availability of the ward manager to cooperate. A day shift in this hospital lasts from 7.30 AM until 4.00 PM, the evening shift from 3.30 PM until 11.00 PM and the night shift from 10.30 PM until 7.30 AM.
The shadowed nurses' activities, behavior (hurrying, whispering, speaking loudly etc.) their verbal, task-related comments or comments about the environment were logged as well as the nurses' interaction with the environment (closing a curtain, switching off a light). Additionally, the first author's perception of environmental aspects such as odours, lighting levels and sound events were written down. No further objective measurements of environmental aspects were conducted. The first author's interpretations based on observed behavior were also recorded, an example is a comment on the shadowed nurse coming across stressed. The logs were used to create a timeline of the three shifts. The interval between log entries varies with the amount of activities of the nurse and the events perceived by the observer.
The staff members working at the ward during the shift were informed of the researcher's presence by their manager. They were told that the indoor environment was

being studied. Three experienced female nurses were assigned by the ward manager and voluntarily cooperated with the study.

2.2. Layout and acoustical conditions

Figure 1 presents a schematic layout of the ward, it consists of two corridors, crossing each other in the middle. Only single patient rooms, 22 in total, are present in this ward. A closed nursing station with a desk in front (marked with 'N' in figure 1) is visible from almost every position in the corridors. The visitor's entrance is separated from the service entrance to part the different traffic flows. A small coffee corner and seating area are situated in a wider part of the corridor, near the visitor's entrance. Besides patient rooms and the nursing station, there are a large meeting room, a doctors' office, a medication room, a rinsing room and storage rooms. The walls in all spaces are either plastered, covered with wallpaper or made of glass. The floor has a hard coated finishing. The ceilings in the corridor, nursing station, medication room and rinsing room are suspended; a mix of glass wool panels and perforated gypsum. The walls and ceilings in the patient rooms do not have any substantial acoustic sound absorption material. Additional panels of mineral wool were installed on the walls of the nursing station and the meeting room.

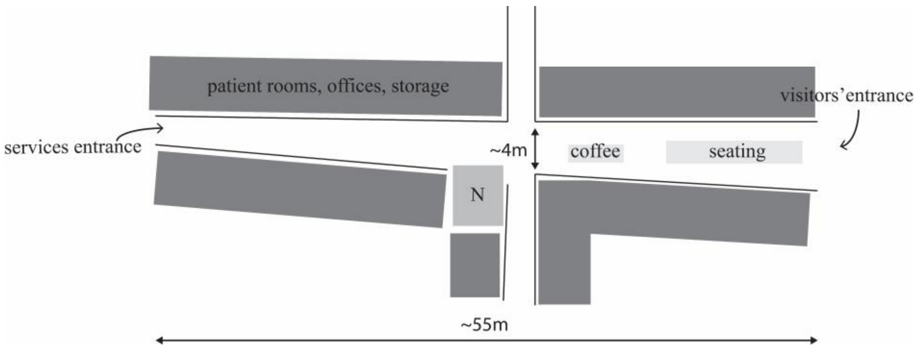

Figure 1: Schematic layout of the ward

3. RESULTS

3.1. Observations

Both the nursing activities and the auditory environment during the night shift were very different from the day- and evening situation. The night shift is therefore not included in this study. Within this section a general overview of the shift is presented, followed by a qualitative analysis of the data by emphasizing specific events.

3.1.1 Shift Schedules

During the day- and evening shift, three experienced nurses are responsible for the ward, and regularly there are one or two nursing students at work. Meals are served by the service staff, they take care of towels and bedlinen as well. Each nurse is responsible for roughly one wing of the ward (7 or 8 rooms), and takes care of his or her own patients during the shift. Most of the tasks are generally handled alone. There is no strict time schedule for tasks to be done, but there is a general order in which the nursing tasks are usually performed. The day shift starts with the change-of-shift report followed by activities to get the patients ready for the day, such as washing up and changing clothes. Then, depending on the doctors' schedules, the nurses accompany a doctor during visiting rounds or start with medication rounds. They try to finish the medication rounds and all necessary measurements before noon. Discharges, installing new patients or transports to the operation room (OR) are occurring throughout the day and fill most of the afternoon. Fixed tasks of the evening shift are a medication round, checking the patients' vitals and getting them ready for the night. Furthermore, similar to the day shift, discharges, new patients and OR trips are occurring. Entering patient data in the hospital's computer system should be performed during the shift, but generally time does not allow this and the nurses work late to finish.

3.1.2 Interruptions and task prioritizing

Figure 2 shows a segment of the timeline constructed from the observations. Logs about environmental aspects other than sounds, the nurses' interactions with the environment unrelated to sound and general comments about the nursing process are not shown here. The timeline indicates that sequential tasking, routine tasks that require taking important decisions, and interruptions are very typical for the nursing job. It shows that while preparing the discharge of patient Y, she is called by patient X. After attending to patient X, she does not immediately return to her original task (the discharge) but starts a new task for patient X. This is supported by a comment from the nurse made at the end of the day shift saying there are always many things of which she thinks "oh right.. this has to be done as well right now".
Even though there is no strict time schedule, it is assumed by the first author that delays in discharge, new patients and visits to the OR can lead to some stress concerning time management. Specific comments of the nurses strengthen this assumption, an example can be seen in a fragment of the timeline logs in figure 2, "relatives of patient Y are not here yet, this messes up the schedule of nurse1".
The first 30 minutes of the observed evening shift are representative of the many interruptions that occur during a shift. As the nurse is starting her medication round she is immediately interrupted by a phone call after which she attends to the needs of a patient. After returning to the medication cart, a beeping sound can be heard that indicates an empty infusion pump. This requires a quick fix and on her way back to the cart she is once more interrupted. When she finally puts on the do-not-disturb vest that nurses are required to wear during medication rounds, she is asked a question by a service employee about the diet of a patient. Then, within 3 minutes of actually looking at the computer for medication specifications the phone rings. This conversation lasts for 5 minutes.

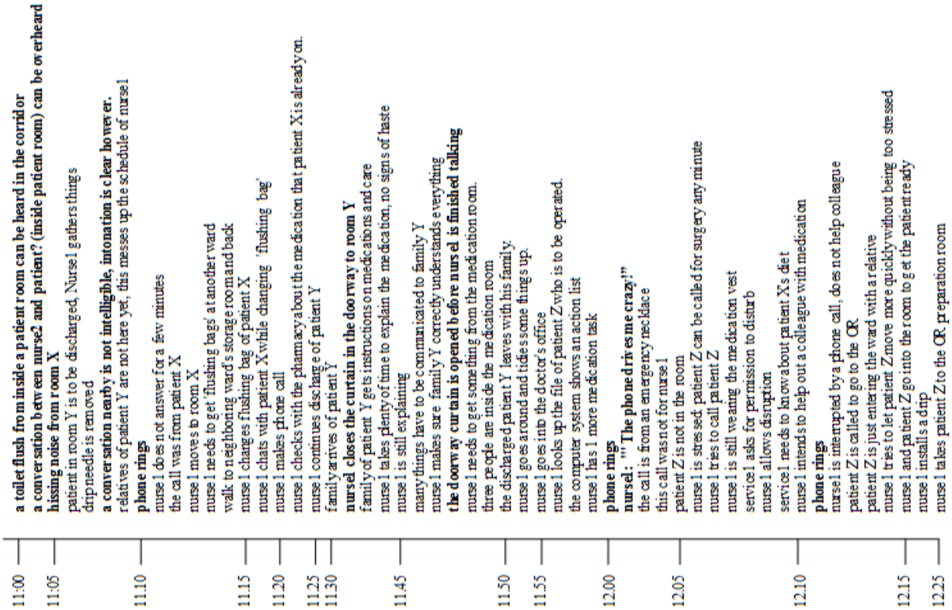

Figure 2: A fragment of the constructed timeline (day shift).

Another assumption based on the observation logs is that besides the well-known risks of medication errors, negligence is a risk for the well-being of patients. At the end of the day shift, the shadowed nurse mentioned feeling as if she did not pay enough attention to a certain patient. Another example occurred during the evening shift; a patient, who had not been seen by the nurse for 2.5 hours, came out of the room asking for wound attending while the nurse was on her way towards another patient. After finishing her current task several other activities were carried out, and it took another 30 minutes before the nurse attended the wounds of the patient. At this point the nurse might have made an informed decision about the urgency of the situation but might also have forgotten about the patient for a moment.

It is suggested by the first author that important aspects to look into are the ability of the nurse to prioritize tasks, to remember these priorities over a longer period of time and to remember to carry out a task at the right time.

3.1.3 The ward corridor

It was observed that the ward corridor is a multifunctional area, used for various forms of communication and concentrated tasks such as medication distribution and recording of patient data. The nurses use a computer cart for looking up and entering patient data as well as medication distribution. There are three of these carts in the ward and they are located in the corridor most of the time. Quick encounters between nurses and doctors take place here, which create the opportunity to discuss a patient, other work related issues or engage socially.

As for the auditory environment, ringing telephones and intelligible conversations are common sounds in the corridor. The timeline of the day- and night shift contains 16 entries about intelligible speech that can be overheard in the corridor, either between nurses and patients, or amongst staff. The timeline contains 19 entries about a phone ringing of which 14 took place during the evening shift. However, since quantifying phone calls or events of intelligible speech was not the goal of the observation it is very probable that events were missed. The corridor was perceived to be the most eventful area of the ward, the first few comments in the timeline in figure 2 are an example of the many auditory events that could be heard in the corridor.

3.2. Supporting literature

The concept of efficient task prioritizing is supported by Potter [5] who studied the cognitive work of nurses. The term cognitive stacking was introduced, an organizational skill that should be mastered to determine which tasks to complete and which should remain on hold. Switching from task to task in the most efficient and patient-centered way requires a combination of decision-making and memory skills. An omission of care can be seen as a planned activity identified by a nurse which is not implemented within the specified time period. The term stacking is also used in earlier work by Ebright [6] who used qualitative techniques to identify a pattern of 'forward thinking'. Prioritizing and delegating based on anticipation of what might happen is considered an important part of the nursing job in her paper. These 'stacking' tasks should remain top of mind and interruptions or distractions could influence this.

Interruptions are thought to be a prominent causative factor of medication errors [7] and care omissions [5]. A review by Biron [7] states that since empirical evidence on the relation is scarce and the definition of an interruption varies amongst different studies it is an important topic to address in future studies. Quantifying and analysing the origin of interruptions could not be performed using the data of the present observational study but from several other studies it can be seen that most interruptions are caused by colleagues and are patient related. The ward environment, however, is also a source of many interruptions. In a Dutch study by Smeulers [8], it was found that 49% of interruptions observed during medication rounds were verbal and mainly (28%) caused by a colleague. Another 25% of observed interruptions were non-verbal and originating from the ward environment. Similar results are presented by Redding [9] who observed that 31% of interruptions (during the shift) were caused by employees asking a face-to-face question and that 22.5% was caused by distracting peripheral conversations.

Most studies define a work interruption as a halt of the current activity to engage in a new activity. Distractions are defined more vaguely, and their occurrence and impact on a nurse are not visible for an observer. An interruption is always caused by a distraction, whereas a distraction does not always lead to an interruption.

4. DISCUSSION

The aim of this study was to construct a hypothesis on the role of the sound environment in a hospital ward on nurses' cognitive performance. Main observations, based on an analysis of the constructed timeline of which a fragment is shown in figure 2, are the many task interruptions and the importance of prioritizing, planning and remembering. Supporting literature was found for both. The nature and origin of most task interruptions was not logged during the observations but from literature it can be seen that auditory events in the vicinity of the nurse are an important factor.

The reported quantifications of disruptions both in the literature and the current observational study are based on visible interruptions of nursing tasks, which means that the observer could see the nurse interrupting an activity in order to start another, or to actively listen to speech. However, whether a nurse is distracted by intelligible speech or other sound events originating in the environment is not discernible for an observer. The cognitive effects of such an invisible distraction during a task may therefore be underestimated. Additionally, the results from an observational study by Cornell [10] show that 8% of a nurses' working time is spent walking without performing any task. The first author presumes that during this time 'in-between' tasks, a nurse will have a different state of mind and greater situational awareness than during a task requiring attention and will therefore be more susceptible to distraction. This might influence the memory for stacking tasks as a result of interference of processes (explained by Banbury, [11]). While the distractive effects of background sounds have been investigated for a range of cognitive tasks in psycho-acoustic studies, no such experiments are known for the cognitive stacking that is typical for nursing care.

From the present observations, the ward corridor was perceived to be the most eventful area of the ward. This view is strengthened by papers from Carthey [12] and Iedema [13] stating that corridors are central to hospital communication, both informal and clinical. The importance of this communication is emphasized by their suggestion that important decision-making takes place here as a result of unplanned encounters between staff and should therefore be facilitated. This is contradictory with the idea that interruptions of tasks are influencing nursing performance. It is a challenge to create an environment that facilitates communication without interrupting and distracting others.

Based on the qualitative analysis of the observational study and literature findings about the origin of interruptions, cognitive processes of nursing, the use of hospital corridors and the cognitive impact of (ir)relevant sounds in various psychoacoustic studies, an idea is formed on the role of the auditory environment on nursing performance. It is hypothesized that the auditory environment of a hospital ward contains distractive events, which have an effect on the decision-making of, and memory for, workflow priorities and medication errors. A follow up study is suggested aimed at quantifying auditory distraction in multiple hospital wards.

5. LIMITATIONS

The hypothesis drawn in this study is based on a single case study in a hospital that has been recently built according to the principles of a healing environment. The high amount of sound absorption in the corridor ceiling and the separation of different traffic flows in the building are unique qualities of the studied hospital and are thought by the first author to have a positive influence on the amount and intensity of auditory distractions.

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REFERENCES

[1] Busch-Vishniac, I.J., West, J.E., Barnhill, C., Hunter, T., Orellana, D. & Chivukula, R.: Noise levels in Johns Hopkins hospital, *The Journal of the Acoustical Society of America*, **Vol.** (2005) 118, no. 6, pp. 3629-3645

[2] Hongisto, V.: A model predicting the effect of speech of varying intelligibility on work performance, *Indoor air*, **Vol.** (2005) 15, no. 6, pp. 458-468

[3] Szalma, J.L. & Hancock, P.A.: Noise effects on human performance: a meta-analytic synthesis, *Psychological bulletin*, **Vol.** (2011) 137, no. 4, pp. 682

[4] Stern, P.N.: 1980, Grounded theory methodology: Its uses and processes, *Image*, **Vol.** (1980) 12, no. 1, pp. 20-23

[5] Potter, P., Boxerman, S., Wolf, L., Marshall, J., Grayson, D., Sledge, J. & Evanoff, B.: Mapping the nursing process: a new approach for understanding the work of nursing, *The Journal of nursing administration*, **Vol.** (2004) 34, no. 2, pp. 101-109

[6] Ebright, P.R., Patterson, E.S., Chalko, B.A. & Render, M.L.: Understanding the complexity of registered nurse work in acute care settings, *Journal of Nursing Administration*, **Vol.** (2003) 33, no. 12, pp. 630-638

[7] Biron, A.D., Loiselle, C.G. & Lavoie Tremblay, M.: Work interruptions and their contribution to medication administration errors: an evidence review, *Worldviews on Evidence Based Nursing*, **Vol.** (2009) 6, no. 2, pp. 70-86

[8] Smeulers, M., Hoekstra, M., van Dijk, E., Overkamp, F. & Vermeulen, H.: Interruptions during hospital nurses' medication administration rounds, *Nursing Reports*, **Vol.** (2013) 3, no. 1, pp. 4

[9] Redding, D.A. & Robinson, S.: Interruptions and geographic challenges to nurses' cognitive workload, *Journal of nursing care quality*, **Vol.** (2009) 24, no. 3, pp. 194-200

[10] Cornell, P., Herrin-Griffith, D., Keim, C., Petschonek, S., Sanders, A.M., D'Mello, S., Golden, T.W. & Shepherd, G.: Transforming nursing workflow, part 1: the chaotic nature of nurse activities, *The Journal of nursing administration*, **Vol.** (2010) 40, no. 9, pp. 366-373

[11] Banbury, S.P., Macken, W.J., Tremblay, S. & Jones, D.M.: Auditory distraction and short-term memory: phenomena and practical implications, *Human factors*, **Vol.** (2001) 43, no. 1, pp. 12-29

[12] Carthey, J.: Reinterpreting the hospital corridor: wasted space or essential for quality multidisciplinary clinical care?, *Herd*, **Vol.** (2008) 2, no. 1, pp. 17-29

[13] Iedema, R., Long, D., Carroll, K., Stenglin, M. & Braithwaite, J.: Corridor work: How liminal space becomes a resource for handling complexities of multi-disciplinary health care, *APROS 11: Asia-Pacific Researchers in Organization Studies: 11th International Colloquium*, pp. 238, Melbourne, Australia, December 2005, Asia-Pacific Researchers in Organisation Studies, (2005)

THERMOGRAPHY ASSISTED ANALYSIS OF TEXTILE MATERIALS AS A PREDICTOR OF HUMAN COMFORT

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Abstract

Infrared thermography is gaining popularity among the researchers in various fields. In the field of textiles, the potential of thermography may be used to observe the production process, material properties, clothing comfort, failure and product development. In this paper, thermography is used to observe the influence of fibre content, yarn count and knit to the drying properties of designed single- and double- jersey fabrics. The results are compared to subjective assessment of drying process and advantages of thermography, as a predictor of human comfort parameters, are outlined.

Keywords*:* *thermography, yarn, fabric, drying, subjective assessment*

1. INTRODUCTION

Infrared thermography is gaining popularity among the researchers in various fields. In the field of textiles, the potential of thermography may be used to observe the production process, material properties, clothing comfort, failure and product development. Generally, any process that leads to a difference in temperature can be subjected to thermographic examination. The most common application is the measurement of thermal properties and heat transfer trough fabrics. Basically, the sample is heated and surface temperature distribution on both sides of the sample is observed. The method is used to measure the properties of textile barriers, as well [1]. Measurements of coupled heat and moisture transport are also studied using thermography. In this context, thermal imaging is used to find the direction of water movement and to explain the drying mechanism of textile product [2, 3]. A dynamic model of water transfer and moisture sorption in porous textiles was also investigated by means of thermography [4]. Furthermore, thermography has application in development of thermo-regulating textile material. For instance, it is used to develop a thermally adaptable, vapour-permeable or water repellent fabric for active wear [5]. Researchers also presented the investigation of the contact resistance of electro-conductive textile material using thermography [6]. Additionally, thermography proved to be a useful method to demonstrate thermo-mechanical coupling in non-woven textiles loaded over their yield point. In this context, nonwoven structure was tested with aim to link its behaviour during uniaxial tensile testing with friction and extension of fabric [7]. Thermogram of human body is very useful tool in the process of clothing design. It is widely used to observe differences in temperature of the body dressed in clothing produced of different materials and with different fitting properties [8]. Among other

numerous uses of thermography, its capacity in non-destructive testing of textile composites should be pointed out [9].
In this paper, thermography is used to observe the influence of fibre content, yarn count and knit to the drying properties of designed single- and double- jersey fabrics. The results are compared to subjective assessment of drying process and advantages of thermography, as a predictor of human comfort parameters, are outlined.

2. METHODOLOGICAL APPROACH

Within this chapter, the design of samples and procedure of investigation are described in details.

2.1. Samples

For the purpose of investigation are designed single- and double- jersey fabrics. Fabrics are produced of cotton yarns in counts 16, 20, 24 and 30 tex. During the production of samples assigned as sample S2, S3 and S4 (Table 1), elastane yarn is added to a defined percentage.

Table 1: Description of samples

Nr.	Fiber	Yarn count	Percentage of elastane, %	Fabric knit
S1	Cotton	16 tex	0	Single jersey
S2	Cotton + Lycra	16 tex + 44 dtex	9	Single jersey
S3	Cotton + Lycra	16 tex + 44 dtex	11	Single jersey
S4	Cotton + Lycra	16 tex + 44 dtex	13	Single jersey
S5	Cotton	16 tex	0	Double jersey
S6	Cotton	20 tex	0	Double jersey
S7	Cotton	24 tex	0	Double jersey
S8	Cotton	30 tex	0	Double jersey

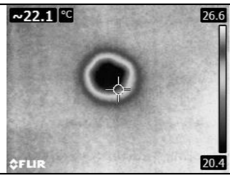
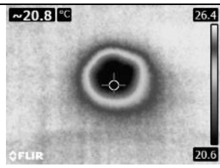
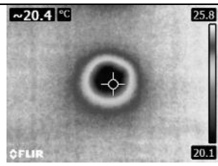
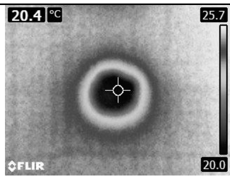
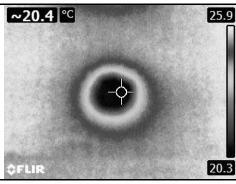
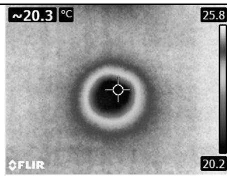
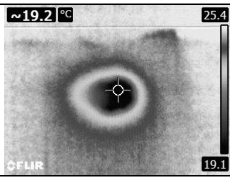
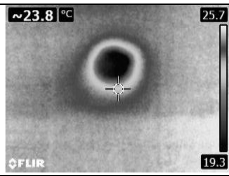
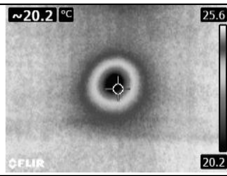
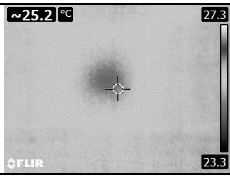
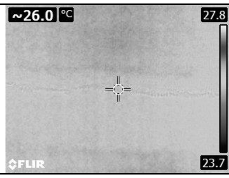
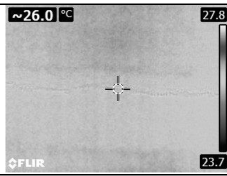
2.2. Measurements

Within the experimental part, produced samples are wetted with tap water in order to simulate two different intensities of sweating, i.e.:

- moderate sweating (MS) – 300 g/m^2/h and
- intensive sweating (IS) – 900 g/m^2/h [10].

After the wetting is completed, samples are left on flat surface in dry and hot environmental conditions, i.e. temperature 25 ± 2 ºC and relative humidity 65 ± 5%. For the measurement is used thermal camera FLIR E5. The specifications of used camera are as follows: IR resolution 120 × 90, MSX resolution 320 × 240, thermal sensitivity <0.10°C and standard temperature range –20°C to +250°C. Thermal image is obtained every ten minutes. The shooting continued until there was no change between the temperatures of wetted and non-wetted area. The table 2 illustrates thermographic images obtained for a single sample (sample S5, in moderate sweating) through the period of 110 minutes. For this sample, 100 minutes after simulated moderate sweating, the temperatures of wetted and non-wetted areas are equal, meaning the fabric is completely dry. At the same time, subjective assessment of surface wetness is carried out and observations are noted in a separate sheet.

Table 2: Example of thermographic images obtained for sample S5

		
0 min	10 min	20 min
		
30 min	40 min	50 min
		
60 min	70 min	80 min
		
90 min	100 min	110 min

3. RESULTS

The results of materials measurements using the thermal camera are presented on the figures 1-4. The graphs show differences between the temperatures of the wetted and non-wetted area of textile fabric over the time.

The influence of the elastane yarn to the drying time is especially well seen in the simulated conditions of intensive sweating. Namely, the total drying time of single jersey fabric produced of 100% cotton yarn (without addition of elastane yarn) is 80 minutes, while the drying time of fabrics with added elastane is 150 minutes. It is interesting to point out that in the case of intensive sweating, the percentage of elastane yarn (9, 11 or 13%) did not affect the total drying time. The results of measurements using thermal camera confirmed influence of yarn count to the total drying time. The influence is more pronounced in the conditions of intensive sweating, where the differences between the total time needed to dry out the fabric are 30 minutes (Fig. 4).

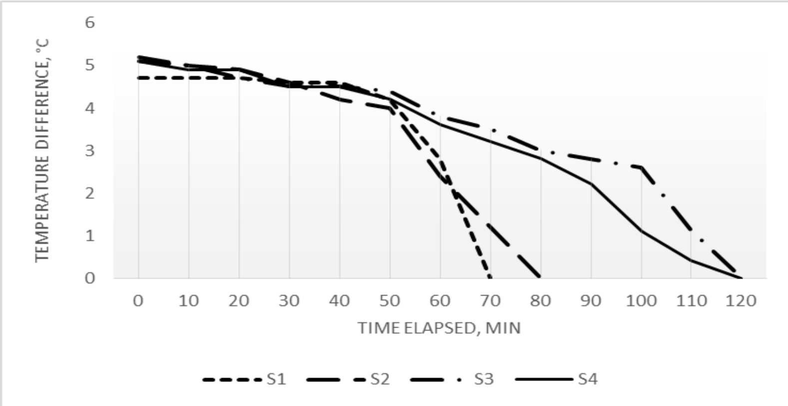


Figure 1: Temperature difference for samples S1–S4, simulated moderate sweating

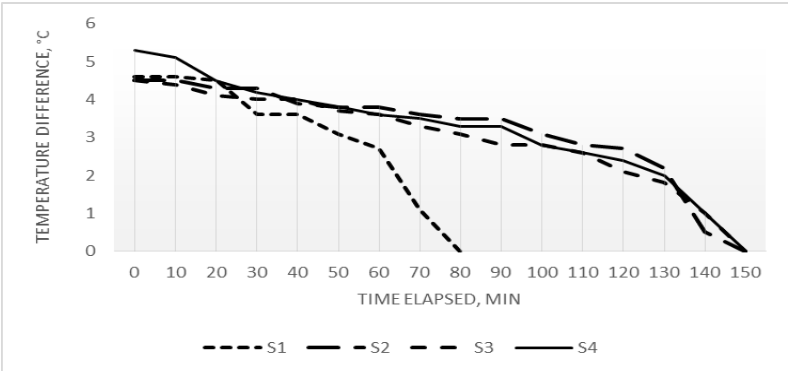


Figure 2: Temperature difference for samples S1 – S4, simulated intensive sweating

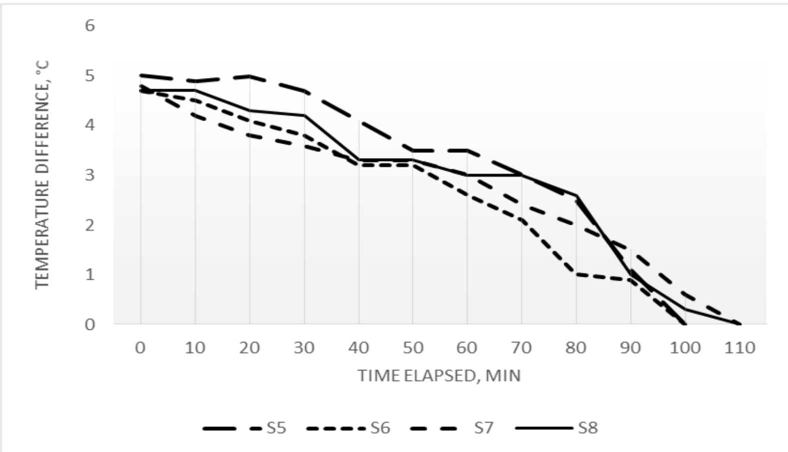


Figure 3: Temperature difference for samples S5 – S8, simulated moderate sweating

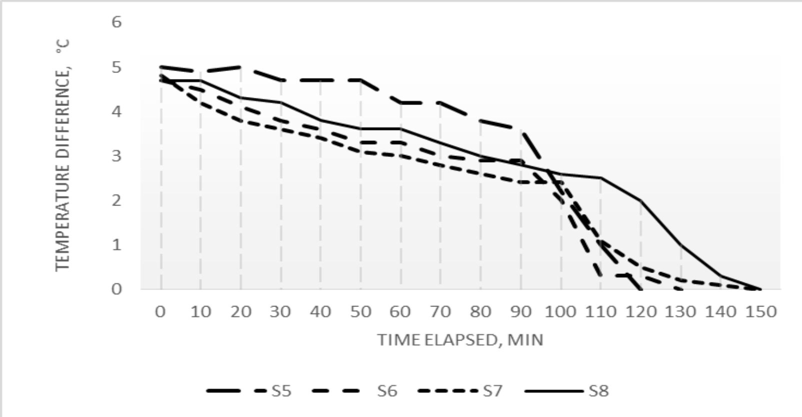


Figure 4: Temperature difference for samples S5 – S8, simulated intensive sweating

Finally, the results showed significant influence of fabric knit to the drying time. The drying time of double jersey fabric seem to be much longer than the drying time of single jersey fabrics (i.e. in moderate sweating 100 min vs. 70 min; in intensive sweating 120 min vs. 80 min).
The described outcomes of measurements should be further used into consideration when predicting properties of material that will assure optimal level of human comfort regarding the sweating process. In order to decrease discomfort due sweating, it is advised to wear single jersey fabrics produced of 100% cotton yarns in counts of 16 tex or less, without addition of elastane yarn.
The comparison of subjective assessment of "dry state" (determined visually) and "dry state" measured by means of thermography is given on the figure 5.

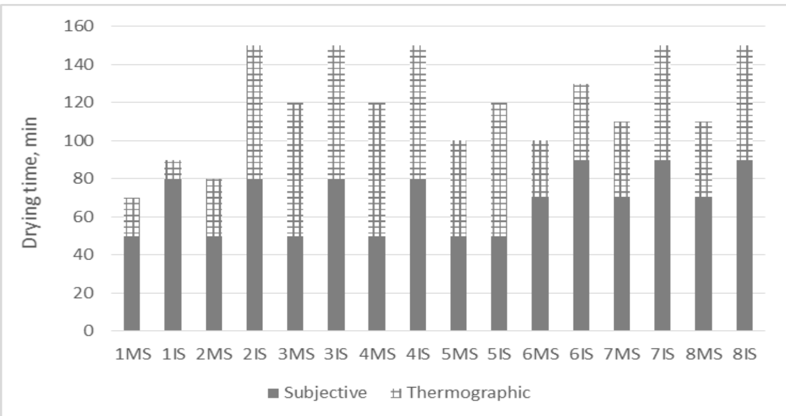


Figure 5: Drying time: subjective vs. thermographic assessment

The comparison of drying times obtained by thermal camera and by subjective observation showed significant differences. Namely, the real drying time (i.e. the one obtained using thermal camera) is up to 70 minutes longer than the one determined subjectively.

4. CONCLUSION

The aim of the paper was to use thermography to observe influences of different fabric parameters to the total drying time of knitted fabrics. Intentionally, all samples are produced of cotton, but small differences within samples are obtained using additional yarn in the structure or by varying knit and yarn count. The results indicated significant differences in total time of drying between designed fabrics what will, in real-life situations, directly affect human comfort. It was shown that drying time of single jersey cotton fabric without elastane may be up to 70 minutes shorter that drying time of similar fabrics used for the same purpose. Finally, the measurements confirmed that, for this purpose, the thermographic method is more reliable than subjective method.

AKNOWLEDGEMENT
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REFERENCES

[1] Michelak, M. Felczak, M. & Viecek, B: A new method of evaluation of thermal parameters for textile material, *Proceedings of 9th International Conference on Quantitative InfraRed Thermography*, Krakow, July 2008.

[2] Banerjee D.: *Development of high resolution optical measurement techniques to investigate moisture content and thermal properties of paper* in Progress in Paper Technology, ed. Samuel Shabel, Shaker Verlag, ISBN 978-3-8322-7984-4, Aachen, (2009)

[3] Gurudatt K., Nadkarn, V. M. & Khilar, K. C.: A study on drying of textile substrates and a new concept for the enhancement of drying rate, *The Journal of The Textile Institute*, **101** (2010) No.7, pp. 635-644, ISSN 1754-2340.

[4] Li Y., Zhu, Q.: Simultaneous heat and moisture transfer with moisture sorption, condensation, and capillary liquid diffusion in porous textiles, *Textile research Journal*, **73** (2003) No.6, pp. 515-524, ISSN 0040-5174.

[5] Chung H., Cho, G.: Thermal Properties and Physiological Responses of Vapor-Permeable Water-Repellent Fabrics Treated with Microcapsule-Containing PCMs, *Textile research Journal*, **74** (2004) No.7, pp. 571-575, ISSN 0040-5174.

[6] Banaszczyk, J.; Anca, A. & Mey, G. D.: Infrared thermography of electro conductive woven textiles, *Proceedings of 9th International Conference on Quantitative InfraRed Thermography*, Cracow, July 2008.

[7] Gautier K.., Wagner Kocher, C & Drean, J.Y.: Anisotropic Mechanical Behavior of Nonwoven Geotextiles Stressed by Uniaxial Tension, *Textile research Journal*, **77** (2007) No.1, pp. 20-28, ISSN 0040-5174.

[8] Matusiak M.: Thermal Comfort Index as a Method of Assessing the Thermal Comfort of Textile Materials, *Fibres and Textiles in Eastern Europe*, **79** (2010) No.2, pp. 45-50, ISSN 1230-3666.

[9] Maldague X. P.: *Theory and practice of infrared technology for nondestructive testing*, John Wiley & Sons Inc., 978-0-471-18190-3, West Sussex, (2001).

[10] Havenith, G.; Fogarty, A.; Bertlett, R.; Smith C.J. & Ventenat V.: Male and female upper body sweat distribution during running measured with technical absorbents, *European Journal of Applied Physiology*, **104**, (2008) 2, 245-255, ISSN 1439-6327.

INVESTIGATING MECHANICAL PROPERTIES OF FILAMENT YARNS USED FOR HEALTH PRESERVATION

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Abstract

Yarns used for dental health preservation, widely known under the term "dental floss", are the most recommended interproximal plaque remover. The research presented in this paper is a part of comprehensive study and presents its segment - insight into the attitude of consumers towards flossing and their preferences for purchase, as well as experimental measurements of floss' properties. The results of survey among consumers indicated that advertising plays an important role in convincing consumers to choose certain product (50%). It is followed by positive experience, price, brand and floss properties (construction, finishing, raw material and tensile properties). From the comparison of different flosses, it was shown that differences within the values of breaking force and elongation may be more than 20%. The same stands for the differences in diameter. Finally, the measurements indicated that, regardless the high price range, some flosses have lower quality that may directly affect the flossing efficiency.

Keywords*:* *yarn, floss, mechanical property, health, survey*

1. INTRODUCTION

Dental floss is a very effective tool for cleaning teeth. It can be inserted into the corner teeth to remove food debris and plaque on teeth niche [1]. Floss is available in string or ribbon form, and can be lightly waxed, waxed, or un-waxed. Ribbon floss is the most effective choice when there are ample spaces between the teeth. Since children's teeth are widely-spaced, ribbon floss is the most common selection for children. On the other hand, when teeth have contact points (i.e. when they come in contact with one another), the preferred choice is the narrower or string floss. Waxed or lightly waxed floss is recommended for use between crowded or crooked teeth [2]. Previous investigation related to dental floss are mostly carried out in the form of clinical investigation [3, 4]. It has been shown that the practice of daily flossing is quite low, and that people are less inclined to floss than to brush. Furthermore, it was confirmed that the ethnicity, socioeconomic status, age and gender affect the floss frequency. The outcomes of studies indicated that periodontists and dentists tend to floss more frequently than the general population [5].
The research presented in this paper is a part of comprehensive research including the survey investigation, laboratory measurements of materials and clinical investigation. The results given in this paper focus at survey and mechanical properties of flosses measured within laboratory for physical-mechanical properties of materials.

2. METHODOLOGICAL APPROACH

The experimental part of this paper includes the pilot survey conducted among consumers and laboratory investigation of floss' mechanical properties, i.e. tensile properties, diameter and abrasion resistance.

2.1. Survey among consumers

The survey regarding the attitude of consumers towards flossing and their preferences for purchase, is conducted among 50 participants (62% female and 38% male) in the age 43-47. For the survey is prepared a questionnaire with 8 questions and the examiner went over the questionnaire with each examinee, making sure that each examinee understood the questions.

2.2. Measurement of mechanical characteristics

In order to compare the properties of dental flosses available on the market, six different samples are purchased and designated for investigation in a random order. The description of samples, given by the producer, is shown in the Table 1. Besides the main descriptors, the Table 1 also gives the information regarding the price range of flosses, where range 1 stands for cheapest flosses and range 3 for the most expensive floss.

Table 1: Description of samples

Nr.	Designation	Description given by producer	Addition of wax/fluorid	Price range
1	T1	Dental floss-mint	+/+	1
2	T2	Dental floss unwaxed	-/+	1
3	T3	Whitening	-/-	2
4	T4	Fresh	-/-	1
5	T5	Oral Fresh Floss	+/-	2
6	T6	Meridol	-/-	3

The following mechanical properties of flosses are investigated: tensile properties, diameter and resistance to abrasion. Tensile properties of flosses are measured on dynamometer Statimat M produced by Textechno, using the method A, as described in the standard ISO 2062 [6].
The yarn diameter is determined from a microscopic image obtained using the Dino-Lite digital microscope. For the exact measurement of diameter, DinoCapture 2.0 software is used. The diameters are determined using the microscopic image with magnification 200x.
The abrasion of samples is conducted using the abrasion device equipped with sandpaper (granulation 80). The changes in appearance are observed from microscopic images of flosses after 50 cycles (phase 1) and 500 cycles (phase 2).

3. RESULTS AND DISCUSSION

Within this chapter, the main outcomes of the pilot survey, as well as the results of floss measurements are presented.

3.1. Results of survey

The most important results of survey among consumers are given on the Figure 1. As can be seen from the results, advertising plays an important role in convincing consumers to choose certain product (50%). It is followed by positive experience (19%), price (8%) and brand (8%). The results also indicated that consumers are aware of the importance of floss properties (4%), but the information regarding properties is rarely given by the producer and therefore is not very crutial for the final decision. Regarding the floss properties that consumers consider important, the construction, finishing, raw material and tensile properties are pointed out (Figure 2).

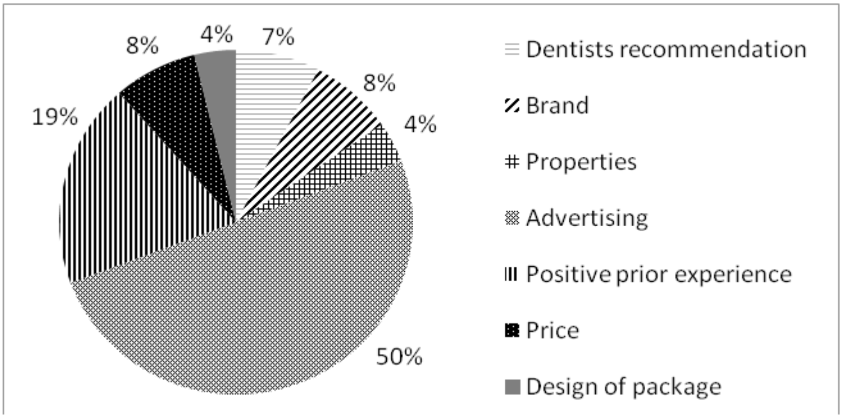


Figure 1: The most important baseline for the decision of purchase

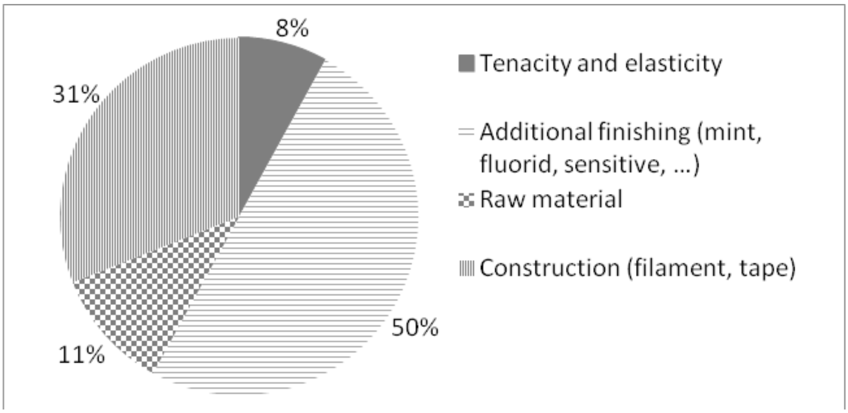


Figure 2: The most important property of dental floss

3.2. Results of floss measurements

The results of the measured tensile properties and diameter are given in the tables 3 and 4. Microscopic images of flosses, after certain number of abrasion cycles, are given in the Table 4.

Table 2: Tensile properties of investigated floss samples

Property	T1	T2	T3	T4	T5	T6
Breaking force, N	44,92	46,07	50,41	49,96	47,33	41,87
Coefficient of variation, %	5,62	4,75	1,83	3,66	3,83	8,89
Standard deviation, cN	2,53	2,19	0,92	1,83	1,81	3,72
Breaking elongation, %	23,1	24,78	27,57	27,08	32,10	38,53
Coefficient of variation, %	10,26	12,81	5,75	20,24	14,58	8,64
Standard deviation, %	2,36	3,18	1,58	5,48	4,68	3,33
Work to rupture, cNxcm	5006,40	6128,69	8061,27	7336,84	9445,50	9973,90
Coefficient of variation, %	21,80	22,17	7,62	35,12	23,21	14,95
Standard deviation, cNxcm	1091,29	1358,59	614,65	2576,87	2192,15	1490,89

Regarding the investigated tensile properties, it should be observed that the breaking forces of samples are in the range 44-50 N, with highest values measured for samples T3 and T4. The same samples have lowest values of variation for the same observed property. The breaking elongation of investigated samples is in the range 23-38%, with lowest variation for the sample T3.

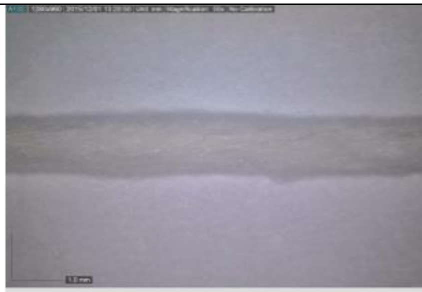
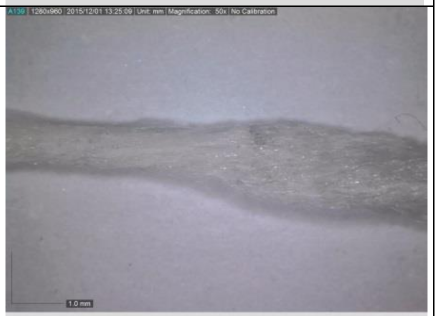
Table 3: Diameter of investigated floss samples

Diameter	T1	T2	T3	T4	T5	T6
Mean value, mm	0,8431	0,9573	1,0339	0,8182	0,8557	0,9983
Standard deviation, mm	0,0118	0,0151	0,0267	0,0205	0,0422	0,3207
Coefficient of variation, %	1,40	1,57	2,58	2,51	4,93	32,12

From the Table 3 is well seen that the largest diameter, among all observed samples, has the sample assigned as T3. This sample is followed by the sample T6. In the context of flossing, a larger diameter may bring some additional problems, and it is recommended that floss diameter is adapted to the spacing between teeth, thus allowing the floss to pass easily and painlessly through the area. Considering the previously defined, the flosses assigned as T1, T4 and T5 would have certain advantage over the investigated samples.

Resistance to abrasion is another important feature of flosses. The microscopic images taken after a certain number of cycles showed no changes in the structure of flosses, except for the samples T4 and T6. Therefore, in the Table 4 are extracted the images of these two flosses in different phases (i.e. before the abrasion and after different number of abrasion cycles). Within the investigation of this property, it is shown that the dental floss T6, regardless the highest price range among all investigated samples, has lowest resistance towards abrasion. The figures show that this floss has the greatest tendency of disintegration. Such characteristics can harm the gums but also bring discomfort during the use.

Table 4: Microscopic images

	T4	T6
Before		
Phase 1		
Phase 2		

5. CONCLUSION

On the basis of the research, the following conclusions may be drawn:

- The most important results of survey among consumers indicated that advertising plays an important role in convincing consumers to choose certain product (50%).

It is followed by positive experience, price, brand and floss properties (construction, finishing, raw material and tensile properties).

- From the comparison of different flosses, it was shown that differences within the values of breaking force and elongation may be more than 20%. The same stands for the differences in diameter.
- Finally, the measurements indicated that, regardless the high price range, some flosses have lower quality that may directly affect the flossing efficiency.

This investigation will be continued with in-vivo experiments, so the overall approach will be applied in order to get a comprehensive overview.

REFERENCES

[1] Phonhan C.; Yangyuen S.; Wongkasem S.: The design and developmend of machine for producing natural dental floss, *Available from: www.sciencedirect.com Accessed 2016-01-20*

[2] Foster, Malcolm S.: *Protecting Our Children's Teeth: A Guide to Quality Dental Care from Infancy through Age Twelve,* Insight Books (a division of Plenum Publishing Corporation), 1992, pp. 186-90. *Available from http://www.madehow.com/Volume-2/Dental-Floss.html Accessed 2016-01-20*

[3] Schiff T.; Proskin H.M.; Zhang Y.P.; Petrone M.; DeVizio W.: A clinical investigation of the efficacy of three different treatment regiments for the control of plaque and gingivitis, *Journal of Clinical Dentistry*, **17** (2006) 5, 138-44.

[4] Gerald Z. Wright, W. H. Feasby, D. B. Banting: The effectiveness of interdental flossing with and without a fluoride dentifrice, *Pediatric Dentistry*, **2** (1990) 2, 105-109

[5] Davidson PL, Rams TE, Andersen RM. Socio-behavioral determinants of oral hygiene practices among USA ethnic and age groups, *Advanced Dental Research* **11** (1997) 245-253.

[6] ISO 2062:2009 Textiles -- Yarns from packages -- Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester

THE INFLUENCE OF BODY FAT ON MAXIMAL OXYGEN CONSUMPTION OF TAIWAN MALE MILITARY PERSONNEL

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Abstract

Maximal oxygen consumption ($VO_{2\max}$, in ml/kg/min) is an excellent index to assess the cardiopulmonary functions in the area of physical fitness. The understanding of $VO_{2\max}$ is not only necessary to realize the current physical situation and effectiveness of physical training, but also usefully applied on evaluating individual physical activities. In order to realize the $VO_{2\max}$ of male military personnel and how Fat(%) and BMI correlate with $VO_{2\max}$, here we measured $VO_{2\max}$ by Bruce protocol, Fat (%), and BMI (kg/m^2) of Taiwan male military personnel. Forty subjects aged 21 to 40 year-old (10 participants for per 5-year-age group) took part into this study. The results indicated that a significantly positive correlation between BMI and Fat(%) was found (r=0.6709), and that relative $VO_{2\max}$ significantly negatively correlated more highly with Fat(%) (r=-0.6049) than with BMI (r=-0.3613). Therefore, regular physical training made by Taiwan military personnel could help improve their cardiopulmonary capability, and then causing a reduction in Fat (%). On the other hand, with similar BMI but with less Fat(%) seemed supported the effectiveness of the physical training policy consistently performed in Taiwan military.

Keywords*:* *Maximal Oxygen Consumption, Body fat, Body mass index, cardiopulmonary function*

1. INTRODUCTION

Current physical activity patterns are undoubtedly the lowest they have been in human history, with particularly marked declines in recent generations, and future projections indicate further declines around the globe. Studies indicates that higher levels of physical activity are associated with more favorable cardiac structure and function [1]. Higher levels of physical activity also attenuate the cardiovascular disease mortality risk associated with obesity [2-4].

Physical training is important for health and there is no doubt that optimal health and physical fitness are critical to ensure that military personnel can perform their duties well. Maximal oxygen consumption, $VO_{2\max}$, is an excellent index to assess the cardiopulmonary functions in the area of physical training. In Taiwan, Minister of Defense (MOD) asks each military personnel should accept physical training test every year, including push-up, sit-up, and 3000m-running, in which the 3000m-running is a subject to assess individual's cardiopulmonary function. On behalf of the health and keeping the fitness of military personnel, they are allowed and encouraged to make exercise or train themselves after 4 pm every day.

Smith *et al.* [5] showed that high intensity power training significantly improves $VO_{2\max}$ and body composition of both genders. Overall, aerobic exercise training programs consistent with public health recommendations may promote up to modest weight loss (~2 kg), [6] (Swift *et al.*, 2014). In addition, epidemiological data demonstrated that low levels of physical activity are associated with a higher prevalence of obesity [7, 8]. Obesity has become one of the major health concerns of modern times, and it is associated with less physical activity or exercise training, those are supposed to be a negative effect on the cardiopulmonary function.

Overweight and obesity are defined by WHO as abnormal or excessive fat accumulation that may impair health. Body mass index (BMI) is a simple index of weight-for-height that is commonly used to classify overweight and obesity in adults. It is defined as a person's weight in kilograms divided by the square of his height in meters (kg/m^2). BMI provides the most useful population-level measure of overweight and obesity as it is the same for both sexes and for all ages of adults. However, it should be considered a rough guide because it may not correspond to the same degree of fatness in different individuals. The prevalence of obesity and associated chronic diseases has increased rapidly in Taiwan. For adults, obesity prevalence rates defined by BMI ≥27 increased from 10.5% in men and 13.2% in women in the 1993–1996 survey, to around 17% in 2005. Prevalence of overweight, 24≤BMI<27, was around 20% in 1993–1996 for both men and women, and increased to 30% in 2005 for men, but no change was found in women [9]. Table 1 demonstrates the BMI classification from WHO and Ministry of Health and Welfare of Taiwan (MoHW), and it reflects the fact found by Chang *et al.* [10] of at the same classification but with lower BMI for Asians. Deurenberg *et al.* [11] indicated that Chinese females were shorter, lighter and had a lower BMI, but the sum of four skinfolds was much higher than in Caucasian girls. Also, the Chinese boys were shorter and lighter, but their body mass index was not lower compared to Caucasian boys. Their skinfold thickness was much higher compared to Caucasians. In addition, a number of studies have also shown that it is not appropriate to use a single BMI cut-off point to detect obesity as different BMI-%BF relationships have been observed in different ethnic groups [12, 13]. Nevertheless, BMI is also a quick measure to assess percentage of body fat (Fat %). Gallagher *et al.* [14] built a equation to predict Fat(%) through BMI, sex, age, ethnic group. Jackson et al. [15] explored the relationship between BMI and Fat% was quadratic for both men and women, and that BMI and Fat% relationship are not independent of age and gender.

Rowland [16] indicated that relative $VO_{2\max}$ (oxygen consumption per kilogram of body weight, in *ml*/min/kg) and treadmill endurance time both declined as fatness increased (r= −.49 and −.42, respectively). Irwin *et al.* [17] demonstrated that regular exercise such as brisk walking resulted in reduced body weight and body fat among overweight and obese postmenopausal women. McTiernan *et al.* [18] indicated that exercisers with greater increases in pedometer-measured steps per day had greater decreases in weight, BMI, body fat, and intra-abdominal fat, and similar trends were observed for increased minutes per day of exercise and for increases in maximal oxygen consumption.

Taiwan military personnel execute physical training to make fitness, which is expected not only to maintain their BMI in a moderate range, but to improve the cardiopulmonary function. According to above, two hypotheses are proposed as the followings.

1. Military personnel $VO_{2\max}$ is negatively correlated with both Fat(%) and BMI.
2. Military personnel $VO_{2\max}$ is more highly correlated with Fat(%) than with BMI.

Table 1: The BMI classified by WHO and Taiwan MoHW

Classification	WHO	Taiwan	Classification
Very severely underweight	BMI<15		
Severely underweight	15≤BMI<16		
Underweight	16≤BMI<18.5	BMI<18.5	Underweight
Normal	18.5≤BMI<25.0	18.5≤BMI<24.0	Normal
Overweight	25.0≤BMI<30.0	24.0≤BMI<27.0	Overweight
Moderately obese	30.0≤BMI<35.0	27.0≤BMI	Obese
Severely obese	35.0≤BMI<40.0		
Very severely obese	40.0≤BMI		

2. METHODS

2.1. Paticipants

Forty male military personnel aged 21 to 40 years old took part into this study, and ten participants were included in per 5-year-age group, say 21-25 yrs., 26-30 yrs., 31-35 yrs., and 36-40 yrs. The mean (standard deviation, SD) age, height, weight, and BMI associated with each 5-year age group are as shown in Table 2.

Table 2: The demography of participants

Group	Age (years)		Height (cm)		Weight (kg)		BMI (kg/m^2)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
21-25 yr.	21.2	0.8	176.3	6.6	70.2	9.4	22.6	2.1
26-30 yr.	28.1	1.3	174.9	8.5	72.6	10.0	23.7	2.3
31-35 yr.	33.3	1.3	172.3	6.0	71.3	6.2	24.1	2.5
36-40 yr.	37.0	1.2	169.9	6.1	68.5	7.2	23.8	2.3
Overall	29.9	6.1	173.3	7.0	70.7	8.1	23.5	2.3

2.2. Materials and apparutus

In this study, Inbody 220 (Inbody Co., Ltd.) was used to measure percentage of fat (Fat (%)). The $VO_{2\max}$ was measured by mobile cardiopulmonary exercise testing system (Oxycon™ mobile device). Additionally, T5 treadmill (Momentum Series, Greenmaster Inc, Taiwan）was used for measuring $VO_{2\max}$ according to Bruce treadmill test.

2.3. Experimental procedures

First, the experimental procedure and goal were explained, and all participants signed an informed consent. Then participants' demography and Fat(%) were measured. Next, the Bruce treadmill test protocol was employed to measure $VO_{2\max}$. $VO_{2\max}$ refers to the maximum amount of oxygen that an individual can utilize during intense or maximal exercise. It is measured as "millilitre of oxygen used in one minute per kilogram of body weight" (ml/kg/min).

Before formal measurement, participants were asked to rest for 5 minutes. During this period, mean heart rate (HR_{rest}), respiratory exchange ratio (RER_{rest}), and oxygen uptake ($VO_{2\max}$) were recorded. Next, participants warmed up by walking on the treadmill for 3 minutes with a speed adjusted by themselves. Then they rested for 5 minutes to let heart rate back to the level as at rest. This test requires the participant to run for as long as possible on a treadmill whose speed and slope increments at timed intervals. During the measurement the assistant first set the treadmill up with a speed of 6 km/hr. and an incline of 7% (Stage 1) . Next the assistant gave the command "GO", started the stopwatch and the participant commenced the test. The assistant, at the appropriate times during the test, adjusted the treadmill's speed and slope shown in Table 3.

Table 3: The settings for Bruce treadmill test

Stage	Stage Duration (min)	Speed (km/h)	Grade(%)
S1	2	6	7
S2	2	7	8
S3	2	8	9
S4	2	9	10
S5	2	10	11
S6	2	11	12
S7	2	12	13
S8	2	13	14

The test was terminated and considered maximal when subjects reached self-determined exhaustion, and was verified by the two of following criteria: (1) plateau in oxygen consumption despite an increase in workload, (2) respiratory exchange ratio (RER) greater than 1.1, (3) rating of perceived exertion of 18-20, and (4) the heart rate reached the range of $HR_{max}\pm15$, where the HR_{max} is maximal heart rate equal to (220-age).

2.4. Experimental design

One-way ANOVA was first used to test the age-group effect on relative $VO_{2\max}$ (ml/min/kg), BMI and Fat (%). There were 4 year-age groups, say 21-25 yrs., 26-30 yrs., 31-35 yrs., and 36-40 yrs. Furthermore, a correlation analysis was to explore the relationship between $VO_{2\max}$ and BMI and Fat (%).

3. RESULTS AND DISCUSSION

The mean absolute $VO_{2\max}$, relative $VO_{2\max}$, and Fat(%) shown in Table 4 were 3.409 (*l*/min), 48.5 (*ml*/kg/min), and 20.2 (%), respectively. A one-way ANOVA result demonstrated that age-group effect was not significant on relative $VO_{2\max}$, Fat(%), or BMI.

As it can be seen in Table 5, it indicates that relative $VO_{2\max}$ significantly negatively correlated with both BMI (r=-0.3613) and Fat(%) (r=-0.6049), which supports our first hypothesis. A positive correlation between Fat (%) and BMI was also found in present study (r=0.6709); this finding was similar to that f Mehrzad *et al.* [19], who revealed that Fat (%) significantly positively correlated with BMI (p=0.783) for male physical education students.

Relative $VO_{2\max}$ significantly correlated with weight (r=-0.3714) as well. Therefore, worse cardiopulmonary capability of military personnel could be associated with more Fat (%). On the other hand, the correlation coefficient between relative $VO_{2\max}$ and Fat(%)(r=-0.6049) was more pronounced than that between relative $VO_{2\max}$ and BMI (r=-0.3613). It also supports our second hypothesis.

Furthermore, here BMI highly correlated with weight (r=0.6950), but not with height. Fat (%) increased with age (r=0.4747), weight (r=0.3144), and BMI (r=0.6709) significantly, but negatively correlated with height (r=-0.3219).

Table 4: The means (SD) for absolute and relative $VO_{2\max}$, and Fat(%)

Group	$VO_{2\max}$ (*l*/min)		$VO_{2\max}$ (*ml*/kg/min)		Fat (%)	
	Mean	SD	Mean	SD	Mean	SD
21-25 yr.	3.651	0.470	52.3	5.3	17.1	4.2
26-30 yr.	3.489	0.423	48.3	4.0	19.9	2.7
31-35 yr.	3.208	0.351	45.2	5.7	21.7	4.9
36-40 yr.	3.289	0.585	48.3	8.9	22.1	5.2
Overall	3.409	0.480	48.5	6.5	20.2	4.6

Table 5: The results for correlation analysis

	Relative $VO_{2\max}$	BMI	Fat(%)
Age	N.S.	N.S.	.4747**
Height	N.S.	N.S.	-.3219*
Weight	-.3714*	.6950***	.3144*
BMI	-.3613*		.6709***
Fat(%)	-.6049***		

*** p<0.001; **p<0.01; *p<0.05
N.S. means not significant

About the relationship between Fat (%) and BMI, past studies revealed it depends on age, gender and ethnicity [10, 11, 20, 21]. For example, Chang *et al.* [10] showed that Taiwanese subjects had a relatively lower BMI but a higher BF% than Caucasians, and they proposed a new Asia-Pacific BMI cutoffs for overweight (≥23 kg/m^2) and obesity (≥25 kg/m^2) to both male and female Taiwanese subjects. The corresponding Fat (%) cutoffs for overweight would be 23% in male and 35% in female Taiwanese subjects, respectively. For obesity the corresponding Fat(%) cutoffs would be 25% in male and 38% in female Taiwanese subjects, respectively. Based on Chang *et al.* [10], present study showed the average BMI was 23.5, being overweight, but the mean Fat (%) of 20.2 seemed lower than the value of 23. This seemed to imply that military personnel had greater not-fat mass compared with general Taiwanese, which could result from the effectiveness of military physical training.

4. CONCLUSIONS

Our two hypotheses were supported. Relative $VO_{2\max}$ significantly negatively correlated with BMI and Fat (%), and relative $VO_{2\max}$ correlated with Fat(%) more highly than with BMI. A significantly positive correlation between BMI and Fat (%) was found. Therefore, regular physical training like Taiwan military personnel could help improve their cardiopulmonary capability, and then resulting in a reduction in Fat (%). On the other hand, with similar BMI but with less Fat (%) seemed supported the effectiveness of the physical training policy consistently performed in Taiwan military.

REFERENCES

[1] Turkbey, E. B., Jorgensen, N. W., Johnson, W., Bertoni, A. G., Polak, J. F., Roux, A. D., Bluemke, D. A. (2010). Physical activity and physiological cardiac remodelling in a community setting: the Multi-Ethnic Study of Atherosclerosis (MESA). Heart, 96(1), 42-48.

[2] Dwyer, T., Hosmer, D., Hosmer, T., Venn, A., Blizzard, C., Granger, R., Zimmet, P. (2007). The inverse relationship between number of steps per day and obesity in a population-based sample–the AusDiab study. International journal of obesity, 31(5), 797-804.

[3] Hu, G., Tuomilehto, J., Silventoinen, K., Barengo, N., Peltonen, M., & Jousilahti, P. (2005). The effects of physical activity and body mass index on cardiovascular, cancer and all-cause mortality among 47 212 middle-aged Finnish men and women. International journal of obesity, 29(8), 894-902.

[4] Lee, D., Sui, X., & Blair, S. N. (2009). Does physical activity ameliorate the health hazards of obesity? British journal of sports medicine, 43(1), 49-51.

[5] Smith, M. M., Sommer, A. J., Starkoff, B. E., & Devor, S. T. (2013). Crossfit-based high-intensity power training improves maximal aerobic fitness and body composition. The Journal of Strength & Conditioning Research, 27(11), 3159-3172.

[6] Swift, D. L., Johannsen, N. M., Lavie, C. J., Earnest, C. P., & Church, T. S. (2014). The role of exercise and physical activity in weight loss and maintenance. Progress in cardiovascular diseases, 56(4), 441-447.

[7] Jebb, S. A., & Moore, M. S. (1999). Contribution of a sedentary lifestyle and inactivity to the etiology of overweight and obesity: current evidence and research issues. Medicine and science in sports and exercise, 31(11 Suppl), S534-541.

[8] Lahti-Koski, M., Pietinen, P., Heliövaara, M., & Vartiainen, E. (2002). Associations of body mass index and obesity with physical activity, food choices, alcohol intake, and smoking in the 1982–1997 FINRISK Studies. The American journal of clinical nutrition, 75(5), 809-817.

[9] Pan, W. H., Lee, M. S., Chuang, S. Y., Lin, Y. C., & Fu, M. L. (2008). Obesity pandemic, correlated factors and guidelines to define, screen and manage obesity in Taiwan. Obesity Reviews, 9(s1), 22-31.

[10] Chang, C.-J., Wu, C.-H., Chang, C.-S., Yao, W.-J., Yang, Y.-C., Wu, J.-S., & Lu, F.-H. (2003). Low body mass index but high percent body fat in Taiwanese subjects: implications of obesity cutoffs. International journal of obesity, 27(2), 253-259.

[11] Deurenberg, P., Deurenberg Yap, M., & Guricci, S. (2002). Asians are different from Caucasians and from each other in their body mass index/body fat per cent relationship. Obesity Reviews, 3(3), 141-146.

[12] Deurenberg-Yap, M., Schmidt, G., Van Staveren, W., & Deurenberg, P. (2000). The paradox of low body mass index and high body fat percentage among Chinese, Malays and Indians in Singapore. BODY COMPOSITION AND DIET OF CHINESE, MALAYS AND INDIANS IN SINGAPORE, 69

[13] Deurenberg, P., Bhaskaran, K., & Lian, P. L. K. (2003). Singaporean Chinese adolescents have more subcutaneous adipose tissue than Dutch Caucasians of the same age and body mass index. Asia Pacific journal of clinical nutrition, 12(3), 261-265.

[14] Gallagher, D., Heymsfield, S. B., Heo, M., Jebb, S. A., Murgatroyd, P. R., & Sakamoto, Y. (2000). Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. The American journal of clinical nutrition, 72(3), 694-701.

[15] Jackson, A., Stanforth, P., Gagnon, J., Rankinen, T., Leon, A., Rao, D., Wilmore, J. (2002). The effect of sex, age and race on estimating percentage body fat from body mass index: The Heritage Family Study. International journal of obesity and related metabolic disorders: journal of the International Association for the Study of Obesity, 26(6), 789-796.

[16] Rowland, T. W. (1991). Effects of obesity on aerobic fitness in adolescent females. American Journal of Diseases of Children, 145(7), 757-762.

[17] Irwin, M. L., Yasui, Y., Ulrich, C. M., Bowen, D., Rudolph, R. E., Schwartz, R. S., McTiernan, A. (2003). Effect of exercise on total and intra-abdominal body fat in postmenopausal women: a randomized controlled trial. Jama, 289(3), 323-330.

[18] McTiernan, A., Sorensen, B., Irwin, M. L., Morgan, A., Yasui, Y., Rudolph, R. E., Ayub, K. (2007). Exercise effect on weight and body fat in men and women. Obesity, 15(6), 1496-1512.

[19] Mehrzad, S., Saeid, S., & Rouholah, F. (2015). Study of body mass index (BMI), body fat percent (% Bf), and waist to hip ratio (whr) in male physical education students. Физическое воспитание студентов(3), 29-37.

[20] He, W., Li, Q., Yang, M., Jiao, J., Ma, X., Zhou, Y., Zhu, S. (2015). Lower BMI cutoffs to define overweight and obesity in China. Obesity, 23(3), 684-691.

[21] Wang, J., Thornton, J. C., Russell, M., Burastero, S., Heymsfield, S., & Pierson, R. (1994). Asians have lower body mass index (BMI) but higher percent body fat

than do whites: comparisons of anthropometric measurements. The American journal of clinical nutrition, 60(1), 23-28.

GUIDING HUMAN BEHAVIOR TO REDUCE QUALITY CONTROL ERRORS

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Abstract

It is estimated that human error in the quality control checking of product labels on consumer packaging costs the UK retail industry £50m per annum. Our research program aimed to understand the behavior of individuals when performing label checks on fresh produce in order to inform the development of a software application designed to support quality control. On a simulated label checking task, eye-tracking data showed that individuals used different checking methods. A more systematic method led to higher accuracy. Two computer-assisted approaches, varying in the level of computer support provided, were then designed to push checkers towards systematic checking. Greater improvements in accuracy were found under the computer-assisted approaches than under a control condition. A three-month onsite trial of a software application designed on the basis of these research findings led to a 100% decrease in quality control errors.

Keywords: Quality control checking; Distributed cognition; Human error; Cognitive load

1. INTRODUCTION

Quality control checks sometimes fail to detect errors produced when products are packaged and labelled. It has been estimated that such errors cost UK industry £50m per year in recall and replacement (S. Hinks, Product Technical Manager: Fruit and Floral, Sainsbury's Supermarkets Ltd, personal communication). The failure to detect label errors occurs despite rigorous quality control checking procedures carried out independently by three or four different human operatives. Whilst the vast majority of labelling errors are successfully detected in the packaging facility in which they occur, the repercussions of the relatively few errors which do escape the notice of the quality control checkers are great, both financially and environmentally. In the case of fresh fruit and vegetables (the particular concern of the research reported in this paper), mis-labelled produce, once detected, has to be recalled from retail outlets across the country, returned to warehouses, and disposed of. This wastes a large amount of perfectly edible food, disrupts the flow of goods in the supply chain, takes up valuable employee time, results in increased transportation costs, and has a negative impact on sales. Indeed, labelling errors on fresh produce are estimated to cost UK supermarkets some £8-10m a year (S. Hinks, personal communication). As well as the energy, water, and other resources wasted in cultivating the produce in the first place, similar levels of resources are needed to grow and transport replacements. The carbon footprint attached to these errors is thus significant. Research is becoming increasingly concerned with how the capabilities of the human brain can be extended through the use of, and interaction with, technological devices [1, 2]. The work described in this paper demonstrates how an understanding of human cognitive limitations can be used to develop a software application to make quality control checking of product labels more effective, thereby reducing both financial and environmental waste. A multi-stage, mixed-methods research program was undertaken to understand the cognitive processes involved in label-checking. The aim of the project was to use this understanding to produce a technological solution which would reduce or eliminate the human error that leads to detection failures.

2. THE REAL-WORLD ENVIRONMENT

Due to the dynamic environment within which supermarket orders are processed, the wide variety of produce, the last-minute availability of information which labels must contain, and the fact that different hardware is used on different production lines in the packaging facility, it was not possible for the packaging facility to achieve a simple, over-arching software solution to the problem of detecting errors on fresh produce labels (D. Boakes, Technical Development Director, Mack, personal communication). As a consequence, a human-centered approach to solving the problem needed to be found.

As an initial step in understanding label-checking behavior, the packaging and quality control processes and systems were viewed in operation in a large-scale production environment (henceforth referred to as the “pack-house”). Observations of the working systems were undertaken on-site, noting the differing roles of the operatives in the process, together with an examination of the historical error data held by the pack-house and interviews with operatives. The data gathered from these sources highlighted the extremely complex interaction between humans and technology in a highly dynamic working environment. To give an indication of the scale of the operation, in one week, the pack-house deals with 153 stock-keeping units (SKUs) for fruit plus 20 for vegetables, resulting in orders on over 170 SKUs every day. Variations in the size, variety, and grower of the produce must be accommodated when making up orders for a run on a packaging line. Over the course of a month, some 4500 label checks are performed (D. Boakes, Mack, personal communication).

The process begins with the packaging company’s commercial office being contacted by a supermarket’s commercial team with a list of weekly updates to their order (such as size changes to produce, new promotions, etc.). This information is then entered into a product specification sheet. Typically, three to seven versions of the product specification sheet are produced over its week-long lifespan, as orders are changed or errors are detected on earlier versions.

A new product specification sheet is produced and disseminated to the pack-house on the same day each week. At the label production stage, operatives are required to generate labels, drawing information from the product specification sheet to transfer onto the product labels. The specification sheet provides data on, for example, the weight of the fruit, the number of pieces of fruit, the grower of the fruit, the country of origin, and current promotions offered on the product. During this label production process, different types of errors can occur, such as the misplacing or incorrect entry of information, the omission of necessary information, or mistakes in spelling.

After an initial check of the label by the team leader of the line charged with packaging the product in question, the onsite label-checking process is normally performed by experienced quality control staff. However, despite their overall effectiveness in detecting errors, some errors do still escape the pack-house, being picked up instead, and belatedly, in distribution depots or, most seriously, in the supermarkets themselves. When a labelling error results in a product having to be recalled from the supermarket shelves, the fines imposed on the packaging company by their supermarket customers are considerable (running into the tens of thousands of pounds per error). Whilst the overall incidence of label errors might be low, the consequences of even a handful of these passing through quality control undetected are great, with repercussions to the packaging company both financially and in terms of reputation, as well as tying up packaging lines and their operatives with laborious re-packaging tasks and, where mistakes cannot be rectified onsite, leading to massive waste of packaging and products.

3. LABEL-CHECKING

In checking a label, a quality control checker must move between two sources of information. The first of these, the product specification sheet (a simplified version of which is presented in Figure 1), contains details of the supermarket orders for a number of different products. Between three and 11 fields of information are presented for each entry (e.g., product name, best-before date, product weight, country of origin).

PRODUCT	COUNTRY	GROWER	QUANTITY	BB	BARCODE	Promotion Ribbon / Label
BABY COURGETTES	EGYPT	GREEN EGYPT	200g	24-Oct	0118 4648	MIX & MATCH Any 2 for £2.50
BABY COURGETTES	SPAIN	AGRO ORGANICS	200g	25-Oct	0118 4648	MIX & MATCH Any 2 for £4
GLOBE ARTICHOKE	FRANCE	SICAGRI	250g	25-Oct	0043 4648	
COURGETTES	MOROCCO	BIO TROPIC	300g	25-Oct	0109 1922	£2.25
GLOBE ARTICHOKE	KENT, UK	MARK BATCHELOR	250g	25-Oct	0043 7141	Half price

Figure 1: A simplified product specification sheet.

The checker must read off the information from the appropriate row of the product specification sheet and check it against its corresponding entry on the product label (Figure 2, overleaf). In addition to the information printed on the label itself, the checker must also verify that any promotional information is correctly presented on an additional ribbon or sticker accompanying the label (e.g., “2 for £2.50”). Quality control checkers must exercise vigilance when checking every field printed on the label since errors can occur in any of the fields of information on the label. In some cases, fields of information have a statutory legal requirement to be presented correctly.

Figure 2: A fresh produce label for the pack-house's largest supermarket customer.

4. TAKING LABEL-CHECKING INTO THE LABORATORY

Having gained an understanding in situ of label-checking on an organizational level, the research was then taken into the laboratory to investigate the human cognitive behavior involved in the process. A simulated label-checking task was, therefore, presented [3] to both experienced quality control staff (mean years of experience = 5, SD = 4) and university students who were naïve to label-checking.

An Eyelink 1000 Desktop 1000 eye tracker (SR Research Ltd., Ontario, Canada) allowed the use of a gaze-contingent paradigm to mimic the need for label checkers to orientate the product specification sheet and the label itself. Both the product specification sheet and the label were facsimiles of comparable items used in the pack-house. Only one or other source of information was available to participants at any given time, depending on whether they fixated on the upper (the product specification sheet) or lower half (the label) of the computer monitor. Over a series of trials, the participants were asked to check that the details printed on the label correctly matched with the corresponding information set out in the product specification sheet. The number of fields of information shown on the product specification sheet was held constant at seven per label with the same fields being presented on all product labels. The fields in question were the product (vegetable or fruit type), the country of origin, the grower name, the quantity and/or weight of items, the best-before date (indicated by "BB" on the product specification sheet), the barcode number, and details of any promotion ribbon/label to be appended to the packaging (e.g., "Any 2 for £2.50").

In the majority of trials, the information printed on the label matched with that appearing on the product specification sheet. However, labels which contained a mismatch in one field of information were also presented. The ratio across trials was 80% matches to 20% mismatches. Whilst the frequency of labels containing a mismatch was much larger than that generated in the real-life pack-house environment, it was necessary to use such a ratio in order to obtain sufficient data for statistical analysis whilst also ensuring that the task did not become boring or overly time-consuming for participants to the detriment of data quality and participant recruitment.

Eye movements were logged as the participants performed a series of label checks on the simulated checking task. Experienced checkers were found to use different approaches to the task. Those checkers who were most accurate in detecting label errors were also the most systematic in their behavior, reading one field of information from the product specification sheet, checking this against the corresponding entry on the label, and then moving back to the product specification sheet to read the next field of information. Other experienced checkers adopted a chunking approach [e.g., 4], in which they read several fields of information from the product specification sheet before checking them all against the label in a single visual pass. The remaining experienced checkers did not show a discernable pattern in their label-checking behavior, being haphazard in their approach. The level of experience which checkers had with the task did not predict the type of approach which was taken. Moreover, inexperienced undergraduate students were found to be no less accurate at detecting label errors than the experienced checkers. This meant further experiments could be run using naïve participants, thereby making available a larger participant pool for the research.

5. USING TECHNOLOGY TO GUIDE BEHAVIOR

Having established that a systematic approach led to the highest error detection rates [3], the question then became how best to ensure that the behavior of all quality control operatives conformed to this label-checking method. Achieving such conformity would reduce the impact of individual differences and optimize performance.

Unlike traditional approaches which view cognition as occurring solely within the mind of a given individual [5], advocates of distributed or external cognition place much greater emphasis on the dynamic interaction between internal, mental resources and resources available in the environment [6, 7, 8]. These external resources are able to guide, constrain, and shape the way in which cognition proceeds [e.g., 5, 9]. From this perspective, the human agent can be viewed as one (albeit crucial) part of a larger cognitive unit [10]. Distributing cognition over internal and external representations might also serve to reduce cognitive load [11] and, as a result, improve performance [e.g., 12, 13]. In particular, having an external means of ensuring that checkers checked one field of information at a time would be likely to reduce the demands placed on short-term memory [e.g., 14] in temporarily retaining information whilst performing the task. Under this approach, the cognitive demands of the task could be lessened by being distributed either across individuals or between an individual and a software-based tool and, thereby, improve performance.

The first such method to be tested involved distributing the task over two individuals [e.g., 10], with one checker reading out one field of information at a time from the product specification sheet and the second checker verifying the correctness of the corresponding entry on the label. However, a short trial of this approach in the pack-house indicated that this method was not viable since the demands of the work environment meant that two checkers were often not available at the same time. Furthermore, despite generally seeing the value of the method, there was some resistance amongst employees to changing to this new method as it was felt to be too time-consuming and too resource-heavy to be practical.

The second method tested involved distributing the task over a human operative and a computer. By coupling human performance to that of a computer, it was thought that label-checking behavior could be pushed towards a more systematic approach, with the computer guiding the checker through the information one field at a time.

Two computer-coupled methods were tested [15] against a control condition in which no computer support was provided, in order to establish the appropriate level of technological support for guiding the label-checking process towards a systematic approach which was associated with better performance on the simulated task. The two methods differed in the extent to which the computer was involved in guiding behavior. The first method was unimodal and entailed visually highlighting the current field of information to be checked on the product specification sheet. The checker moved a red box onto the next field on the product specification sheet after checking the previous entry on the product label. The second method, which distributed cognition even further, involved highlighting the current field visually but in addition, a pre-recorded voice "read out" the information which should, if correct, be displayed in the current field of the label. Thus, computer support was offered bimodally, with information being provided in both visual and auditory modes at the same time. Participants in all three conditions completed an initial block of 50 trials (Block 1), using their own self-adopted method of checking, allowing performance in Block 2 to be compared against a baseline level.

Mean improvement rates are shown in Figure 3. Overall, regardless of condition, improvement was seen between the first block of trials (where participants used their own idiosyncratic method of checking) and the second block of trials (where the participants continued to use their own method or used a computer-coupled method). However, a one-way unrelated analysis of variance indicated that there was a significant effect of checking method condition on improvement score, $F(2, 55) = 3.39$, $MSE = 0.003$, $p = .041$.

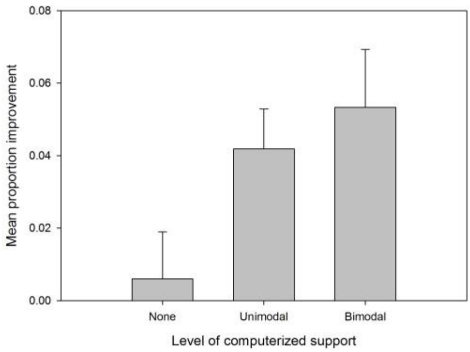

Figure 3: Mean proportion of improvement moving from Block 1 to Block 2.

Post hoc Sidak tests indicated that, compared with the small improvement in overall accuracy in the control condition (where idiosyncratic approaches were carried across from Block 1), the improvement in accuracy was significantly greater for the bimodal condition, $p = .048$. The difference in improvement scores between the unimodal and the control conditions was not statistically significant, $p = .160$, nor was the difference between the two computer-coupled methods, $p = .903$. Whilst both computer-coupled methods led to more accurate performance compared with that of the control condition, only the bimodal method, with its use of both visual and auditory information to guide and aid checking, resulted in a significant improvement in accuracy relative to checkers using their own idiosyncratic methods. Whilst small in absolute terms, the 5% improvement in accuracy seen in the bimodal condition would translate to significant financial and environmental savings, reducing the number of costly large-scale recalls.

6. GREENLIGHT LABEL CHECK

The data collected in the two experiments described above and reported in more detail elsewhere [3, 15] were used to inform the development by Muddy Boots Software Ltd of a simple Windows software application to assist quality control checkers in making decisions about the accuracy of information on labels. Known as "Greenlight Label Check", the application adopts a similar method to the distributed approach tested experimentally, providing both visual and auditory information and cues to facilitate label-checking. The checker is guided through the process of checking, with only one field of information being presented at a time for verification. In this way, a strictly serial approach to the label-checking task is ensured. In addition to the control of the visual information available to the checker, speech production software can read out the relevant entry on the product specification sheet for checking against the label. Once the checking of the product label is completed, the results are distributed via a mailing list to relevant managerial staff and are also stored centrally for effective data management. Images of the label can be captured if further evidence is needed for record keeping.

Greenlight Label Check was given a three-month live site trial at a large pack-house facility. Over this period, the number of label errors which got through to the final customer dropped to zero. Comments from quality control staff indicated that they found the new system more efficient, allowing quicker and more accurate checking of labels (D. Boakes, Mack, personal communication).

7. CONCLUSION

The program of research and development described in this paper has achieved noteworthy success in reducing the frequency with which fresh produce label errors escape detection by quality control operatives. The results of the live on-site trial indicate that a computer-coupled method of checking is even more successful in situ than in the artificial confines of the controlled laboratory setting. The economic and environmental benefits of reducing the waste associated with mislabeled produce are obvious. Moreover, the simplicity and effectiveness of the Greenlight Label Check software application also means that the task of label-checking no longer needs to be restricted to specialist quality control staff. This frees them to focus on other aspects of the role for which their skills are required by allowing less experienced staff to undertake the label checking task with confidence.

In conclusion, the results of this research program indicate how psychological principles can be applied successfully to solving real-world problems, helping to guide software designers towards producing a label-checking application underpinned by cognitive theory. It has been argued that communication between humans and machines can be made more effective if the differences in their capacities are stressed rather than downplayed [2]. The methodical, serial approach to checking one piece of information at a time is just the sort of task at which a machine excels and which, by contrast, taxes human operatives, due to its attentional and memory demands, particularly over sustained periods of activity. Greenlight Label Check adopts just such a serial approach, taking over that part of the checking task which inaccurate human label-checkers find most problematic.

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REFERENCES

[1] Baranyi, P. & Csapó, A.: Definition and synergies of Cognitive Infocommunications, *Acta Polytechnica Hungarica*, **9** (2012) 1, pp. 67-83, 1785-8860

[2] Baranyi, P., Csapó, A. & Varlaki, P.: An overview of research trends in CogInfoCom, *IEEE 18th International Conference on Intelligent Engineering Systems (INES 2014)*, pp. 181-186, July 2014

[3] Smith-Spark, J.H., Katz, H.B., Marchant, A.P., & Wilcockson, T.D.W.: The quality control checking of fresh produce labels: Reducing errors by changing behaviour, manuscript in preparation.

[4] Miller, G. A.: The magical number seven, plus or minus two: Some limits on our capacity for processing information, *Psychological Review*, **63** (1956) 2, pp. 81-97, 0033-295X

[5] Zhang, J. & Norman, D.A.: Representations in distributed cognitive tasks, *Cognitive Science*, **18** (1994) 1, pp. 87-122, 1551-6709

[6] Scaife, M. & Rogers, Y.: External cognition: How do graphical representations work?, *International Journal of Human-Computer Studies*, **45** (1996) 2, pp. 185-213, 1071-5819

[7] Clark, A. & Chalmers, D. J.: The extended mind, *Analysis*, **58** (1998) 1, pp. 10-23, 0003-2638

[8] Zhang, J.: The nature of external representations in problem solving, *Cognitive Science*, **21** (1997) 2, pp. 179-217, 1551-6709

[9] Clark, A.: Coupling, constitution, and the cognitive kind: A reply to Adams and Aizawa, In *The Extended Mind*, MIT Press, 0-262-01403-8, Cambridge, MA, (2010), pp. 81-100

[10] Hutchins, E.: *Cognition in the wild*, MIT Press, 0-262-58146-9, Cambridge, MA, (1995)

[11] Sweller, J.: Cognitive load during problem-solving: Effects on learning, *Cognitive Science*, **12** (1988) 2, pp. 257-285, 1551-6709

[12] Kirsh, D. & Maglio, P.: On distinguishing epistemic from pragmatic action, *Cognitive Science*, **18** (1994) 4, pp. 513-549, 1551-6709

[13] Glasspool, D.W., Oettinger, A., Smith-Spark, J.H., Fox, J., Castillo, F.C. & Monaghan, V.E.L.: Supporting medical planning by mitigating cognitive load, *Methods of Information in Medicine*, **46** (2007) 6, pp. 636-640, 0026-1270

[14] Cowan, N.: What are the differences between long-term, short-term, and working memory? *Progress in Brain Research: Vol. 169*. *Essence of Memory*, Elsevier, 0-444-53164-3, Amsterdam, (2008), pp. 323-338

[15] Smith-Spark, J.H., Katz, H.B., Marchant, A. & Wilcockson, T.D.W.: Label-checking strategies to adapt behaviour to design, *Proceedings of ECCE 2015: The 33rd annual conference of the European Association of Cognitive Ergonomics*, Warsaw, Poland, July 2015

FEMALE STUDENTS' BODY SEGMENTS RATIOS

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Abstract

A total of 25 anthropological measures were taken from a sample of 68 female students of the University of Zagreb, up to 29 years of age, from all regions of Croatia, central 90 % of which were determined by using calculated amounts for 5 and 95 percentiles. Arithmetic mean and harmonic mean of body ratios h_i/h and functional dependence $h_i=f(h)$ for individual anthropometric measures h_i in relation to the standing body height h were also determined. Presented research is only a smaller part of a larger scale research. Calculated arithmetic mean of female students body ratios h_i/h will be compared with results of many simultaneous researches for other populations of respondents such us: male engine drivers from Croatia for all age groups, male and female tram drivers from Zagreb for all age groups and male students of the University of Zagreb up to 29 years of age. A hypothesis of calculated arithmetic mean of body ratios h_i/h of different groups of respondents dependent on age, gender, demographic and socioeconomic factors, with the possibility for using results and /or simplified calculation method during the design of driver's cab in new trams and trains custom for Croatia market, will be researched.

Keywords*:* *female students, body lengths, ratios, functional dependencies*

1. INTRODUCTION

Presented results in this paper are only a smaller part of a larger scale research. Sixty eight (68) female students of the University of Zagreb from all regions of Croatia, who were the object of research, were in the range from 20 to 29 years of age.
Generally considering, for all the members of the same nation, it is widely known that amounts of anthropological measures h_i dominantly depend on age, gender, demographic and socioeconomic factors.
Within the larger scale research will be questioned the main hypothesis that the amounts of body ratios h_i/h for individual anthropometric measures h_i in relation to the standing height h, which are calculated as the arithmetic mean $\overline{h_i / h}$ or harmonic mean H, do not change significantly with the age, gender, demographic and socioeconomic factors.
Age is a significant factor of body stature [1]. The whole development of body dimensions reaches its peak towards the end of teenage or in the early 20s for men, while women reach this development a few years earlier. After maturity the body dimensions of both genders begin to decrease with age which is illustrated in Figure 1. Socioeconomic factors also have a significant influence on body stature [1]. Since a

socioeconomic factors are related to getting higher education level, the studies on students have indicated that students are taller than those of their age who do not study.

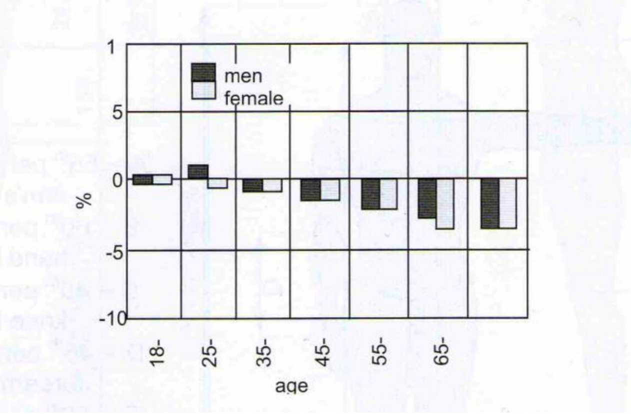

Figure 1: Relative changes in body stature depending on age and gender, for men and women at the age of 18 to 79
Source: Taken from Ujević, D. et al., 2009 [1]

The age of male engine drivers significantly affects body height *h*, that was confirmed by the own coauthors measurement results shown in Table 1 [2], and affects other anthropological measures h_i that are functionally dependent on the standing body height *h* (with a few minor exceptions). Results for standing body height *h* and mass *m* shown in Table 1 confirm the fact that is necessary to divide all the respondents of the same gender, such as male engine drivers from Croatia and/or male or female tram drivers from Zagreb, in a different age groups. One of the possible reasons for the different age when development of male body height *h* reaches its peak between the scientific claims from literature [1] and the results obtained from the past co-authors' research [2] could be an insufficient and unequal number of male engine drivers in four age groups.

Table 1: Body height *h* and mass *m* of male engine drivers in Croatia depending on age groups

Anthropo-logical measures	Symbol (unit)	age groups									
		all sample *(n = 51)*		up to 29 years *(n = 9)*		from 30 up 39 years *(n = 13)*		from 40 up 49 years *(n = 18)*		from 50 up 59 years *(n = 11)*	
		M	SD	M	SD	M	SD	M	SD	M	SD
Body height	*h (cm)*	178.9	5.7	177.2	6.0	180.6	6.2	178.6	6.1	178.5	4.0
Mass	*m (kg)*	91.9	14.1	81.4	13.9	96.5	12.9	91.2	11.3	95.6	16.5

Source: Taken from Mikulčić, M. et al., 2015 [2]

In the first part of a larger scale research arithmetic mean of body ratios $\overline{h_i / h}$ for female students of the University of Zagreb up to 29 years of age presented in this paper will be compared with arithmetic mean of body ratios $\overline{h_i / h}$ for female tram drivers from Zagreb up to 29 years of age, due to research of possible influence of socioeconomic factors on the respondents of the same age group and same sex.

Afterwards, in the second part of a larger scale research arithmetic mean of body ratios $\overline{h_i / h}$ for female students of the University of Zagreb up to 29 years of age presented in this paper will be compared with arithmetic mean of body ratios $\overline{h_i / h}$ for male engine drivers from Croatia up to 29 years of age, male and female tram drivers from Zagreb up to 29 years of age and male students of the University of Zagreb up to 29 years of age, due to research of possible influence of socioeconomic factors and gender.
Finally, in the last step of a large scale research, when male and female tram drivers and male engine drivers will be divided in the age groups, the main hypothesis will be investigated: "Is it possible that the age, gender, demographic and socioeconomic factors of respondents do not significantly affect on body ratios h_i/h in relation to the current standing body height h for all the anthropological measures h_i important for cabin design?"

2. MEASUREMENT RESULTS AND BODY RATIOS

Measurements were conducted during the first three months of the year 2016. Anthropological measures were taken at the same time of day, for the body's segments of the 62 respondents to the left side of the human body, because 62 of total 68 female students are right-handed. For the 6 left-handed respondents, there were measured the anthropological measures to the right side of the human body. The results are rounded to integers in centimeters.
If known, the arithmetic mean *M* and sample standard deviation *SD*, *5* centile and *95* centile for all anthropological measures h_i can be calculated [3], according to formulas (1) and (2).

$$5{,}0 \cdot c = M - 1{,}65 \cdot SD \quad (1)$$

$$95{,}0 \cdot c = M + 1{,}65 \cdot SD \quad (2)$$

Expression (3) for $\Delta h_{90\%}$ shows the calculated range of studied anthropological measures in the central 90% of sixty eight (68) female students of the University of Zagreb from the sample.

$$\Delta \mathrm{h}_{90\%} = 5{,}0 \cdot c \div 95{,}0 \cdot c \quad (3)$$

Figure 2 and Table 2 shows twenty five (25) typical anthropological measures in the sagittal and frontal planes, with all anthropological measures which are important for the design of driver's working environment in tram or train cabin, with labels by Kroemer et al. and Muftić et al. [3, 4]. Label 19 was added by co-authors.

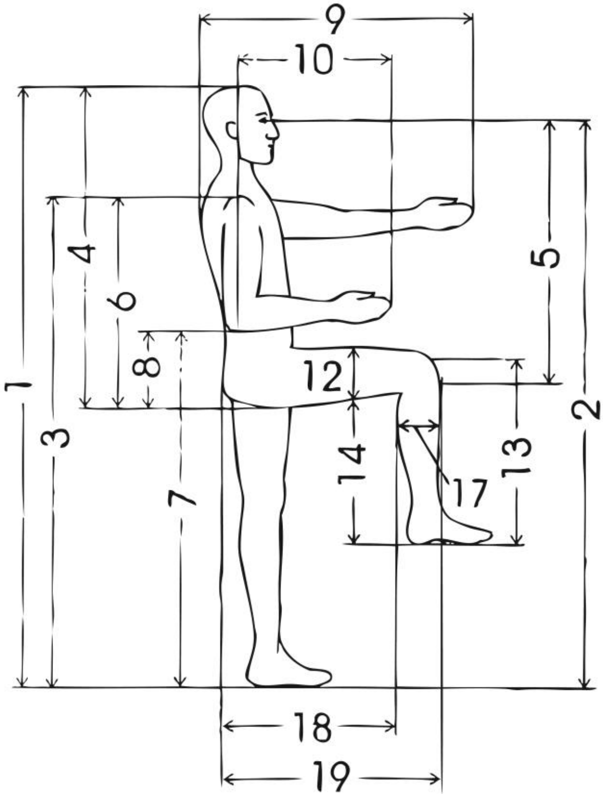

Figure 2: *Showing typical static anthropological measures in the sagittal plane by Kroemer*
Source: Complemented taken from Muftić et al., 2001 [4]

Results from Table 3 show calculated arithmetic mean $\overline{h_i / h}$ and harmonic mean H of body ratios h_i/h for individual anthropological measures h_i in relation to the standing body height h. Arithmetic mean $\overline{h_i / h}$ and harmonic mean H of body ratios h_i/h were calculated according to the formulas (4) and (5).

$$\overline{h_i / h} = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{h_i}{h} \qquad (4)$$

$$H = \frac{n}{\sum_{i=1}^{n} \frac{1}{x_i}} = \frac{n}{\sum_{i=1}^{n} \frac{1}{\left(\frac{h_i}{h}\right)}} \qquad (5)$$

Table 2: Anthropological measures sampled on female students up to 29 years

Name of anthropological measures/body segments	Symbol	Label by Fig. 2	all sample (*n = 68*)			
			M	*SD*	Percentiles	
			cm (kg*)	cm (kg*)	*5 %*	*95 %*
					cm (kg*)	
Body height	h	1	168.3	6.2	158.1	178.4
Mass*	m		61.8	10.4	44.7	78.9
Range of horizontally outstretched arms	h_{11}	11	165.5	7.9	153.6	179.5
Eye height in standing position	h_2	2	157.7	6.8	146.4	169.0
Shoulder height in standing position	h_3	3	140.1	8.0	126.9	153.2
Elbow height in standing position	h_7	7	106.6	10.2	89.7	123.5
Leg length	h_n		96.2	5.7	86.9	105.5
Normal arm reach (from the rear side of the elbow to the middle of a clenched fist)	h_{ndr}		33.5	1.9	30.5	36.6
Maximum arm reach (from the rear side of the acromion to the middle of a clenched fist)	h_{mdr}		61.1	3.1	55.9	66.2
Sitting height to vertex	h_4	4	88.7	3.6	82.8	94.6
Eye level in sitting position	h_5	5	78.4	3.6	72.5	84.3
Shoulder level in sitting position	h_6	6	59.5	3.1	54.3	64.6
Elbow level in sitting position	h_8	8	25.2	3.2	19.9	30.5
Knee height in sitting position	h_{13}	13	50.6	3.1	45.5	55.8
Foot length	h_{sd}		24.3	1.2	22.3	26.4
Ankle joint height	h_{sv}		6.8	0.9	5.4	8.2
Horizontal reach of outstretched arm (from back to the middle of a clenched fist)	h_{hdr}	9	69.4	3.9	62.9	75.9
Length of forearm and hand (from rare side of the elbow to the tip of the middle finger in a horizontal position)	h_{10}	10	44.5	2.0	41.2	47.8
Arm length (from acromion to the tip of the middle finger in a vertical position)	h_r		72.2	3.6	66.2	78.1
Hand length (distance between tip of the middle finger and the first crease in the wrist)	$h_{š}$		18.1	1.1	16.3	20.0
Below knee height in sitting posture	h_{14}	14	44.6	3.8	38.4	50.8
Bi-acromial range (shoulder width)	$h_{šr}$	15	35.1	3.3	29.6	40.6
Bi-iliocristal range	$h_{šb}$		27.6	2.2	24.0	31.2
Length from buttocks to the below knee	h_{18}	18	49.3	3.3	43.9	54.7
Length from buttocks to the top of knee	h_{19}	19	59.4	3.3	53.9	64.9

Source: 2016 authors' measurement results

Table 3: Female students' body segments ratios and functional dependence $h_i=f(h)$

Name of anthropological measures / body segments	Symbol	Label by Fig. 2	up to 29 years (*n = 68*)		
			Ratio		*R* for *hi=f(h)*
			$\overline{h_i/h}$	*H*	
Range of horizontally outstretched arms	h_{11}	11	1.00	1.00	0.75
Eye height in standing position	h_2	2	0.94	0.94	0.82
Shoulder height in standing position	h_3	3	0.83	0.83	0.67
Elbow height in standing position	h_7	7	0.63	0.63	0.44
Leg length	h_n		0.57	0.57	0.64
Normal arm reach (from the rear side of the elbow to the middle of a clenched fist)	h_{ndr}		0.20	0.20	0.61
Maximum arm reach(from the rear side of the acromion to the middle of a clenched fist)	h_{mdr}		0.36	0.36	0.71
Sitting height to vertex	h_4	4	0.53	0.53	0.73
Eye level in sitting position	h_5	5	0.47	0.47	0.71
Shoulder level in sitting position	h_6	6	0.36	0.36	0.70
Elbow level in sitting position	h_8	8	0.15	0.15	**0.31**
Knee height in sitting position	h_{13}	13	0.30	0.30	0.47
Foot length	h_{sd}		0.15	**0.14**	0.67
Ankle joint height	h_{sv}		0.04	0.04	0.50
Horizontal reach of outstretched arm (from back to the middle of a clenched fist)	h_{hdr}	9	0.41	0.41	0.53
Length of forearm and hand (from rare side of the elbow to the tip of the middle finger in a horizontal position)	h_{10}	10	0.27	**0.26**	0.77
Arm length (from acromion to the tip of the middle finger in a vertical position)	h_r		0.43	0.43	0.74
Hand length (distance between tip of the middle finger and the first crease in the wrist)	$h_{š}$		0.11	0.11	0.68
Below knee height in sitting posture	h_{14}	14	0.27	**0.26**	0.45
Bi-acromial range	$h_{šr}$	15	0.21	0.21	**0.38**
Bi-iliocristal range	$h_{šb}$		0.16	0.16	**0.36**
Length from buttocks to the below knee	h_{18}	18	0.29	0.29	0.41
Length from buttocks to the top of knee	h_{19}	19	0.35	0.35	0.51

Source: 2016 authors' measurement results

Harmonic mean H is usually used for the ratio of two measured values, such as body ratios h_i/h for measured individual anthropometric measures h_i in relation to the measured standing body height h. Calculated arithmetic mean of body ratios $\overline{h_i / h}$ is much better parameter for statistical analysis for several reasons.

Results shown in Table 3 confirm that there are no big differences between amounts of calculated harmonic mean H and calculated arithmetic mean $\overline{h_i / h}$ of human body ratios (only three minor differences on the second decimal place).

The linearity of functional dependencies $h_i=f(h)$ between anthropological measures h_i and standing body height h were evaluated using correlation coefficient R. A minor number of functional dependencies $h_i=f(h)$ of individual anthropological measures h_i of standing body height h have very little correlation coefficient R. Between all investigated anthropological measures there were weak correlations for bi-acromial range and bi-iliocristal range width standing body height h. Results for female students of the University of Zagreb shown in Table 3 indicate weak correlations for bi-acromial range width standing body height h in female students ($R = 0.38$), and also weak correlations for bi-iliocristal range width standing body height h in female students ($R = 0.36$).

Similar studies with similar results [5] also indicate weak correlations for bi-acromial range width standing body height h in females ($R = 0.26$), as well as very weak correlations for bi-iliocristal range width standing body height h in females ($R = 0.19$), but both are considered for the entire sample of female respondents ($n = 121$) without dividing into age groups.

3. CONCLUSION

Sixty eight (68) female students of the University of Zagreb up to 29 years of age, who were an object of research presented in this paper, will be a comparable group of female respondents for comparison of amounts of the arithmetic mean $\overline{h_i / h}$ for individual anthropometric measures h_i in relation to the standing height h with results for female tram drivers up to 29 years of age, in the first step of a larger scale research, which is still in progress. Finally, in the last step of a larger scale research, a main hypothesis will be questioned. Is it possible that amounts of body ratios h_i/h, which are calculated as the arithmetic means $\overline{h_i / h}$ or harmonic means H, do not change significantly with the age, gender, demographic and socioeconomic factors, despite the change of standing body height h and other anthropological measures h_i, when comparing different group of respondents from the same nation on the age, gender, demographic and socioeconomic factors?

Regarding the main hypothesis, by the results of the future research the possibility of using an arithmetic mean of body ratios $\overline{h_i / h}$ will be evaluated for the design of driver's cab interior, only when standing body height h range and mass m range in the central 90% from random and sufficient sample of respondents of the target population of drivers is known, in purpose calculating ranges of all needed drivers' anthropological measures in the central 90%.

It has not explored that deviations of calculated anthropological measures in relation to the measured anthropological measures are acceptable, despite of the possible different

body constitutions and/or different amounts of BMI index of single respondents according to age and gender groups.
Final results of a larger scale research should not be limited only to the Croatian population, which is Caucasian population very similar to other Slavic and/or southeastern European population, considering the body constitutions and ranges of anthropological measures according to age and gender groups.

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REFERENCES

[1] Ujević, D. et al.: *Theoretical Aspects and Application of Croatian Anthropometric System (CAS)*, Faculty of Textile Technology University of Zagreb, ISBN: 978-953-7105-28-0, Zagreb, (2009)
[2] Mikulčić, M., Modrić, M., Sumpor, D.: Application Possibility of Engine Drivers' Body Segments Ratios in Designing the Cab' Working Environment in Croatia, *Proceedings of the 26th International DAAAM Symposium on Intelligent Manufacturing and Automation, DAAAM 2015*, Katalinić, B. (Ed.), pp. 842-848, ISSN: 2304-1382, Zadar, 21st – 24th October 2015, Published by DAAAM International, Vienna, (2015)
[3] Kroemer, K.H.E., Grandjean, E.: *Fitting the Task to the Human*, *A Textbook of Occupational Ergonomics*, *Fifth Edition*, Published by Taylor & Francis Ltd., ISBN: 953-191-096-0, London, (1997)
[4] Muftić, O., Milčić, D.: *Ergonomics in Safety*, College of Occupational Safety and Health, Iproz, Zagreb, (2001), (In Croatian)
[5] Ozaslan, A., Karadayi, B., Kolusayin, M. O., Kaya, A.: Stature Estimation from Bi-acromial and Bi-iliocristal Measurements, *Romanian Journal of Legal Medicine*, Romanian Society of Legal Medicine, Vol.19 (2011) No.3, Bucharest, pp. 171-176, ISSN: 1844-8585

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IS IT POSSIBLE TO EFFECTIVELY IMPLEMENT ERGONOMIC CONSIDERATIONS IN PRODUCT DEVELOPMENT?

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Abstract

Although the ergonomics is the practice of designing products, systems or processes to take proper account of the interaction between them and the people who use them, it is almost impossible to assure proper and purposeful ergonomics considerations implementation in product development, and predict desired consequences. Paper objective is to investigate most common problems that complicate implementation of ergonomics in order to ensure effective design process and ergonomically designed products. If properly implemented, meaningful and user friendly product utilization through properly applied ergonomics guidelines and suggestions may be achieved. Consequently, this improves human performance and efficacy in demanded tasks.
The most pronounced finding indicates that the real problem is in the great diversity of ergonomic design problems and in multidisciplinary of necessary skills and knowledge. Furthermore, there is the uncertainty of end-effects of their implementation, dependence on subjectivity and of course, the education system which fails to cover all domains of ergonomics into integral knowledge platform. Finally, it is somewhat confusing which steps and strategies would enable desired effect: is it education, proper behavior in design phases or something else.

Keywords*:* *ergonomic considerations, product development, effective design*

1. INTRODUCTION

Humans throughout the history utilized everything that is helpful for the tasks encountered, in order to complete them easier and more effective. Of course, evolution of lifestyle, industries and professions increase the requirements which permanently demands never-ending improvement of complete ergonomic system so called human-machine-environment or simply HME, with human in center as human centered system. If properly implemented, meaningful and user friendly product utilization through properly applied ergonomics guidelines and suggestions may be achieved. Consequently, this improves human performance and interaction with demanded tasks.
Since there is large variety with wide spectrum of different parameters and factors involved, we focused on improving the creative phase in product development and their improvements. The end effects may be considered from various aspects, but if we enable to manage improving human centered design process from the first step, we are able to assume that we have improved prevention of errors, failures and dissatisfaction, injuries and other consequences and downsides of bad design and design process.

Objective of this paper is to identify how the product design engineers will be able to effectively integrate ergonomics into their creative design process. This is important since design engineers and their product design have impact on user satisfaction, production and economics of the product. This process is mostly the decision making process, which starts with conceptualization, embodiment and is followed by detailed phase. Several issues about integrating ergonomics into engineering and product development were discussed [1, 2], however, it may be resumed that this is not objective that can be accomplished straightforward. Other findings [3, 4] also confirm this conclusion, but the answer to proper and effective integration of ergonomics into engineering practice and project management is still open.

On the other hand, it seems possible to manage this integration, but how? Products, tools and instruments, work objects in general have evolved throughout human history, as well as technologies, but did we forget to use these principles? What are the reasons that in certain circumstances we (engineers, designers) only partially apply ergonomic principles, but mostly neglect them? The complexity and diversity of methods and available knowledge cause that ergonomics is considered applied by itself?

This and many more questions may be asked, but the answer could be masked with plenty of reasons, thus, the root cause for these issues might be the primary lead. If we manage to identify what would be the doubts and issues that are the cause of severe neglect of ergonomics criterions and considerations, it may be easier to close the gap. The conducted pilot case study objective is to help identify the most common issues that the product design engineers may encounter which prevents them in proper ergonomics consideration integration into their creative product improvement or development process. As others concluded earlier [3], the experience may be very important, so our intention is to address the problem before the experience mask the root causes for these issues.

2. METHOD

For the purpose of this paper, pilot case study is used with objective to identify the real life issues in product development design process where ergonomics may be neglected. In order to compare the findings and conclusions more easily, this case study is designed as comparison of different design circumstances, but with same design goal selected from consumer products items, product for targeted population, with specific demands in functionality. However, it should be emphasized that the product itself (drilling machine) is of none importance, but the product proposals should emerge significant differences in design engineers behavior and reasoning. The 12 design teams are formed from unexperienced students, especially in the field of ergonomics, of product design/development engineering course, following the indication [3] that experience may be very important in ergonomics considerations integration. They are selected randomly with motivation to participate, all from master of engineering program, and from its final phase. Students were divided into 12 teams of two, with total number of students as 24. The main criterion for election of students and their engagement was that they are competent and able to propose the product design concept, where the competence is determined by the specific set of finished and approved courses from the program.

The 12 design teams are subdivided into 3 different groups, each one with different task details provided, as presented in Table 1, respectively.

Table 1. Details of provided tasks dedicated to each group of 8 students

GROUP:	Provided task details:
1 (G1) (8 students)	4 teams have to use only the knowledge from the product design/development engineering course, without understanding of the purpose of the project
2 (G2) (8 students)	4 teams are informed that we want to use ergonomics considerations in addition to other criterions for product design/development, but without any advices or instructions how;
3 (G3) (8 students)	4 teams are advised and instructed about the project purpose and ergonomics principles in general, but without exact method or evaluation system to be applied. However, they are not instructed on how the proper ergonomics implementation would be recognized

After the completion, project proposals were presented and discussed with all 12 teams in form of a forum.

The groups of considerations that are expected to be identified are:

- Human-machine interaction,
- Adaptability to user needs,
- Visual design,
- Intuitiveness of use,
- Safety,
- Effort and fatigue,
- All-inclusive design issues,
- User foreknowledge and experience,
- Necessary psychophysical abilities and
- Anthropometric data.

The evaluation for every team proposal is analyzed by the parameters and features included in their evaluation system, consisting from complete set of features and specifications, but with special focus on user-machine interaction. Beside, other functional and structural properties and features are also considered for final proposal evaluation, although as of secondary importance.

3. DISCUSSION

The results of performed pilot case study for the purpose of this paper are very diverse, as expected, but very interesting. The groups of teams were confronted with different circumstances for the project proposals, so the findings are somewhat impossible to compare directly. Thus, we will extract only the most important differences and conclusions for each group of teams, respectively.

Group 1 has used all common knowledge learned from the course, with focus on product functionality, features, architecture and mechanical integrity. The ergonomics is not even mentioned, even as general criterion without specific details. However, it seems that just a few details of their project proposals indicated that they had in mind the intuitive intention to take care about some ergonomics issues of the product, although unaware of it. After the discussion, they realize the proportions of ergonomics neglect in their proposals.

Group 2 showed high motivation to implement ergonomics considerations into their proposals, in addition to other design properties, as was the case with G1. What is very indicative, since they were aware about case study objective, they tried to improve their proposals by ergonomics criterions and considerations. However, they were very confused about the evaluation procedure, proper selection of ergonomic parameters, criterions and their end effect, and finally with identification of project improvements achieved with this implementation. What is even more significant, they mostly considered visual and safety criterion, but fatigue, all-inclusive design issues, user foreknowledge and experience, necessary psychophysical abilities and anthropometric data was significantly neglected. After the discussion, they realize that the neglecting of ergonomics is present, although they considered few important issues. They discussed that they didn't attended any ergonomics course before this case study, and that they realize a lot of potential for project proposals improvement if ergonomics is properly implemented.

Group 3, as expected, generated the most complete proposals, but from ergonomics point of view, far from good enough. They tried to implement much more than previous 2 groups, but beside their effort and motivation, the outcome was not much better. What was significant, they selected large set of features they considered to be involved as ergonomics, but they were confused about their evaluation. Finally, they seems to separate ergonomic from other features and product details, which also have its cause and consequence.

The results of teams' behavior and ergonomics criterions applied in evaluation are systematized in Table 2, where the final score is presented in scale range of 0 to 3. Mark 0 represents that the criterion in not implemented, and mark 3 that the implementation is adequate and appropriate.

It should be mentioned that few of the team members from all groups have some user experience with drilling machine, so their influence on proposals was significant, that caused advanced, somewhat different proposals in comparison with teams that are unfamiliar with drilling machine utilization.

This experience was the key why some ergonomic criterions were identified better by some teams, which also confirms findings of references [3]. Thus, this caused that in the same group were created better technical proposals by those teams, but the level of implemented ergonomics influenced the proposals even more.

Table 2. Systematized results of evaluation of ergonomics implementation

	G1	G2	G3
Human-machine interaction	**1**	**1**	**2**
Adaptability to user needs	**1**	**1**	**2**
Visual design	**0**	**2**	**2**
Intuitiveness of use	**0**	**0**	**1**
Safety	**1**	**2**	**3**
Effort and fatigue	**0**	**0**	**1**
All-inclusive design issues	**0**	**0**	**2**
User foreknowledge and experience	**0**	**0**	**1**
Necessary psychophysical abilities	**0**	**0**	**1**
Anthropometric data	**0**	**1**	**2**

4. CONCLUSION

It is finally possible to discuss and draw some conclusions from this pilot case study, however, it should be emphasized that there are certain limitations to be aware of. What is most important, there is no exact method to quantify the real-time neglecting of ergonomic considerations, or to precisely predict their effect on product success. It should be noted that every single product development project may require completely personalized set of features and parameters to be evaluated, which is highly impacted by team leader and the company management. Therefore, the direct comparison would be very uncertain, except in the case of uniform task, as our case study presents. Furthermore, the estimation of implemented ergonomics was performed just to recognize the consequences that different circumstances that the teams were confronted to may cause, thus may show the impact of lack of knowledge and experience. To improve the evidence based and more solid results, it may be advisable to use larger number of participants, and maybe even more differently engaged groups of teams.
As this pilot case study shows, there are significant differences caused by different management behavior (the different details provided to teams), the team leaders should comply (decide the relevance of features and functions) and lead the teams accordingly, and design engineers have to follow the demanded framework and fulfil the expectations (competent proposals). There should be mentioned that, after the analysis of proposals by three groups of teams, there are issues that are present for all groups almost uniformly, while the other issues are caused by the provided tasks details to each group of teams, respectively.
We can identify most important findings of this paper, starting with the issues present in all groups first, as they seem not affected by different task details. The most concerning issue is that the teams are not able to identify valid evaluation criterions, even if some methodology and general understanding is present. The other issue is that they do not

realize the basic principle of human centered design, so the focus is put on technical properties and specifications, rather than on how the product should be designed and utilized to improve performance in real task. The last of these issues is that user and utilization experience of the product plays important role in designer behavior in generating features of proposals, so it should be taken into account when design teams are formed. It should be recognized also that the decision making at this stage of design, conceptualization is highly subjective, so the real-time estimation of decision made is very uncertain, as what would be the manufactured product utilization experience. Essentially, students were aware of the definition of ergonomics, so we cannot conclude that they don't have knowledge about it, but obviously they are not able to recognize the way of its effective implementation. Despite this, without special instructions or the appropriate guidelines, they fail to use ergonomics considerations in their evaluation system, which significantly question its effective implementation.

Specific differences between the groups of teams that emerged through this pilot case study indicates that no matter what ergonomics guidelines were available, its implementation is not significantly improved, but the differences are obvious. Furthermore, it seems that even if they had available method that could be used in order to reduce the subjectivity of proposals structure evaluation, apparently that without specifically designed guidelines, they won't know how to select a list of features that would include ergonomics considerations in an appropriate manner. Of course, the common issue is that there is no clear, exact path to follow or guidelines available, just recommendations, and finally, there is high uncertainty of made decisions effect.

Finally, despite extensive knowledge and variety of methods available for ergonomics implementation, it is important to emphasize that it is not clearly defined or suggested how to improve utilization of ergonomics into design and production, and how to assure effective improvements where needed. Therefore, it is somewhat confusing which steps and strategies would enable desired effect: is it education, proper behavior training for implementation in design phases or something else.

REFERENCES

[1] Broberg, O.: Integrating ergonomics into the product development process; *International Journal of Industrial Ergonomics*, **19** (1997), pp 317–327

[2] Broberg, O.: Integrating ergonomics into engineering: empirical evidence and implications for the ergonomists; *Human Factors and Ergonomics in Manufacturing*, **17** (4) (2007), pp 353–366

[3] Stanton, N.A., Young, M.S.: Giving ergonomics away? The application of ergonomics methods by novices; *Applied Ergonomics*, **34** (2003), pp 479–490

[4] Zare, M., Croq, M., Hossein-Arabi, F., Brunet, R., Roquelaure, Y.: Does Ergonomics Improve Product Quality and Reduce Costs? A Review Article; *Human Factors and Ergonomics in Manufacturing & Service Industries*, **26** (2) (2016), pp 205–223

THE IMPACT OF ANTHROPOMETRIC VARIABLES ON FEMALE BODY SHAPE AND GARMENT FIT

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Abstract

The aim of the paper is to show the impact of the relationship between body height and leg length on body shape and visual impression. The body that has harmonious proportions is easier to dress. The relationship between leg length and body height plays a major role of good impression. Longer legs and a shorter torso are an important factor in favor of good proportion as well as body proportion in line with the golden ratio. The study was performed on a sample of 294 test subjects aged 19 to 34 years, and four anthropometric variables were analyzed. The results obtained were processed using standard statistical procedures to determine basic descriptive statistics parameters. The relationship between body height and leg length affects body shape, and this relationship is considered as one of the relevant parameters for defining body shape and it is the basis of good proportions in order to make a positive impression with the clothing one wears. Symbols for labeling clothes are proposed to select an appropriate garment length more easily.

Keywords*:* *anthropometric measurements, body shape, garment fit*

1. INTRODUCTION

Three data sets relevant for clothing manufacturing are obtained by anthropometric measurements and statistical analysis of results: garment labeling system, standard and proportional body measurements and share of individual garment sizes. Body types are determined on the basis of anthropometric measurements in order to determine garment sizes. Female body types are based on the difference between bust girth and hip girth. According to the results of the anthropometric measurements taken in Croatia female body types are divided into: Type a0 – especially narrow hips, Type A – very narrow hips, Type B – narrow hips, Type C - normal hips, Type D – wide hips, Type E – very wide hips, Type e0 – especially wide hips [1,2].

It is necessary to add important longitudinal measurements of the body to anthropometric measurements of body girth. The relationship between body height and leg length visually changes the body, regardless of body type and height. Leg length is an important factor that affects the perception of the beauty of the female body. According to research, there are three factors that affect the aesthetic appearance of the legs: length, volume and shape [3].

Based on an idealized body type in the fashion industry experts determine measurements for pattern making and evaluate garment fit, designers create their designs that are used by manufacturers for clothing presentations. This kind of approach cannot satisfy an average woman who is different form that imposed ideal. Thompson and Gray developed the CDRS (Contour Drawing Rating Scale) scale [4,5] consisting of 9 female contour drawings that gradually increase in size from emaciated to obese. The scale was constructed for accuracy measurements of the perception of the person who assesses and places himself in a particular location on the scale, and this is not the correct definition of body types.

Different sectors such as fashion, retail and fitness define body types for different purposes, their division is similar, but there are differences in names. When defining types of the female body the alphabet is used such as: H, O, A, X, R, I and S body shapes; names of geometric shapes such as: rectangle, ellipse (oval), triangle. The names of fruits are also used in the classification of body types such as: apple and pear that are commonly used in medical sciences [6]. Some body types are called: hourglass, beans, heart etc. [7]. Former model Mary Duffy developed the so-called HOAX formula [8] in which she defined figures of female bodies according to the letters of the alphabet. Some studies determine body types according to the actual data obtained with measurements, where the above-mentioned terminology is used [9-16]. What makes the body look visually taller or shorter is leg length which is measured in relation to body height. Studies show that women with longer legs are considered more attractive [17]. Studies cover the ratio between leg length and body height (LBR, Leg to Body Ratio) in which the leg to body ratio for women amounts to about 0.53 and more [18]. According to these studies legs should be slightly longer than half of total body height which is different from the proportions of the golden ratio. In addition to contributing to good proportions, leg length also affects appearance and attractiveness [18-23].

2. METHODS AND TEST SUBJECTS

Anthropometric measurements necessary for this research were taken on a sample of 297 female students aged 19 to 34 years from the Faculty of Textile Technology of the University of Zagreb. Anthropometric measurements were taken using the conventional method with the one-blade anthropometer.

Sets of measurements obtained by direct measurements of subjects as well as data obtained by calculations on the basis of the data measured form the basis for research results. The validity and reliability of the data depends on the validity and reliability of the data collected. Random errors may occur if the measurer misreads the values during taking measurements. They also occur as a result of minor lack of accuracy of measuring instruments as well as errors occurring during data entry.

Basic descriptive statistical parameters were determined in data processing. The statistical evaluation of the measurement results obtained was achieved by use of appropriate statistical methods and procedures: tabulation, processing by Statistica 8.0 software package, graphical and tabular presentations, use of the mean value (arithmetic mean), use of scattering such as standard deviation and range. The following anthropometric variables were analyzed: body height, navel height, hip height and head height. These heights are necessary to calculate their relationships and ratios. Several other data relevant for the determination of body proportions were obtained from the measured data. Leg length was determined in relation to body height indicating the proportion of upper and lower body. Navel height in relation to height was determined according to the golden ratio. Ranges of all measured and calculated amounts were determined.

3. RESULTS

The statistical evaluation of the measurement results obtained was achieved by use of appropriate statistical methods and procedures: tabulation and processing by Statistica 8.0 software package, graphical and tabular presentations, use of locations, use of the mean value (arithmetic mean), use of scattering such as standard deviation and range (minimum, maximum and frequency), table 1.

Table 1. Relevant data of descriptive statistics of anthropometric measurements taken on 297 female subjects

	Arithmetic mean	Standard deviation	Minimum	Maxsimum
Tv /cm	166,6	6,32	152,0	184,0
Vp/cm	100,0	4,71	86,0	116,0
Vk/cm	84,6	4,79	71,0	96,0
Vg/cm	22,3	0,96	20,0	24,5
Tv/Vg	7,4	0,35	6,5	8,5
Vk/Tv	0,50	0,01	0,46	0,54
Tv/Vp/	1,66	0,03	1,55	1,81

Tv – body height, Vp – navel height, Vk – hip height, Vg – head height, Tv/Vg ratio of body height and head height, Vk/Tv ratio of hip height and body height (leg length in relation to body height), Tv/Vp ratio of body height and navel height, comparison with the golden ratio

The correlation of body height with hip height is shown in Fig. 1.

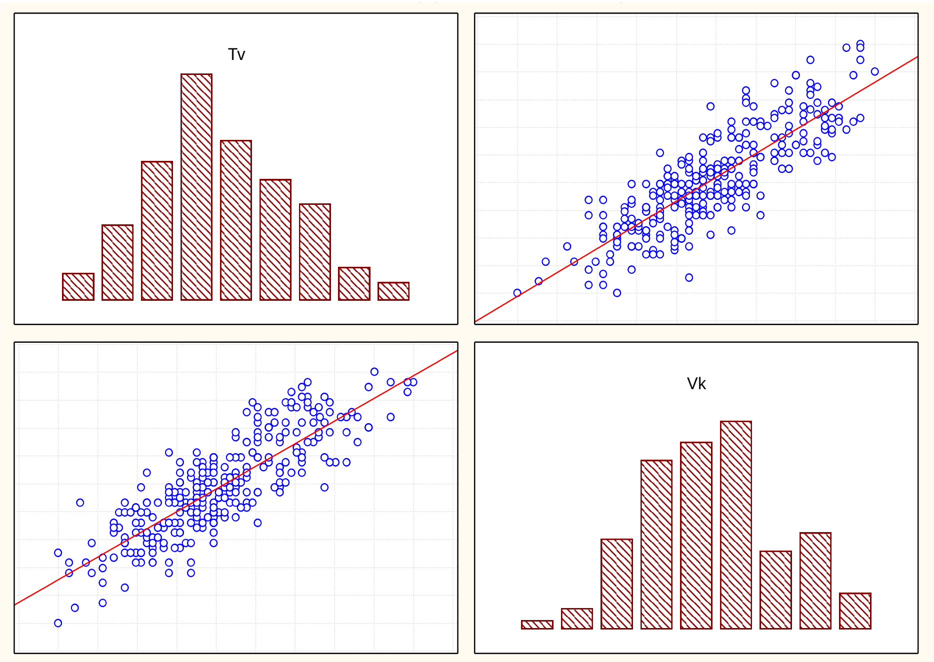

Figure 1: Body height (Tv) and hip height (Vk)

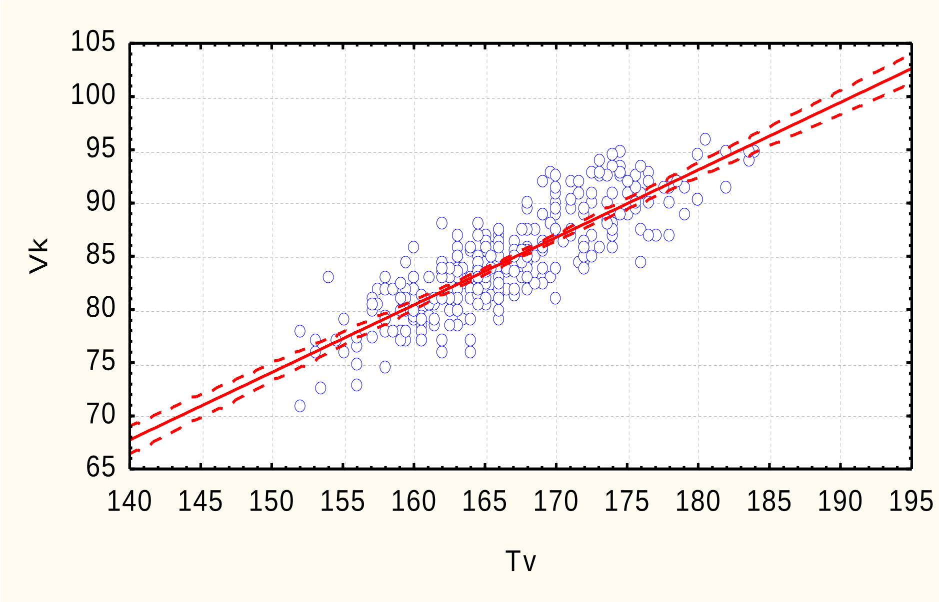

Figure 2: Relation hip height (Vk) i body height (Tv)

The figures 1 and 2 show histograms of measured values and graph of linear regression. The abscissa of the graph of linear regression shows the characteristic value whose histogram is plotted above the graph of linear regression, and the ordinate of the graph of linear regression shows the characteristic value which is plotted in the histogram to the right of the graph of linear regression.
In table 2 are show the results of simple linear regression, and in the table 3 is shoe matrix values of Pearson′s liner correlation coefficient

Table 2: Results of simple linear regression

The dependent variable	**Independent variable**	**a**	**b**	R^2
Navel height	Body height	0,6496	-8,2493	0,7577
Hip height	Body height	0,6344	-21,0830	0,6990
Head height	Body height	0,0490	14,2030	0,1042

Table 3: Matrix values of Pearson's linear correlation coefficient

	Tv	**Vp**	**Vk**	**Vg**
Tv	1,000000	0,870443	0,836057	0,322789
Vp	0,870443	1,000000	0,829689	0,320833
Vk	0,836057	0,829689	1,000000	0,252447
Vg	0,322789	0,320833	0,252447	1,000000

4. DISCUSION

According to the results in Table 1 the average body height of female subjects was 166 cm, while the ratio of body height and head height was 7.4, whereby the average head height was 22.4 cm. If the body height of the theoretical model of the ideal female body, whose ratio of head height and body height amounts to 1:8, is calculated, a body height of 179.2 cm is obtained. It follows from the above that this is a female person of high stature. Average hip height is 84.5 cm, and according to the calculation, when hip height is divided by body height, it is found that it is just at half body height, which is line with the golden ratio. Navel height does not fall completely into the golden ratio, and it amounts to 1.66 cm. However, it should be noted that the difference is small. In a sample of 297 female subjects it was calculated only for 10 female subjects that the navel was exactly at the height of the golden ratio or 1.61, making up only 3.36%.
Average hip height gradually increases with body height. Although the amount of the average hip height obtained by anthropometric measurements was exactly at half body height, being in line with hip height according to the golden ratio, hip heights were measured that do not match this average. Thus, the lowest calculated value of the relationship between hip height and body height amounted to 0.46 and the highest to 0.54. The lowest and highest calculated value differed from the golden ratio which amounts to 0.5. When these values were compared with the investigations conducted in [17], it was found that the ideal ratio (LBR – Leg to Body Ratio) amounted to 0.53, which was slightly different from the highest ratio calculated, but the difference compared with the lowest calculated ratio was significant. Heights on a human body change with changes in body height. Taking these data into account, the question arose whether there is a correlation between body height and measured body heights. The correlation coefficients listed in Table 3. lead to the conclusion that there is a strong positive correlation between body height and navel height where r = 0.870443. The correlation coefficient between body height and hip height is slightly lower, where r = 0.829689, but still there is a strong positive correlation between these two values. In contrast to what was said beforehand the correlation coefficient between body height and head height was r = 0.320833, which leads to the conclusion that the correlation between these two variables is weak. The results of the conducted linear regression also indicate a positive correlation between body height and navel height.
The share of common values between body height and navel height is 75.77% which leads to the conclusion that there is a strong correlation between these two variables. The regression coefficient listed in Table 2 has a negative sign, meaning that an increase in the body height of female subjects accompanies a reduction in navel height or that an increase in navel height is not in line with an increase in body height and hip height. The results of the linear regression indicate the correlation between body height and hip height visible in Fig. 2.
A share of common values, which for these two variables amounts to 69.9%, is also noticeable. This leads to the conclusion that there is a strong correlation between these two variables. The negative effect of the regression coefficient indicates that an increase in body height accompanies a reduction in hip height or that a more substantial increase in body height does not accompany such a substantial increase in hip height in the same way.

5. CONCLUSION

Based on the research results obtained and the discussion on body proportions the following conclusions were drawn: An increase in body height is accompanied by an increase in hip height, but an increase in body height is not accompanied by an increase in navel height. The results of this study are shown in Fig. 3. With the help of six representations of female body three most frequently mentioned body types are shown by use of symbols: apple, pear and hourglass. Symbols are a proposal for labeling clothing for ease of reference when choosing clothes. The left-hand side of the symbol indicates body type and the right-hand side indicates leg length. Downwards arrow indicates shorter legs, while two arrows, one upwards arrow and the other downwards arrow indicate average leg length. The same principle can be applied to other body types as well as to the symbol for longer legs, where an upwards arrow should indicate longer legs.

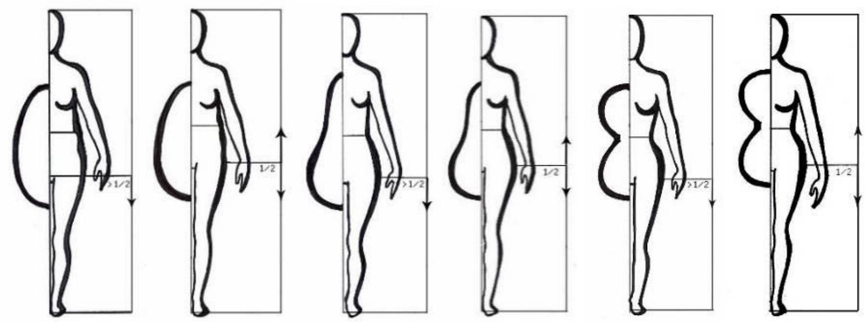

Figure 3: Symbols Types of women's bodies to length of leg

5. REFERENCES

[1] Ujević D at all.:Theoretical aspects and application of Croatian anthropometric system, University of Zagreb, Faculty of Textile Technology, Croatia, ISBN 978-9537-105-20-0

[2] Anthropometric System, – Measuring body and labeling clothing size and footwear, Croatian technical report, HRI 1148:2012, HZN, 2012., ICS 01.040.61:61.020 (in Croatian)

[3] Chih-Cheng Tsai, Sin-Daw Lin, Chung-Sheng Lai and Tsai-Ming Lin: Aesthetic Analysis of the Ideal Female Leg, Aesthetic Plastic Surgery, 24 (2000) 4

[4] Thompson, M. and Gray, J.: Development and validation of a new body-image assessment scale, Journal of personality assessment, 64 (1995) 2, ISSN: 1532-7752

[5] Borland, H. and Akram, S.: Age is no barrier to wanting to look good: women on body image, age and advertising, Quantitative Market Research: An International Journal, 10 (2007) 3, ISSN: 1352-2752

[6] Hensrud, D. D: Mayo Clinic about healthy weight, Mayo Clinic, Rochester, Minnesota, Zagreb, 2005, ISBN 953-176-273-2 (in Croatian)

[7] Devarajan, P.: Validation of “Female Figure Identification Technique (FFIT)” for Apparel Software, Journal of Textile and Apparel; Technology and Management, 4

(2004) 1, 2004., http://www.ergoeg.com/uploads/books/devarajan_full_106_04.pdf, rujan, 2011.
[8] Duffy, M.: The H-O-A-X Fashion Formula, Penguin Group (USA) Incorporated, 1987., ISBN: 0895865815
[9] Ross, S.M.: Style Preference and Benefits Sought by Women for Customized Swimwear Based on Body Shape, Age, and Dress Size, Magisterij, 2010, http://etd.auburn.edu/etd/bitstream/handle/10415/2176/style%20preference%20and%20benefits%20sought.pdf?sequence=2, listopad, 2011.
[10] Newcomb, B.: 2005 Apparel Tech Conference – Changing the Way Apparel Companies Think about Body Shape, Journal of textile and apparel, technology and management, NC State University, 5 (2005) 1
[11] Ho Sun Lim: Three Dimensional Virtual Try-on Technologies in the Achievement and Testing of Fit for Mass Customization, Sjeverna Carolina, 2009, …http://www.optitex.com/public/NCSU_Hosun_Lim_Dissertation.pdf, listopad, 2014.
[12] Newcomb, B., Istook, C.: A Case for the Revision U.S. Sizing Standards, Journal of textile and apparel, technology and management, NC State University, 4 (2004) 1
[13] Simmons, K., Istook, C.L., Devarajan, P.: Female figure identification technique (FFIT) for apparel, Part II: Development of shape sorting software, Journal of textile and apparel, technology and management, NC State University, 4 (2004) 1
[14] Petrak, S, Rogale, D., Šabarić, I.: Computer-Aided Garment Construction Based On 3d Body Models Of Different Anthropometric Properties, Book of Proceedings of the 4th International Textile, Clothing & Design Conference 2008 - Magic World of Textiles,Dragčević, Z. (ur.), Zagreb: Faculty of Textile Technology University of Zagreb, (2008). 641-646
[15] Šabarić, I., Vinković, M., Petrak, S., Ujević, D.: Computer-Aided Analysis of 3d Female Body Type of Different Figures as a Starting Point for Garment Design, Book of Proceedings of the 4th International Textile, Clothing & Design Conference 2008 - Magic World of Textiles, Dragčević, Z.(ur.), Zagreb: Faculty of Textile Technology University of Zagreb, (2008). 1023-1028
[16] Clarke, A., Miller, D.: Fashion and Anxiety, Fashion Theory, 6 (2002) 2, 191-213, ISSN 1362-704X
[17] Swami, V., Einon, D., Furnham, A.: The leg-to-body ratio as a human aesthetic criterion, Body Image, 3 (2006) 4, 317-323, **ISSN:** 1740-1445
[18] Sorokowski, P., Pawlowski, B.: Adaptive preferences for leg lenght in a potential partner, Evolution and Human Behavior, 29 (2008) 2), 2008.
[19] Bertamini M., Bennet K. M.: The effect of leg length on perceived attractiveness of simplified stimuli, Journal of Social, Evolutionary, and Cultural Psychology 3 (2009) 3, 233–250, http://137.140.1.71/jsec/articles/volume3/issue3/bertaminifinal.pdf, rujan, 2011.
[20] Frederick DA, Hadji-Michael M, Furnham A, Swami V.: The influence of leg-to-body ratio (LBR) on judgments of female physical attractiveness: assessments of computer-generated images varying in LBR". Body Image 7 (2010) 1, 51–5, **ISSN:** 1740-1445
[21] Voracek M, Fisher ML, Rupp B, Lucas D, Fessler D.M.: Sex differences in relative foot length and perceived attractiveness of female feet: relationships among anthropometry, physique, and preference ratings, Percept Mot Skills, 104 (2007) 3-2, 1123–38, ISSN: 0031-5125

[22] Sorokowskia P., Pawlowskib B.: Adaptive preferences for leg length in a potential partner, Evol Hum Behav 29 (2008) 2, 86–91, ISSN: 1090-5138
[23] Entwistle, J.: Fashion and the Fleshy Body: Dress as Embodied Practice, Fashion Theory, 4 (2000) 3, 323-348, ISSN 1362-704X

STABILITY ANALYSIS OF DENTAL GUIDES

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Abstract

In dental implantology surgical guides for implant placement have been used in last few years but little research has been done to preoperatively analyze stability of these guides and uniqueness of fit. Recently, few mathematical models have been developed to predict the stability of the guides prior the operation. In this study adapted mathematical model was used to investigate correlations between different mesh density representations of dental anatomical surfaces and stability scores derived from the mathematical model. Tested surfaces (guides) resulted in quite stable behavior regarding translational stability (MT = 1,27 ± 0,14) and less in the field of rotational stability (MR = 7,55 ± 4,75). Future work suggests analyzing large data set to investigate the unknown population based rules related to dental guides design process and stability.

Keywords: *dental implantology, dental guides, stability model*

1. INTRODUCTION

Computer aided design (CAD) and rapid prototyping technology (RP) in the last few years have become widely used in dental implantology. Many studies show that using preoperative planning on the computer and patient specific guides improves stability and accuracy in implant placing procedures. The guides are designed to fit in a unique position onto the patient anatomy so that preoperative plan can be easily transferred from the computer to the operation room. The main task of the guide is to provide a drilling or cutting direction for the surgeon.

Although many studies show that using custom made guides improves accuracy the procedures used are not flawless. Usage of dental drill guides still leads to deviations from the plan. The following differences might be connected to the handling of the computer tomography: The positioning of the radiographic template, image segmentation, modeling of the images and prototype production, stability of the guide on the patient anatomy or fitting of the metal sleeves [1, 2].

In this preliminary study the focus is set on stability of the dental drill guides. Recently, there have been some studies which resulted in providing a feedback through developing a mathematical model for predicting stability of surgical guides [3, 4].

Anatomical surface which is used to support the guide is analyzed during the planning procedure so that stability of the guide could be maximized. The standard form for representing anatomical 3D models is an STL file format (Standard Tesselation Language, native format for stereolitography software). The continuous surface of a 3D anatomical model is represented by discrete number of small connected surface

triangles. Higher density of triangles equals to better representation of an observed surface.
Usually, anatomical models are acquired from CT/MRI images or a 3D scanner so the user doesn't know what will be the exact density of the mesh representing the surface. If there were two engineers acquiring the 3D model from the same CT/MRI image the models would not have the same number and orientation of triangles representing the surface (mesh density would be in the order of magnitude but different).
As demonstrated by research [3] the mesh density doesn't influences the stability scores derived from the mathematical model developed. If we know that representation of anatomical surface for positioning of dental guides can have up to 50k triangles, the question is wouldn't it be more efficient for analyzing the stability scores to use surfaces with fewer number of triangles when there's no influence of the mesh. That way the analysis would require fewer computer resources and also the other problem is that there is no specified threshold for the minimum mesh density so that the calculated stability scores are still valid. Although it has been proven that minor changes in mesh density don't influence the stability scores if the number of triangles would be gradually reduced to zero at some point the mathematical model has to crash.
So the idea of this preliminary study is to further investigate correlations between stability scores and mesh density and also to try finding a threshold at which the mathematical model crashes. The adapted mathematical model for analyzing stability and tests conducted are described in the following sections of this paper.

2. MATHEMATICAL MODEL

The developed mathematical model is used to verify the stable position of a surgical guide during the guide design phase. The mathematical model roots to the domain of robotic grasping and work piece fixturing. The contact points are positioned in such a way that an external force can be resisted. This requirement can be considered similar to the required stability of a surgical guide.
The original model for comparing different grasps and fixtures has been introduced by Lin et al. (2000) [5] and further developed by Van den Broeck (2015) [3]. For a given contact surface, a wrench vector w_i is created for each of the N different contact points, using its coordinates $\mathbf{p}_i$ and a unit outward normal vector $\mathbf{n}_i$:

$$w_i = \alpha_i \left[n_i \, p_i x n_i \right], \text{ where } \alpha_i = \sqrt{S_i} \qquad (1)$$

A weight factor α_i, based on the triangle surface s_i of each contact point eliminates influence of the STL mesh density. However, this results in a scale dependence of the analysis. To cancel out this scale effect, prior to complete analysis, the contact surface is scaled such that the mean distance of the point coordinates to the center of gravity is equal to one [6].

These can be combined in a matrix **W** for all N points:

$$W = \left[w_1 w_2 \ldots w_n \right] \qquad (2)$$

A spatial stiffness matrix **K** can be created using this wrench matrix:

$$K = WW^T = \left[ABB^T D\right] \tag{3}$$

The 6 x 6 stiffness matrix **K** is a symmetric, positive semi-definite matrix with a block-diagonal structure, where **A**, **B** and **D** are 3 x 3 sub-matrices. These sub-matrices are used to define two new matrices:

$$C_w = A^{-1} \tag{4}$$

$$K_v = D - B^T A^{-1} B \tag{5}$$

The eigenvalues of these matrices have been proven to be frame-invariant [5]. The translational compliance of the contact is represented by matrix $\mathbf{C}_w$, hence the eigenvalues σ_1, σ_2 and σ_3 of the matrix $\mathbf{C}_w^{-1}$ are the principal translational stiffness parameters. These will give an indication of the translational stability of the analyzed contact surface. Matrix $\mathbf{K}_v$ represents the rotational stiffness of the contact and its eigenvalues μ_1, μ_2 and μ_3 are the principal rotational stiffness parameters.
The principal rotational stiffness parameters are scaled to allow the comparison between translational and rotational stiffness parameters. The equivalent rotational stiffness parameters are then defined, linking the rotational stiffness of the contact to a user defined target point [5]:

$$\mu_{eq,i} = \frac{\mu_i}{\rho^2 + (\omega_i \cdot v_i)^2} \tag{6}$$

Where ω_i is the eigenvector of $\mathbf{K}_v$ corresponding to eigenvalue μ_i and ρ is the distance of the target point to the instantaneous axis of rotation parallel to ω_i and through point q_i:

$$q_i = \frac{\omega_i x v_i}{\|\omega_i\|^2} \tag{7}$$

And v_i is calculated as follows:

$$v_i = -A^{-1} B \omega_i \tag{8}$$

The translational stability parameter (M_T) and rotational stability parameter (M_R) have been derived from the analytic expression of the target registration error [7]:

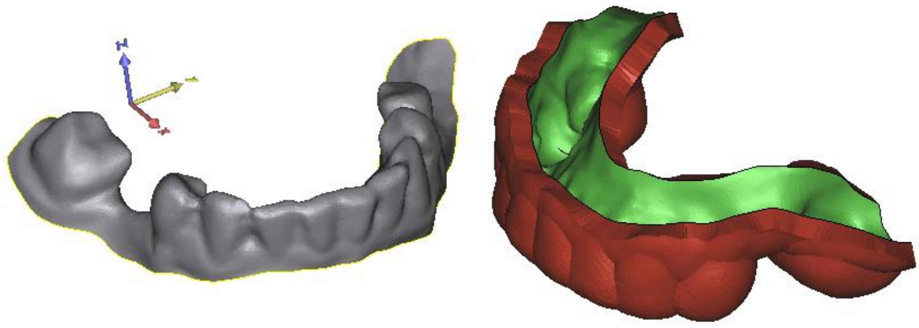
$$M_T = \sqrt{\frac{1}{\sigma_1} + \frac{1}{\sigma_2} + \frac{1}{\sigma_3}} \tag{9}$$

$$M_R = \sqrt{\frac{1}{\mu_{eq,1}} + \frac{1}{\mu_{eq,2}} + \frac{1}{\mu_{eq,3}}} \qquad (10)$$

The stability scores will decrease if the stiffness parameters increase and give an indication of the average quality of the contact. The scores are used to predict the translational and rotational stability of a designed guide in contact with its supporting anatomy. The closer the score is to zero, the more stable the contact will behave. The model was implemented in Matlab (v.R2012.a, The MathWorks, Inc., Natick, MA, USA).

3. METHODS

Three dental castings have been obtained from the dental clinic from three different patients. Castings have been 3D scanned using an industrial 3D scanner, Comet5 1.4MP (Carl Zeiss Optotechnik GmbH, Neubeuern, Germany). The STL files of castings were later processed in Mimics Innovation Suite software (Materialise, Leuven, Belgium) and surfaces needed for dental guides design were acquired (Figure 1).
The same surfaces that are used as a start point for design of guides are also the ones that are tested for the stability score because the guides are positioned on that surface. Some general features that describe observed surfaces are listed in the Table 1.



a. b.

Figure 1: a) Anatomical surface and b) Dental guide

Table 1: General surface features

	Surface A	Surface B	Surface C
Number of triangles	30992	43350	24150
Area, mm2	2518,2	3485	2096
Mesh density, NoT/mm2	12.3	12.44	11.52

As it can be observed from Table 1 every surface has different initial number of triangles representing it, so for testing and comparing between surfaces, the mesh

density parameter was used to confront stability scores, and not number of triangles (NoT) representing the surface.
To find out the correlations between mesh density and stability scores the following procedure was done. The stability scores were first calculated using the original surface. After that the mesh density was reduced for 20% from the initial mesh density and the stability scores were calculated again. The two step procedure was repeated until the number of triangles representing the surface could not be more reduced. During testing it has been discovered that main disturbances of the algorithm are localized below the 20% density of the initial mesh. Accordingly, the step for mesh density reduction in that area was changed so that finer representation of the data could be achieved. The example of the data gathered during testing is presented in Table 2. Similar values have been obtained for surfaces B and C. Also, as it can be seen the computation time for running the algorithm was measured too.

Table 2: Data collected for surface A

Surface reduction, %	NoT	Mesh density, NoT/mm2	MT	MR	Computation time, s
100	30992	12.3	1.4279	4.1983	107.3067
80	24794	9.85	1.4360	4.2130	90.6916
60	18595	7.38	1.4311	4.2113	65.0448
40	12396	4.92	1.4329	4.2197	44.5713
20	6198	2.46	1.4298	4.2016	22.3367
10	3099	1.2	1.4507	4.2886	12.2291
5	1550	0.6	1.4812	4.4862	6.7815
2.5	775	0.3	1.5521	5.1375	4.0096
1,6	498	0.197	1.5838	8.4554	2.9528

4. RESULTS

The tests indicate a difference in stability for all guide designs. The data measured is displayed in the Figure 2 and Figure 3. It is expected that different guide designs (surface A, B, C) have different stability scores. This happens because of the differences in anatomy between patients. Also, it is shown that reduction in mesh density influences more on rotational stability (Figure 3), while the translational stability parameter tends to be more rigid and disturbances caused by reduction in mesh density generate smaller deviations (Figure 2).

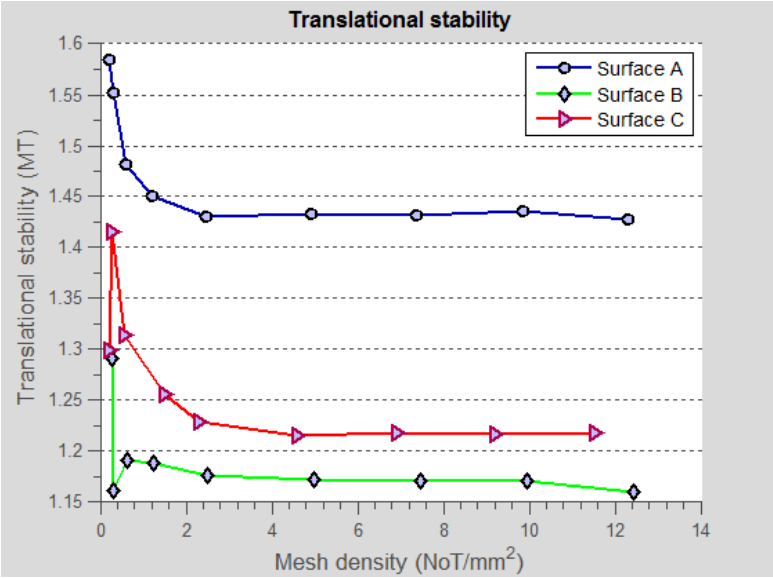


Figure 2: Translational stability

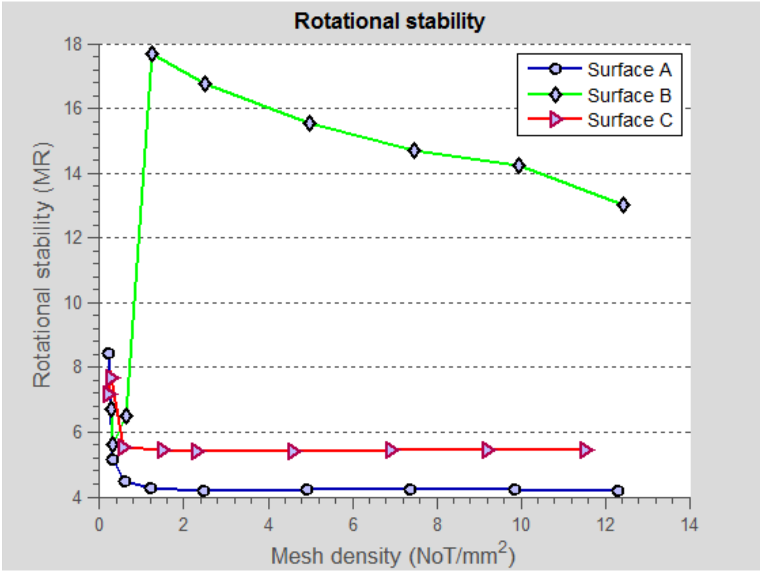


Figure 3: Rotational stability

Van den Broeck (2015) roughly determined that differences in stability score should be over 0,5 to indicate a significant difference in stability [3]. Therefore, the mesh density for dental guides can easily be reduced up to 20% of the initial mesh and the stability scores would still be valid. Very interesting behavior is seen in rotational stability test for surface B. While the mesh density is reduced the stability scores increase almost lineary. This can't be explained at this moment and should be investigated in future on large dataset. From the table 2, it can be observed that reducing mesh density speeds up the computation time. Concretely for surface A, if the mesh density would be 20% of the initial mesh the algorithm would roughly be five times faster. Similar values have also been obtained for surfaces B and C.

5. CONCLUSION

This preliminary study explains evaluating stability parameters of dental guides during design process. Van den Broeck (2015) used presented mathematical model to predict stability of surgical guides for total knee arthroplasty (TKA). There has been no application of this model in the field of dental implantology yet. Three anatomical surfaces for design of dental guides have been tested. Calculated stability scores suggest that dental guides are quite stable regarding translational stability (MT_A = 1,43; MT_B = 1,17; MT_C = 1,21; MT_{AVG} = 1,27 ± 0,14), and less regarding rotational stability (MR_A = 4,21; MR_B = 13,0; MR_C = 5,46; MR_{AVG} = 7,55 ± 4,75). Also mesh density has a small influence on translational stability and higher on rotational stability. If the mesh density is reduced up to 80% the stability scores would still be valid. Reducing the mesh density the stability algorithm could be up to five times faster in execution. For future work conducting a stability analysis on large dataset is a must. Analyzing large dataset could lead to general improvements in design process of dental guides, like defining optimal surfaces for guides positioning and detecting unknown population based rules.

REFERENCES

[1] Van Assche, N.; Van Steenberghe, D.; Quirynen, M.; Jacobs, R.: Accuracy assessment of computer‐ assisted flapless implant placement in partial edentulism. *Journal of Clinical Periodontology*, **Vol.** 37 (2010) No.4, pp.398-403, ISSN1600-051X.

[2] Vercruyssen, M.; Jacobs, R.; Van Assche, N.; Van Steenberghe, D.: The use of CT scan based planning for oral rehabilitation by means of implants and its transfer to the surgical field: A critical review on accuracy. *Journal of Oral Rehabiltation,* **Vol.** 35 (2008) No.6, pp.454‐ 74, ISSN 1365-2842.

[3] Van den Broeck, J.; Wirix-Speetjens, R.; Vander Sloten, J.: Preoperative analysis of the stability of fit of a patient-specific surgical guide. *Computer Methods in Biomechanics and Biomedical Engineering*, **Vol.18** (2015) No.1, pp.38-47, ISSN 1476-8259.

[4] Mattheijer, J.; Herder, JL.; Tuijthof, GJM.; Valstar, ER.: Docking Robustness of Patient Specific Surgical Guides for Joint Replacement Surgery. *Journal of Mechanical Design*, **Vol.**137 (2015) No.6, ISSN 0161-8458.

[5] Lin, Q.; Burdick, J.; Rimon, E.: A stiffness-based quality measure for compliant grasps and fixtures. *IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION*, **Vol.**16 (2000) No.6, pp.675-688, ISSN 1042-296X.

[6] Radermacher, K.: *Computerunterstutze Operationsplanung und ausfuhrung mittels individueller Bearbeitungsschablonen in der Orthopadie,* RWTH-Aachen, Achen, (1999).

[7] Ma, B.; Ellis, R.: Analytic expressions for fiducial and surface target registration error. *Medical Image Computing and Computer-Assisted Intervention - MICCAI 2006.* R. Larsen, M. Nielsen, and J. Sporring. (Ed.), ISBN – 3540447075, Copenhagen, Denmark, October - 2006, Springer – Verlag, Berlin Hei

STUDY ON GAIT PATTERN OF INDIAN ADULTS WITH RESPECT TO AGE

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Abstract

The study aims to analyze the age related changes in functional gait patterns among healthy Indian male adults. The adjustments made by young and elderly subjects to maintain balance during walking was determined by analyzing gait parameters. Data was collected with the help of Qualysis 3D motion analyzer and Kistler force platforms from Indian subjects of age 21 to 30 years, 31 to 40 years, 41 to 50 years and 51 to 60 years. Significant changes in the gait parameters were identified which detect the liability to suffer from lower limb problems with ageing. Elderly subjects were not able to increase their speed and stride length when required, presumably seeking greater stability and showed higher cadence rates and stride width, more double limb support compared to younger subjects. Thus, in elderly subjects with prime physiological abilities, ratifying a reduced speed, shorter stride length and wider stride width was a motorized effort to reduce the risk of falls while walking. Therefore, changes in gait parameters with age in Indian male adults can be used as an input during designing of workstation and assigning work for aged workforce in industries and other occupations.

Keywords*:* *Gait 1, Indian male adults 2, Age 3.*

1. INTRODUCTION

Walking, an important activity of daily living is a mode of bipedal locomotion in which a period of double support, i.e. when both feet are in contact with the ground, is followed by a period in which the body is supported by one lower limb while the other is swung forward [9]. Gait is the manner of walking. We do not all have an identical walking pattern. Perhaps the most commonly reported measurements of gait are the temporal-spatial parameters. These include walking speed, stride time and length, step time and length, as well as the durations of stance phase and swing phase. These measurements have been referred to as the “basic gait parameters” and the “vital signs of walking” [14, 15, 10]. This last statement reflects the fact that these measurements are very useful indicators that a gait pattern may be abnormal and, if so, the extent of that abnormality, without necessarily indicating the cause of the problem. The temporal-spatial parameters are relatively easy to measure, requiring little more than a stopwatch, making them practical for clinical use. In particular, we want to understand the patterns of time-distance gait parameters such as stride length, stride time, and cadence which are potentially measurable by computer vision techniques, under various speed conditions.

Balance is challenged during gait when the body is forced to make a postural alteration due to disturbances to the body and a failure to compensate posture changes that results in falls. A key to improve the balance is to increase the stability of the system. Changes in temporal and spatial parameters with age during locomotion are evident from many previous studies [6, 7].

The lower extremities must overcome all stresses for the movement production. In order to prevail over the stress on the musculoskeletal system, the body may need to work harder to counter balance all the biomechanical changes. Each joint will display changes in its angle, moments of force, and power, while muscle recruitment patterns will be altered. Therefore, there is a need to understand how ageing changes the biomechanics of gait as well as the muscle activities in Indian adults (construction workers) engaged in manual material handling.

Consequently, the purpose of this study was to determine the effect of age on human gait and posture adaptation presented by examining three-dimensional dynamic gait parameters of lower extremity among construction workers executing manual material handling.

2. OBJECTIVES

This study aims to analyze the age related changes in functional gait patterns among healthy Indian adults (construction workers)

3. MATERIALS AND METHODS

3.1 Experimental subjects

A cross sectional study was conducted among 120 construction workers from a local construction site in Mumbai, India. The study was commenced after taking permission from the relevant authorities. A written consent was taken from the authority and the details of the study were explained. Information about the study was given at their workplaces. Selections of the subjects were based on non-probability convenient sampling. Selection of the construction site has been a mix of convenience and chance. Data was collected with the help of 3D motion analyzer.

There were the following groups:

1. Male construction workers of age 21 to 30 years
2. Male construction workers of age 31 to 40 years
3. Male construction workers of age 41 to 50 years
4. Male construction workers of age 51 to 60 years

Exclusion criteria-

1. Volunteers suffering from any clinical lower limb problems
2. Volunteers undergone any surgical procedure of lower limbs
3. Work experiences in the same type of job less than 5 years

3.2 Data collection procedure

The motion of each subject was assessed at the laboratory for biomechanics, Ergonomics Department, National Institute of Industrial Engineering (NITIE, Mumbai). Thirty six reflective markers were placed on specific locations of each volunteer's legs and pelvic region. The defining markers, which enabled Visual 3D to reconstruct the digital skeleton of the volunteers, included the following anatomical positions: ASIS (anterior superior iliac spine), PSIS (posterior superior iliac spine), greater trochanters, thigh, shanks, lateral and medial side of knee joint line, lateral and medial malleolus, heel marker was placed on the posterior side of the calcaneus of both the legs and two markers were placed on the first and fifth metatarsal bone of both the legs. After the static trial, heel, knee and hip markers were not needed so were removed during the motion trial.

The OQUS cameras and the Qualisys Motion Capture System, Sweden were used to film the volunteers walking along a 76 meter circular walkway with a diameter of 24.19 m. Each volunteer first walked along the walkway at their self-selected speed. Each volunteer followed the same protocol for all the testing conditions. The volunteers were allowed to walk on both the force plates (Kistler, Switzerland). Force plate-1 and force plate-2 were stepped by left foot and right foot respectively. The volunteers were asked to walk for 15 minutes during which the activity was recorded by the OQUS infrared digital cameras and was considered for analysis.

To ensure that the cameras and force plates recorded properly from both sides of the y-axis (defined as the direction of walking), the test subject entered the analyze-space from positive y-direction half of the trials, while the other half from the negative y-direction. The reflective markers were used to define the different anatomical points on the test subject's body. It was ensured that the cameras and force plates recorded properly all the three coordinate axis. The motion data were then collected and considered for analysis. The data was analyzed.

Postural stability was assessed by measuring the Quadriceps angle (Q- Angle), an angle formed by the crossing of two imaginary lines. The first line extends from the ASIS to the centre of the patella (CP). The second line is drawn from the tibial tuberosity (TT) to the CP. The angle formed between these two lines represents the Q angle [11]**.** The Q angle has come to be accepted as an important factor in assessing knee joint function.

4. RESULTS AND DISCUSSIONS

A total 120 construction workers of different age groups were selected from different construction sites in Powai, Mumbai, India.

4.1 Demographic Details of the subject groups

The characteristics of the sample represented by demographic parameters in Table 1

Table 1 Demographic data

Age Groups	Age (years)	Height(cm)	Weight(kg)
21 to 30	24.76 ± 2.45	166.2 ± 5.83	57.68 ± 10.05
31 to 40	35.6 ± 2.57	162.3 ± 5.16	64.4 ± 5.70
41 to 50	45.17 ± 2.66	158.97 ± 5.87	57.68 ± 10.05
51 to 60	55.8±2.87	168.73 ± 8.18	62.97 ± 7.83

Mean ± Standard Deviation

In Table 1, means and standard deviations for physical characteristics like age (55.8±2.87 years and 45.17 ± 2.66 years for elderly groups) and (35.6 ± 2.57 years 24.76 ± 2.45 years for younger groups), height (168.73±8.18 cm and 158.97 ± 5.87 cm for elderly groups) and (162.3 ± 5.16 and 166.2±5.16 cm young men), weight (62.97±7.83 kg and 57.68 ± 10.05 kg for elderly groups) and (64.4±5.70 kg and 57.68 ± 10.05 kg for young groups) were represented.

4.2 Motion Analysis of the subject groups

Motion analysis had been performed by 3D motion gait analyzer to provide an objective and quantifiable assessment of dynamic functional stability of lower limbs with increasing age has been represented in the following Table 2.

Table 2 Gait Parameters in healthy Indian adults (N=120) with reference to age

Age Groups / **Parameters**	**21-30years (n=30)**	**31-40years (n=30)**	**41-50years (n=30)**	**51-60years (n=30)**
Speed(m/s)	3.6±0.16	3.4±0.13	3.01±0.09	2.37±0.40
Stride width(m)	0.08±0.01	0.09±0.01	0.29±0.06	0.37±0.09
Stride length(m)	1.39±0.08	1.29±0.05	1.21±0.04	1.14±0.04
Cadence(steps/min)	98.7±5.97	112.8±4.83	128.0±8.38	135.9±10.65
Double Limb Support time(s)	0.15±0.04	0.19±0.01	0.63±0.06	0.68±0.04
Cycle time(s)	1.02±0.14	1.25±0.29	1.34±0.17	1.33±0.05
Knee angle flexion (degree)	65.7±3.54	65.6±3.74	64.5±3.50	59.5±3.78
Ground Reaction Force (Newton)	666.5±97.61	668.8±95.27	634.1±94.11	621.7±98.84

Mean ± Standard Deviation

The changes in the gait parameters were noted. The walking speed (m/s) has found to decrease with the increase of age. The stride length (m), stride width (m), cadence (steps/min), double limb support (sec) and the cycle time (sec). The knee flexion angle (degree) and the ground reaction force (Newton) gradually decrease with the increase of age. Wide-based gait is considered indicative of imbalance [3]. Reference [12] showed similar result where stride length of young adults showed a greater increase but double limb support were less than in the older subjects. Reference [8] had observed that elderly subjects exhibited slower walking velocity, shorter step length and cycle time variability but greater stride width compared to young subjects.

Postural control and dynamic balance are essential in activities of daily living and for optimal performance in work. It is affected by knee alignment under static and dynamic conditions. It was measured through quantitative measuring of Quadriceps angle (Q-angle) by standard drawing method and universal goniometry. The static postural equilibrium had been measured in the study to identify the functional disability of the lower limb in construction workers. Change in Q angle with age had been revealed in Table 3.

Table 3 Quadriceps angle (Q angle) measured in degree among healthy Indian adults

Age Groups/ Leg Dominance		**Age Group 21-30 years (n=30)**	**Age Group 31-40 years (n=30)**	**Age Group 41-50 years (n=24)**	**Age Group 51-60 years (n=22)**
Right Leg Q angle (degree)	Mean	12.30	12.77	16.0	17.0
	SD	1.08	0.66	0.98	0.65
Left Leg Q angle (degree)	Mean	10.40	10.8	14.96	15.4
	SD	0.89	0.86	0.62	0.90

The independent t-test was used to compare the Q angles between the four age groups of young and elderly subjects. The result summarized in Table 3 showed that the elderly subjects had significantly higher Q-angles than their younger counterparts in both legs. Increased Q-angle during walking is associated with an increased prevalence of knee injury among older adults [4]. The paired t-test was used to compare the right and left Q-angles (RQA and LQA) in each group. All the subjects had significantly higher RQA.

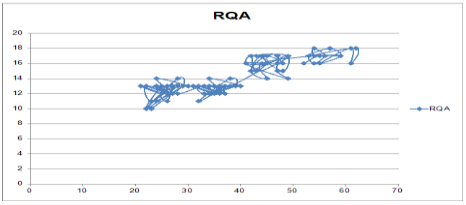

Figure 1 Age v/s Right Quadriceps angle

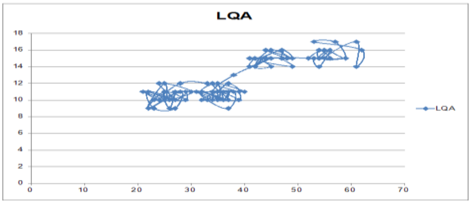

Figure 2 Age v/s Left Quadriceps angle

Higher Q angle influences biomechanics of knee joint and especially patella-femoral articulation by creating an abnormally high valgus angle. This exerts a laterally directed force leading to malt racking and excessive pressure on the patella-femoral articulation and shifts the patella laterally and rotates it medially, thus increasing patella-femoral contact pressure, which consequently results in anterior knee pain [1]. The values of Q

angle documented by various researchers in literature vary. Normal values of Q angle for adult males are less than 14 degree [2].
As the Q angle exhibited a high correlation with reference to age in the present study, it was also correlated with other gait kinematics. It is observed that Q angle has negative correlations with walking speed, stride length and cadence with $p<0.001$ level, whereas positive correlations with stride width and double limb support with $p<0.001$(Table 4). Findings of the present study showed changes in gait kinematics with age. This observation is in resemblance with the study conducted by [13, 5] in which older adults showed reduced gait speed and stride length but increased stride width.

Table 4: Correlation of Q angle with gait parameters

Correlation of Q angle with	**Correlation (r)**
Speed (m/s)	-0.52
Stride width (m)	0.78
Stride length (m)	-0.75
Double limb support (times)	0.82
Double limb support (s)	0.87
Cadence (steps /min)	-0.68

5. CONCLUSION

Walking while doing manual material handling is a daily work in construction sites. It needs to be as efficient and injury-free as possible. Working pattern has affected various regions of lower limb because of overuse of the body part. The changes in the biomechanical parameters were identified to detect the liability to suffer from lower limb problems with ageing among the construction labors engaged in intensive and rigorous manual work. A visual estimation of the Q angle has given important clues about the role this postural distortion plays in a variety of pain complaints. In the lower extremity, a large quadriceps angle (Q angle), is a static postural distortion involving patella femoral biomechanics. An exaggerated Q angle can lead to knee pain and knee pathologies, as well as compensations in other regions of the body. The dynamic postural adjustments used by young and elderly construction workers to maintain balance during walking were task specific and was determined by analyzing the temporal and distal kinematics of gait (Human waking pattern). When required to walk quickly, elderly workers were not able to increase their speed and stride length to the same extent as younger workers. This was presumably because the elderly workers were more cautious and opted for greater stability. Elderly workers showed higher cadence rates and stride width, taken more double limb support and reduced stride length than the younger workers. The elderly workers with a risk of falling modified their basic walking pattern to ensure that their safety. Therefore, there were changes in lower limb kinematics with age in healthy workers. This can be used as an input during designing of workstation and assigning work for aged workforce in industries and other occupations.

REFERENCES

[1] Abdel-aziem, A. A.; Abdelraouf, O. R.; El-Gohary, T. M. & El-Gohary, T. M.: Effect of Body Position on Measurement of Q Angle in Trained Individuals with and without Patellofemoral Pain, *International Journal of Therapies and Rehabilitation Research*, **Vol. 3** (2014) 3., pp. 1-5, ISSN: 2278-0343.

[2] Clifford, R.: Q angle of the knee, *Wheeless textbook of orthopaedics*, Data Trace Internet Publishing, Electronic Book, United States, (2012).

[3] Fredericson, M. & Yoon, K.: Physical examination and patellofemoral pain syndrome, *American Journal of Physical Medicine and Rehabilitation*, **Vol. 85** (2006) 3., pp. 234-243, ISSN: 0894-9115.

[4] Gross, K.; Niu, J.; Tseng, Y.; Zhang, Y.; Hillstrom, H. J.; Mattson, D. J. & Felson, D. T.: The relationship between quadriceps angle during walking and patellofemoral osteoarthritis in older adults: the most study, *Osteoarthritis and Cartilage*, **Vol. 20** (2012), pp. 17, ISSN: 1063-4584.

[5] Hylton, B.; Menzstephen, R. L. & Fitzpatrick, R. C.: Age-related differences in walking Stability, *Age and Ageing*. **Vol. 32** (2003) 2., pp. 137–142, ISSN: 0002-0729.

[6] Kinoshita, H.: Effects of different loads and carrying systems on selected biomechanics parameters describing walking gait, *Ergonomics.* **Vol. 28** (1985) 9., pp. 1347-1362, ISSN: 0014-0139.

[7] Knapik, J.; Harman, E. & Reynolds, K.: Load carriage using packs: A review of physiological, biomechanical and medical aspects, *Applied Ergonomics*, **Vol. 27** (1996) 3., pp. 207-216, ISSN: 0003-6870.

[8] Menz, H. B.; Stephen, R. L. & Fitzpatrick, R. C.: Age-related differences in walking Stability. *Age and Ageing*, **Vol. 32** (2003) 2., pp. 137–142, ISSN: 0002-0729.

[9] Obaidi, S. A.; Wall, J. C.; Yaqoub, A. A. & Ghanim, M. A.: Basic gait parameters: A comparison of reference data for normal subjects 20 to 29 years of age from Kuwait and Scandinavia. *Journal of Rehabilitation Research and Development*, **Vol. 40** (2003) 4., pp. 361-366, ISSN: 0748-7711.

[10] Öberg, T.; Karsznia, A. & Öberg, K.: Basic gait parameters: reference data for normal subjects, 10-79 years of age. *Journal of Rehabilitation Research and Development*, **Vol. 30** (1993) 2., pp. 210-23, ISSN: 0748-7711.

[11] Raveendranath, V.; Nachiket, S.; Sujatha, N.; Priya R. & Rema, D.: Bilateral Variability of the Quadriceps Angle (Q angle) in an Adult Indian Population. *Iranian Journal of Basic Medical Sciences*, **Vol. 14** (2011) 5, pp. 465-471, ISSN: 2008-3866.

[12] Shkuratova, N.; Morris, M. E. & Huxham, F.: Effects of Age on Balance Control during Walking. *Archives of Physical Medicine and Rehabilitation*, **Vol.85** (2004), pp. 582-588, ISSN: 0003-9993.

[13] Sussman, D. H., (1993). Characteristic Patterns Of Gait In Aged Populations Compared To A Young Adult Population, *Proceedings of 11 International Symposium on Biomechanics in Sport*. Hamil, J.; Derric, T. R. & Elliot, E. H. (Ed.), pp. 83-85, ISSN: 1999-4168, Amherst, Massachusetts - USA, June 23 - 26, (1993).

[14] Wall, J. C.; Hogan, D. B.; Turnbull, G. I. & Fox, R. A.: The kinematics of idiopathic gait disorder. A comparison with healthy young and elderly females. *Scandanavian Journal of Rehabilitation Medicine* . **Vol. 23** (1991) 3, pp.159-64, ISSN: 1650-1977.

[15] Wall, J. C. & Scarbrough, J.: Use of a multimemory stopwatch to measure the temporal gait parameters. *Journal of Orthopaedic & Sports Physical Therapy*, **Vol. 25** (1997) 4, pp. 277-281, ISSN: 0190-6011.

DESIGNING ERGONOMIC WORKSTATIONS FOR PEOPLE WITH RESTRICTED ABILITIES USING EMA SIMULATION SOFTWARE

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Abstract

The number of people with restricted abilities due to permanent physical impairments is growing, particularly in industries that rely on manual production tasks. Companies are facing high costs for reintegrating such employees - and even more if reintegration fails. We present an innovative approach for supporting the integration of people with restricted abilities during the design phase of new assembly lines by means of digital human modelling. The simulation software EMA is able to systematically consider physical impairments in the set-up of the production processes and in the assessment of results.

Keywords: *demographic change, digital human models, employees with impaired abilities, workplace design*

1. INTRODUCTION

The demographic change with an increasing ageing workforce is an upcoming challenge for companies around the globe. With growing age, the share of musculoskeletal diseases increases [1]. In addition, companies face a high rise of employees with physical impairments. Studies have shown, that workplaces with good ergonomic conditions are associated with less absence from work and a reduced error rate [2]. Especially the production sector needs highly efficient production processes for its competitive ability and they need an optimized value added assignment of employees in particular for the people with restricted abilities.

Employees with impaired abilities are people with temporary or long-term restrictions in their physical or mental performance. Mostly, these people cannot perform their regular job anymore, which results in productivity losses [3]. In addition there are many different types of restrictions that mostly occur in combinations. To ensure a value-adding work task it is necessary to provide these employees with a job and workplace that is adapted to their specific abilities and needs. An efficient deployment of employees with impaired abilities needs new concepts for production planning and series production.

2. CONCEPTS

2.1. General strategy

One reasonable instrument for a value-adding integration of restricted people is an individual matching between available employees and workplaces. This needs a systematic two-sided comparison of equal attributes on both sides (employee and the profile of workplace requirements). First of all it is essential to conduct a systematic classification of individual abilities and workplace requirements. Abilities and restrictions should therefore be divided into categories of possible physical strains like static postures (e.g. trunk bending/rotating), action forces (on finger/arm system), and manual load handling. Other requirements may apply to work organization like working in night shifts or cycled production lines. In the next step, the comparison between the employee and the workplace results in a decision whether the employee-workplace profile matches. If it doesn't match, further workplaces would need to be analyzed until a perfect individual match between one employee and one workplace is found (see Figure 1 for an example match analyses).

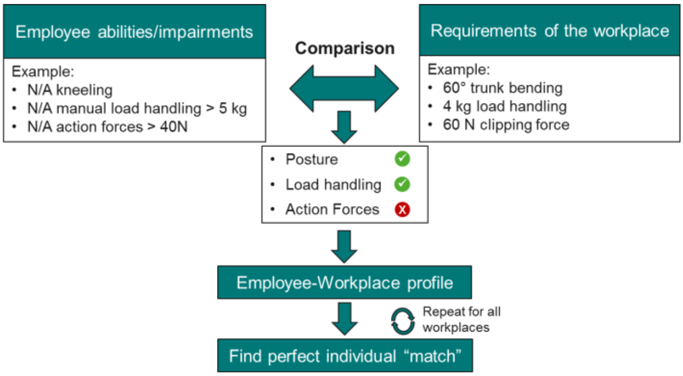

Figure 1: example of a matching process

With standardized categories, the company physician is able to rank the workers and their individual restrictions. On the other hand, the matching process needs a workplace profile with an assessment of the requirements related to the individual performance. Especially in early production planning an objective estimation is necessary, but in this phase useable data usually does not exist. The tools of the digital factory can be used for such assessment. In this case, digital human models (DHM) provide possibilities to design workplace prospectively and for an early validation of feasibility, process time and physical strain.

2.2. Virtual Planning with DHM

Current DHM are adjustable in gender or body height, but special abilities cannot be simulated. The Editor for Manual Work Activities (EMA) is a planning method based on a 3D digital human model which supports the early phase of product, process and resource planning [4]. It allows the dynamic simulation of manual work processes and

can be used to perform feasibility studies of operating processes. Furthermore EMA can perform an automatically generated risk assessment of physical strain based on the Ergonomic Assessment Worksheet (EAWS) [5]. The addition of parameters of human performance abilities is the next step to a holistic consideration of work place design.
Figure 2 shows an example of a workplace within a pre-assembly line that has been designed with EMA. These workplaces were designed for employees with restricted abilities, who can participate at an value-added production, regardless of their individual physical restrictions. The assessment with EAWS shows a very low risk score on all three workplaces.

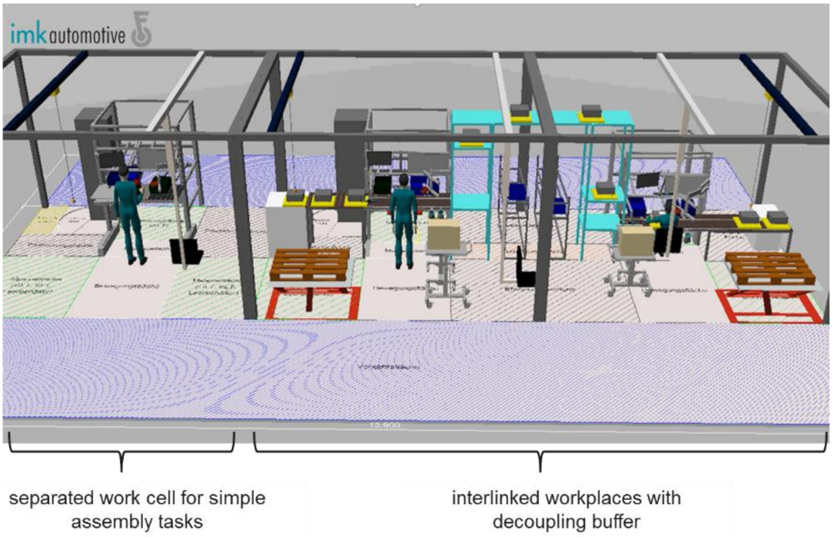

Figure 2: example of workstations with a low-risk for physical strain

In addition to the general EAWS score, the future system will be able to provide an assessment of the specific work ability for the simulated individual worker. Moreover, it is planned to show an overview about the general requirements of the simulated workplace. With the help of this information it is possible to derive proposals for a redesign of the workplace to fit the employee's needs.
For the implementation of impaired abilities into a DHM it is necessary to define groups of performance prerequisites similarly to the matching process, for example manual load handling over 5 kg or forced body postures like working over shoulder level. Implementation of these impairments needs a synthesis of a model to transfer factors into interpretable parameters for the DHM. For example joint-movement-restrictions as a result of musculoskeletal diseases can affect the range of movements of the DHM. Another possibility would be the (automatic) generation of alternative movements to compensate the individual restrictions by new motion strategies. For example an alternate walking route can be simulated to avoid a trunk rotation while picking up an object.

3. DISCUSSION

This overview about strategies and concepts shows the spectrum of prospects to integrate employees with impaired abilities. It's necessary to perform individual and detailed evaluation in order to find a suitable workplace. The integration of individual performance attributes as an add-on for simulation software of DHM is a chance to simulating and efficiently integrating employees with impaired abilities. In general, an ergonomic workplace design can avoid the aggravation of existing diseases as well as the development of new work-related diseases for all employees.

REFERENCES

[1] Reinhart G.; Egbers, J.: Integrating Ability Limitations into Assembly System Design, *Enabling Manufacturing Competitiveness and Economic Sustainability - Proceedings of the 4th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV2011)*, ElMaraghy, H. (Ed.), pp. 35-40, ISBN 978-3-642-23860-4, Montreal, October 2011, Springer, Berlin, Heidelberg, (2012)

[2] Fritzsche, L.; Wegge, J.; Schmauder, M.; Kliegel, M.; Schmidt K.: Good ergonomics and team diversity reduce absenteeism and errors in car manufacturing, *Ergonomics*, **Vol.** 57 (2014) No. 2, pp. 148-161, ISSN 0014-0139

[3] Rudow, B.; Neubauer, W.; Krüger, W.; Bürmann, C.; Paeth, L.: Die betriebliche Integration leistungsgewandelter Mitarbeiter – ein Arbeits- und Personalprojekt aus der Automobilindustrie, *Arbeit: Zeitschrift für Arbeitsforschung, Arbeitsgestaltung und Arbeitspolitik*, **Vol.** 2 (2007) No. 16, pp. 118-131, ISSN 0941-5025

[4] Illmann, B.; Fritzsche, L.; Leidholdt, W.; Bauer, S.; Dietrich, M.: Application and Future Developments of ema in Digital Production Planning and Ergonomics, *Digital Human Modeling and Applications in Health, Safety, Ergonomics, and Risk Management, DHM/HCII 2013, Held as Part of HCI International*, Duffy, V.G. (Ed.), pp. 66–75, ISBN 978-3-642-39181-1, Las Vegas, July 2013, Springer, Berlin, Heidelberg, (2013)

[5] Schaub, K.; Caragnano, G.; Britzke, B.; Bruder, R.: The European assembly worksheet, *Theoretical Issues in Ergonomics Science*, **Vol.** 14 (2013) No. 6, pp. 616-639, ISSN 1463-922X

DEVELOPMENT OF PROJECTION BASED ASSISTANCE SYSTEM FOR MANUAL ASSEMBLY

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Abstract

The requirements for the configuration of assembly systems are changing. With innovation times and product life cycles constantly being shortened, as well as an increasing number of variants and small batches contributing to this phenomenon, industries are faced with the challenge to create efficient processes with high process capability. In particular, assembly errors happen because of activities with larger work content and fluctuating demands. In addition, under these conditions often quantity or rather productivity targets are missed [1]. The reasons for this are the insufficient support of learning processes for new employees as well as the missing preparation of assembly information, which should be designed to be spotted quickly and implemented intuitively correct. In a study at the Laboratory of Industrial Engineering of the Ostwestfalen-Lippe University of Applied Sciences, a prototype of a projection based assistance system for manual assembly has been developed and tested. The system contains functionalities for ergonomic display of work instructions. These include, markers and precise positioning representations corresponding with these, a pick-to-light function and other features. By adapting the representation to the context-sensitive information, the complexity of large work contents can be made manageable.

Keywords: *manual assembly, assistance systems, worker assistance, usability, pick-to-light*

1. INTRODUCTION AND INITIAL SITUATION

The rising demand for individual products and the fluctuating customers' needs increases the exigencies on industrial establishments with assembly areas and also the requirements on the employees [1]. One of the difficulties in manufacturing varied products lies in mastering complex, constantly changing mounting contents in compliance with consistent quality and productivity. The frequent changes of work operations cause a relatively early cancel of the learning curve of the worker [2] and can lead to high learning times, especially for complex assembly tasks, and a higher error rate. Simultaneously industries with large manual assembly areas are faced, in view of demographic trends [3], with the challenge to configure assembly systems with the aim to ensure the employability of the employees for these tasks and guarantee high productivity.

In practice, new media are increasingly being used to assist the assembly process [4], however, the common media for providing information in manual assembly remain paper and monitor screen. Assembly descriptions or patterns on paper have the disadvantage that they can be easily damaged or become soiled. If they do not

sufficiently describe the task or if language barriers exist, comprehension problems can occur. Each different order may change the assembly plan which then must be sought out. This increases, in particular at a high product variance, search times, and carries the risk of confusion in itself. The assembly process is therefore more prone to errors and includes higher non-value operation times.
Furthermore, the problem of paper-based methods lies in the concentration, selection and the demand suitable preparation of information. From the perspective of labour psychology, people should not be overburdened with too much or time-consuming quests for information [5]. This can lead to substandard reading of work instructions or assembly schedules [6]. Innovative assistance solutions with a user-friendly representation of information on the other hand help to increase flexibility, quality and productivity in order to meet requirements for a customized and varied assembly [7].
The following figure, in reference to Schlick et al. [8], shows a morphology of possible types of information input and output between human and assembly assistance system.

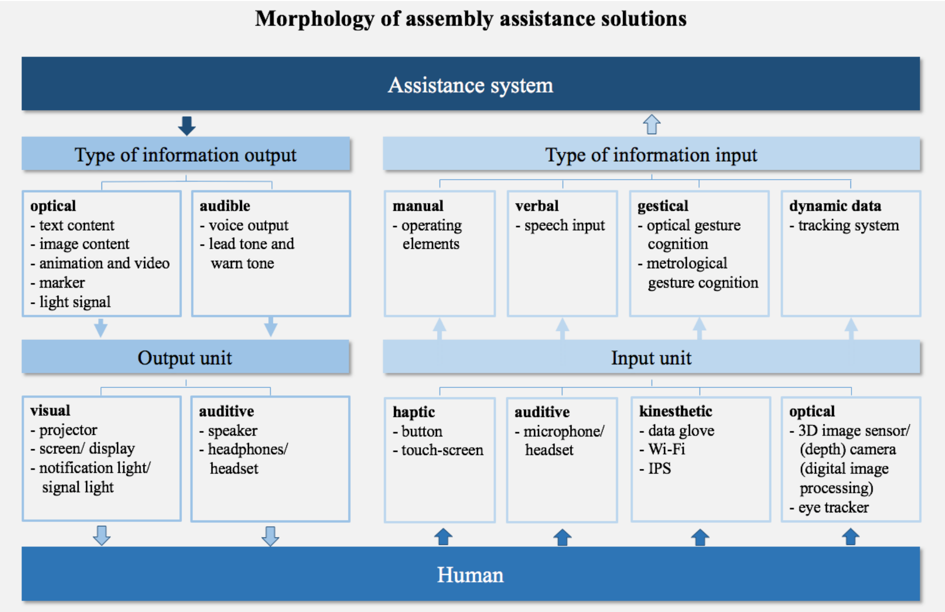
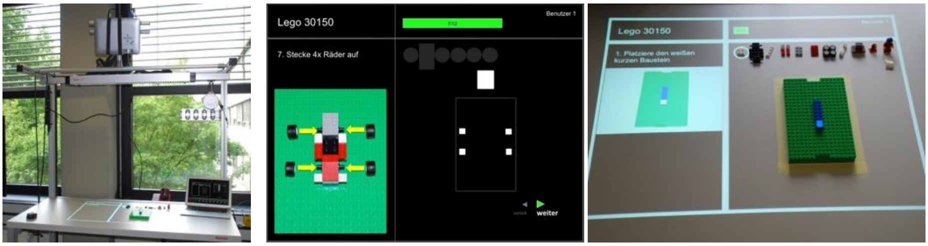


Figure 1: Morphology of assembly assistance solutions

The selection of appropriate input and output units should adapt to the user, the given task and the environmental conditions. To meet these targets, combining items in the configuration can be considered.

2. OBJECTIVE AND METHODOLOGY

A projection-based assistance system can be used to indicate digital instructions to the user, so that he can perform his task successfully. As a field of application for such assistance systems, workspaces with manual assembly activities are suited best.
The projection-based assistance system should contain particular functionalities for ergonomic display of work instructions. It should moreover show the user precisely which part, at what point and in which way needs to be mounted. Only the relevant information for the individual operation is provided. This is not only supposed to reduce the error rate significantly, but also increases the learning time substantially. By adapting the displayed work instructions to the context-sensitive information, the complexity of large work contents can be made manageable. Over and above that, the system should increase the efficiency and quality, reduce stress and strain for the employee and improve the flexibility and adaptability of the working system.
The procedure for the development of the assistance system is based on the human-centred design for interactive systems according to the international standard ISO 9241-210:2010 [9], which provides for the holistic development process a continuous evaluation with users.
In a first step, staff interviews were carried out at a manufacturer of woodworking machines to assess the needs of employees.
In a second step, the graphical user interface was developed. The basic structure consists of four areas: the pick-to-light area, the positioning and marking area, the instruction area with instructions, based on images, text and shape animations, and a status area, with displays gamifications like progress information and process-related data.
The developed concept was evaluated in subjects' experiments. For the evaluation of the graphical user interface (GUI) demonstrator, a LEGO car was chosen as the assembly object (see Figure 2), because it can be mounted in a number of different ways.



a. b. c.

Figure 2: Experimental setup of the GUI demonstrator for mounting the LEGO car: a. Hardware setup, b. Software layout, c. Representation of digital instruction

Subsequently, the developed concept for the projection-based worker assistance was adapted to a product of an industrial plant, because it ensures a realistic simulation of the developed assembly workflow GUI. At a simulation assembly workstation at the Laboratory of Industrial Engineering, the system was tested.

3. DEVELOPMENT AND TEST RESULTS

As a result of the staff interviews, it has been deduced clearly that workers place great value on an appealing and intuitive visual presentation that is intended to reflect only the information relevant at a certain point in time. They expected shorter learning periods and the prevention of errors from implementing the system in their workplaces.
The basis for the development and study was the application of the manual assembly of a product the workers had previously been unfamiliar with. The worker is supported by an assistance system that projected the required information about the workflow onto the workspace or onto the part or the product. A paper-based workflow was investigated first. From this the underlying information was extracted and processed in a software layout (see Figure 3 a.). This software-based information was then presented to the user by a graphical user interface projected into the direct field of view (see Figure 3 b./ c.). This approach has the advantage that the user does not need to look away from the work area as opposed to using a screen to read the current work instruction. The representation of information on a work surface on the manual assembly workspace can improve the efficiency in manual assembly itself [10].
Figure 3 b. shows a workpiece carrier with a workpiece onto which two green rings are projected as a positioning aid. The container with washers and nuts is visually identified for the purpose of pick-to-light. The work instruction in the form of text and image is projected onto the designated area. Figure 3 c. shows the illumination of the relevant container with the additional information of the withdrawal amount for the purpose of pick-to-light.

a. b. c.

Figure 3: Experimental setup of the GUI demonstrator: a. Software layout, b. Representation of assistance information, c. Representation of assistance information with pick-to-light including the withdrawal quantity

To review the concept of representation, a usability study was carried out, which surveys the usability of a demonstrator. It is to show whether the worker was able to complete the assembly task successfully using the assistance demonstrator. The usability was determined in subjects' experiments by using a questionnaire.
According to Brooke an index needs to be calculated for determining the usability, also referred to as system usability scale (SUS), by using reference questions [12]. Brooke describes a proven method of execution and appraisal of usability tests and thus for determining the usability. The associated questionnaire comprises ten questions.
Each of the ten questions can be rated on a scale from 1 to 5. 1 corresponds to the statement "I strongly disagree" and 5, the highest rate, to the statement "I fully agree".
By using a formula, the SUS rate of these assessments can be calculated. The SUS rate

results in a value range from 0 to 100. The higher the value, the more user-friendly is the system. This average can be interpreted as a percentage [13]:

- 100% corresponds to a *perfect* system *without usability problems*.
- Values above 80% indicate a *good* to *excellent* usability.
- Values between 60% and 80% are to be interpreted as *borderline to good*.
- Values below 60% are indications of *significant usability problems*.

A preliminary test showed that subjects prefer the visual work instructions in the form of assembly workflow GUI instead of paper. The intuitive navigation through the assembly workflow using the buttons, voice command or gesture cognition satisfied the subjects. This has proven the SU rate, as it rose from very good (91%) in the preliminary test to excellent (95%) in the evaluation of the GUI for the LEGO car. It has also shown that the developed GUI concept for supporting the worker in completing his assembly task could prove useful.

The subsequent main evaluation using an industrial product showed that the subjects were able to use the visual work instructions in the form of assembly workflow GUI well to successfully complete the assembly. This is validated by the SU rate which corresponded to a *very good* system usability.

4. APPRAISAL AND CONCLUSION

The testing of the developed projection-based assistance system has shown that the manual assembly could do without long learning times. The worker may proceed directly to the assembly, without previous knowledge of the assembly process of a component and only after a short introduction to the projection-based assistance system. He can attain a high degree of exercise because of the visual guidance and then, if necessary, adjust the displayed assembly information individually. It is possible, for example, to go through the assembly process without the presentation of text content and guided only by visual signals. Thus, a contribution can be made to avoiding errors or mistakes even among already experienced worker.

The complexity regarding manual assembly processes and the increasing numbers of variants can be made manageable by the visual worker guidance in terms of projection-based assistance systems.

It should be noted that the projection system has not yet been tested in “real” environments and therefore statements about the robustness, durability, economic efficiency and workers’ acceptance of the system cannot be made as of yet. These reservations are simultaneously an outlook for the next steps of this project.

REFERENCES

[1] Haller, E.; Heer, O.; Schiller, E. F.: Innovation in Organisation schafft Wettbewerbsvorteile - Im DaimlerChrysler-Werk Rastatt steht auch bei der A-Klasse-Produktion die Gruppenarbeit im Mittelpunkt, *FB-IE: Zeitschrift für Unternehmensentwicklung und Industrial Engineering 48*, **Vol.** (1999) 1, pp. 8-17, ISSN 0340-8302

[2] Wiesbeck, M.: *Struktur zur Repraesentation von Montagesequenzen für die situationsorientierte Werkerfuehrung*, Herbert Utz Verlag, ISBN 3831643695, Munich, (2014)

[3] Hunter, J. E.; Schmidt, F. L.; Judiesch, M. K.: Individual differences in output variability as a function of job complexity, *Journal of Applied Psychology 75,* **Vol**. (1990) 1, pp. 28-42, ISSN 0021-9010

[4] Statistisches Bundesamt (Federal Office of Statistics): *Statistisches Jahrbuch 2014 - Deutschland und Internationales*, Statistisches Bundesamt, ISBN 978-3-82461-029-7, Wiesbaden, (2014)

[5] Wiesbeck, M.; Zaeh, M. F.; Rudolf, H.; Vogl, W.: New Media and Technology Support in Manual Assembly, *Research in Interactive Design: Proceedings of Virtual Concept*, Fischer, X. et al., ISBN 978-2-28748-363-9, Playa Del Carmen, Mexico, 26. Nov. - 1. Dec. 2006, Springer, Paris, (2006)

[6] Muenzberger, E.: Modularer Lehrbrief “Einfuehrung in die Arbeitsmedizin”, Abschnitt Einfuehrung in die Arbeitsphysiologie, *Available from* http://arbmed.med.uni-rostock.de/lehrbrief/arbphys.htm *Accessed:* 2015-08-04.

[7] Dreyer, J.: *Situative Informationsbereitstellung an Fertigungseinrichtungen Informationsmodell und Erstellungssystematik*, Jost-Jetter, ISBN 978-3-93694-783-0, Heimsheim, (2006)

[8] Mueller, R.; Vette, M.; Mailahn, O.; Ginschel, A.; Ball, J.: Innovative Produktionsassistenz für die Montage - Intelligente Werkerunterstützung bei der Montage von Großbauteilen in der Luftfahrt, *wt Werkstattstechnik online 104*, **Vol.** (2014) 9, pp. 552-560, Springer-VDI, Dusseldorf

[9] Schlick, C. M.; Bruder, R; Luczak, H.: *Arbeitswissenschaft*, Springer, ISBN 978-3-54078-332-9, Heidelberg Berlin, (2010)

[10] ISO 9241-210:2010: *Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems*, International Organization for Standardization, (2010)

[11] Stoessel, C.; Wiesbeck M.; Stork S.; Zaeh, M. F.; Schuboe, A.: Towards Optimal Worker Assistance: Investigating Cognitive Processes in Manual Assembly, *Manufacturing Systems and Technologies for the New Frontier*, Mitsuishi, M., Ueda, K. & Kimura, F. (Eds.), pp. 245-250, Springer, London, (2008)

[12] Ablassmeier, M.: *Multimodales, kontextadaptives Informationsmanagement im Automobil*, Dissertation TU Munich, Munich, (2009)

[13] Brooke, J.: SUS: A “quick and dirty” usability scale, *Usability Evaluation in Industry*, Jordan, P. W., Thomas, B., Weerdmeester, B. A. & McClelland, A. L. (Eds.), Taylor and Francis, London, (1996)

[14] Rauer, M.: Quantitative Usablility-Analysen mit der System Usability Scale (SUS), *Available from* https://blog.seibert-media.net/blog/2011/04/11/usablility-analysen-system-usability-scale-sus/ *Accessed:* 2015-11-19.

WORKING IN FLEXED POSITION CAN AFFECT TRUNK STABILITY AND INCREASE THE CHANCE FOR BACK PAIN

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Abstract

Low back pain (LBP) is the most common work related musculoskeletal disorder. Although recent epidemiological meta-analyses did not show the causal effect of working in awkward postures on LBP, there is a growing body of laboratory evidence that repetitive or sustained flexion can increase risk of LBP. Nevertheless, at work place studies are still lacking. Lumbar range of motion and postural reflex reactions to sudden loading of the hands has been assessed in 27 harbor crane operators and 49-matched control male subjects before and after a typical day at work. 2-way RMANOVA has shown significant main effect of work time on obliquus internus muscle (p = 0.041) reflex activation onset timing with significant work time x work place interaction (p = 0.048) indicating more co-contraction orientated stabilizing strategy in crane operators after work.

Keywords*:* *Trunk flexion, spine stability, low back pain, postural reflexes, trunk mobility.*

1. INTRODUCTION

European working population perceives ergonomic factors as a strong health risk. More than one quarter of the interviewed population mentioned repetitive movements and tiring or painful positions (28%) as one of the main health and safety risk and additional 24% reported lifting, moving or carrying loads on daily bases as an important risk [1]. Lifting and carrying, frequent bending and twisting and exposure to whole-body vibrations were also recognized as harmful by the USA National Research Council Institute of Medicine (2001). Nevertheless a recent set of review articles concluded that there is no sufficient evidence of causality and lack of evidence about dose response relationship between those traditionally recognized risk factors and low back pain (LBP) [3–5]. Multifactorial nature of LBP and the interrelation between different work-related risk factors lead to proposal of new combined measure assessing the cumulative load of the spine [6]. Furthermore, potential mechanisms responsible for the onset of LBP should be better understood in order to clarify the relationship between the work characteristics and the LBP.
Repetitive and sustained trunk flexion has been shown to alter intrinsic trunk stiffness and neuromuscular control [7–9], the two important components contributing to the spine stability [10]. The model based on animal studies suggested that excitability of mechanoreceptors in passive tissue decreases with duration of flexion. Simultaneously

stabilizing contribution from the passive viscoelastic tissues decreases due to passive viscoelastic tissues creep deformation, altogether resulting in decreased robustness of the spinal stability [11]. The model further differentiated between low and high risk loading where (i) following low risk loading the excitability of the mechanoreceptors slowly returned to baseline level and (ii) the high risk loading where the excitability increased beyond the initial level during the recovery period. This hyper-excitability coincided with the marked increase in the inflammation markers suggesting the sub-failure damage of the tissue [11].

Two types of tissue loading have been differentiated during trunk flexion namely the "creep deformation loading" (constant load is applied to passive viscoelastic structures usually at the end range of movement) and the "stress relaxation loading" (the position is held constant and the contribution from passive viscoelastic tissues slowly decreasing). Further it has been shown that several other factors such as flexion angle [12], flexion rate [13], continuity [14], external loads [15], age and sex [14] contribute to the degree of viscoelastic tissue deformation during flexion. However there is some inconsistency regarding the effect of the duration of the loading. It has been suggested that majority of the passive viscoelastic tissue deformation develop within first two minutes [12]. In line with that, Hendershot and colleagues [16] did not find any difference in trunk stiffness or reflex gains following 2 and 16 minutes of trunk flexion. On the other hand, Parkinson and Colleagues [17] suggested that the changes may vary with the longer duration of the flexion. They have shown trend towards decreased trunk intrinsic stiffness following a 30-minute set of lifting and lowering a load. The trend was reversed following the second 30-minute set of lifting with the intrinsic stiffness approaching or even exceeding the initial intrinsic trunk stiffness. In support of the two-phasic response are also the results of our previous study indicating significant increase of intrinsic trunk stiffness following 1 hour of repeatedly sustained flexion (manuscript submitted for review).

There is a lack of information about the effect of longer lasting trunk flexion on trunk neuromuscular control specifically following the real life occupational demands. The goal of the present study was therefore to assess the differences in trunk mobility and neuromuscular control following regular day of harbor crane operator work. Furthermore, this was compared to a control group of age- and weight-matched control subjects working in the same port. We hypothesized that the range of motion (RoM) will increase more in crane operators after the work. Further we hypothesized that muscle reflex responses will show larger latencies and that the maximal moment (M_{max}) will decrease in crane operators indicating the fatigue of the trunk extensor muscles.

2. METHODS

2.1. Participants

The present study was performed in the Port of Koper and the participants were recruited from the employees. 38 male crane operators were initially measured but only 27 of them (on average [mean (standard deviation)] 39 (8) years old, 183 (45) cm height and 97 (15) kg weight) worked their normal shift on the crane due to the variability of the work demands. Only those 27 were included in the further analysis. Control group has been recruited from the same Port and included 51 male office workers and supervisors (on average 41.4 (8.8) years old, 181 (6) cm height and 91 (13) kg weight) both having predominantly sedentary work. The participants estimated their current

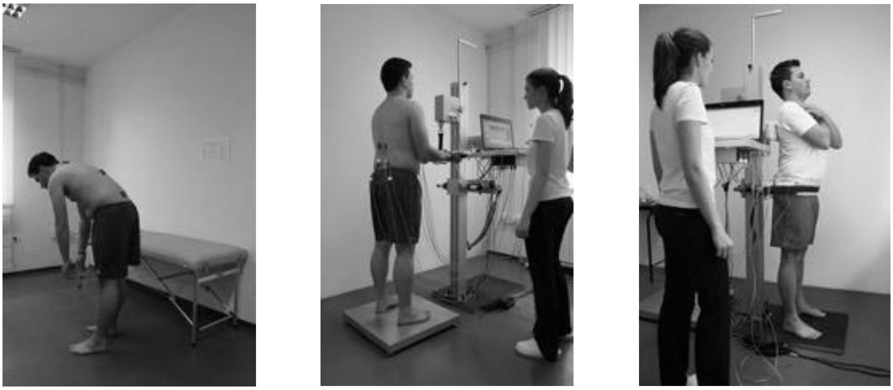
LBP on a visual analog scale (VAS) and there were no significant differences in average scores between crane operators (VAS 2.1 (2.4)) and control group (VAS 1.8 (2.2)). The National Medical Ethics Committee has approved the study and the participants signed the informed consent agreement prior to the measurements.

2.2. Measurements

All participants were measured prior to the beginning of the morning shift between 6 and 9 o'clock in the morning. Post work measurements were performed between 12:30 and 16:30. Crane operators' day at work is divided into two bouts lasting two hours on the crane with 2 hours break in between. The timing of the afternoon measurements was therefore scheduled to allow the crane operators to work two shifts lasting 2 hours on the crane with at least one to two hour brake in-between and for the control group to perform their usual work for at least 6 hours. Measurements were performed in the quiet and warm room within the Port and the participants were transported to and from the facility by the means of internal transports taking less than 5 minutes.

Measurements were performed always in the same order to reduce potential confounding effects of the foregoing measurements. Measurements were performed in the following order: 1) measurements of trunk and hip passive RoM, 2) measurements of the active trunk repositioning error, 3) body sway measurements during standing on a single leg (the push-off leg), 4) measurements of anticipatory postural adjustments, 5) measurements of postural reflex reactions (PRR) to sudden loading, 6) measurements of M_{max} in the direction of trunk extension, side-flexion and flexion, and 7) finally, the measurements of the resistance to fatigue in the direction of trunk extension were performed. This report will focus on the measurements of the lumbar RoM, PRRs and M_{max} in the direction of the extension.

After the standardized warm-up (20 high knee rises, 10 squats, 10 wall pushups, 10 single leg dead lifts with hands abducted) the participants were equipped with the inertial measurement units (IMU, S2P Ltd., Ljubljana, Slovenia), one placed over the sacrum and another at the level of the 1st lumbar vertebra. IMUs were attached to the skin using double-sided self adhesive tape and additional elastic fixation net if needed. Further, 9 electromyography (EMG) electrodes (custom made, S2P Ltd., Ljubljana, Slovenia) with two active sites (r = 0.5 cm) with fixed 2 cm center-to-center distance were placed bilaterally over the multifidus muscle (MF) at the level of 5th lumbar vertebrae, over the erector spinae longisimus muscle (ES) at the level of the 1st lumbar vertebra, over the obliqous muscle (OE) and over the obliqous internous muscle (OI) [18]. Finally, the reference electrode was placed over the trochanter major. Custom developed software (LabView 2011, Austin, USA) was used for signal acquisition and post-processing.



a. b. c.

Figure 1: Measurements of range of motion (a.), postural reflex reactions in response to sudden perturbation applied to the hands (b.) and of maximal isometric moment (c.) are shown.

Lumbar RoM measurements were performed in a standing position (Figure 1a) with knees extended. The instruction to the participants was to bend the back as much as possible trying to touch the flor with the fingers or trying to touch the knees with the forehead [9]. The lumbar angle was calculated as the difference in the inclination of the two IMUs. The IMUs were offset in upright position and RoM was calculated as the difference between upright position and maximal lumbar flexion position. Participants performed three repetitions and the largest RoM was taken for further analysis.

PRRs to sudden loading of the hands were measured in upright standing position (Figure 1b) as previously described in our reliability study [18]. The participant bend the elbows to 90° and the 7 kg weight was set at the appropriate height for the weight handles to lightly touch the participant`s hands. The weight was randomly released every 5 to 12 seconds, by the electromagnetic clutch mechanism and fall freely on participants` hands. The instruction was to stop the movement of the weight as fast as possible and to maintain the position for two seconds before raising the handle allowing the mechanism to reconnect. The participant performed 2 sets of 10 repetitions with a 2-minute break between the sets. EMG Signals were band-pass filtered (10 Hz/1 kHz) and rectified using root mean square method. Automatic computer detection (Labview, National Instruments, Texas, USA) was used to determine the beginning of muscle activity. The processed EMG signal was assessed using a 25-ms sliding window. The muscle was considered to become active when the processed EMG signal exceeded the average plus 2 standard deviations of the baseline EMG signal calculated from the 50-ms reference window (directly before the activation onset detection limits). All signals were later manually inspected and corrected when activation was obviously incorrectly detected by the software due to EMG artefacts. When there was no activation of the investigated muscle or the activation was not within detection limits, the signal was deleted.

M_{max} of the extensors was measured in the upright standing position with pelvis fixated (Figure 1c) to the padded support placed posteriorly at the level of the participant`s sacrum and the padded belt firmly passing anteriorly just below the anterior superior iliac spine. Another padded horizontal support with a force sensor (Z6FC3 - 200 kg, HBM, Nemčija) was placed posteriorly just below the spinae scapulae. The instruction to the participant was to push the upper body support posteriorly with slowly increasing force to reach maximal force within 2 to 3 seconds and to push with as much force as possible for 3 seconds and then slowly release. Three repetitions were performed with short rest periods in-between. Maximal force was evaluated as the peak value within one-second time interval and the highest obtained force was used to calculate the maximal momentum. The distance between the upper and the lower support was used as the length of the leaver arm for the calculation of the lumbar M_{max}.

2.3. Data analysis

Assumption of normality of the data distribution was assessed by the Shapiro-Wilk test and by additional visual inspection of the distribution plots. Logarithmic transformation has been used to meet the distribution assumptions, when needed. Further sphericity was checked using Mauchly's test. The demographic data was checked using a two-tailed T-test for independent samples. To investigate whether the RoM, PRRs or M_{max} change during the working day and if the change was different between the crane operators and the control group, a 2-factor (*Time* (2) × *Work* (2)) analysis of variance for repeated measures (RMANOVA) was used. Significant main effects and interaction effects were followed up by Bonferroni corrected pair-wise comparison. Effects were considered significant when $p < 0.05$.

3. RESULTS

The analyses have shown significant main effect of *Time* ($p = 0.022$ $F = 5.52$ $\eta^2 = 0.07$) indicating significant increase in RoM regardless of the working position ($p = 0.862$ $F = 0.03$ $\eta^2 < 0.01$). By work separated *post-hoc* pairwise comparison did not show significant difference in crane operators ($p = 0.080$) nor control group ($p = 0.128$). Although the trend of stronger increase of RoM in crane operators is visible (Figure 2a) there was no significant interaction effect ($p < 0.645$ $F = 0.22$ $\eta^2 < 0.01$). The main effect of *Time* has been also significant for M_{max} ($p = 0.037$ $F = 4.52$ $\eta^2 = 0.06$). By work separated *post-hoc* pairwise comparison has show significant difference in crane operators ($p < 0.01$) but not in the control group ($p = 0.928$). The different effect of work on M_{max} was confirmed by the significant *Time* x *Work* interaction effect ($p = 0.028$ $F = 4.99$ $\eta^2 = 0.06$). The results of PRRs measurements (Figure 2c) have not shown any significant main effects. Nevertheles the significant *Time* x *Work* interaction effects on MF and OI muscle has been shown. Delay of MF PRRs after work tended to increase in crane operators and decreased in control group and the the oposite has been seen in OI. Taking all into count, more co-contraction patern of muscle activation has been seen in crane operators after the work.

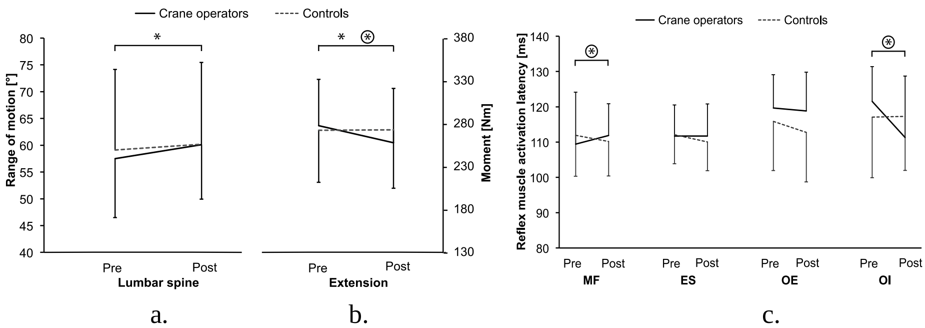


Figure 2: Change of the range of motion (a.), maximal moment (b.) and postural reflex reactions (c.) measured before (Pre) and after (Post) the work in crane operators and control group. *- main effect of time < 0.05; ⊛- interaction effect < 0.05; MF-multifidus muscle; ES-erector spinae longisimu muscle; OE-obliqus externus muscle; OI-obliqus internus muscle;

Table 1: RMANOVA results for postural reflex reaction measurements

Muscle	Factor	p	F	η_p^2
Multifidus	Time	0.730	0.120	0.002
	Work	0.718	0.131	0.002
	Time x Work	**0.044**	**4.217**	**0.056**
Erector spinae	Time	0.224	1.502	0.021
	Work	0.857	0.025	0.001
	Time x Work	0.195	1.709	0.024
Obliqus externus	Time	0.325	0.982	0.014
	Work	0.085	3.043	0.042
	Time x Work	0.427	0.639	0.09
Obliqus internus	Time	0.054	3.846	0.053
	Work	0.678	0.174	0.003
	Time x Work	**0.038**	**4.465**	**0.061**

4. CONCLUSION

The aim of the present study was to investigate the acute effects of the work that demands sustained trunk flexion in comparison with work that does not have such demands. In line with the hypothesis the RoM increased after work and only the crane operators have shown significant decrease in the $M_{max.}$ The back extensor muscles have shown the trend of increased PRRs` latencies but the difference was not statistically significant. On the other hand the OI muscle presented significantly shorter latencies in crane operators. Together with the delayed onset of trunk extensors this is suggesting more co-contractive stabilization strategy.

Such strategy is expected in the conditions when the preservation of trunk stability is more challenging. It has been previously shown that during sudden perturbations higher loads elicited co-contraction responses [19] and it has been shown that older adults show more co-contractive response strategy than young persons do. Further, Van Dieen and colleagues [20] have shown increased co-activation of trunk muscles when lifting unstable loads in comparison with lifting a stable load of identical mass. Based on the results we can assume that in crane operators after work the same load presented more challenging perturbation, therefore, central control initiated co-contractive postural response instead of more efficient push backward contraction mode [21].

Previous studies concluded that the central control system is well adopted to the fatigue development in the trunk stabilizing muscles [22]. Granata and colleagues [23] have shown that baseline muscle activity increases in the fatigued muscles as well as in their antagonists, indicating increased co-activation. In most of the previous studies effects of fatigue were confounded with the creep deformation of viscoelastic passive tissues and it has been suggested that passive viscoelastic tissue deformation is responsible for most of the changes seen after flexing [9]. To support that in our previous study (manuscript submitted for review) increased baseline muscle activity and increased stiffness has been shown after one hour of crane operators work simulation even when the upper body support was offered and no fatigue was expected.

To summarize, present study have shown that after work the passive viscoelastic tissues contribution to trunk stability is reduced and the fatigue of trunk extensor muscles can be expected in crane operators. Furthermore, changes in motor control are indicating the reduced robustness of stability therefore increasing the chance of low back injury and pain.

REFERENCES

[1] European Commission. Eurobarometer 398: Working conditions (2014). *Available from:* http://ec.europa.eu/public_opinion/flash/fl_398_en.pdf *Accessed:* 2016-2-5.

[2] National Research Council Institute of Medicine. Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. *National Academies Press (US)*; 2001.

[3] Roffey D.M., Wai E.K., Bishop P,. Kwon B.K. & Dagenais S.: Causal assessment of occupational sitting and low back pain: results of a systematic review, *Spine Journal*, **Vol. 10** (2010) No. 3, pp. 252–61.

[4] Kwon B.K., Roffey D.M., Bishop P.B., Dagenais S. & Wai E.K.. Systematic review: occupational physical activity and low back pain, *Occup Med*, **Vol. 61** (2011), No. 8, pp. 541–8.

[5] Wai E.K., Roffey D.M., Bishop P., Kwon B.K. & Dagenais S.: Causal assessment of occupational bending or twisting and low back pain: results of a systematic review, *Spine J*, **Vol. 10** (2010), No. 1, pp. 76–88.

[6] Coenen P., Kingma I., Boot C.R., Twisk J.W., Bongers P.M. & van Dieen J.H. :Cumulative low back load at work as a risk factor of low back pain: a prospective cohort study, *J Occup Rehabil*, **Vol. 23** (2013), No.1, pp. 11–8.

[7] Muslim K., Bazrgari B., Hendershot B., Toosizadeh N., Nussbaum M.A. & Madigan M.L.: Disturbance and recovery of trunk mechanical and neuromuscular behaviors following repeated static trunk flexion: influences of duration and duty cycle on creep-induced effects, *Appl Erg*, **Vol. 44** (2013), No. 4, pp. 643–51.

[8] Hendershot B.D., Toosizadeh N., Muslim K., Madigan M.L. & Nussbaum M.A.: Evidence for an exposure-response relationship between trunk flexion and impairments in trunk postural control, *J Biomech*, **Vol. 46** (2013), No. 14, pp. 2554–7.

[9] Sánchez-Zuriaga D., Adams M.A. & Dolan P.: Is activation of the back muscles

impaired by creep or muscle fatigue?, *Spine (Phila Pa 1976)*, **Vol. 35** (2010), No. 5, pp. 517–25.
[10] Panjabi M.M.: The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement, *J Spinal Disord*, **Vol. 5** (1992), No. 4, pp. 383–9.
[11] Solomonow M.: Neuromuscular manifestations of viscoelastic tissue degradation following high and low risk repetitive lumbar flexion, *J Electromyogr Kinesiol*, **Vol. 22** (2012) No. 2, pp. 155–75.
[12] Bazrgari B., Hendershot B., Muslim K., Toosizadeh N., Nussbaum M.A. & Madigan M.L.: Disturbance and recovery of trunk mechanical and neuromuscular behaviours following prolonged trunk flexion: influences of duration and external load on creep-induced effects, *Ergonomics*, **Vol. 54** (2011), No. 11, pp. 1043–52.
[13] Lu D., Solomonow M., Zhou B., Baratta R.V. & Li L.: Frequency-dependent changes in neuromuscular responses to cyclic lumbar flexion, *J Biomech*, **Vol. 37** (2004), No. 6, pp. 845–55.
[14] Adams M.A. & Dolan P.: Time-dependent changes in the lumbar spine's resistancc to bending, *Clin Biomech*, **Vol. 11** (1996), No. 4, pp. 194–200.
[15] Toosizadeh N. & Nussbaum M.A.: Creep deformation of the human trunk in response to prolonged and repetitive flexion: measuring and modeling the effect of external moment and flexion rate, *Ann Biomed Eng*, **Vol. 41** (2013), No. 6, pp. 1150–61.
[16] Hendershot B., Bazrgari .B. Muslim K., Toosizadeh N., Nussbaum MA. & Madigan M.L.: Disturbance and recovery of trunk stiffness and reflexive muscle responses following prolonged trunk flexion: influences of flexion angle and duration, *Clin Biomech (Bristol, Avon)*, **Vol. 26** (2011), No. 3, pp. 250–6.
[17] Parkinson R.J., Beach T.A.C. & Callaghan J.P.: The time-varying response of the in vivo lumbar spine to dynamic repetitive flexion, *Clin Biomech (Bristol, Avon)*, **Vol. 19** (2004), No. 4, pp. 330–6.
[18] Voglar M. & Sarabon N.: Reflex delays of the trunk muscles in response to postural perturbations: A reliability study, *J Biomech*, **Vol. 11** (2014), No. 47, pp. 2807–12.
[19] Krajcarski S.R., Potvin J.R. & Chiang J. The in vivo dynamic response of the spine to perturbations causing rapid flexion: effects of pre-load and step input magnitude, *Clin Biomech*, **Vol. 14** (1999), No. 1, pp. 54–62.
[20] van Dieën J.H., Kingma I., van der Bug P. & van der Bug J.C.E.: Evidence for a role of antagonistic cocontraction in controlling trunk stiffness during lifting, *J Biomech*, **Vol. 36** (2003), No. 12, pp. 1829–36.
[21] Robert T. & Latash M.L.: Time evolution of the organization of multi-muscle postural responses to sudden changes in the external force applied at the trunk level, *Neurosci Lett*, **Vol. 438** (2008), No. 2, pp. 238–41.
[22] Potvin J.R.& O'Brien P.R.: Trunk muscle co-contraction increases during fatiguing, isometric, lateral bend exertions. Possible implications for spine stability, *Spine*, **Vol. 23** (1998), No 7, pp. 774–80.
[23] Granata K.P., Orishimo K.F. & Sanford A.H.: Trunk muscle coactivation in preparation for sudden load, *J Electromyogr Kinesiol*, **Vol. 11** (2001), No.4, pp. 247–54.

USING CONCEPT MAP TO ASSESS THE EFFECT OF DIFFERENT EXPERTISE COMMUNICATION: A STUDY IN HIP MODEL

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Abstract

With the development of work patterns, crossing-domain collaboration becomes the trend of future work. The main factor of successful collaboration work in cross-field should consider the difference of communicators' expertise and help address to comprehend the speaker's concept and knowledge. This paper focuses on how to evaluate the communication effectiveness between expert and layperson, and explore a tool to be applied to analyze the communicators' concept and knowledge during conversation. In this study, expert and layperson drew concept map respectively with their structure knowledge after orally discussing what HIP model is. It was found that concept map can help communicators to assess and inspect the mutual difference at expertise and understanding level which can improve communication effectiveness. This study procedure can be used as reference for designing communication aids.

Keywords: *Concept map, Communication, Human factors, Human information process)*

1. INTRODUCTION

To achieve successful crossing-domain collaboration relies on the consensus reached by the team members; however, the team members usually have different knowledge levels on some domains, e.g., expert and layperson. Therefore, it is very critical to make knowledge gap less within a team via an effective communication between expert and layperson, for it is associated closely with the performance of a team work.

To communicate effectively with a layperson, an expert needs to estimate layperson's knowledge [3][4][12] to adjust their ways of communication to fit whose knowledge [5][7][9][10][11], and judge what level the layperson understands [4][8][14][15].

Although previous research has shown that experts should be well positioned to convey their professional knowledge to laypersons, the organization of that knowledge and particularly its level of abstraction may make it difficult for them to do so [9]. Likewise, layperson is difficult to organize the different concepts and understand the expertise by oral conversation at same time. Moreover, it is unavoidable that experts' estimates of laypersons' knowledge are likely to be biased towards their own knowledge [8][10]. On the other side, laypersons' knowledge could be overestimated that would generate comprehension problems [12].

To determine and estimate the communication effect is very difficult. However, it is rare that the studies apply quantitative ways to assess the effect of communication on those expertise topics. In the present study, concept maps were used as a means for collecting data to evaluate the differences before and after the implementation of communication tasks. Concept maps are graphical tools for representing and organizing concept relationships in people's cognitive structure. A concept is a unit of meaning and described by a word or phrase. Novak and Gowin ever proposed a scoring method to determine the learner's conceptual understanding level [2]. This method focuses on four components: propositions, hierarchy levels, cross-links and examples. The definition of components and scoring are described below:

Propositions:
The text on the line (linking words or phrases) describes the relationship between these two concepts. A proposition consists of two or more concepts connected using linking words or phrases to form a meaningful statement (semantic unit). The propositions are established between two concepts. The accuracy of the label and the direction of the arrow would be taken into consideration. Each meaningful or valid proposition shown is to score 1 point.

Hierarchy levels:
The topic of expertise used in this study is the Wickens (1984) HIP model which have seven main components (see Figure 1) and hierarchical structures are not always necessary [6], therefore, the hierarchy scores in this study were modified to determine by the model's components. Each valid level of the hierarchy scores 5 points.

Cross-links:
The relationships or links between concepts within the concept map in different segments or domains. If the connections between one segment of the concept hierarchy and another segment are meaningful, they will be scored with 10 points for each cross link because they are valid and significant.

Examples:
The specific examples of events or objects that help to clarify the meaning of a given concept. Each valid instance of those designated by the concept label can be scored 1 point.

As noted above, it is very important to help the experts accurately to estimate what laypersons know, develop a more accurate mental model about their recipient's knowledge and thereby improve their communication with the layperson. Therefore, the purpose of this study is to explore an assessment tool which can support an expert in evaluating the knowledge and concept level of a layperson communication.

2. METHOD

2.1. Materials

The communication material referred to the Model of Human Information Processing (HIP) proposed by Christopher Wickens (1984). This model integrates components and processes as a series of stages with a feedback loop that is commonly agreed upon and has been substantiated by research. There were seven main components in this model: Sensory processing, Perception, Attention, Memory (working memory and long term memory), Response selection, Response execution and Feedback (see Fig. 1). Based on the HIP model, thirteen human factors terminologies were constructed to design a questionnaire to assess and identify how much participants understood the related domains of human information process. In addition, three questions related HIP model concept examined participants' knowledge level.

2.2. Participants

2.2.1 Expert.
One ergonomics expert volunteered to participate in this study. This male expert is fifty years old and received a doctorate in industrial engineering and ergonomics studies who has more than ten years of working experience in the field of human factors.

2.2.2 Layperson.
Participants in the layperson group were no ergonomics or psychology background and did not understand what human information process model is. In order to explore the participants' common background and pre-knowledge level, it is necessary to filter those who had sufficient knowledge in HIP model with a questionnaire. Before the experiment, questionnaires were filled out by twelve participants. Of these participants, two had to be excluded for failing to meet one or more of the following criteria:
(a)It must be less than fifty percent of fourteen questions about HIP terminologies that the participant ever heard. (b)It must be less than two thirds of the correct answers for three questions that the participant takes the pre-knowledge test. (c)It must be less than fifty percent of fourteen questions about HIP terminologies that the sum of participant's responses is rated as moderate applied with Likert 5-point scale (1: Totally not understand; 2: Not understand; 3: Moderate; 4: Understand; 5: Much understand).
After finishing and passing the questionnaire, researcher would ask participants to describe what the HIP model is by their own thought. Researcher would investigate if the participants were suitable for the experiment once again. There were 10 participants passed the pre-knowledge test and joined in the layperson group (5 male and 5 female). Their age was between 20 to 31 (Mean=24.5 years, SD = 4.0 years).

2.3. Experimental Design

The dyads of expert and laypersons were arranged in individual sessions in the experiment. An experimental session was composed of pre-test phase, communication phase, and post-test phase, which needed about one and a half hours.

2.3.1 Pre-Test Phase
At the beginning of the pre-test phase, laypersons needed to pass the pre-knowledge test and complete oral description what the HIP model was. All descriptions were recorded on audiotape and then transcribed word by word. Additionally, the expert and laypersons would draw a concept map of their thought about the HIP model.

2.3.2 Communication phase
In the communication phase, the expert and layperson took seats at a table on opposite sides. No time limit was given in the conversation. The layperson`s task was to understand the HIP model via conversation with expert. In experiment, expert cannot

use any tool to communicate with the laypersons (e.g., drawing a picture), but layperson can take notes using papers and pens.

2.3.3 Post-Test Phase

After the communication phase, laypersons would draw what they thought of HIP model by concept map again while the conversation was ended. After completion of the post-test, the layperson and the expert would express their thought about the efficiency of concept map if used in the communication process.

2.4 Procedures

All participants undertook the following procedures: (1) completed the demographic data, common background questionnaire and pre-knowledge test (10 minutes); (2) a briefing of the study and learned how to draw a concept map (20 minutes); (3) performed the communication task until communicators were confident that the layperson already understood the HIP model (30-60 minutes); (4) layperson drew the concept map about HIP model again (15-20 minutes); (5) answer the semi-structure questionnaire and debrief subject's feedback (10-15 minutes). To developing participants concept maps, a free software IHMC Cmap tools (available at http://cmap.ihmc.us/) was selected for creating concept map. In order to make participants familiar with the tool, they attended a training course before the experiments. All participants were instructed about the tool's usage and used the tool by themselves during tasks.

3. RESULTS AND DISCUSSION

As shown in Table 1, the concept map score increases from 18 points (SD = 11.75) before communication to 77 points (SD = 23.03) after communication. Also, the average time participants spent in communication is 49 minutes (SD = 15.6).
Table 1 also represents the four scoring items of concept maps. The average propositions numbers increase from 7 to 17 (SD = 4.59). After communicating with the expert, laypersons' expertise concepts were more integrated than the phase before communication. The average hierarchy numbers of most laypersons reached to 7 (SD = 1.2). The average cross-links numbers was increased from 0 to 3 (SD = 1.28); however, the example numbers without any change (SD = 1.40). Only two participants described valid instances after communication. Compared with the score before communication, the concept map of the layperson after communicating with expert at the items of propositions and hierarchy were markedly increased.

Table 1: Statistics expert and layperson's concept map score and component number

Items	Expert	Laypersons	
		Before communication	After communication
Concept map scores	126	18	77
Propositions number	24	7	17
Hierarchy number	7	2	7
Cross-links number	6	0	3
Examples number	7	1	1

To determine the communication effect, the components of concept maps illustrate the quantified scores (see table1). After communicating with the expert, laypersons propositions were better than before. The result can support previous findings that the propositions show the principal elements that make up human's knowledge structures and cognitive process in the brain [13]. In Table 1, laypersons' hierarchy reaches 7 points, which means most of laypersons not only have better description about the content of HIP model, but also have more ability to integrate the relationship among different HIP concepts (see figure 4). The results show laypersons already established the primary knowledge structure of the HIP model; however, to take instances to explain the model with the knowledge laypersons just learned seems to be difficult. Compared with expert's concept map, both of crosslink and example showed by laypersons (after communication) were lower than expert. Additionally, cross-link and example score by laypersons had no obvious change between before and after communication, which indicates that cross-links often represent creative leaps on the part of the knowledge producer while in the creation of new knowledge [13]. With the changes of cross-link and examples score, laypersons' understanding level might be inspected.

Despite most researcher thought when the two communicators differed in expertise, the high-knowledge speaker should have adapted to their listener in conversation [3]. From the expert perspective in this study, it is hard to judge what the layperson's understanding level is in communication process. Therefore, the way the expert relied was to ask layperson questions to estimate whether he/she comprehended the expertise. In addition, the expert usually explained with the identical examples in real life, e.g., the common experience that the expert considered the layperson might have. During the conversation, the expert was less to speculate layperson's background and knowledge level. Likewise, in this study it was found that cultural factors might impact the expert to ask and confirm if layperson could understand the main issues in conversation process, e.g., the expert concerned laypersons' self-respect or thought that was impolite question. Thus, if laypersons did not give any information (verbal or non-verbal) to the expert, the expert would not easily adapt the proper content for laypersons. Additionally, it was found with viewing experiment videos that laypersons lacked non-verbal information or not obvious body movement, e.g., gesture and facial expression, laypersons' questions were few in conversation .

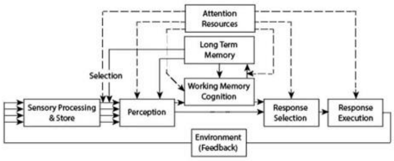

Figure 1. Human information process model proposed by Wickens (1984)

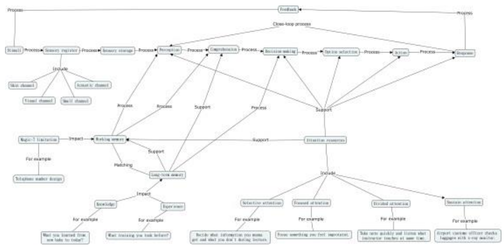

Figure 2. Expert's concept map about the knowledge of HIP model

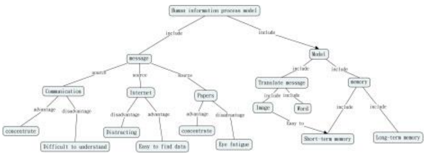

Figure 3. Layperson-2's concept map about HIP model (Before communication)

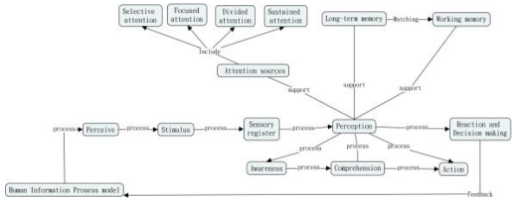

Figure 4. Layperson-2's concept map about HIP model (After communication)

Semi-structure questionnaires were used in this study to understand communicators' perspective. The expert considers concept map using before communication can help to speculate the layperson's knowledge level and what layperson thinks of the expertise. From Ausubel and Novak' theoretical perspective [1], learning takes place by the assimilation of new concepts and propositions into an existing concept and propositional frameworks held by the learner. If so, expert can used concept map to decrease the barriers to estimate what laypersons know. Meaningful knowledge exchange is possible only if the communication partners share a common vocabulary and common assumptions about the topic [16]. The expert and layperson via watching concept map of each other can promote themselves to facilitate mutual understanding concept structure and establish common ground. Before communication, via laypersons' concept map expert knows what level laypersons understand the expertise, so that the expert can adjust specific ways of explication to fit laypersons (see Figure 2). On the other hand, the layperson also can refer expert concept map to establish primary concept of expertise, examine the symmetry of complex ideas and arguments and make an association with the related terminology before communication (see Figure 3). Indeed, after communication, expert can use the concept map to assess laypersons' comprehension level about the communication objectives, concepts, and also the relationship among those concepts (see Figure 4).
Although previous research has shown that experts should be well positioned to convey their professional knowledge to layperson, the organization of that knowledge and particularly its abstraction level might make it difficult for them to do so [9]. Likewise, layperson is difficult to organize the different concepts and understand the expertise by oral conversation at real time. Moreover, experts' estimates of laypersons' knowledge are likely to be biased towards their own knowledge [8][10]. During the process of

drawing a concept map, an expert can organize and glean key concepts, their relationships and hierarchy from his/ her expertise knowledge.
As noted above, it is very important to help the experts accurately estimating what laypersons know. Furthermore, for improving communication efficiency, it is necessary to develop a more precise mental model about their recipient's knowledge. Therefore, this study tried to explore an assessment tool which could support experts in evaluating the knowledge of a layperson's concept level in communication.

4. CONCLUSION

This is a pilot study for inspecting and evaluating communication content by a concept map in the process of conversation. The concept map could illustrate the main issues of communication between expert and layperson and be beneficial to figure out what they really addressed. Additionally, the expert can rely on the map to identify the layperson's understanding level and reveal whose obscure points after conversation. Indeed, the expert can also reflect knowledge contents and organize the concept structure before communicating with a layperson.
As noticed above, the findings of this research can be used to develop a communication tool to assess communicator's concept content and knowledge structure. The tool can be a method to improve the communicators' skill between different professional domains. However, it is restricted that concept map used as a tool for communication aids is only suitable for the topics of structural knowledge or abstract concept relationship. It is positive way to achieve a consensus during the dialogue process between expert and layperson. Nevertheless, communicators need to spend time to learn and practice the concept map until the map is correct and understandable. In future work, the research is going to investigate how to shorten learning and practicing time but maintain the same communication efficiency.

REFERENCES

[1] Ausubel, D. P., Novak, J. D., & Hanesian, H.: Educational psychology: A cognitive view (2nd ed.). Holt, Rinehart & Winston, New York, (1978).
[2] Novak, J. D., & Gowin, D. B.: Learning how to learn. Cambridge University Press, United Kingdom, (1984).
[3] Isaacs, E. A., & Clark, H. H.: References in conversation between experts and novices. Journal of experimental psychology: general, Vol 116. (1987) No 26., pp. 26-37.
[4] Fussell, S. R., & Krauss, R. M.: Coordination of knowledge in communication: effects of speakers' assumptions about what others know. Journal of personality and social psychology, Vol 62. (1992) No 3., pp. 378-391.
[5] Cegala, D. J., McNeilis, K. S., & McGee, D. S.: A study of doctors' and patients' perceptions of information processing and communication competence during the medical interview. Health Communication, Vol 7. (1995) No 3., pp. 179-203.
[6] Ruiz-Primo, M. A., & Shavelson, R. J. Problems and issues in the use of concept maps in science assessment. Journal of research in science teaching, Vol 33. (1996) No (6)., pp.569-600.

[7] Lau, I. Y. M., Chiu, C. Y., & Hong, Y. Y.: I know what you know: Assumptions about others' knowledge and their effects on message construction. Social Cognition, Vol 19. (2001) No 6., pp.587-600.

[8] Bromme, R., Rambow, R., & Nückles, M.: Expertise and estimating what other people know: The influence of professional experience and type of knowledge. Journal of experimental psychology: Applied, Vol 7. (2001) No 4., pp. 317-330.

[9] Hinds, P. J., Patterson, M., & Pfeffer, J.: Bothered by abstraction: the effect of expertise on knowledge transfer and subsequent novice performance. Journal of applied psychology, Vol 86. (2001) No 6., pp. 1232-1243.

[10] Nückles, M., Wittwer, J., & Renkl, A.: Information about a layperson's knowledge supports experts in giving effective and efficient online advice to laypersons. Journal of Experimental Psychology: Applied, Vol 11. (2005) No 4., pp. 219-236.

[11] Nückles, M., Winter, A., Wittwer, J., Herbert, M., & Hübner, S.: How do experts adapt their explanations to a layperson’s knowledge in asynchronous communication? An experimental study. User Modeling and User-Adapted Interaction, Vol 16. (2006) No 2., pp. 87-127.

[12] Wittwer, J., Nückles, M., & Renkl, A.: Is underestimation less detrimental than overestimation? The impact of experts’ beliefs about a layperson’s knowledge on learning and question asking. Instructional Science, Vol 36. (2008) No 1., pp. 27-52.

[13] Novak, J. D., & Cañas, A. J.: The theory underlying concept maps and how to construct and use them. Available from http://cmap.ihmc.us/docs/theory-of-concept-maps: 2016-02-14.

[14] Jucks, R., & Bromme, R. Choice of words in doctor–patient communication: An analysis of health-related Internet sites. Health communication, Vol 21. (2007) No3., pp. 267-277.

[15] Jucks, R., Paus, E., & Bromme, R. Patients’ medical knowledge and health counseling: What kind of information helps to make communication patient-centered?. Patient education and counseling, Vol 88. (2012) No 2., pp. 177-183.

[16] Lewalter, D., Geyer, C., & Neubauer, K.. Comparing the effectiveness of two communication formats on visitors’ understanding of nanotechnology. Visitor studies, Vol 17. (2014) No 2., pp. 159-176.

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HOW CAN SMES BE MOTIVATED TO ENGAGE IN THE TOPIC OF AGE-BASED WORKPLACES? EXPERIENCES AND FINDINGS OF A PROJECT IN AUSTRIA

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Abstract

Demographic change generally, and the support of older employees particularly are challenges for Small and Medium sized Enterprises (SMEs). Although there exist a lot of guidelines and suggestions for age-based and ergonomic workplace design, the impression is, that SMEs have little motivation or problems to implement the solutions in their business. On this point the project, funded by the AUVA started with the aim, to develop a motivating and sustainable training-concept for SMEs. Based on a motivation theory, a literature review, an online-survey and interviews a concept was created, implemented in two SME´s and evaluated.

Keywords: *Demographic Change, Age-based workplaces, Training, SMEs*

1. RELEVANCE

As a result of demographic change and the uprating of retirement age in Austria, age-based and ergonomic workplaces become more relevant for companies. In the last years an increasing number of guidelines and projects deal with the topic, but the impression is, that especially SMEs have problems to start and implement the topic in their business. The reasons are manifold. Perhaps there is little motivation to deal with the topic in the companies because they don´t see a pressure to act so far. It may also be that the available information is too generic and does not consider the complexity of the topic.[1]. Using a motivational background, sustainable trainings were developed and evaluated. The aim was to teach participating companies how to deal with the subject of demographic change as well as age-based and ergonomic work places.

2. MAIN STEPS IN THE PROJECT

The figure below shows the main steps in the project. The results of a detailed literature review (Step 1) that focused on the development of more than 20 physical and psychological abilities with increasing age were summarized in a booklet. An online survey was conducted with 56 companies (Step 2). The purpose of the survey was to identify how SMEs deal with this topic, what actions they have already taken, and any other special interests they may have in this domain. In Step 3 we conducted 9 interviews with 21 persons in companies which are already engaged in the field of demographic change. We received positive examples and experiences, but also identified potential implementation problems. The results of Steps 1 -3 made up the basis for a one-day-training concept we realized in two SMEs to create awareness for the topic and help motivate them to implement solutions. The trainings were evaluated in two steps. The first evaluation was performed directly after the training. The second evaluation followed six months later and focused on identifying which tasks had been implemented.

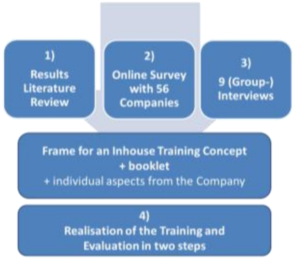

Figure 1: Main steps in the project

3. RESULTS

3.1. Literature Review and Booklet

The guidelines for dealing with workplaces for older employees are sometimes very common. 51% of the SMEs in our online survey stated that the information on this topic is too general to be useful. Additionally, it is a fact that the performance gap widens with increasing age and this makes it difficult to give SMEs a general recommendation for limit values in age-based workplaces. However it is worth to have a closer look on the individual abilities. Because some of them change less or later than others, are only relevant for very special workplaces (e.g. reaction time) or can be saved with training for the most part (i.e. fine motor skills). For the booklet, the results of the literature review were presented as a summary with more than 20 abilities such as: vision, hearing, learning, reaction time, flexibility etc. (see Table 1).

Table 1: Development of flexibility with increasing age

Fields of Work	Development	Suggestions for Workplaces
- Catching components and work pieces - Observation - Lifting and bending down	The maximal isometric ability to flex and to extend the torso muscles starts to decrease between the ages of 45 and 50. Also, the rotation angle of the upper body decreases. There are individual differences between the persons.	- Vertically adjustable workplaces - Training - Arranging workplace objects in such a way as to avoid employees having to reach over long distances.

3.2. Online-Survey

What are the reasons, why companies are engaged (or not) in the field of demographic change and what do they require for successful action? As background for this question we used Heckhausen & Rheinberg's [2] motivation theory that claims that, besides other factors, the estimated individual importance of a consequence and the probability of success are important preconditions for action. Transferred to the field of demographic change, the following aspects are of interest: Are the companies already

affected by the outcomes of demographic change (for example difficulty finding staff). Do they feel well prepared, i.e. feel no pressure to engage more? Which measures are estimated as promising?
The results demonstrate that the pressure to act in this field is not very strong at the moment. Less than half of the surveyed companies feel that the topic is highly-relevant at the moment. However, 80% think that it will become very relevant within the next 10 years. For the design and realization of the training it was interesting to identify which topics are considered of interest and where more details are needed. The companies showed strong interest in the following fields: „Development of Mental Performance with increasing age“ (72%), „Health Promotion“ (70%), „Tools for Workplace Evaluation“ (66%), and also more than 60% were interested in „Ergonomic Workplace Design“ and „Development of Physical Performance“. Generic information about demographic development which is often used in guidelines was of no interest for a large number of the surveyed SMEs. 61% report having already made positive experiences with „Ergonomic Workplace Design“, „Workplace Health Promotion“ (55%) and the „Evaluation of Workplaces“ (46%).

3.3. Interviews

SMEs benefit from authentic examples and best practices from other companies [3]. In three companies, already dealing with demographic change, (Group)-Interviews with 21 people from different areas (worker, manager, human resources developer, occupational medicine, workplace health promotion etc.) were conducted. Apart from concrete examples for the training, such as design or structure of workplaces and company health promotion, we identified additional interesting factors. A good way for getting introduced to this topic is the evaluation of workplaces prescribed by law in Austria. This evaluation can be the basis for further discussions and improvements, especially when problems with workplaces arise. The interviews also showed that, in practice, it is often difficult for SMEs (e.g. manufacturing) to follow some popular advice which says, that older employees with health problems should work in the field of quality management because of their long experience. However, it is often the case that there are not enough such positions in companies. So instead of reassigning roles, it is necessary to implement a system (like job rotation and qualification), so that employees do not stay in a critical job for too long, sometimes years or even decades. This system would benefit both younger and older employees.

3.4. The Training

Steps 1-3 of the figure showed before formed the base for a Training/Workshop-Concept that was tested with two SMEs in Austria. Afterwards it was useful, that the members of the group came from different divisions in the company, similar to the groups in our interviews (3.3.), because it allowed for the topics to be discussed from different points of view. A day prior to the workshop, we visited the business to inspect critical workplaces and to get an overview of the activities in the field of workplace design and health promotion. In the first part of the training, the participants were asked to identify physical and psychological strain in different jobs and estimate how these jobs may cause problems for older employees. This helped raise awareness of the topic. In the next section, participants received detailed information about the development of abilities with increasing age (s.3.1.). Based on this information, the participants identified in groups principal action fields for a further involvement in the topic of demographic change and age-based workplaces in their own working area. In the afternoon, group members inspected critical workplaces by using an evaluation concept for age-based workplaces [4], age-simulation-suits, and measuring instruments for volume, lighting, etc. Afterwards, they developed first ideas for improvements and made an action plan.

The training was evaluated twice. Once directly after the workshops, to get an impression of the participant satisfaction with the training-contents. The training received the evaluation "very good", in particular for the aspect that participants were fully involved in the process. Six months after the workshop we had a call with our contact person to find out more about further actions. Fortunately, the SMEs reported extensive further actions. One of the SMEs implemented an improved evaluation system for workplaces in collaboration with the occupational medicine. Every workplace in production had been evaluated against its unrestricted suitability for female and male employees above the age of 50. Beside the classic „Leitmerkmalmethode", the evaluation also considered influences like lighting and vision. Furthermore, workplaces that had been evaluated as „critical" had been systematically improved and equipped, for example with individual assistance-systems like lifting aids and electric operating lift trucks, to improve their suitability for older employees. A third step was a project for improved standardization of workplaces, which will facilitate long-term job rotation.

4. CONCLUSION

We can conclude, that it is possible to motivate SMEs towards sustainable engagement in demographic change and age-based workplaces. A good basis for starting are the legally prescribed workplace evaluations in Austria. There are sporadic limit values for this topic, because performance with increasing age is very individual and companies therefore have to find individual solutions. However, companies can benefit from detailed, scientifically-based knowledge in this area, as well as ideas and examples from other businesses. A main factor of success in this project was the involvement of employees from all areas of the company in improving the workplaces. This will facilitate long-term improvements for younger and older employees.

REFERENCES

[1] Chodora, M.: Fachkräftesicherung demografie (me). Heute dem demografischen Wandel aktiv begegnen. *Proceedings of 59. Kongress der Gesellschaft für Arbeitswissenschaft*, Gesellschaft für Arbeitswissenschaft (Ed.), pp. 89-92, ISBN: 978-3-936804-14-0, Krefeld March 2013, GfA press, Dortmund, (2013)

[2] Rheinberg, F.: Intrinsic motivation and flow. In Heckhausen, J. & Heckhausen, H. (Eds.), *Motivation and action* (pp. 323-348), ISBN 978-0521852593. Cambridge. (2008)

[3] Sczesny, C.; Keindorf, S.; Droß, P., Jasper, G. *Kenntnisstand von Unternehmen und Beschäftigten auf dem Gebiet des Arbeits- und Gesundheitsschutzes in KMU*, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, ISBN 978-3-88261-005-5, Dortmund, (2014)

[4] Morschhäuser, M.; Matthäi, I: *Leitfaden zur Arbeitsplatzbeobachtung. Ermittlung alterskritischer Arbeitsbedingungen „55 plus".* Available from: http://www.lago-projekt.de/medien/instrumente/Leitfaden_Arbeitsplatzbeobachtung.pdf (at last: 14.03.2016)

RESEARCH ON AN INDIRECT VISION DRIVING SYSTEM FOR SPECIAL VEHICLES

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Abstract

Some special vehicles have to be driven in some dangerous environment, and the visual field of traditional indirect vision driving systems is narrow and invariable. A new indirect vision driving system including HD cameras, panel displays and visual transmit devices are assembled on a large SUV. In outdoor experiment, thirteen voluntary drivers have driven this SUV pass a test course loop five times. The mental workload and task performance of these voluntary drivers are recorded and analyzed. The research result shows that human driver has a strong adaptability for indirect vision driving environment. It means that with proper training and practices, drivers' task performances are greatly improved while mental workloads are greatly relieved.

Keywords: *indirect vision driving, special vehicles, mental workload, task performance*

1. INTRODUCTION

The driver's fields of view can be classified based on direct versus indirect fields. The direct field consists of the views that the driver sees directly by moving his or her eyes and head. These include forward view (through the windshield), rear view (directly looking back through the rear window), and side views (directly looking through the left and right side windows). The indirect field is what the driver views indirectly by use of imaging devices such as the inside mirror, outside mirrors, or display screens showing camera views or locations of objects detected by other sensors [1].

For special vehicles whose working environment is very dangerous, the indirect vision driving systems should be equipped for protecting drivers. And for new concept vehicles which integrated design result in limited direct vision, indirect vision systems that provide driver a high-fidelity representation of the area around their vehicle should be utilized. Furthermore, indirect vision driving system can also be applied to compensate for the lack of direct vision and augment vehicle informationization.

In this paper, a new indirect vision driving system with HD cameras and panel displays for a large SUV (Sport Utility Vehicle) is integrated and experimented out of doors. As only mono vision can be provided by display, the influence to driver's spatial position ability is unavoidable. For studying the mental workload and task performance, heart rate, oxygen saturation, electroencephalogram and complete task time, were measured.

In the tests, thirteen voluntary drivers drove this SUV pass test course loop five times. Most voluntary drivers reported significant intense and fatigue at the first time, and the total data of mental workload and task performance expressed the same result. But with the test times increased, the level of mental workload is decreased while task performance is turn to better. The research result shows that human driver has a strong adaptability for indirect vision driving environment. It means that with proper training and practices, drivers' task performances are greatly improved while mental workloads are greatly relieved.

The aim of the paper is mainly to introduce our indirect vision driving system for special vehicles and discuss the mental workload and task performance of the voluntary drivers working in this indirect vision driving environment.

2. EVOLUTION OF INDIRECT VISION DRIVING SYSTEM

As a traditional indirect vision driving system, the periscopes are used with narrow and invariable visual field. But with the development of electro-optical technology, some novel indirect vision driving systems with cameras and panel displays were presented and experimented.

As early as 1994, driving with camera view, as a new concept for vehicle driving, was launched and developed by Van Erp and Padmos [2-4]. In 1996, Kane discussed the visual perception issues while driving with night vision enhancement systems [5]. In 1999, Brendle and Karjala described the Flat panel display utilization in a military tracked vehicle which was developed by US Army as Crew Integration and Automation Testbed [6]. This testbed equipped with indirect vision driving system was experimented outdoors in 2000 [7], and was sequentially developed as Vetronics Technology Testbed [8]. Based on earlier researches, more advanced indirect vision driving systems developed for tracked vehicle [9] and wheeled vehicle [10] were experimented.

While the indirect vision driving system was developed in hardware, the issues on human factors or ergonomics for those drivers in indirect vision driving environment were emerged. In 2000, Smyth completed a research on field of view, in which driving performance was measured for natural and indirect vision, he found that mental workload of indirect driving system is higher than that of a traditional system [11]. Oving et al. also pay a lot of attention to motion sickness of visual feedback on head roll and of stereoscopic view with the head-slaved camera system in 2002 [12]. Van Erp and Padmos carried out three experiments to identify the critical image parameters of indirect viewing system on vehicle control and found that when the image parameters are adequately chosen such system can be proficient [13]. In 2005, Hill and Tauson present some of the issues related to the effects of vehicle motion on soldier performance that including vibration, visual displays, manual control, interactions among soldiers, cognitive functions, and workload [14]. McDowell suggested that indirect vision driving also has performance and workload consequences for tested drivers, and current indirect vision technologies will require enhancements to achieve direct-vision driving capability [15]. The research results of Davis et al. indicated that lag variability significantly reduced driving performance [16]. And recently, the indirect vision driving systems with stereoscopic displays were tested and showed that voluntary drivers completed their tasks significantly faster when they used stereoscopic displays in 3-D mode compared to the baseline two-dimensional view condition [17].

Our research team started to develop indirect vision driving system in 2011, and designed a prototype version for a large SUV. Based on the experiments carried out of door sequentially, the driver's mental workload and task performance were studied [18] and the impact of image parameters on driver is also discussed [19]. The new indirect vision driving system updated the resolution of camera and area of main display is going to introduce in the following section.

3. DRIVING EXPERIMENT

3.1. Experimental Indirect Vision Driving System

The new indirect vision driving system equipped on the test vehicle consisted of three HD (High Definition) cameras, three 16:9 wide screen LCD (Liquid Crystal Display) and the devices for video transmission.
For acquiring more visible area, a 23 inch wide screen LED (Light Emitting Diode) backlit LCD with resolution of 1920×1080 pixels has be used as main screen to replace previous 18.5 inch display. Two 11.6 inches LED backlit LCD with resolution of 1366×768 pixels are turned 90 degrees individually and seamlessly fixed on both side of main display as assistant screens.
The main screen displays directly ahead perspective transmitted from the main camera. The main camera adopts 1/3 inch two mega pixels CMOS (Complementary Metal Oxide Semiconductor) image sensor and encoding DSP (Digital Signal Processor) to produce 1080P HD-SDI (Serial Digital Interface) image. The assistant screen displays both side front perspectives transmitted from the left and right assistant cameras. The main camera adopts 1/3 inch 976×582 pixels CCD (Charge Couple Device) image sensor and output composite AV (Analog Video) signal.
The left and right assistant cameras were individually mounted on the frameworks of side rear-view mirrors. For mounting main camera, three locations, middle, middle left and top, on test vehicle had been tried before formal experiments were carried out. And based on the suggestion from majority voluntary drivers, the middle position on the centre of windshield bottom beam was finally selected.
The assembling of flat displays and cameras on the test vehicle is shown in Figure 1.

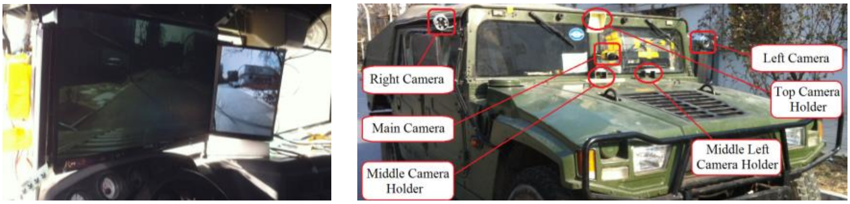


Figure 1: Assembling position of flat displays and cameras on the wheeled test vehicle

As the standard of image signal output from the main camera is SDI and the main display only have HDMI (High Definition Multimedia Interface) and VGA (Video Graphics Array) input ports, a SDI to HDMI convertor has been utilized. For transmitting the image signal from assistant cameras to assistant displays, two LCD drive modules with AV and VGA input ports were utilized.

3.2. Test Course Loop

The outdoors experiment was carried out in weekend for avoiding interruptions of pedestrians and vehicles. The voluntary drivers have driven the test vehicle on a test course loop which total length is nearly 600 meters delineated from our campus road. The schematic diagram of test course loop is shown in Figure 2.

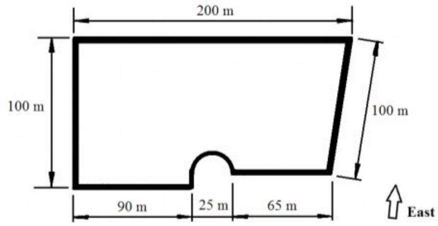


Figure 2: Schematic diagram of test course loop

3.3. Voluntary Drivers Background

Thirteen voluntary drivers from our institute have been recruited for the outdoors experiment, and their primary information is listed in Table 1.

Table 1: Primary information of voluntary drivers

No.	Drivers	Career	Age	Drive Age	Gender	Driving Skill	Indirect Vision Driving Experience
1	W. Z.	Teacher	42	17	Male	Very Good	Has
2	Z. Y.	Teacher	30	7	Female	Very Good	Has
3	F. Y.	Teacher	36	8	Male	Very Good	No
4	L. Q.	Student	34	9	Male	Very Good	No
5	W. J.	Student	25	2	Male	Normal	Has
6	B. J.	Student	24	2	Female	Normal	Has
7	R. A.	Student	26	3	Male	Good	No
8	Q. Z.	Student	23	4	Female	Good	No
9	Z. J.	Student	25	2	Female	Normal	Has
10	Y. Y.	Student	23	3	Female	Normal	No
11	N. J.	Student	24	4	Male	Good	No
12	Z. J.	Student	27	4	Male	Good	Has
13	A.Q.	Student	19	1	Male	Normal	No

3.4. Experiment Program

According testing program, each driver should complete five loops driving on test course loop. The drivers' physiological index, such as heart rate, oxygen saturation and electroencephalogram have been measured and recorded.

Heart rate is mostly widely used in ergonomics research, which shows typical rise when the mental workload exceed the normal level [20]. Oxygen saturation is a percentage that indicates the saturation of the combination of oxygen and hemoglobin, which will decline when mental workload increases because the human bodies need certain amount of oxygen supply for extra workload [21]. In this experiment, a wrist pulse oximeter, Heal Force Prince-100G was used to measure heart rate and oxygen saturation.

As reflecting the activity of human brain, the electroencephalogram (EEG) is often considered in cognitive task experiment [22]. Many studies found that EEG, particularly Alpha (8-13Hz) bands, has certain correlations with mental workload [23]. Some researches show that Alpha band of EEG decreases during high cognitive task and Delta

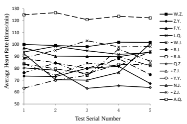
band of EEG increases at the same time compared with that found during low workload situation [24]. In this experiment, the MindWave headset, a safe EEG measure device developed by NeuroSky, was used to measure brainwave signals. The headset can record Alpha, Beta, Theta, Delta and Gamma band of EEG signal, and provide an algorithm to calculate the attention and meditation of drivers according to these signals.
Additionally, for assessing driving speed performance, the time consumptions of each driver for one loop driving were recorded.

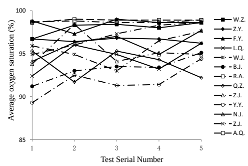
4. EXPERIMENTAL RESULTS

During whole trial process, the new indirect vision driving system has suffered the vibrations and impulses from paved test course loop and been working well. In despite of there are significant intense and fatigue were reported by most voluntary drivers taking indirect vision driving first time, all driving tasks can be finished successfully.

4.1. Heart rate and oxygen saturation

After processing the surplus pulse oxygen (SpO2) data from the wrist pulse oximeter, the results of heart rate and oxygen saturation have been obtained, as shown in Figure 3.

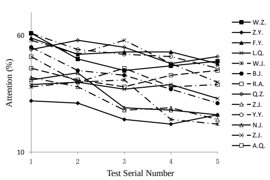


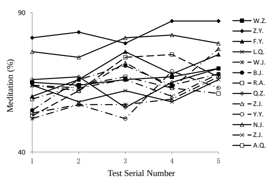


(a) Average heart rate (b) Average oxygen saturation
Figure 3: The experiment results of heart rate and oxygen saturation

4.2. EEG

After processing the EEG data collected by MindWave headset, the experiment results of attention and meditation have been obtained, as shown in Figure 4.





(a) Drivers' attention (b) Drivers' meditation
Figure 4: The experiment results of driver's attention and meditation

4.3. Complete Task Time

The complete task time of each driver is easy to be measured and recorded by a timekeeper, the experiment results of complete task time are shown in Figure5.

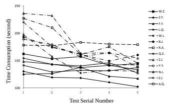
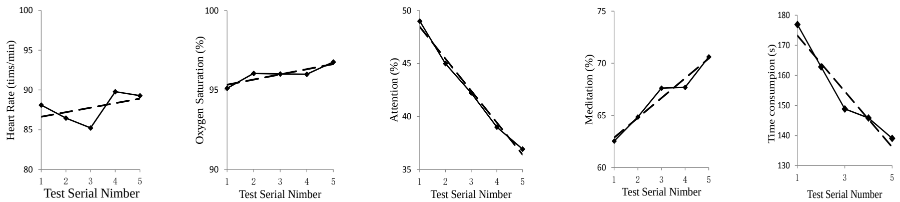


Figure 5: The change on complete task time of drivers

5. ANALYZE AND DISCUSS

To finding the trend of change, the averages of thirteen voluntary drivers' experimental results were calculated, as shown in Figure 6.



(a) Heart rate (b) Oxygen saturation (c)Attention (d) Meditation (e) Complete time
Figure 6: The change trend of drivers' experimental results

In the Figure 6 (a), the trend line of heart rate change is smooth, and in the Figure 6 (b), the trend line of oxygen saturation change is climbing slowly. It means that driver's rate of oxygen consumption decreased with driving times increased.
In the Figure 6 (c), the trend line of drivers' attention change is ascending clearly, and in the Figure 6 (d), the trend line of drivers' meditation change is descending clearly. It means that driver's EEG activity decreased with driving times increased.
In the Figure 6 (e), the trend line of time consumption change is descending clearly. It means that driver's adaptability is increased with driving times increased.
Considering the results of heart rate, oxygen saturation, driver attention meditation synthetically, a descending trend of mental workload with driving times increased can be found. And considering the results of complete task time, an ascending trend of task performance with driving times increased can be found.

6. CONCLUSION

Indirect vision driving system equipped with HD visual devices can be fitted on special vehicles and provide more realistic driving experience for driver.
Human driver has a strong adaptability for indirect vision driving environment. It means that with proper training and practices, drivers' task performances are greatly improved while mental workloads are greatly relieved.
Based on results of qualitative analysis, further quantitative analysis on individual driver's physiological data should be done as a future work. The relationship between the driver adaptability and driver background should be researched in the future.

REFERENCES

[1] Bhise, V. D.: *Ergonomics in the Automotive Design Process*, CRC Press, ISBN: 9781439842102, Boca Raton, (2011), pp. 107-108.
[2] Van Erp, J. B. F.; Padmos, P.: *Driving with Camera View: a Field Experiment*, TNO Report, (1994), TNO Human Factors Research Institute, Netherlands.
[3] Van Erp, J. B. F.; Padmos, P.: *Driving with Camera View: a Simulator Experiment*, TNO Report, (1995), TNO Human Factors Research Institute, Netherlands.
[4] Gale, A. G.; Brown, I. D.; Haslegrave, C. M.; Taylor, S. P.; (Ed): *Vision in Vehicles – V*, Elsevier Science, ISBN: 9780444814777, Amsterdam, (1996), pp. 219-228.
[5] O'Kane, B. L.: Driving with Indirect Viewing Sensors: Understanding the Visual Perception Issues, *Proc. SPIE*, *Enhanced and Synthetic Vision*, (1996), **Vol.** 2736, pp. 248-258, ISBN: 9780819421173, Bellingham, SPIE Press.
[6] Brendle, B. E.; Karjala, M. J.: Crew Integration and Automation Testbed: display utilization, *Proc. SPIE*, *Cockpit Displays VI: Displays for Defense Applications*, (1999), **Vol.** 3690, pp. 115-120, ISBN: 9780819431646, Bellingham, SPIE Press.
[7] Downs, G.; Roller, G.; Brendle, B. E.; Tierney, T.: Military Application of Flat Panel Displays in the Vetronics Technology Testbed Prototype Vehicle, *Proc. SPIE*, *Cockpit Displays VII: Displays for Defense Applications*, (2000), **Vol.** 4022, pp. 75-84, ISBN: 9780819436481, Bellingham, SPIE Press.
[8] Pritchett, W.; Wood, B.: Vetronics Technology Testbed: Experience Report, *Proc. SIGAda'01*, ACM, NY, USA, (2001), pp. 115-116, ISBN: 1581133928, New York, ACM Press.
[9] Boon, Ng Keok; Choo, Tey Hwee; Wah, Chan Chun: *Autonomous Unmanned Ground Vehicle and Indirect Driving*, DSTA Horizons (2005), Defence Science & Technology Agency, Singapore.
[10] Jaster, J. F.: TARDEC's Intelligent Ground Systems Overview, *Proc. SPIE*, *Unmanned Systems Technology XI*, (2009), **Vol.** 7332, p. 73321K, ISBN: 9780819475985, Bellingham, SPIE Press.
[11] Smyth, C.C.: Mental Workload and Task Performance for Indirect Vision Driving with Fixed Flat Panel Displays, *Proc. Human Factors and Ergonomics Society Annual Meeting*, July (2000), **Vol.** 44, No., 36, pp. 541-544.
[12] Oving, A. B.; Van Erp, J. B. F.; Schaap, E.: Motion Sickness When Driving With a Head-Slaved Camera System. *RTO Human Factors Symposium on Spatial Disorientation in Military Vehicles: Causes, Consquences and Cures*, La Coruna, Spain, (2002), RTO-MP-086.

[13] Van Erp, J. B. F.; Padmos, P.: Image Parameters for Driving with Indirect Viewing Systems, *Ergonomics*, (2003), **Vol.** 46(15), pp. 1471-1499, ISSN: 00140139.
[14] Hill, S. G.; Tauson, R. A.: *Soldier Performance Issues in C2 "On the Move"*, Tech. Report. U.S. Army Research Laboratory, Human Research and Engineering Directorate, Aberdeen Proving Ground, MD, (2005).
[15] McDowell, K.; Oie, K. S.; Tierney, T. M.; Flascher, O. M.: Addressing Human Factors Issues for Future Manned Ground Vehicles (MGVs). *ARMY AL&T*, (2007), (1-3), pp. 20-23, ISSN: 08928657.
[16] Davis, J.; Smyth, C.; McDowell, K.: Mitigating the Effects of Time Lag on Driving Performance, *Proc. Ground Vehicle Systems Engineering and Technology Symposium*, (2009).
[17] Chen, J. Y.; Oden, R. V.; Kenny, C.; Merritt, J. O.: *Effectiveness of Stereoscopic Displays for Indirect-Vision Driving and Robot Teleoperation*, Tech. Report. U.S. Army Research Laboratory, Human Research and Engineering Directorate, Aberdeen Proving Ground, MD, (2010).
[18] Wu, J. J.; Wu, Z. C.; Bao, J.: Study on the Impact of Indirect Driving System on Mental Workload and Task Performance of Driver, *Proc. 2013 IEEE International Conference on Vehicular Electronics and Safety*, (2013), pp. 53-56, ISBN: 9781479903788.
[19] Bao, J.; Wu, Z. C.; Wu, J. J.: The Impact of Image Parameters of Indirect Viewing Systems on Driver Fatigue and Task Performance, *Advanced Materials Research*, (2013), **Vol.** 765-767, pp. 2046-2050, ISSN: 16628985.
[20] Roscoe, A. H.: Assessing pilot workload: Why measure heart rate, HRV, and respiration?, *Biological Psychology* **Vol.** 34, Issues 2–3, November (1992), pp. 259–288, ISSN: 03010511.
[21] Sassaroli, A. et al.: Discrimination of Mental Workload Levels in Human Subjects with Functional Near-Infrared Spectroscopy, *Journal of Innovative Optical Health Sciences*, (2008), **Vol.** 1, No., 2, pp. 227–237, ISSN: 17935458.
[22] Davidson, R. J.; Jackson, D. C.; Larson, C. L.: Human electroencephalography, In Cacioppo, J.T.; Tassinary, L. G.; Bernston, G. G. (Ed.), *Handbook of psychophysiology 2nd ed.*, Cambridge University Press, ISBN: 052162634X, Cambridge, England, (2000), pp. 27–52.
[23] Pfurtscheller, G.; Klimesch, W.: Event-related desynchronization during motor behavior and visual information processing, *Electroencephalography & Clinical Neurophysiolog*, (1991), Supp. **Vol.** 42, pp. 58-65, ISSN: 04248155.
[24] Wilson, G. F.: An Analysis of Mental Workload in Pilots During Flight Using Multiple Psychophysiological Measures, *International Journal of Aviation Psychology*, (2002), Vol. 12(1), pp. 3-18, ISSN: 10508414.

EFFECT OF EFFORT-REWARD IMBALANCE AND SLEEP QUALITY ON DEPRESSIVE SYMPTOMS RISK IN TRAIN DRIVERS IN CHINA

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Abstract

To investigate the relationships for effort-reward imbalance (ERI), sleep quality, and depressive symptoms, a cross-sectional epidemiological study was conducted in 1402 train drivers in China. Extrinsic effort, reward, and overcommitment were measured using the Chinese version of ERI questionnaire. Depressive symptoms were assessed by the Chinese version of CES-D. Sleep quality were evaluated by the Chinese version of PSQI. This study showed that after adjusted for confounders, both high efforts and low rewards (OR=4.93)was the greatest contributors to depression symptoms in ERI model; ERI and sleep quality were shown to be independently associated with depressive symptoms, importantly, sleep quality could estimate the risk of depression symptoms (OR=6.18) more accurately than that of ERI; Combined effect of ERI and sleep quality was larger than the separate one, and both high ERI and poor sleep quality (OR=15.40) was the greatest contributors to depression symptoms in combined effect model.

Keywords*:* *Depression symptoms; Effort- Reward Imbalance; Sleep Quality; Combined effect*

1. INTRODUCTION

In recent years, psychological problems, suicide and karoshi caused by large work pressure and fatigue frequently were seen in the media. People who attempt to suicide were significantly associated with mental illness, especially the depression [1, 2]. In 2003, Occupational Safety and Health Administration reported that depression caused by job stress resulted in $ 30.4 billion direct and indirect economic losses in American; In China, the incidence of mental disorders and chronic fatigue syndrome has risen to 30%-40% in some professional population. An investigation showed that depression has become the second disease in the burden of medical expenses, and the proportion accounted for total medical expenses reached 6.2% [3]. Excluding its influence on individual mental health, depression also results in worker absenteeism, leads to the reduced productivity in the workplace [4]. Thus, there is indispensable to pay more attention to the depressive symptoms of workers from a social perspective. In recent two decades, most psychosocial studies in developed countries revealed a strong association between bad work environment and depression symptoms [5-7]. Some studies found that depressive symptoms were more prevalent in workers with high effort-reward imbalance [8-11]. In addition, recently, some studies have been conducted to observe

the relationship between sleep quality and depressive symptoms, which suggested that shorter sleeping time and poorer subjective sleep quality was associated with a higher risk of depressive symptoms [12-14]. However, no study has been conducted on the combined effect of job stress and sleep quality on depressive symptoms risk so far.
According to the work characteristics of occupational population, train driver was a kind of occupation population who continued be in a work state of highly centralized and paramilitary as well as have the characteristics of higher work responsibilities, longer continuous work, faster running speed, irregular working hours, stay up late, mandatory sleep, smaller work space, larger noise intensity, and poorly ventilated environment, etc. These characteristics more likely to lead poor psychological status during work along with the poor sleep quality. Prolonged poor psychological status at work along with the poor sleep quality may lead to adverse psychological condition, especially to the depression symptoms. Therefore, in this study we selected the train driver as the subjects to explore the effects of Effort-Reward Imbalance(ERI) and sleep quality on depressive symptoms. Meanwhile, the study attempt to evaluate whether the combination of ERI and sleep quality may induce the greater risk of depression symptoms when compared with ERI or sleep quality alone.

2. TECHNICAL REQUIREMENTS

Study Population

This cross-sectional study was conducted in Henan Province, located in the central region of China, from Mar 2012 to Sep 2012. A total of 1 042 train drivers were recruited from a depot of Railway Bureau, who included 75 China Railway High-speed drivers, 301 passenger train drivers, 678 train freight drivers, and 348 passengers. The informed consents were signed by the subjects and the study protocol was approved by the Medical Ethics Committee of the Henan Provincial Institute of Occupational Health. Each subject was given a questionnaire at his/her workplace and required to complete the questionnaire within 45 min. The questionnaire was designed to collect following information: age, job tenure, education level, smoking and alcohol use histories, effort-reward imbalance, sleep quality and depression symptoms.

Measurement Methods

Effort-reward imbalance

The Chinese version of effort-reward imbalance (ERI) questionnaire was used in this study [15], it consists of the following three scales: extrinsic effort (6 items), occupational reward (11 items), and overcommitment (6 items). The questionnaire was also formulated by means of translation and back-translation. Extrinsic effort was evaluated by measuring the psychosocial workload; occupational reward focuses on the worker’s financial status (i.e. salary), self-esteem, and career opportunity (e.g. promotion prospects and job security). Overcommitment as a personal (intrinsic) component was defined as a set of attitudes, behaviors, and emotions reflecting excessive striving along with a strong desire for approval and esteem. Cronbach’s alpha of effort, reward, and overcommitment scales were 0.83, 0.71, and 0.65, respectively. Furthermore, according to the theoretical formulation a ratio of effort / (reward×0.5454) was calculated to assess the degree of imbalance between high effort and low reward at work where a value >1.0 indicates the critical condition. ≥1.0 indicates high ERI level and <1.0 indicates low ERI level. In addition, extrinsic effort, occupational reward, and overcommitment were split by the median value.

Sleep quality

Sleep quality was assessed using the Chinese language version of the Pittsburgh Sleep Quality Index (PSQI), which is originally developed by the University of Pittsburgh and translated by Yu [15]. The PSQI consists of 14 items including subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. Each question uses a 4-point Likert scale (0-1-2-3). Higher score indicates poorer quality of sleep. Cronbach'a of the PSQI in this sample was 0.90. This study used the median value indicating a sleep disorder. People with 19 or more points were defined as poor sleep quality population, while people with below 19 points were defined as good sleep quality population.

Depressive Symptoms

Depressive symptoms were measured by the Center for Epidemiological Studies Depression (CES-D) Scale. The CES-D scale consists of 20 items related with characteristic symptoms and behaviors of depression. Each question displayed using a 4-point Likert scale (0-1-2-3), and higher scores indicated higher depression. Cronbach'a of the DES-D in this sample was 0.91.We applied in this study the threshold value 19 recommended for identifying subjects with depressive symptoms by this scale. This scale has been used extensively in China since 1980's. Based on the threshold of 19 points to screen this survey population with depressive symptoms, the subjects with a score 19 or more points were classified as subjects with depressive symptoms, while below 19 points were those subjects no depressive symptoms.

Potential Confounding Variables

In this study, the potential confounding variables included individual factors, (such as driver types, age (≤25 years,25 to 35 years, 35 to 45 years, and ≥45 years), job tenure (≤5 years, 5 to 10 years, 10 to 15 years, 15 to 20 years, 20 to 25 years, and≥25 years), educational level [high school and below (elementary school, junior high school, high school), college and over], marital status [married, never married, divorced and widowed, remarried, and unmarried cohabitation], smoking habit (current-smoker, non-smoker, and ex-smoker), and drinking habit (current-drinker, non-drinker, and ex-drinker).

Statistical analysis

Chi-square test was carried out to analyze the differences of general characteristics in the group with different depressive symptoms. Hierarchical multiple binary logistic regression analysis was performed to test the relationships between ERI, sleep quality, combined effect of ERI and sleep quality, potential confounding variables (independent variables) and depressive symptoms; Logistic regression analysis was used to estimate the association between ERI, sleep quality, combined effect of ERI and sleep quality

and depressive symptoms. Multivariate odd ratios (ORs) and 95% confidence intervals (CIs) were derived from the logistic regression models. In logistic regression analysis, the confounding factors such as driver types, age, job tenure, education level, marital status, smoking habit, and drinking habit were controlled.
All the statistical analyses were performed with SPSS for Windows (version 19.0; SPSS Inc., Chicago, IL), with P values less than 0.05 was considered significant. All significant statements were two-tailed.

3. RESULTS

Descriptive statistics

The general characteristics of 1402 participants showed that age ranged from 20 to 59 years (mean 35.0 years) and job tenure ranged from 2 to 37 years (mean 13.1 years). The mean of depression symptoms, ERI, and sleep scores were 24.41 (S.D.=10.5), 1.27 (S.D.=0.5) and 19.55 (S.D.=8.6), respectively. The distribution of depression symptoms was split by 19-point threshold of the total CES-D score, among the subjects, 955 (68.1%, 955/1 402) were defined as with depressive symptoms. Chi-square test results showed that the distribution of depression symptoms score according to driver types, age, job tenure, marital status, smoking habit, and drinking habit did not show statistically differences. But a depressive symptoms rate in EMU drivers or high-speed rail drivers (74.7%, 56/75), 35 to 45 year-age group (72.2%, 249/345), 10 to 15 year-job tenure group (73.5%, 150/204), divorced and widowed (82.8%, 24/29), Non-smoker (70.7%, 424/600) and Non-drinker (70.3%, 474/674) were highest in the same type of group. A depressive symptoms rate was significant differences between the subjects with (college and over) and low educational level group (high school and below), and a depressive symptoms rate in high educational level group (72.0%, 372/517) were higher than low educational level group (65.9%, 583/885).

Relationship between the ERI model, sleep quality and and depression symptoms

Table 1 displays the associations between ERI, sleep quality, and potential confounding variables (independent variables) and depressive symptoms. The results of the hierarchical multiple logistic regression analysis revealed that after adjusted for potential confounding variables, ERI and sleep quality were shown to be independently associated with depressive symptoms, and combined effect of ERI and sleep quality was also a risk factor for depressive symptoms ($P \leq 0.01$), suggesting that higher ERI and poor sleep were both associated with higher depression symptoms. Importantly, combined action of ERI and sleep quality significantly increased the depression symptoms level. Moreover, education level and drinking habit in the general characteristics were entered into most of Model, and the results showed that high educational level was a risk factor for depression symptoms, but drinking habit was a protective factor for depression symptoms. Table 2 describes the number and percentage of the train drives. The results showed the ERI (i.e. high efforts and low rewards) and three components (efforts, rewards, and overcommitment), sleep quality, combined effect of ERI and sleep quality (i.e. high ERI and poor sleep quality). Furthermore, the association between each of the variables and depression symptoms was analyzed using multivariate logistic regression analysis. After adjusting for the confounding variables, the subjects with high efforts, high rewards and high overcommitment have 2.08, 0.40

and 1.98 times higher depression symptoms than the subjects with low efforts, low rewards and low overcommitment. Similar results were found for sleep quality (Adj OR=5.82, 95% CI=4.52-7.49). In addition, the results showed efforts, overcommitment and sleep quality were risk factors for depression symptoms, but rewards were protective factors. Furthermore, the risk of depressive symptoms for train drivers with both low efforts and low rewards, both high efforts and high rewards, both high efforts and low rewards were 2.04, 1.57,and 4.93 times respectively as high as that for train drives with both low efforts and high rewards. With regard to combined effect of ERI and sleep quality on depression symptoms, the results showed the risk of depressive symptoms for train drivers with both low ERI and poor sleep quality, both high ERI and good sleep quality, both high ERI and poor sleep quality were 10.09, 2.38 and 15.40 times respectively as high as that for train drives with both low ERI and good sleep quality. Moreover, this study found that sleep quality could estimate the risk of depression symptoms more accurately than that of ERI, the combined effect of ERI and sleep quality was larger than the separate one.

Table 1. Hierarchical multiple logistic regression of explanatory for depressive symptoms

variables	Model 1[a]		Model 2[b]		Model 3[c]		Model 4[d]		Model 5e	
	B	*Wald*	*B*	*Wald*	*B*	*Wald*	*B*	*Wald*	*B*	*Wald*
Job type	0.048	0.438	0.052	0.489	0.053	0.459	0.051	0.426	0.074	0.942
Age	0.156	1.737	0.151	1.565	0.166	1.652	0.165	1.623	0.187	2.240
Job tenure	-0.025	0.164	- 0.045	0.527	- 0.017	0.063	-0.032	0.225	-0.022	0.113
Education level	0.373	7.740*	0.310	5.015*	0.415	8.163*	0.353	5.794*	0.415	8.460*
Marital status	-0.053	0.487	- 0.035	0.199	- 0.047	0.324	-0.035	0.169	-0.032	0.159
Smoking habit	-0.118	1.866	- 0.174	3.810	- 0.058	0.390	-0.095	1.029	-0.077	0.698
Drinking habit	-0.128	1.792	- 0.194	3.789	- 0.283	7.210*	-0.305	8.205*	-0.284	7.440*
ERI			1.152	76.988*			0.658	21.077*		
Sleep quality					1.816	177.218*	1.630	132.359*		
Combined effect of ERI and sleep quality									1.631	137.571 *
Constant	0.166	0.212	- 0.472	1.554	- 0.620	2.474	-0.870	4.690	-0.563	2.108

Note. a Adjusted by job type, age, job tenure, education level, marital status, smoking habit and alcohol drinking; bAdjusted for Model 1 plus ERI; cAdjusted for Model 1 plus sleep quality; dAdjusted for mode1 plus ERI and sleep quality; eAdjusted for mode 1 plus combined effect of ERI and sleep quality. *p<0.05 or 0.01.

Table 2 Crude and adjusted ORs for the associations between the ERI model, sleep quality and combined effect of ERI and sleep quality, and depression symptoms

variables Classification	N(%)	Crude OR(95%CI)	Adj OR(95%CI)*
ERI model			
Efforts			
Low	765（54.6）	1.00	1.00
High	637（45.4）	1.98(1.57～2.50)[a]	2.08(1.64～2.64)[a]
	P＜0.001		
Rewards			
Low	689（49.1）	1.00	1.00
High	713（50.9）	0.41(0.33～0.52)[a]	0.40(0.32～0.52)[a]
	P＜0.001		
Overcommitment			
Low	825（58.8）	1.00	1.00
High	577（41.2）	1.89(1.49～2.39)[a]	1.98(1.55～2.52)[a]
	P＜0.001		
ERI			
Low efforts and high rewards	463(33.0)	1.00	1.00
Low efforts and low rewards	312(22.3)	1.86(1.37～2.53)[a]	2.04(1.49～2.80)[a]
High efforts and high rewards	255(18.2)	1.52(1.11～2.10)[a]	1.57(1.13～2.17)[a]
High efforts and low rewards	372(26.5)	4.19(3.00～5.86)[a]	4.93(3.46～7.01)[a]
	P＜0.001		
Sleep quality			
poor	712（50.8）	1.00	1.00
good	690（49.2）	5.85(4.50～7.61)[a]	6.18(4.73～8.07)[a]
	P＜0.001		
Combined effect of ERI and sleep quality			
Low ERI and good sleep quality	282（20.1）	1.00	1.00
Low ERI and poor sleep quality	96（6.8）	9.20(6.62～12.79)[a]	10.09(7.18～14.20)[b]
High ERI and good sleep quality	418（29.8）	2.33(1.71～3.17)[a]	2.38(1.74～3.26)[b]
High ERI and poor sleep quality	606（43.2）	14.97(6.63～33.79)[b]	15.40(6.76～35.10)[b]
	P＜0.001		

Note. * Adjusted for driver types, age, job tenure, education level, marital status, smoking habit, and drinking habit. **Linear-by-Linear Association. b: P<0.01.

4. CONCLUSION

This study suggested that both high efforts and low rewards was the greatest contributors to depression symptoms in ERI model; ERI and sleep quality were shown to be independently associated with depressive symptoms, importantly, sleep quality could estimate the risk of depression symptoms more accurately than that of ERI; Combined effect of ERI and sleep quality was larger than the separate one; Both high ERI and poor sleep quality was the greatest contributors to depression symptoms in combined effect model.

REFERENCES

[1] World Health Organization: Pharmacological treatment of mental disorders in primary health care. *World Health Organization*, 1-68, ISBN: 9789241547697, Geneva (2009).

[2] Jeon HJ.; Lee JY. & Lee YM.: Life time prevalence and correlates of suicidal ideation, plan, and single multiple attempts in a Korean nationwide study. *J Nerv Ment Dis*, 2010, 25:643–646, ISSN:0022-3018.

[3] Murray CJ. & Lopez AD.: Evidence-based health policy--lessons from the Global Burden of Disease Study. *Science*, 1996, 274(5288):740-743. ISSN: 1813-4890

[4] Leykin Y.; Roberts CS.; Robert J.: Decision-making and depressive symptomatology. *Cogn Ther Res*, 2011,35:333-341.ISSN: 0147-5916 (Printed)

[5] Saijo Y.; Ueno T. & Hashimoto Y.: Job stress and depressive symptoms among Japanese fire fighters. *Am J Ind Med*, 2007; 50, 470-80, ISSN: 0271-3586(printed)

[6] Shields M.: Stress and depression in the employed population. *Health Rep*, 2006, 17, 11-29. ISSN: 2196-3002 (Online)

[7] Bonde JPE.: Psychosocial factors at work and risk of depression: a systematic review of the epidemiological evidence. *Occup Environ Med*, 2008; 65,438-45. ISSN: 1351-0711(printed)

[8] Niedhammer I.; Tek ML. & Starke D.: Effort-reward imbalance model and self-reported health: cross-sectional and prospective findings from the GAZEL cohort. *Soc Sci Med*, 2004, 58, 1531-41. ISSN: 0277-9536(printed)

[9] Kivimaki M.; Vahtera J. & Elovainio M.: Effort-reward imbalance, procedural injustice and relational injustice as psychosocial predictors of health: complementary or redundant models? *Occup Environ Med*, 2007; 64, 659-65. ISSN: 1232-1087

[10] Tsutsumi A.; Kawanami S. & Horie S.: Effort-reward imbalance and depression among private practice physicians. *Int Arch Occup Environ Health*, 2012, 85, 153-61. ISSN: 0340-0131 (Printed)

[11] Sakata Y.; Wada K. & Tsutsuki A.: Effort-reward imbalance and depression in Japanese medical residents. *J Occup Health*, 2008; 50, 498-504. ISSN: 1341-9145

[12] Lee CM.; Chang CF. & Pan MY.: Depression and Its Associated Factors Among Rural Diabetic Residents. *J Nurs Res*, 2016 Mar 19. [Epub ahead of print]. ISSN: 1682-3141

[13] Tan Y.; Chen Y. & Lu Y.: Exploring Associations between Problematic Internet Use, Depressive Symptoms and Sleep Disturbance among Southern Chinese Adolescents. *Int J Environ Res Public Health*, 2016 14(5);13(3) ISSN: 1661-7827

[14] Choi SH.; Terrell JE. & Pohl JM.: Factors associated with sleep quality among operating engineers. *J community health*, 2013, 38(3):597-602. ISSN: 1470-2738

[15] Yu S.; Gu G. & Zhou W.: Psychosocial work environment and wellbeing: a cross-sectional study at a thermal power plant in China. *J Occup Health*, 2008 50(2):155-162, ISSN: 1341-9145

DESIGN PROCESS OF ELECTROSPUN LIGHTWEIGHT THERMO-INSULATING MATERIAL

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Abstract

Nanofibers being the main unit of electrospun materials have paid attention in the last decades as their potential applications are increasing each day. In this work single and blend polymers solutions were prepared from polyurethane (PU), poly(ethylene oxide) (PEO) and (PU/PEO). The solutions were electrospun into porous microstructures and evaluated with regard to their fiber diameter and pore area distribution using SEM analysis. The mean fiber diameter and pore area decreased for almost 200 nm and 4 µm^2 respectively, for both dual polymer electrospun systems, influenced by the water extracted amount of the water soluble PEO. Statistically the difference showed significance, but an inverse effect for the pore area as expected was not reached due to wet fibers agglutination.

Keywords*:* *electrospun, nanofibers, PU, PEO, blends.*

1. INTRODUCTION

Among many application areas of nanofibrous materials including: biomedicine, energy storage and conversion, environment protection, chemistry and textiles, an interesting subarea is the design of thermally protective clothing. Electrospun nanofibrous materials provide moisture and vapour transport, thermal insulation due to air entrapped between the nano/micro pores, as well as lightweight which is an advantage in protective garment production [1]. The final function of a product primarily depends on the fundamental characteristics of an electrospun material, which includes fibers diameter and pore size. Many studies reported on the control of these parameters in materials tend to be used in different field of applications. E.g. for effective filter design polyamide 6 (PA 6) nonwovens were electrospun with the analysis of three processing parameters: polymer solution concentration, volume flow rate and tip to collector distance. Ultra-fine fibers were delivered at lower concentrations, smaller volume flow rates and bigger distances from the collection system [2]. Another study related to filtration properties of polyvinyl alcohol (PVA) electrospun material reported on the improved structure compared to polypropylene (PP) meltblown or spunbonded sublayers, due to twice smaller fiber diameters of 200 nm and smaller pore sizes. An optimal relation between the electrospun weight added to the meltblown material, and a pressure drop was important for the significant level of filtering effects and minimal pressure drop [3]. When polyethylene terephthalate (PET) fibers were electrospun from different polymer solutions (15-27%) and a range of voltages applied (15-25 kV), the fibers diameter decreased at the higher concentrations and increasing applied voltage

[4]. Apart from controlling the processing parameters and solution characteristics, desired electrospun material structure can be obtained on the basis of versatility in the process production. E.g. polyethylene oxide (PEO) and PA 6 were electrospun separately as well as in a simultaneous mixture and fine fibers in the range of 50-100 nm and 100-200 nm were obtained, respectively. In a blend of the two electrospun fibers with removal of the PEO material with water, being its solvent, the pore size distribution was reported to be broader and 50% of the pores increased in their diameter [5]. The current study concerns the electrospinning of single and dual polymer microfibrous webs emphasizing the morphological aspects and the reduction of fiber and pore sizes with water soluble component removal. In this way the materials structure can be controlled which is directly related to its insulative properties.

2. MATERIALS AND METHODS

Polymer solutions of single polymers were prepared firstly by dissolving PEO in distilled water with concentration of 8 wt%. Then, by dissolving polyurethane (PU) in a mixture of two solvents: N,N-dimethylformamide (DMF) and tetrahydrofuran (THF) by weight ratios of 2:3 respectively, with concentration of 10 wt%. Finally, blend of PU and PEO, with weight ratio of 1:1, were dissolved in dual solvents, DMF in a combination with THF or dichloromethane (DCM) with concentration of 15 wt% by solvent weight ratio of 7:3. The polymer solutions were electrospun by NT-ESS-300 electrospinning system. The processing conditions (concentration, C; electrical voltage, U; needle tip to collector distance, NTCD and flow rate, q) are given in Table 1.

Table 1: Processing conditions

Polymer	C (wt %)	U (kV)	NTCD (cm)	q (ml/h)
PU	10	18	20	1
PEO	8	19	18	1
PU/PEO	15	18	15	1

The dual polymer PU/PEO electrospun webs with both solvent combinations of DMF/THF and DMF/DCM, after drying were immersed in distilled water for 12 hours, in order to remove the water soluble PEO component. The water was changed after every 3 hours [6]. The morphology of the electrospun webs was observed under SEM-FE MIRA II LMU. *Image J (NIH)* software was used for the fiber diameters and pore area measurement. The measurements were carried out manually by randomly selected both 100 fibers and areas between the fibers.

3. RESULTS AND DISCUSSION

The fundamental aspect of an electrospun thermo-insulating material design concerns its structural characteristics which include morphology, fiber diameter and formed pores. Desired requirements are to be met by optimal electrospinning technical parameters set, as well as right polymer solution choice. Representative SEM images, Figures 1(a, d), show the single electrospun materials PU and PEO, respectively. Fibers interconnections in the shape of polygonal pores were observed for both electrospun nonwoven webs. No intra pores (pores within the fibers) were present in the materials, so an analysis was made for the inter pores only (the pores between the fibers). Figures

1 (b, c, e, f) give the fiber diameter d (nm) and pore area A (μm^2) distribution for both electrospun single polymer solutions with the range of 100-700 nm and 0-6 μm^2 for the PU and 150-350 nm and 0-5 μm^2 for the PEO, respectively. It is to be noticed that the electrospun PEO showed finer fibers almost twice than those of the electrospun PU, with less variance in the uniformity along the fiber length. This observation is a result of the difference in the processing conditions as well as the lower polymer concentration of the PEO at 8 wt%, which affects the fiber diameter inversely. In case of the pore area distribution, the variables are similar. This could be assigned to the less uniformity of the PU fibers, having less thicker and higher percentage of finer fibers interconnected forming smaller pores in between. In case of the dual polymer electrospun solutions, Figures 2, 3 (a-c), the total variance of the morphological characteristics of the webs is much more evident than in the previous, single polymer electrospun systems.

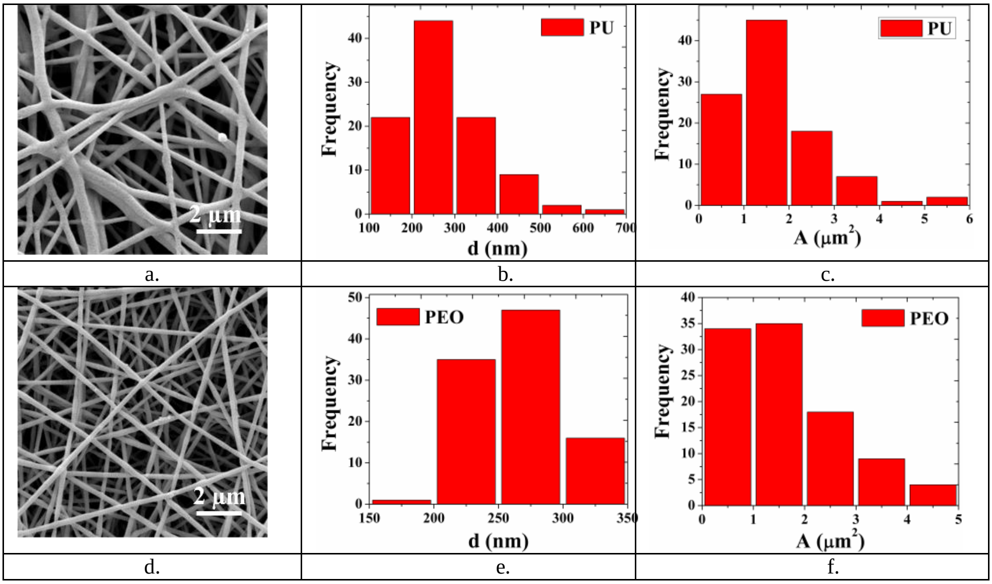

Figure 1: SEM image of the electrospun PU (a), PU fiber diameter distribution (b) PU pore area distribution (c), electrospun PEO (d), PEO fiber diameter distribution (e) and PEO pore area distribution (f).

It is to be noticed that not only the differences in the polymers chemical properties, but also the difference in the solvent characteristics affects the polymer solution, amenable for the fiber and pore final appearance. The morphological variability is reported to be due to polymer solubility, dielectric constant, dipole moment, boiling point and density differences of the used solvents, e.g. fibers diameter decreases with increasing solvent density and boiling point [7-9]. Generally, the dual polymer system gave thicker fibers, due to much higher polymer concentration of 15 wt%, and less uniformness in the fiber diameters, Figures 2, 3 (a, d).

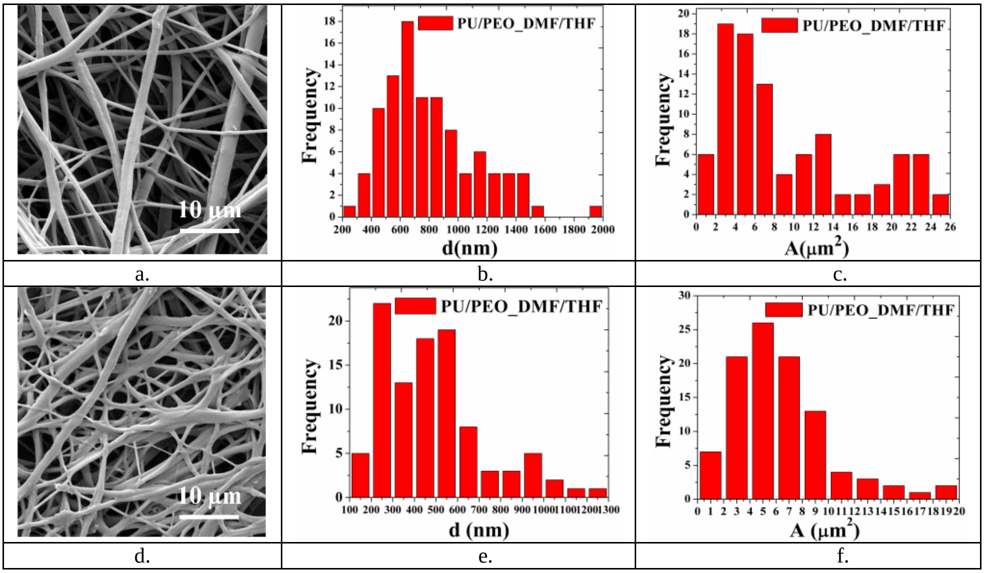

Figure 2: SEM image of the electrospun PU/PEO_DMF/THF (7:3) system, before water treatment (a), fiber diameter (b), pore area distribution (c), electrospun PU/PEO_DMF/THF (7:3) system, after water treatment (d), fiber diameter (e) and pore area distribution (f).

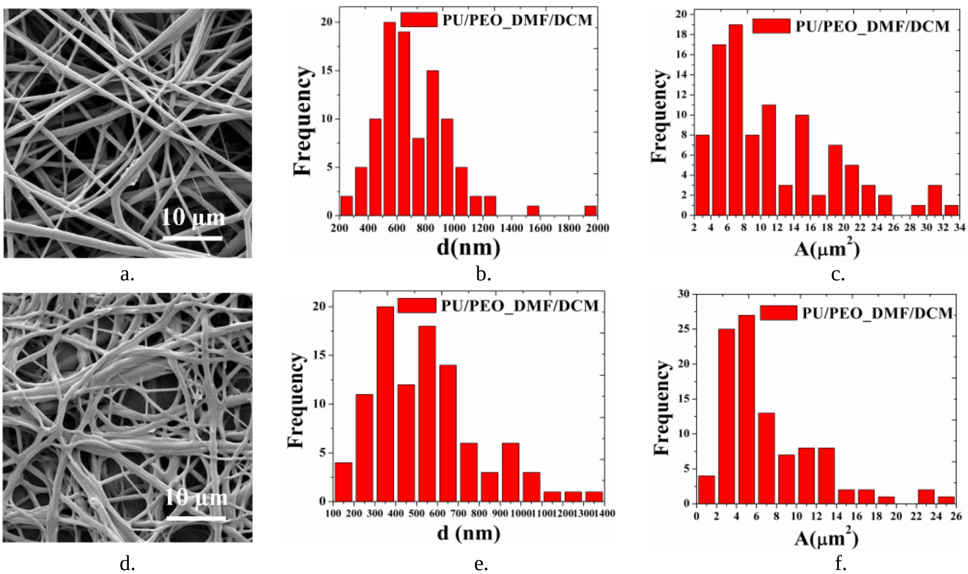

Figure 3: SEM image of the electrospun PU/PEO_DMF/DCM (7:3) system, before water treatment (a), fiber diameter (b), pore area distribution (c), electrospun PU/PEO_DMF/THF (7:3) system, after water treatment (d), fiber diameter (e) and pore area distribution (f).

The shape of the inter-pores formed between the fibers was polygonal, Figures 2, 3 (a), but also oval pores were present for the water treated samples, Figures 2, 3 (d). The SEM images of water extracted PEO component webs show that due to the water dissolution of the PEO most of the fibers were agglutinated and interconnected, forming network. The range of the electrospun PU/PEO_DMF/THF (7:3) fibers diameter and pore areas is between 200-1600 nm and 0-26 μm^2, Figure 2 (b, c). After PEO extraction the range for both parameters was reduced between 100-1300 nm and 0-20 μm^2, Figures 2 (e, f). Similarly, in case of the electrospun PU/PEO_DMF/DCM (7:3) system, the range of the fiber diameters and pore areas was between 200-2000 nm and 2-34 μm^2 before, 100-1400 nm and 0-26 μm^2 after water treatment, Figures 3 (b, c, e, f). It means that the water used influenced the reduction of the variability in the structures morphology. The majority of the fibers after water treatment in both systems were mostly in the ranges between 200-700 nm for the PU/PEO_DMF/THF (7:3) system and 200-800 nm for the PU/PEO_DMF/THF (7:3) system, thus only negligible amount of fibers were above 1μm thick. Similarly, the ranges of the pore areas were narrowed after the water treatment, but the highest frequency was for pores with bigger areas. Negligible amount of pores with areas higher than 20 μm^2 was in the case of the electrospun materials with no water treatment. Figures 4 (a, b) present the mean fiber diameter and pore area distribution for all electrospun materials, single polymer, PEO and PU and double polymer PEO/PU with the dual solvent systems used.

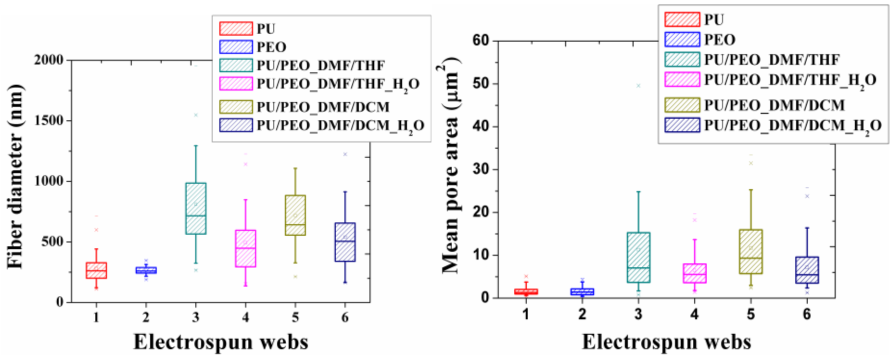

Figure 4: a. Mean fiber diameter of the single and dual polymer electrospun solutions. b. Mean pore area of the single and dual polymer electrospun solutions. (mean ± SD).

The mean fiber diameter for the single electrospun materials was 281,32±106,42 nm and 264,57±32,86 nm for the PU and PEO respectively. For the dual polymer electrospun materials PU/PEO_DMF/THF (DMF/DCM) (7:3) the fiber diameter was 809,30±323,17 nm and 717,12±260,27 nm, respectively before water treatment and 492,29±237,10 nm and 538,8±249,62 nm after water treatment. The mean pore area for the single electrospun materials was 1,68±0,99 μm^2 and 1,64±1,06 μm^2 for the PU and PEO respectively. For the dual polymer electrospun materials PU/PEO_DMF/THF (DMF/DCM) (7:3) was 11,34±12,14 μm^2 and 11,68±7,44 μm^2 before water treatment and 6,44±3,75 μm^2 and 7,15±4,94 μm^2 after the water treatment. Shapiro-Wilk (OriginPro 7,5) test was conducted to test the normality of fiber diameter and pores area distribution for all of the electrospun materials. Except for the PEO single polymer system, the normality was strongly rejected by the very small p value ($p<0,001$) for all sample types. Thus, a nonparametric method, Mann-Whitney U test, was further performed to compare the dual polymer electrospun systems for both variables (fiber diameter and pore area). The analysis showed statistically significant difference ($p<0,05$) between the samples made at same processing conditions, indicating the effect of the extraction of the water soluble polymer PEO.

4. CONCLUSION

PEO, PU and their mixture dissolved in dual solvent systems of DMF/THF and DMF/DCM were successfully electrospun into nonwoven mats. Their morphology, structure uniformness, fiber diameter and pore area were evaluated with the accent on the dual polymers electrospun materials in order to examine how the water treatment carried out influenced the materials morphology as the water soluble polymer was extracted out of the system. The water treatment decreased the mean fiber diameter as well as the mean pore area, for both solvent types of the double polymer systems, with statistically significant difference. The reason for the presence of smaller pores is assigned to the agglutination of the fibers, thus closing the pores. This might reduce the air coming out of the material, thus increasing its thermo-insulative property.

REFERENCES

[1] Gibson, W. P. et al.: Application of Nanofiber Technology to Nonwoven Thermal Insulation, *Journal of Engineered Fibers and Fabrics*, **2** (2007) 2, pp. 32-40, ISSN: 1558-9250.
[2] Zhang, S.; Shim, W. S.; Kim, J.: Design of ultra-fine nonwovens via electrospinning of Naylon 6: spinning parameters and filtration efficiency, *Materials and Design*, **30** (2009) 9, pp. 3659-3666, ISSN: 0264-1275.
[3] Qin, X.-H.; Wang, S.-Y.: Filtration properties of Electrospinning Nanofibers, *Journal of Applied Polymer Science*, **102** (2006) 2, pp. 1285-1290, ISSN: 1097-4628.
[4] Mohan, A.: Formation and Characterization of Electrospun Nonwoven webs, Thesis for the degree of Master of Science, North Carolina State University, (2002).
[5] Frey, M. W.; Li, L.: Electrospinning and porosity measurement of Naylon-6/Poly(ethylene) Oxide Blended Nonwovens, *Journal of Engineered Fibers and fabrics*, **2** (2007) 1, pp. 31-37, ISSN: 1558-9250.
[6] Margaritis A. G.; Kalfoglou N. K.: Compatibility of Poly(vinyl chloride) with Polyalkyleneoxides. I. Poly(methylene oxide) and Poly(ethylene oxide), *Polymer Physics*, **27** (1988) 8, pp. 1767-1779, ISSN: 1099-0488.
[7] Wannatong, L.; Sirivat, A.; Supapho, P.: Effects of solvents on electrospun polymeric fibers: preliminary study on polystyrene, *Polym Int*, **53** (2004) 11, pp. 1851-1859, ISSN: 1097-0126.
[8] Pattamaprom, C. et al.: The influence of solvent properties and functionality on the electrospinnability of polystyrene nanofibers, *Macromol Mater Eng*, **291** (2006) 7, pp. 840–847, ISSN: 1439-2054.
[9] Kim, K. et al: Unique surface morphology of electrospun polystyrene fibers from N,N-Dimethylformamide solution, *Macromolec Research*, **13** (2006) 6, pp. 533-537, ISSN: 2092-7673.

SELECTIVE ATTENTION OF CROATIAN RAILROAD ENGINEERS FROM 25 TO 59 YEARS OF AGE: EMPIRICAL FINDINGS AND IMPLICATIONS

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Abstract

The findings on selective attention (SA) aging decline, although depending on the specific SA test, have significant implications for the population of professional drivers, in particular given their role in traffic safety. For this reason, we found it vital to examine the effects of aging on SA in railroad engineers and its' relation to different measures of SA interference. A study was conducted by using 2 forms of the Stroop test: the 1st - verbal uncoloured and the 2nd - verbal coloured paper-and-pencil form. Both forms consisted of two parts: with incongruent stimuli (measured SA and processing speed, i.e. PS) and with neutral stimuli (measured PS). The subjects were male drivers of the Croatian Railways, ages 25-59, non-evenly distributed into 4 age groups distinguished by specific functional characteristics of professional drivers. 50 subjects completed the 1st and 52 completed the 2nd form. The subjects' task was to cross out as many of the target words in the context of distractors during 60 seconds (with distraction more intensive at incongruent stimuli). Descriptive statistics for both forms of the SA interference (SA time – PS time) indicates expected mean scores, with normal distributions. The interference variability across age groups was homogenous at the 1st Stroop form, but not at the 2nd one. The mean number of errors in the 1st Stroop form is as expected, very low with positive asymmetric distributions and homogenous variability, while in the 2nd one, errors are evident only for the 30-39 age group. For the 1st Stroop form, a significant difference in SA interference time was found between the 40-49 and 50-59 age groups, the latter showing a higher interference. For the 2nd Stroop form, no significant effects of age on SA interference were found. The effect of specific experience of railroad engineers with colours (red-green) is indicated by the results. The findings are discussed in relation to the theory of cognitive aging and empirical findings in the general population, with the implications on railroad engineers aging process.

Keywords*:* *selective attention, aging process, railroad engineers*

1. INTRODUCTION

Population ageing strongly affects the view on workforce and related expectations. Since in developed countries people are living longer and the number of births is decreasing, the workforce is growing slower and the earlier retirement is discouraged (while return to work is more encouraged than ever), so the questions of enabling workforce to work longer [1], as well as relating the job performance with age, becomes even more important. Reviews of the workers age and the work outcomes suggest that there are numerous processes that should be examined in relation to job performance, such as cognitive ability, personality, work motivation, etc. [1].

This kind of issues are particularly important for the transportation sector because of demanding tasks and schedule-depending working hours [2]. Therefore, it is relevant to explore the age-related changes at transportation sector employees in order to ensure effective and safe job performance. Since decline in cognitive abilities is “most acknowledged psychological change with age” [3] - and it is especially true of attention and memory - this study aims to get better understanding of SA in railroad engineers’ population. The SA is a set of cognitive processes with related neural basis, which purpose is to select receiving certain stimuli from some excitatory situation, while ignoring other stimuli from the same situation [4]. This is a key aspect of attention, since without it any other cognitive process couldn’t function well. Mostly, SA is measured by Stroop test, which consists of incongruent and neutral component and has been proven as reliable and stable measure of inhibitory mechanisms efficiency in a large variety of studies [5] [7] [9].

Performance in all Stroop tasks have the same common rationale: to inhibit more dominant distractor response while producing less dominant target response (for example, to name the colour in which the word is printed, while ignoring the word meaning) [6]. Interference of more and less dominant response is produced by stimulus incongruence (colour vs meaning) and is of less intensity when inhibition processes are stronger, i.e. when SA is larger. Inhibition efficiency assessment is usually conducted by comparing the performance in incongruent Stroop test component with the neutral component performance (naming the colour of the coloured patches) and is measured by Stroop effect: difference between response latencies and/or the number of errors in the incongruent component as compared to the neutral one [5].

The age effect on the SA has been tested for years and age-related performance decline has been generally confirmed [8] [9] [10] [11]. Moreover, the most of the studies compared two groups, younger (average age 25) and older (average age 65) adults, and showed that interference is larger in elderly, since older people were less able to control the activation of conflicting word information. There are various explanations of the cause of the Stroop effect age related increase, but the most accepted one is the general cognitive slowing and sensory loses with age, including the aging deterioration of colour perception [9]. Furthermore, fMRI research revealed that younger and older adults differ in the patterns of neural activity associated with Stroop performance, whereby the older ones show less extensive activity in the brain area known as dorsolateral prefrontal cortex [11].

Taking into account previously mentioned importance of the SA for all other cognitive functions, and thus the work performance, this study significance imposes by itself. Vision and attention are extremely important for the railroad engineers work performance [1] that have quite challenging work conditions and great responsibility for traffic safety. As far as we know the SA age-related changes, measured by the Stroop, effect haven’t been analysed in railroad engineers’ population up to now, especially in Croatia. Data on SA efficiency and its age-related changes in railroad engineers can help experts to maximize traffic safety for both drivers and passengers by programming possible preventive interventions.

2. AIM AND HYPOTHESIS

The aim of the study is to examine the SA ageing effects of Croatian railroad engineers from 25 to 59 years of age through four age categories distinguished by specific functional characteristics of professional drivers[1], in relation to the type of SA operationalization - weather it contains traffic relevant colours or not.

1. *Hypothesis:* SA, expressed by interference time measures of the two Stroop test forms, changes non-linearly throughout the four functionally determined age categories: it is mostly stable in the 20-29 year and 30-39 period, while gradually declining during the 40-49 age and 50-59 age category.
2. *Hypothesis*: age-related changes in the observed SA measures differ throughout the four observed age categories depending on whether they contain traffic relevant colours or not.
3. *Hypothesis*: age related changes in colour versions of the SA measures point to certain specificities of the Croatian railroad engineers in relation to the general population of that age, which can be related to the job specificities and partially influenced.

3. METHOD

3.1. Participants

The participants were 102 male railroad engineers from 26 to 58 years of age, employed by the Croatian Railways. Since the research was conducted in two parts (July and end of September, 2015) 50 participants (M_{age1} = 40,9, SD_{age1} =9,35) were included in the first and 52 (M_{age2} =41,3, SD_{age2} =7,26) in the second part of the research. The participants were non-evenly distributed into 4 age groups (20-29, 30-39, 40-49 and 50-59 age group) distinguished by specific functional characteristics of professional drivers.

3.2. Materials

Two paper and pencil test forms of the SA have been included in related two parts of research, representing two different operationalizations of the Stroop test. Both of them consisted of incongruent and neutral stimuli components that were separately administered in immediate succession (whereby the neutral stimuli component usually presents a conventional perceptual speed test).
Incongruent stimuli component of the first SA operationalization is an incongruent form (so-called "incongruence condition") of the Lexical version of the Stroop test [12]. The component consists of 232 words, with fifty per cent of them being the word "big" and the other fifty per cent being the word "small" (in Croatian, "veliko" and "maleno", respectively). Furthermore, fifty percent of both words are randomly written in upper-case letters and the other fifty percent in lower-case letters. Their semantic content and

[1] Reaction time (RT) ergonomics literature suggests ten years intervals in aging process analysis, starting from the age of 20, because of significant RT increment during that intervals [14]

position varied randomly within the lines and pages of the test. The participants' task was to cross out as many of the words "small" as possible within 60 seconds and without skipping words or lines, no matter the word "small" was written in lower or in upper-case letters.

Neutral stimuli component of the first SA operationalization is a neutral form of the Lexical version of the Stroop test. The component consists of 448[2] words with fifty per cent of them being the word "big" and the other fifty per cent of them being the word "small" (in Croatian, "veliko" and "maleno", respectively). All the words are written in lower case letters, and their semantic content and position varied randomly within the lines and pages of the test. The participants' task was to cross out as many of the words "small" as possible within 60 seconds, without skipping words or lines.

As the testing outcome, in both tests' components (incongruent and neutral) two variables were registered: (1) "the time for crossing out one target word" and (2) the number of errors (crossed out words "big" or omitted target words), with "the time for crossing out one target word" being the main variable. The primary SA measure was expressed by difference between the two test components' main variables: "the time for crossing out one target word" in the incongruent component and "the time for crossing out one target word" in the neutral component (i.e. *SA time – PS time)*. The secondary SA measure was expressed by difference between the two test components' number of errors.

Discriminability of primary SA measure is high, indicated by variability coefficients (CV) with an average of 41.7 per cent. Also, there were no effects of floor or ceiling and the distributions of the primary SA results were normal at all four observed age periods (KS_{z1} = .175[3], p =.200; KS_{z2} = .171, p =.200; KS_{z3} = .134, p = .200; KS_{z4} = .192, p =.200). Objectivity is highly obeyed because research assistants were previously trained for testing procedure, and then conducted the measurement in mostly standard conditions. Content validity is high because the test is very similar (beside the content itself) to coloured and other versions of Stroop test that is a widely accepted measure of selective attention [10] [13]. Discriminability of secondary SA measure is low because errors in these tests occur very rarely (at least 94% of all participants made no errors in the tests) and therefore calculating CV had no real meaning. Very low variability of this SA measure precluded reliable computation of all other metric characteristics and that's the reason for not including this measure in further SA analysis, but only as control variable.

In the second SA operationalization (applied in the second part of the research), incongruent stimuli component is an incongruent form (so-called "incongruence condition") of the paper and pencil version of the Stroop test which is often named as the "block version" of the test [5]. The component consists of 232 words in lower case, fifty per cent of them being the word "red" and the other fifty per cent being the word "green" (in Croatian, "crveno" and "zeleno", respectively). Furthermore, fifty percent of both types of the words are randomly printed in red, and fifty percent in green. Their semantic content and position again varied randomly within the lines and pages of the test. The participants' task was to cross out as many of the words "green" as possible - without skipping words or lines - within 60 seconds, no matter they're printed red or green.

[2] Larger number of neutral condition stimuli was needed since more of them are usually crossed out then the incongruent ones

[3] KSz = Kolmogorov-Smirnov z-statistic

Neutral stimuli component of the second SA operationalization is a neutral form (so-called “reading condition”) of the “block version” of the Stroop test. The component consists of 448 words with fifty per cent of them being the word “red” and the other fifty per cent being the word “green” (in Croatian “crveno” and “zeleno”, respectively). All the words were printed black and in lower case letters. The semantic content and position of the words again varied randomly within the lines and pages of the test. The participant’s task was to cross out as many of the words “green” as possible within 60 seconds, without skipping words or lines.

Similarly as in the first SA operationalization, in both tests’ components (incongruent and neutral) of the second SA operationalization, the two variables were registered: (1) “the time for crossing out one target word” and (2) the number of errors (crossed out words “red” or omitted target words), with “the time for crossing out one target word” being the main variable Again, the primary SA measure was expressed by difference between the two test components’ main variables: “the time for crossing out one target word” in the incongruent component and “the time for crossing out one target word” in the neutral component. The secondary SA measure was expressed by difference between the two test components’ number of errors.

Concerning the objectivity and content validity of the second SA operationalization, the same can be stated as in the first SA operationalization. On the other hand, variability and, therefore, discriminability of the primary measure of this SA operationalization is even higher (average of 119,68 per cent). Again, there were no effects of floor or ceiling and the distributions of the primary SA results for three observed age groups were normal (KS_{z2} = .105, p =.200; KS_{z3} = .183, p = .135; KS_{z4} = .104, p =.200), while normality statistics couldn’t be calculated for the first group since it contained only two participants. Discriminability of the secondary SA measure (error number) was again very low (more than 95% of all participants made no errors in the tests), which precluded reliable computation of all other metric characteristics. That was again the reason for treating errors number as control variable in SA analysis.

3.3. Procedure

The research was conducted with the participant’s consent and on the official premises of the Croatian Railways at the main railway station in Zagreb, during July and September of 2015. It was a part of a more comprehensive study which, besides the SA tests, included several other psychological measures and a set of anthropometric variables. Although the testing in small groups was originally planned (up to 10 participants), it has been conducted predominantly individually (before or after the participant’s work shift)[4].

After taking participant’s personal data, the research assistants firstly red the standardized test instructions and explained the task to the participants by using examples. When stated understanding the instructions and measurement readiness, the participants attended the first test component in the given time (60 s). The two test components – incongruent and neutral – were rotated across the participants (in order to avoid the threats of repeated measure design). Research assistants monitored completion time by using a stopwatch and registered possible disturbances and relevant factors in a

[4]The insight in the measurement protocols revealed no systematic relation between the participant’s age and testing before/after the work shift, so we didn’t find it relevant for the research hypotheses to test possible impact of testing time on the results.

measurement protocol. After completing the first test component, the participant immediately attended the second one, by using the same procedure. After completing all other psychological tests, materials were collected and the researchers answered participants' possible questions concerning the whole study. Testing conditions were not laboratory primarily due to the low, but variable background noise and occasional entrance to the testing area by a third party. However, the measurement protocols analysis revealed low and non-systematic appearance of measurement disturbances, with no relation to participant's age (as the main observed independent variable of the research design).

4. RESULTS

Since errors number in speed test might be related to response time, in order to exclude possible effects on primary SA measure, we first analysed that variable at in-congruent component of both versions of Stroop test.

Table 1: Descriptive statistics and results of Kolmogorov-Smirnov normality test for the errors number

	Age groups	*N*	*M*	*SD*	min-max	Z_{skew}	KS_z
Measurement 1 (Stroop1)	20-29	9	0	0	0-0	/	/
	30-39	13	0.23	0.44	0-1	2.36	.470**
	40-49	17	0.06	0.24	0-1	7.85	.538**
	50-59	11	0.09	0.30	0-1	5.02	.528**
Measurement 2 (Stroop2)	20-29	2	0	0	0-0	/	/
	30-39	23	0.04	0.21	0-1	9.97	.539**
	40-49	17	0	0	0-0	/	/
	50-59	10	0	0	0-0	/	/

**p<.01

As can be seen from the results, particularly those regarding the coloured (or block) version of the Stroop test, extremely small number of errors was detected. Namely, in the first (lexical) version of the Stroop test no errors were recorded for the youngest group of the railroad drivers, while the average number of errors for the rest of the age groups was almost zero. In the second (block) version, in the whole group of 52 participants only one of them (from the 30-39 age group) made one error.

The distributions of errors number, in all age groups where errors were detected, were significantly positively asymmetric, as shown by skewness z-test and by Kolmogorov-Smirnov normality test. They mostly resemble the Poisson distribution by which errors are usually distributed.

These data suggest that possible *speed-accuracy trade-off* (strategy of certain number of participants to favour speediness against accuracy despite the instructions setting the priority to correct answers) is not probable. That suggestion was confirmed by calculating Spearman correlation between errors number and the time needed for crossing out one target word - which was nonsignificant for both Stroop test versions (r_S=-0.141, p>.05 and r_S=-0.238, p>.05, for lexical and coloured Stroop test respectively).

All these results show that, although the errors number might be interesting variable for interference measurement (since interference potentially causes errors by creating confusion in participant's fast responses), its contribution to age-related SA changes analysis is of marginal value.

Table 2: Descriptive statistics and results of Kolmogorov-Smirnov normality test for the selective attention measure (*SA time – PS time*)

	Age groups	*N*	*M*	*SD*	min-max	Z_{skew}	KS_z
Measurement 1 (Stroop1)	20-29	9	0.2	0.05	0.3-0.28	-0.08	.175
	30-39	13	0.16	0.11	-0.03-0.32	-0.16	.171
	40-49	17	0.16	0.08	0.05-0.37	1.56	.134
	50-59	11	0.29	0.07	0.12-0.37	0.52	.192
Measurement 2 (Stroop2)	20-29	2	-0.11	0.17	-0.24-0.01	/	/
	30-39	23	0.06	0.07	-0.05-0.25	1.67	.105
	40-49	17	0.09	0.09	-0.02-0.28	1.24	.183
	50-59	10	0.12	0.17	-0.15-0.41	0.1	.104

Average Stroop interference values in first measurement (block version) are as expected, highest for the oldest group of railroad engineers and the lowest value for the 30-39 and 40-49 age groups. To examine the results variability differences among four groups, variability coefficients are calculated. They indicate high variability for the first (lexical) and especially for the second (block) version of the Stroop test, as commented in the Method. Regarding the second measurement it should be emphasized that, in the youngest age group of railroad engineers, only two participants formed that age sample, therefore confining further analyses for that group. The mean values of second measurement point to continuous growth of the Stroop interference from the youngest to the oldest age group, but the significance of the change has to be tested. All distributions are normal and symmetric, as indicated by the Kolmogorov-Smirnov and z_{skew} test, respectively, although they should be treated with caution because of small sample size.

In order to verify the significance of the previously mentioned means differences, ANOVA and related nonparametric tests were conducted for each measurement separately. The ANOVA prerequisite assumptions analysis showed that, although in both measurement sets the results were measured on ratio scale and were independent within a certain age group, all other assumptions were not unambiguously met. Namely, (1) age-related samples were not drawn probabilistically from the population, although the sample covered some 30% of the population, (2) sample sizes, related to various age groups, were not equal (see Table 2), and (3) Levene's homogeneity of variances test was barely insignificant in the first (*F*=2.44, df_1 =3, df_2 =46, *p*= .08), but not in the second (*F*=3.51, df_1 =3, df_2 =48, *p*= .02) measurement.

In the first measurement the ANOVA results (*F*=2.72, df_1 =3, df_2 =46, *p*=0.055) showed that the SA differences among four age groups were almost significant. In order to include deviations from ANOVA assumptions in the analysis, Welch robust test and nonparametric Kruskal-Wallis test were conducted and both of them pointed to significant SA age-related changes.

Table 3. Robust ANOVA and nonparametric test results for age differences in the selective attention measure

		F/χ^2	*df1*	*df2*	*p*
Age groups (Stroop 1)	Welch	3.01	3	24.16	.05
	Kruskal-Wallis	8.12	3	/	.044
Age groups (Stroop 2)	Welch	1.11	3	4.48	.43
	Kruskal-Wallis	4.60	3	/	.204

Further analyses indicated that the difference was significant between 40-49 and 50-59 age groups of the railroad engineers ($U_{Mann-Whitney}$ = 33, z= -2.85, p= .004).

In the second measurement the ANOVA results (F=2.93, df_1 =3, df_2 =48, p=0.043) showed that the SA differences among four age groups were significant, but heterogeneous variances and large differences in sample sizes (2 vs 23) strongly suggested robust and nonparametric tests. The results of these tests clearly reversed the test conclusion by showing that there were no significant SA age-related changes in the coloured version of the Stroop test.

Incongruence in ANOVA and related robust and nonparametric tests findings should be overcame with statistical scrutiny, which suggest obeying ANOVA prerequisite assumptions. In that sense, the findings of robust and nonparametric tests are the relevant ones.

On the other hand the incongruence might stem from the nature of SA variable, i.e. *SA time – PS time*. Namely, that variable, although theoretically well based, is saturated with great portion of error variance, since it is calculated as the difference between two highly correlated variables (r_1=0.89, r_2=0.83, for the first and second measurement, respectively).

The way to take into account the very nature of SA measure when analysing its age-related changes, would be analysis of covariance (ANCOVA), whereby *SA time* being dependent variable, *age group* being independent variable, and *PS time* being covariate. The ANCOVA results are almost the same as the ANOVA ones (F_1=2.63, df_1 =3, df_2 =45, p=0.062 and F_2=3.28, df_1 =3, df_2 =47, p=0.029, for the first and second measurement, respectively), but they are also subjected to almost the same prerequisite assumptions – which were not unambiguously met. More precisely, it has one additional prerequisite assumption – equal β coefficients in covariate-dependent variable regression, for every level of independent variable – which is also not perfectly met: (1) in the first measurement β_1 =0.96, β_2 =0.69, β_3 =0.94, β_4 =0.93, (2) in the second measurement β_2 =0.85, β_3 =0.82, β_4 =0.77 (β could not be calculated in the first age group since it contained only 2 participants).

Therefore, the possible advantage of ANCOVA approach in relation to ANOVA approach and its robust and nonparametric variations, is questionable - so we favoured the findings of robust ANOVA and nonparametric tests.

Finally, in order to analyse the shape of barely significant SA age-related changes in the first measurement (lexical version of Stroop test), we compared linear regression and some non-linear regression models fit. The curve estimation analysis (with SA measure being dependent and age group being independent variable) revealed that SA age-related changes resembled quadratic (R^2= 0.15, df_1=2, df_2=47, p=0.022) much more than the linear (R^2= 0.015, df_1=1, df_2=48, p=0.397) function, which is obvious from the Figure 1.

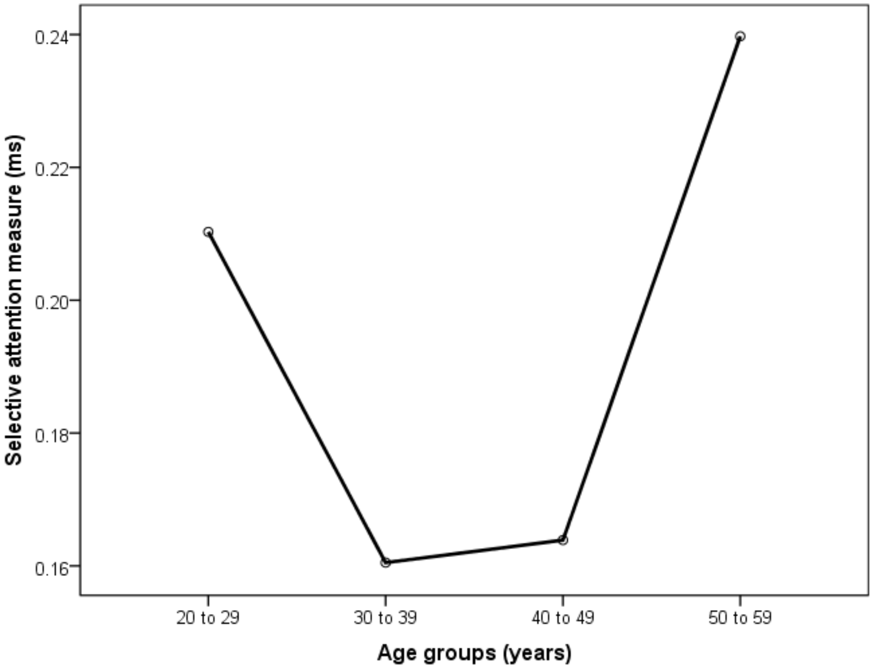

Figure 1. Age-related changes of selective attention magnitude in four observed age groups in the first measurement (lexical version of the Stroop test)

The first measurement sample of Croatian railroad engineers' selective attention obviously changed non-linearly with age: it declined non-significantly in the age range 20-29, stagnated in the age range 30-49, and then increased significantly during the last observed decade (from 40-49 to 50-59).

5. DISCUSSION

In order to examine non-linear SA ageing decline in Croatian railroad engineers from 25 to 59 years of age, two possible interference indicators (i.e. inverted SA measures) were initially planned to consider – error based, and latency based Stroop effect .
The number of errors, although interesting and useful interference measure [5] [15] [16], in this research didn't show the properties needed for error based Stroop effect calculation. Namely, in applied Stroop tests the errors were extremely rare and related low variability didn't ensure minimal psychometric qualities for including the errors number in Stroop effect calculation. Similarly to some previous research of Stroop effect [16] where errors were also rare, we used the errors number only to check possible speed-accuracy trade off, and since we didn't find it, the errors number were excluded from further analysis.

Latency based Stroop effect clearly showed non-linear SA age-related changes in lexical, but not in coloured ("blocked") version of the Stroop test. Moreover, in coloured Stroop test version, the SA age-related changes were not even significant, although there was certain tendency of aging related deterioration. Based on previous findings [5] [9] [11] significant SA deterioration was expected in coloured Stroop test version, especially between youngest and the oldest age group, because interference effect differs the most between students and all older age groups (mostly over 60 years). Possible explanations for the insignificance will be noted in further results difference analysis of two applied Stroop test versions.

On the other side, in lexical Stroop test version, the SA age-related changes were faintly significant just because the oldest two groups (40-49 and 50-59 years) differed significantly. These results are not completely in line with previous findings, which show that younger adults are generally more successful in SA tasks than the older ones [8] [9] [11] [17]. Namely, although the lexical Stroop effect decline from 20-29 to 30-39 years group is not significant, the opposite insignificant trend (i.e. growth) is expected. Possible explanation of somewhat larger interference values at the youngest group might lie in methodological confinement: the youngest sample size was the smallest one in the 1st measurement and under greater influence of sampling bias. Furthermore, it is little bit surprising that we got significant age-related difference using the variable with considerable portion of error variance (difference between two correlated variables), especially between two the oldest groups - both younger than 60 - since the greatest cognitive deterioration happens after the age of 60 [18] [19] [20] [21][5]. We might speculate of some earlier SA deterioration process in the observed sample of railroad engineers (at least in Croatia), and that it might be the consequence of generally negative health trends by all professional drivers [23] [24] [25].

Considering whether the SA age related changes depend on the presence of traffic relevant colours in applied Stroop test clearly confirmed that interference size, and its age-related changes depended on the type of interference. Namely, in Croatian railroad

[5] There is no specific data on the size of SA deterioration after the age of 60, but previous research [5] [10] [22] suggest that significant cognitive deterioration can be registered only by comparing younger persons with the ones older than 60 or 65 years (although it depends mostly on Stroop test version) [5] [10]

engineers the Stroop effect age-related changes didn't occur in coloured version, but did in lexical version of the Stroop test. These findings, at least partially, were in line with Brink and McDowd [10], who noted that differences in the colour-block version of the Stroop test performance depend on the type or complexity of the test. Moreover, MacLeod [7] pointed to the number and kind of processes Stroop task includes (for example, colour-naming of the incongruent colour word includes more processes than colour-reading and thus causing greater interference effect) [8].

Different performance and age-related changes of two applied Stroop tests in this particular research might stem from the properties of railroad engineers performance in coloured version Stroop test. Namely, green and red colours from the research are frequently used for traffic signalization so they are very important and very familiar to railroad engineers. Their frequent exposure to these colours could be seen as training or exercise, which usually decrease Stroop effect, i.e. interference, even in older people [2] [11]. Therefore, although the older groups have larger interference than the younger ones, they also have longer experience with the relevant colours (green, red), which mutually compensates and final outcome is higher probability for insignificant age-related coloured Stroop effect. Putting together that outcome with (1) very small sample size of the youngest group (and related unreliable mean score), (2) weak cognitive deterioration under the age of 60 and (3) SA measure with considerable portion of error variance, we easily come to an explanation of nonsignificant age-related changes of the coloured Stroop effect. One might also assign non-significant SA age-related differences to positively selected participants by means of regular health and psychological check-ups, where all railroad engineers with severely damaged relevant functions are sent to prequalification [26].

The finding on practice effects has important implication for the experts responsible for facilitating and improving railroad engineers work conditions. These experts should not only analyse health determinants, bad habits and other harmful life style factors relevant for cognitive motor system activated during SA performance, but also stimulate exercise and training in various types of SA tasks. The ability to maintain well a set of cognitive functions, which includes activation and inhibition of responses dependent upon stimuli discrimination, is very important for the railroad drivers, especially when taking into account the nature of their shift work. If they would be trained with some new skills and educated how to better use the skills they already have, some of their work difficulties could be kept to a minimum and their related abilities could maximize.

6. CONCLUSION

Lack of data on railroad engineers SA age-related changes led to this research that included not only more age groups, but also more SA operationalization then conventional studies of SA age-related differences. Non-coloured SA operationalization mostly confirmed the expected non-linear SA ageing deterioration, showing that at 20-49 years age range there were nonsignificant decrements, which were found to be significant after the age of 50. Nevertheless, coloured (red-green) SA operationalization indicated age-related SA decrement through whole 20-59 age period, but didn't reach significance, probably because of low reliability of SA operationalization, low general aging deterioration under the age of 60, positive health-based railroad engineers selection, and biased participants' sample size which is at least partially assumed to be exposed to specific red-green traffic differentiation experience. Such a kind of "everyday SA training", together with the similar SA exercise and certain amount of health and working conditions interventions aimed to preserve SA neurological base (mostly concerned with environmental factors, working shifts and life style habits), presents an expert field for SA improvement. However, in order to reveal specific SA aging deterioration mechanisms in railroad engineers, more comprehensive studies are needed with probabilistic sample (that might include subgroup of health damaged and prequalified railroad engineers) and environmental factors measurement, but also including more reliable SA operationalization and the set of health and life style variables.

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REFERENCES

[1] Kanfer, R. & Ackerman, P.L.: Aging, adult development, and work motivation, *Academy of Management Review,* **29.** (2004) 3, pp. 440-458, 1930-3807
[2] Popkin, S.M.; Morrow, S.L.; Di Dimenico, T.E. & Howarth, H.D.: Age is more than just a number: Implications for aging workforce in the US transportation sector, *Applied Ergonomics,* **39.** (2008), 5, pp. 542-549, 0003-6870
[3] Mather, M. & Carstensen, L.L.: Aging and motivated cognition: the positivity effect in attention and memory, *Trends in Cognitive Sciences,* **9.** (2005) 10, pp. 498-502, 1364-6613
[4] Sternberg, R.J.: *Kognitivna psihologija,* Naklada Slap, 953-191-262-9, Jastrebarsko, (2005)
[5] Ludwig, C.; Borella, E.; Tettamanti, M. & de Ribaupierre, A.: Adult age differences in the Color Stroop Test: A comparison between an Item-by-item and Blocked version, *Archives of Gerontology and Geriatrics,* **51.** (2010) 2, pp. 135-142, 0167-4943
[6] Jensen, A.R. & Rohwer, W.D.: The Stroop color-word test: A review 1, *Acta Psychologica,* **25.** (1966) 1, pp. 36-93, 0001-6918
[7] MacLeod, C.M.: Half a century of research on the Stroop Effect: An Integrative Review, *Psychological Bulletin,* **109.** (1991) 2, pp. 163-203, 0033-2909

[8] Mutter, S.A.; Naylor, J.C. & Patterson, E.R.: The effects of age and task context on Stroop task performance, *Memory & Cognition,* **33.** (2005) 3, pp. 514-530, 1532-5946

[9] Ben-David, B.M. & Schneider, B.A.: A sensory origin for Color-Word Stroop effects in aging: A meta-analysis, *Aging, Neuropsychology, and Cognition*, **16.** (2009) 5, pp. 505-534, 1774-4128

[10] Brink, J.M. & McDowd, J.M.: Aging and selective attention: An issue of complexity or multiple mechanisms?, *Journal of Gerontology: Psychological Sciences*, **54.** (1999) 1, pp. 30-33, 1758-5368

[11] Davidson, J.D.; Zacks, R.T. & Williams, C.C.: Stroop interference, Practise and Aging, *Neuropsychology, development, and cognition. Section B, Aging, neuropsychology and cognition*, **10.** (2003) 2, pp. 85-98, 1744-4128

[12] Rimac, I.; Žebec, M.S. & Jurić, D.: Verbal Uncolored Paper-and-Pencil Version of the Stroop Test – Metric Properties, *Available from* https://biblio.irb.hr/prikazi-rad?&rad=276661 *Accessed:* 2016-02-05.

[13] Christ, S.E.; White, D.A.; Mandernach, T. & Keys, B.A.: Inhibitory control across the lifespan, *Developmental Neuropsychology,* **20.** (2001) 3, pp. 653-669, 1532-6942

[14] Woodson, W. E., Tillman, B., Tillman, P.: Human Factors Design Handbook, Second Edition, McGraw-Hill, Inc., 1992.

[15] West, R & Alain, C.: Age-related decline in inhibitory control contributes to the increased Stroop effect observed in older adults, *Psychophysiology*, **37.** (2000) 1, pp. 179-189, 0048-5772

[16] MacLeod, C.: Training on integrated versus separated Stroop tasks: The progression of interference and facilitation, *Memory and Cognition*, **26.** (1998) 2, pp. 201-211, 1532-5946

[17] McGaughy, J. & Eichenbaum, H.: It is time to pay attention to attention in aging, *Learning and Memory*, **9.** (2002) 4, pp. 151-152, 1072-0502/02

[18] Ardila, A.: Normal aging increases cognitive heterogeneity: Analysis of dispersion in WAIS-III scores across age, Archives of Clinical Neuropsychology, 22. (2007) 8, pp. 1003-1011, 0887-6177

[19] Salthouse, T.A. & Davis, H.P.: Organization of cognitive abilities and neuropsychological variables across the lifespan, Developmental Review, 26. (2006) 1, pp. 31-54, 0273-2297

[20] Salthouse, T.A., Pink, J.E. & Tucker-Drob, E.M.: Contextual analysis of fluid intelligence, Intelligence, 36. (2008) 5, pp. 464-486, 0160-2896

[21] Span, M.M, Ridderinkhof, K.R. & van der Molen, M.W.: Age-related changes in the efficiency of cognitive processing across the life span, Acta Psychologica, 117. (2004) 2, pp. 155-183, 0001-6918

[22] Madden, D.J. & Langley, L.K.: Age-related changes in selective attention and perceptual load during visual search, Psychology and Aging, **18.** (2003) 1, pp. 54-67, 0882-7974

[23] Tse, J.L.M., Flin, R. & Mearns, K.: Bus driver well-being review: 50 years of research, Transportation Research Part F, 9. (2006) 2, pp. 89-114, 1369-8478

[24] Backman, A.L.: Health survey of professional drivers, Scandinavian Journal of Work, Environment & Health, 9. (1983) 1, pp. 30-35, 0355-3140

[25] Taylor, A.H. & Dorn, L.: Stress, Fatigue, Health and Risk of Road Traffic Accidents Among Professional Drivers: The contribution of physical inactivity, Annual Review of Public Health, 27. (2006), pp. 371-391, 0163-7525

[26] Pravilnik o ovlaštenju strojovođa [Regulation on Railroad Engineer Licence]. Narodne novine [Official Gazette], 96/2013,

PERCEPTUAL SPEED OF CROATIAN RAILROAD ENGINEERS FROM 25 TO 59 YEARS OF AGE: EMPIRICAL FINDINGS AND IMPLICATIONS

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Abstract

A general decline in cognitive functions with age has a significant impact on professional functioning, especially for professional drivers, and it is dominantly explained by the age-related reduction of processing speed. Given the significant impact of processing speed decline in ageing railroad engineers on the safety of passengers and transport of goods, it is important to register the intensity of that decline, its possible specificities and to indicate its main causes. One of the most important aspects of processing speed is perceptual speed (PS) and therefore a study of PS age-related changes was conducted with the aim of investigating the intensity and possible specificities of those changes. The participants were 103 male drivers of the Croatian Railways, ages 25-59, assigned to 4 age groups, distinguished by specific functional characteristics of professional drivers. Two equivalent perceptual speed tests were applied individually. The participants' task was to cross out as many of the target words in the context of distractor words in 60 seconds. Descriptive statistics indicates expected average PS values, with slightly positive asymmetric distributions and an optimal and homogenous variability. The average number of errors shows the expected very low value with very positive asymmetric distributions and homogenous variability. The effect of speed-accuracy trade-off was nonexistent. A statistically significant nonlinear PS decline with increasing age is evident, while there are no changes in inter-individual variability and number of errors. The results are discussed in relation to the theory of cognitive aging and empirical findings in the general population, with the implications on railroad engineers ageing process. Some of the key causes of the PS decline with age and possible interventions are reviewed.

Keywords*:* *perceptual speed, aging process, railroad engineers*

1. INTRODUCTION

Demands to work past the traditional retirement age or to return to work post-retirement, are getting more frequent and are particularly important for the transportation industry in countries such as Croatia, in which the work force is systematically aging because of demographic changes [1]. Aging is often associated with decline in various types of cognitive domains (fluid intelligence, longer study and decision time and lower accuracy) [2] [3], which are substantial for successful functioning in the job environment, especially when it is characterized by long, irregular work shifts and demanding physical and mental tasks [4]. Having this in mind and the fact that professional drivers, particularly railroad engineers, are responsible for their own safety, the safety of the passengers and the goods being transported, it is particularly important to investigate the specific impacts of aging within the transportation industry. Given the well-documented negative relation between age and various measures of cognitive functioning, the research focuses on the specificities of age-related changes of human processing speed of railroad engineers.

Processing speed reflects a rate at which tasks can be performed and it's thereby typically assessed with timed tasks. The related measures might range from reaction times [5], to more complex speed attributes with specific variables being tied to different research traditions [6]. In psychometric research, one of the most frequent variables is the perceptual speed (PS), which is assessed by test of simple content that everybody would complete flawlessly if there were no time limit. Paper-and-pencil tests are used most commonly including tasks that often involve comparison, search or substitution operations [6].

The central role of speed variables in exploring cognitive aging has been emphasized in Salthouse's theory: age related decrement in processing speed prevents individuals to successfully complete cognitive operations in a given time and pose a threat to higher cognitive functions, such as abstraction and integration, by reducing the amount of simultaneously available information need for their execution [7]. Salthouse's research has shown significantly higher correlation (e.g. -.52) of processing speed and reaction time with age, than for any other cognitive variable included in the analysis (almost 80% of the age related variance in various cognitive variables was shared with measures of PS) [8]. Furthermore, when applying different analytical methods to 16 different data sets with total of 169 various cognitive variables, only two distinct factors appeared to be sufficient to account for at least 75% of the age related variance of those variables, whereby the processing speed was identified as having a prominent role in those factors [9]. Therefore, Salthouse pointed out general age-related slowing as one of the most commonly and best-documented behavioural phenomena of aging.

Although most of cognitive aging studies have mainly focused on age level, or magnitude of performance – and therefore analysed age related differences in central tendency measures (mostly in means) - some interest has been given to cognitive dispersion measures within age categories [10]. Those analyses give a more complete picture of cognitive aging, since the central tendency measures become less informative as the amount of intersubject variation increases [11]. Certain number of research points to an increase in interindividual cognitive performance differences with increasing age [10] [11], whereby proposing performance variability - including the speed performance – as a part of explanation of life-span developmental change [12]. In favour of these findings, the authors also point out the results of case studies of career development which indicate movement of increasingly differentiated positions obtained by employees over time [11]. Exploring interindividual variability in different age groups becomes even more intriguing when considering Morse review-based finding that cross-sectional data does not always show larger standard deviations for older groups compared to younger ones [13].

The above mentioned findings clearly suggest negative correlation between cognitive aging and job performance (because of negative age-cognition relations and positive cognition-job performance), although large number of methodologically criticized studies found little or no relations between age and job performance [14]. The negative (cognitive) aging-job performance correlation has been justified by Fozard and Nuttall's study (showing that less than 50% of workers at the age of 60 would be able to qualify for many jobs according to the General Aptitude Test Battery score), cited by Salthouse [15]. Research in traffic related occupations and activities clearly justified negative relations between age and performance - mostly based on cognitive deterioration - and were conducted on: (a) air traffic controllers (where processing speed and flexibility, inductive and deductive reasoning, selected and divided attention were negatively correlated with age) [15]; (b) commercial truck drivers (where significant decrements in perceptual, cognitive and psychomotor abilities with advanced age has been noted, whereby younger participants under the age of 50 showed significantly faster response time in decision making and information processing tasks as compared to older ones over the age of 65 years) [16]; (c) general population of motor vehicle drivers (where slower cognitive speed of processing was a significant predictor of driving cessation) [17].

A rare study conducted by Drenovac and Zajc [18] that had focused on age differences in mental efficiency and speed of railroad engine drivers, has shown that differences were found on all mental efficiency and speed measures, with older subjects having poorer performance. Furthermore, there was evident increase in time needed to complete the visual orientation and visual identification of number tasks after the age of 35, and the increase was more rapid in the group of subjects older than 41 [18]. Due to extremely negative effects of possible failure in job performance of railroad engineers, the purpose of this study was to verify the results obtained by Drenovac and Zajc (conducted 20 years ago) and contribute to the research of Croatian railroad engineers' cognitive functioning specificities.

2. AIM AND HYPOTHESIS

The aim of the study is to examine the effects of aging on PS of Croatian railroad engineers from 25 to 59 years of age through four age categories distinguished by specific functional characteristics of professional drivers.

4. Hypothesis: PS, measured by the average number of correctly crossed out target words per unit of time, changes non-linearly throughout the four functionally determined age categories: mostly stagnant in the 20-29 year and 30-39 year categories, slightly declining during the 40-49 category and considerably declining in the 50-59 age category.
5. Hypothesis: interindividual variability in PS measures increases systematically throughout the four observed age categories.
6. Hypothesis: age related changes of magnitude and variability of the observed PS measure point to certain specifics of the Croatian railroad engineers in relation to the general population of that age, which can be related to the specifics of their profession and have a partial impact on them.

3. METHOD

3.1. Participants

The participants were 103 male railroad engineers of the Croatian Railways (51 participants were included in the first part of the research and 52 in the second part), ages 25 to 59 (M = 41,1, sd = 8,32).

3.2. Materials

The research consisted of two sets of measurements in which two equivalent paper and pencil test forms of PS were administrated, one in the first part of the research conducted in the summer (July, 2015) and the other in the second part of the research conducted in autumn (end of September, 2015).

The first form of the PS test used is a neutral form of the Lexical version of the Stroop test [19]. The test consists of 448 words with fifty per cent of them being the word "big" and the other fifty per cent of them being the word "small" (in Croatian, "veliko" and "maleno", respectively). All the words are written in lower case letters, and their semantic content and position varied randomly within the lines and pages of the test. The participants' task was to cross out as many of the words "small" as possible within 60 seconds, without skipping words or lines. Two outcome variables are used as test results: the time for crossing out one stimulus (target word) and the number of errors (crossed out words "big" or omitted target words), with the time for crossing out one stimulus being the main variable.

The second form of the PS test is a neutral form (so-called "reading condition") of the paper and pencil version of the Stroop test, which is, in the literature, often referred to as the "block version" of the test [20]. The test consists of 448 words with fifty per cent of them being the word "red" and the other fifty per cent of them being the word "green" (in Croatian "crveno" and "zeleno", respectively). All the words are written in black ink and lower case letters. The semantic content and position of the words varied randomly within the lines and pages of the test. The participant's task was to cross out as many of the words "green" as possible within 60 seconds, without skipping words or lines. The results are recorded as the time for crossing out one stimulus (target word) and the number of errors (crossed out words "red" or omitted target words) with the time for crossing out one stimulus being the main variable for analysis.

The PS measure was expressed as an inverse value of the output variable of the time for crossing out one stimulus of the test.

Discriminability of the test is high as indicated by the variability coefficients that ranged from 16 to 21,55 per cent across age groups with an average of 19,26 per cent. Additionally, there were no floor or celling effects and the distributions of the test results were normal at all four observed age groups (KS_{z1} = .218[6], p = 151; KS_{z2} = .129, p = ,136; KS_{z3} = .101, p = .200; KS_{z4} = .106, p =.200). Content validity is also high due to strong similarities between the two parallel PS test forms used in this study and the Coding test from Wechsler Adult Intelligence Scale [21] which is a widely accepted PS measure.

3.3. Procedure

The testing was conducted with the participant's consent and on the official premises of the Croatian Railways at the main railway station in Zagreb, during July and September of 2015. It was part of a more comprehensive study which, in addition to PS, included several other psychological measures and a set of anthropometric variables. Although the testing in small groups was originally planned (up to 10 participants), it has been conducted predominantly individually (before or after the participant's work shift).

[6] KSz = Kolmogorov-Smirnov z-statistic

After taking participant's personal data, the research assistants read the standardized test instructions and explained the task to the participants by using examples. After stating understanding of the instructions and measurement readiness, the participants completed the test in the given time (60 s). Research assistants monitored completion time by using a stopwatch and registered possible disturbances and relevant factors in a measurement protocol. After completing all other psychological tests, materials were collected and the researchers answered participants' possible questions concerning the whole study. Testing conditions were not laboratory primarily due to the low but variable background noise and occasional entrance to the testing area by a third party. However, the measurement protocols analysis revealed low and non-systematic appearance of measurement disturbances, with no relation to participant's age (as the main observed independent variable of the research design).

4. RESULTS

Before testing the hypotheses on age-related PS changes, it was relevant to check if the data were influenced by responding strategy. Namely, although testing instructions clearly set priority to correct and then to fast answers, certain percentage of participants tend to favor speediness against accuracy. This strategy is known as *speed-accuracy trade-off* and, in order to check it, descriptive statistics for the number of errors and the correlation between the number of errors and the speed of crossing out target words is analyzed.

Table 1: Descriptive statistics and the results of Kolmogorov-Smirnov normality test for the number of errors for the four age groups

Age groups	*N*	*M*	*sd*	*min-max*	z_{skew}	KS_z
20-29	11	.09	.30	.00-1.00	5.02**	.528**
30-39	36	.03	.17	.00-1.00	15.27**	.538**
40-49	35	.06	.34	.00-2.00	14.86**	.539**
50-59	21	.05	.22	.00-1.00	9.14**	.539**

$^{**}p<.01$

The average number of errors for all the age groups is zero and the related distributions in all the age groups are extremely positively asymmetric as shown by the z-scores for skewness and the results of the Kolmogorov-Smirnov test. Thus they mostly resemble the Poisson distribution by which errors are usually distributed. The data are in accordance with the reported findings in the literature [22] since they slightly suggest the greatest number of errors in road driving at the beginning of the career of professional drivers, and a lower number of errors at the end of the career.
Variability of the errors number in all the age groups is several times higher than their mean values (that is specific for high positively skewed distributions). Although there is a noticeable trend of decline and growth of the standard deviation values across the age groups, the results of the Levene's test indicate that the variability of the errors number does not change significantly with age (F = .715, df_1 = 3, df_2 = 99, p = .545).
The presented data (especially, mean errors number and theoretically expected Poisson distribution) indicates that the speed-accuracy trade-off effect is not present in this data

set. That is confirmed by calculating the Spearman correlation[7] between the speed of crossing out target words and the errors number, which was low and insignificant for the whole sample (*rho* = .135, *p* =.175), while in the case of an existing speed-accuracy trade-off effect, the correlation between those two variables should have been significant and negative. Moreover, the presented errors data also confirm that errors number has justifiably been treated as the secondary outcome variable of the examination, which has had only control role in the study.

In order to test the main hypotheses of the study, descriptive statistics are presented and the mean values, distributions and variability of the main PS measure are commented for the four age groups of railroad engineers.

Table 2: Descriptive statistics and the results of Kolmogorov-Smirnov normality test for the PS measure (number of crossed out target words per unit of time) for the four age groups (with regard to age)

Age groups	*N*	*M*	*sd*	*min-max*	z_{skew}	KS_z
20-29	11	1.43	.31	1.05-1.92	.395	.218
30-39	36	1.39	.22	.91-1.92	.407	.129
40-49	35	1.33	.27	.73-2.00	-.002	.101
50-59	21	1.18	.23	.77-1.62	.177	.106

According to the mean values presented in Table 2 it is evident that the participants of all four age groups were able to cross out, on average, more than one target word per second. Those values of the PS measure (number of crossed out target words per unit of time) are in line with expectations, and its relation to age indicates a tendency of continuous PS decline from the youngest to the oldest group. The significance of that tendency will be tested by the ANOVA and the Kruskal-Wallis tests.

Regarding the distributions of the PS, the skewness z-scores show they are symmetrical for all the age groups, with a slight tendency toward positive asymmetry (the only exception was 40-49 age group, which shows almost perfect symmetry). However, none of the distributions deviate significantly from normal as indicated by the results of the Kolmogorov-Smirnov normality test. None the least, these results should be considered with caution, seeing how the sample size is small and the normality test is not overly sensitive.

Variability of the results is optimal as indicated by the variability coefficients (CV): 21.53%, 16%, 19.89% and 19.67% for all the age groups respectively, with the average variability coefficient being 19.2%. Unlike the recorded age decline in the mean values, the variability of the observed distributions of the PS results decline notably only from the 20-29 to the 30-39 age group. The significance of that decline has been verified by conducting the Levene's test of equality of variances, which showed that inter-individual variability of the observed PS measure does not change significantly with age (F = 1.254, df_1 = 3, df_2 = 99, p = .294).

To verify the significance of the previously observed tendency of continuous decline in PS magnitude (i.e. means) across four age groups, an ANOVA is suggested. In order to get valid interpretation of ANOVA results, the related prerequisite assumptions are tested. The distributions normality (Kolmogorov-Smirnov test) and homogeneity of variance (Levene's test) of PS at the observed four age groups has been proven. As far

[7] Highly skewed errors distribution underestimated speed-errors relation calculated by Pearson correlation

as the other assumptions are concerned, the results are measured on ratio scale and they are independent within a certain age group, but the samples are not drawn probabilistically form the population and the age groups are of different sizes. Therefore, it can be concluded that four of six ANOVA assumptions are met and that it is possible to rely on the robustness of this statistical test.

According to the results of the ANOVA test it is evident that PS, in the sample of railroad engineers, changes significantly with age (F = 3.99, df_1 = 3, df_2 = 99, $\eta^2 = .11$) although only 11% of all the PS variance in this sample can be explained by the effects of age. However, due to deviations from the two ANOVA assumptions, an analog nonparametric test (Kruskal Wallis test) was performed and the results of this test confirmed the abovementioned findings (χ^2 = 9.961, df = 3, p = .019).

Furthermore, in order to verify which age groups differ significantly from one another and weather these differences point to possible non-linear PS age related changes, post hoc analysis was conducted too.

Table 3: Bonferroni post hoc comparisons of age group differences in the PS magnitude

Compared age groups		Mean difference	Std. error	*p*
20-29	30-39	.042	.086	1.000
	40-49	.099	.086	1.000
	50-59	.257*	.093	.041
30-39	40-49	.058	.059	1.000
	50-59	.215*	.069	.014
40-49	50-59	.158	.069	.147

The results of the post-hoc analysis show that the statistically significant differences in PS are evident only between the two younger age groups (20-29 and 30-39) in comparison to the oldest age group (50-59), meaning that the participants in the oldest age group exhibit lower PS in comparison to the participants in the two younger age groups. Since no other significant differences were found, it is suggested that in the sample of Croatian railroad engineers PS changes non-linearly: it stagnated or declined very slowly in the age range 20-49, and then decreased significantly during the last observed decade (40-49). The proof for non-linear PS age decline came from quadratic regression, whose goodness of fit indicator (R square = 0,107) was somewhat higher then linear regression one (R square = .096). The same finding is obvious from graphic presentation of ANOVA plot of PS -age group relation.

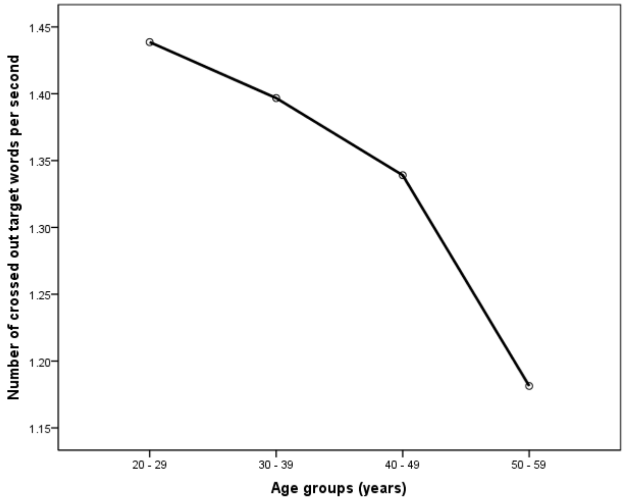

Figure 1: Age-related changes of PS magnitude in four observed age groups

5. DISCUSSION

Preliminary PS test analysis of the number of errors justified its control variable status and rejected the existence of the *speed-accuracy trade-off* effect. Namely, errors were extremely rare and almost nonexistent, the related distributions in all four age groups mostly resembled theoretically expected Poisson distribution, and the number of errors were independent from the main PS variable (the number of crossed out target word in unit of time) – which all disabled any further meaningful analysis of this variable.
Next, the analysis of the PS variable is commented in light of the first hypothesis. As it can be seen from the results, there was a visible tendency of PS decline across the four age groups of railroad engineers with a relatively small differences between the two youngest groups (20-29 and 30-39), slight decline towards the third age group (40-49) and a more noticeable decline in the oldest group (50-59). However, the significance of that decline was shown only between the two youngest and the oldest age group confirming our expectations of a non-linear PS decline. The results are somewhat in accordance with those of Drenovac and Zajc [18], who found a tendency of a slight speed decrease between the two youngest groups (younger than 30 and 31-35), a somewhat noticeable decrease in the third age group (36-40) and more considerable decline in the oldest one (older than 41). The noticeable decline occurred somewhat earlier than in our own study, possibly due to a much greater sample and by measuring speed via reactionmeter (another explanation based on eventually worse working conditions 20 years ago that led to earlier cognitive deterioration has to be checked). However, regarding PS measures expressed in time per item, Salthouse [3] found a positive acceleration age-PS function (higher results indicating poorer performance) accounting for a significant quadratic age trend of PS decline in a sample of 18 to 80 year olds, with greater acceleration beginning at the age of 50. Similar trends for PS measures were also found in Verhaegen and Salthouse meta-analysis [8] that yielded at least two significant findings: (1) a significant negative quadratic age-cognition relation of accelerated decline with increasing age and (2) a stronger correlation of age and speed measures for the older group of participants over the age of 50.

Well documented PS aging decline still raises the questions on underlining mechanisms, but also generates the related possible explanations. Collins [23] points out that age merely represents the cumulative effect of different risk factors such as effects of alcohol use, diet, exposure to toxic agents, neurological trauma and so on. A non-less important factor is the natural biological aging of the organism. In his review article, Ecart [5] indicates that total gray matter volume of the brain has been associated with the differences in processing speed, theoretically by degrading mental representations that would slow down cognitive operations. On the other hand, Kerchner and his colleges [24] have found that the white matter integrity loss was a significant cause of age related decline in processing speed among a sample of healthy adults over the age of 55. Another study revealed that a large amount of variance in white matter integrity is common to different tracts, indicating that the shared integrity across neural tracts is associated with processing speed and that impaired cortical connections can be seen as a global process affecting simultaneously major trajectories [25]. The loss of myelination that occurs with increasing age could slow down conducting rates between neurons and therefore processing speed [5]. Furthermore, brain regions that were shown to be unique predictors of age related changes in perceptual and motor speed were the frontal lobes (most likely driven by cerebral small vessel disease), and cerebellar regions [26].
Regarding our second hypothesis, we expected that interindividual variability in PS measure would increase systematically throughout the four age categories. However, as indicated by the variability coefficient values, there was an evident variability decline only from the 20-29 to 30-39 group, while Levene's homogeneity of variance test showed that interindividual PS variability did not change significantly with age. Results of other studies, regarding variability of reaction time measures in different age groups, have been mixed. The Morse meta-analysis [13] indicated that older groups of participants showed greater variability in reaction time measures in comparisons to younger groups, and that the reaction time CV scores increased by 22%. However, when all the measures of the studies have been included in the analysis there were no significant differences among the age groups indicating that there were certain tasks in which the older adults may show greater variability. Hale and colleges [27] pointed out that variability as indicated by standard deviation units may be confounded with the mean values, which also tended to rise (for reaction time) with increasing age and thus standard deviations are not compared under equal conditions. Although variability differences in reaction time measures of the Hultsch and colleges study [10] could not be attributed to the artifact of the mean and standard deviation relationship, the magnitude of the age related variability differences was relatively small and evident from the mid-50s to the late 80s. It is, however, possible that work related experience can soften age related declines in cognitive abilities which was shown from the studies reviewed by Popkin and colleagues [4] conducted on pilots. Nevertheless, Salthouse and Mitchell [28] did not find that work experience prevents age related declines in processing speed.
Taking into account the study results and previous empirical findings presented in regard to the first hypotheses (greater decline in performance of PS measures beginning after the age of 50 [3]; stronger correlation of age and speed measures for the participants over the age of 50 [8]) and second hypotheses (no age-related differences in the observed PS variability, no differences in variability among the age groups when including all the variables of PS measures in the meta-analysis [13]; age related variability differences relatively small and evident from the mid-50s to the late 80s [10]) it can be concluded that there were no age related changes in magnitude and variability

of the observed PS measures that were specific for the railroad engineers in relation to the general population, thus providing an answer for the third hypothesis of this research. Furthermore, the specific content of the applied PS test, hardly suggest any component of the railroad engineers' specific experience that would affect PS results. To be more precise, we might expect some earlier deterioration of cognitive functions of this population because of generally negative health trends by all professional drivers [29] [30] [31], but, on the other hand, these negative effects are counterbalanced by excluding from their position (through regular health and psychological check-ups) all railroad engineers that have any severe health problem [32]. Nevertheless, the comparison of Croatian railroad engineers' PS with the general population's PS might additionally be confined with (1) specific age categorization used in the study and (2) different PS tasks content in relation to the ones from previous studies. Namely, Salthouse [3] indicates that various task characteristics may act as potential mediators of the relation between speed and age, and points out that several studies have shown that the degree of slowing is greater for tasks involving spatial information than for tasks involving verbal information, which were used in this study, and which may have resulted in a reduced decline in PS.
Considering the data obtained under all three tested hypotheses, we should emphasize some limitations that confine study conclusions. First, the possible relation of work shift timing and testing outcome hasn't been analyzed, since it wasn't in the scope of this study, but the insight in the measurement protocols revealed no systematic relation between the participant's age and testing before/after the work shift, so we didn't find it relevant for the research hypotheses. Second, actual health status, psychophysical readiness, circadian rhythms and sleeping habits should be measured prior to the PS testing. Third, in order to reveal specific PS aging deterioration mechanisms in railroad engineers, the actual study should be expanded with more comprehensive studies with a probabilistic sample that might even include subgroup of health damaged and prequalified railroad engineers. Fourth, future studies should include measurement of environmental factors and additional PS operationalization (in order to rise construct validity of the study).
Finally, we find it valuable to present several insights in how to reduce or delay the negative impact of age on processing speed. The interventions range from biological (given that cerebellar gray matter predicts processing speed, leptin[8] treatment studies suggest using leptin supplement because of its positive effect on the cerebellar gray matter volume in leptin deficient patients) [5] to the social ones (a study conducted on a sample of participants ranging in age from 70 to 103 years, concluded that maintaining an engaged and active life style may alleviate PS declines) [34]. Some randomized intervention trials have shown that visual processing speed training might improve older drivers driving capabilities and increase their driving safety performance [35]. Furthermore, speed of processing training led to improvements in visual attention and higher order processing speed, resulting in fewer dangerous driving maneuvers [36]. It also led to reduction of at-fault collisions for drivers over 65 years of age [37] and to processing speed improvement by 2.5 standard deviations for participants that attended 10 initial and 8 booster sessions (whereby the effects of initial training were maintained over a 5-year period) [38]. At last, Llaners and his colleagues [16] have shown that compensatory and training interventions led to an improvement in driving related

[8] Leptin is a regular body hormone that helps to regulate energy balance by inhibiting hunger and persons that have problems with its production go under leptin supplement treatment [33]

abilities by at least temporary enhancing certain perceptual, cognitive and psychomotor abilities, while drivers who used in-vehicle navigational system made fever navigational errors, showed better speed adjustment and monitoring performance. Seeing how cognitive speed is an important factor in job performance of railroad engineers, cognitive training and ergonomic options should be further explored so as to help maximize their abilities.

6. CONCLUSION

To summarize, the conducted study was one of few that focused on age-related differences in railroad engineers' cognitive functions - more specifically PS - especially in Croatia. Results indicate that PS decline across different age groups was not linear and the only significant decline was found among the two youngest age groups and the oldest group of railroad engineers, indicating mainly similar patterns as those found in the general population. On the contrary, interindividual variability for the PS measure did not change significantly across the observed age range. The observed PS decline with increasing age may be due to differences in life styles, exposure to different kind of risk factors during life or neurobiological changes that accompany advanced age. Seeing how processing speed declines with advanced age and that it can impact higher level cognitive functions it is necessary to acknowledge the potential risk that the decline holds for adequate job performance of railroad engineers and to consider the usage of processing speed trainings that have proven useful. Further research, streaming towards probabilistic sampling, including different PS measures and controlling for possible mediator variables such as psychophysical readiness and health, is needed to verify these findings.

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REFERENCES

[1] Nejašmić, I. & Toskić, A.: Starenje stanovništva u Hrvatskoj – sadašnje stanje i perspektive, *Hrvatski geografski glasnik*, **Vol**. 1 (2103) No. 75, pp. 89-110, ISSN: 1331-5854
[2] Bors, D. A. & Forrin, B.: Age, speed of information processing, recall and fluid intelligence, *Intelligence*, **Vol.** 20 (1995) No. 3, pp. 229-248, ISSN: 016034-2896
[3] Salthouse, T. D.: The nature of the influence of speed on adult age differences in cognition, *Developmental Psychology*, **Vol.** 30 (1994) No. 2, pp. 240-259, ISSN: 0012-1649
[4] Popkin, S. M.; Morrow, S. L.; Di Domenico, T. E. & Howarth, H. D.: Age is more than just a number: implications for an aging workforce in the US transportation sector, *Applied Ergonomics*, **Vol.** 39 (2008) No. 5, pp. 542-549, ISSN: 0003-6870

[5] Eckert, M. A.: Slowing down: age-related neurobiological predictors of processing speed, *Frontiers in Neuroscience*, **Vol.** 5 (2011), pp. 1-13

[6] Salthouse, T.: Aging and measures of processing speed, *Biological Psychology,* **Vol.** 54 (2000) No. 1-3, pp. 35-54, ISSN: 0301-0511

[7] Salthouse, T. A.: The processing –speed theory of adult age differences in cognition, *Psychological Review*, **Vol.** 103 (1996) No. 3, pp. 403-428, ISSN: 1939-1471

[8] Verheghen, P. & Salthouse T. A.: Meta-analysis of age-cognition relations in adulthood: estimates of linear and nonlinear age effects and structural models, *Psychological Bulletin,* **Vol.** 122 (1997) No. 3, pp. 231-249, ISSN: 0033-2909

[9] Salthouse, T. A.: How many causes are there of aging-related decrements in cognitive functioning, Developmental Review, **Vol.** 14 (1994) No. 4, pp. 413-437, ISSN: 0273-2297

[10] Hultsch, D. F.; MacDonald, S. W. S. & Dixon, R. A.: Variability in reaction time performance of younger and older adults, *Journal of Gerontology*, **Vol.** 57B (2002) No. 2, pp. 101-105, ISSN: 1758-5368

[11] Nelson, E.A. & Dannefer, D.: Age heterogeneity: fact or fiction? The fate of diversity in gerontological research, *The Gerontologist*, **Vol.** 32 (1992) No. 1, pp. 17-23, ISSN: 1758-5341

[12] Miller, P. H.: Order in variability, variability in order, *Human Development*, **Vol**. 45 (2002) No. 3, pp. 161-166, ISSN: 1423-0054

[13] Morse, C. K.: Does variability increase with age? An Archival study of cognitive measures, *Psychology and Aging*, **Vol.** 8 (1993) No. 2, pp. 156-164, ISSN: 0882-7974

[14] Salthouse, T. & Maurer, T.: Aging, job performance and career development, In *Handbook of the psychology of aging,* Academic Press, ISBN: 9780121012601, San Diego, (1996), pp- 353-364

[15] Salthouse, T.: Consequences of age-related cognitive declines, *Annual Review of Psychology*, **Vol.** 63 (2012) No. 5, pp. 201-227

[16] Llaneraus, R. E.; Swezey, R. W.; Brock, J. F.; Rogers, W. C. & Van Cott, H. P.: Enhancing the safe driving performance of older commercial vehicle drivers, *International Journal of Industrial Ergonomics,* **Vol.** 22 (1998) No. 3, pp. 217-245, ISSN: 0169-8141

[17] Edwards, J. D.; Bart, E.; O'Conner, M. L. & Cissell, G.: Ten years down the road: predictors of driving cessation, *The Gerontologist,* **Vol.** 50 (2010) No. 3, pp. 393-399, ISSN: 0016-9013

[18] Drenovac, M. & Zajc M.: The efficiency of cognitive functioning across different age groups, *Čovjek i promet*, **Vol.** 18 (1992) No. 1-4, pp. 27-32,

[19] Rimac, I.; Žebec, M.S. & Jurić, D.: Verbal Uncolored Paper-and-Pencil Version of the Stroop Test – Metric Properties, Available from https://biblio.irb.hr/prikazi-rad?&rad=276661 Accessed: 2016-02-05.

[20] Ludwigm C.; Borella, E.; Tettamanti, M. & de Ribaupierre, A.: Adult age differences in the color Stroop test: A comparison between an item-by-item and a blocked version, *Archives of gereontology and geriatrics*, **Vol.** 51 (2010) No. 2, pp. 135-142, ISSN: 0167-4943

[21] Wechsler, D.: *Wechsler adult intelligence scale – fourth edition. Administration and scoring manual,* Pearson Assessment, ISBN: 9780749150013, San Antonio TX, (2008)

[22] Freeman, J.; Barraclough, P.; Wishart, D. & Rowland, B.: Using the driver behaviour questionnaire to predict crash and demerit point loss: does it get better with larger sample size, *Proceedings of* Occupational safety in transport conference, pp. 1-11, 9781921897535, Queensland, Australia, September, 2009, QUT ePrints, Queensland, (2014)

[23] Collins, L. M.: Comment on "How many causes are there of aging-related decrements in cognitive functioning", *Developmental Review*, **Vol.** 14 (1994) No. 4, pp. 438-443,ISSN: 0273-2297

[24] Kerchner, G. A.; Racine, C. A.; Hale, S.; Wilheim, R.; Laluz, V. & Miller, B. L.: Cognitive processing speed in older adults: relationship with white matter integrity, *PLOS ONE*, **Vol.** 7 (2012) No. 11, pp. 1-10

[25] Penke, L.; Munoz Maniega, S.; Murray, C.; Goe, A. J.; Valdez Hernandez, M. C.; Clayden, J. D.; Starr, J. M.; Wardlaw, J. M.; Bastin, M. E. & Deary, I. J.: A general factor of brain white matter integrity predicts information processing speed in healthy older people, *The Journal of Neuroscience*, **Vol.** 33 (2010) No. 22, pp. 7569-7574, ISSN: 1529-2401

[26] Eckart, M. A.; Keren, N. I.; Roberts, D. R.; Calhoun V. C. & Harris, K. C.: Age related declines in processing speed: unique contributions of the cerebellar and prefrontal cortex, *Frontiers in Human Neuroscience*, **Vol.** 4 (2010), pp. 1-14

[27] Hale, S.; Myerson, J.; Smith, G. A. & Poon, L.W.: Age, variability, and speed: between subject diversity, *Psychology and aging*, **Vol.** 3 (1988) No. 4, pp. 407-410, ISSN: 1939-1498

[28] Salthouse, T. & Mitchell D. R. D.: Effects of age and natural occurring experience on spatial visualization performance, *Developmental Psychology*, **Vol.** 26 (1990) No. 5, 845-854, ISSN: 0012-1649

[29] Tse, J.L.M., Flin, R. & Mearns, K.: Bus driver well-being review: 50 years of research, *Transportation Research Part F*, **Vol.** 9. (2006) No. 2, pp. 89-114, 1369-8478

[30] Backman, A.L.: Health survey of professional drivers, *Scandinavian Journal of Work, Environment & Health*, **Vol**. 9. (1983) No. 1, pp. 30-35, 0355-3140

[31] Taylor, A.H. & Dorn, L.: Stress, Fatigue, Health and Risk of Road Traffic Accidents Among Professional Drivers: The contribution of physical inactivity, *Annual Review of Public Health*, **Vol**. 27. (2006), pp. 371-391, 0163-7525

[32] Pravilnik *o ovlaštenju strojovođa [Regulation on Railroad Engineer Licence]. Narodne novine* [*Official Gazette*], 96/2013, 74/2015.

[33] Paz-Filo, G.; Mastronadi, C. L. & Licinio, J.: Leptin treatment: facts and expectations, *Metabolism*, **Vol.** 64 (2015) No. 1, pp. 146 – 156, ISSN: 1532-8600

[34] Lowden, M.; Ghisletta, P. & Lindenberger, U.: Social participation attenuates declines in perceptual speed in old and very old age, *Psychology and aging*, **Vol.** 20 (2005) No. 3. pp. 423-434, 1939-1498

[35] Ball, K. K.; Edwards, J. D. & Ross, L. A.: The impact of speed of processing training on cognitive and everyday functions, *Journal of Gerontology*, **Vol.** 62B (2007) No. 1, pp. 19-31, 1758-5368

[36] Roenker, D. L.; Cissell, G. M.; Ball, K. K.; Wadley, V. G. & Edwards, J. D.: Speed-of-processing and driving simulator training results in improved driving performance, *Human Factors*, **Vol. 45** (2003) No. 2., pp. 218-233, 0018-7208

[37] Ball, K. K.; Edwards, J. D.; Ross, L. A. & McGwin, G.: Cognitive training decreases motor vehicle collision involvement in older driver, *Journal of American Geriatric Society*, **Vol**. 58 (2010) No. 11, pp. 2107-2113, 0002-8614

[38] Ball, K. K.; Ross, L. A.; Roth, D. L. & Edwards, J. D.: Speed of processing training in the ACTIVE study: how much is needed and who benefits? *Journal of Aging and Health*, **Vol**. 25 (2013) No. 8, pp. 655-845, 1552-6887