OESEM
19th INTERNATIONAL CONFERENCE "MAN AND WORKING ENVIRONMENT"
OCCUPATIONAL AND ENVIRONMENTAL SAFETY ENGINEERING & MANAGEMENT
www.znrfak.ni.ac.rs/oesem2022

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ADVANCED PHYSICAL ERGONOMICS AND NEUROERGONOMICS RESEARCH ON AN ASSEMBLY WORKSTATION

Abstract: *Workers who perform repetitive and tiring activities assembling parts and components into the final product at a traditional assembly workstation often suffer from musculoskeletal disorders (MSDs) and other occupational diseases associated with greater effort of tendons, muscles and nerves on the hands and wrists, and neck and lower back pain. These activities also reduce attention span and concentration, which causes mental fatigue and consequently, errors (which negatively affect the quality of the final product), and in some cases even injuries at work.*

Manual, monotonous and repetitive assembly tasks can be partially automated by the application of new technologies of Industry 4.0 which provides benefits in terms of minimizing the number of movements, inadequate body positions, bending, twisting, human errors, etc. The main focus of future development of the industry workstations is the human-centric approach and the introduction of a collaborative robot, which is in line with the goals of Industry 5.0.

The aim of this paper is to present the results of advanced electro psychophysiology research (electroencephalography - EEG and electromyography - EMG) and the analysis of data collected in real-time by applying innovative technologies (EMG sensors and EEG caps) on a traditional workstation in order to establish the ergonomic risks to which assembly workers are exposed. In this way, it is possible to determine when muscle fatigue and/or reduced attention span and concentration of workers will be likely and which ergonomic risks, that can lead to occupational diseases and injuries at work, may occur. The analysis of the results of the experimental study shows that the assembly workers are exposed to physical and mental overload during the performance of assembly activities.

Key words: assembly workstation, EEG, EMG, golden zone, improvement of workplace safety, safety 4.0

INTRODUCTION

Workers who perform monotonous, repetitive, and tiring assembly activities at a workstation are constantly exposed to the ergonomic risk of musculoskeletal disorders (MSDs), and in some cases, due to a decrease in attention span and concentration, injuries may occur at work. One of the main goals of contemporary production organizations that operate in accordance with the lean principles and principles of world-class production is the improvement workers' safety and health.

Although production processes in modern industrial systems are largely automated and digitized, there are still workplaces where repetitive work activities that cannot be fully automated are performed. These tasks are monotonous and workers mostly perform them manually. This is mainly due to the high complexity of the assembly activities and the limited flexibility of traditional assembly workstations. Therefore, there is a need to promote traditional assembly stations in order to improve the health and safety of workers who perform repetitive, tedious, and monotonous assembly activities over a long period of time in an ergonomic position.

The repetitiveness of manual tasks is an important risk factor for the occurrence of MSDs (e.g., carpal tunnel syndrome, wrist tendonitis, etc.) (Ellegast, 2016).

Considering the fact that the appearance of MSDs negatively affects the effectiveness and productivity of workers, it is very important to monitor the muscle activity of the operator when performing repetitive assembly activities at a workstation. In this way, it is possible to establish the load and strain of the muscles of the neck and hands, examine the frequency of pain in these parts of the body, and determine when the first symptoms of MSDs appear.

Assembly workers are exposed to a significant physical workload. Due to reduced worker's attention span and concentration, mental overload and fatigue can occur, which in turn cause errors and irregularities in the assembly of parts and components (which has a negative impact on the quality of the final product). Therefore, it is necessary to monitor the brain activity, mental effort and attentiveness of the operator.

The aim of this research paper is to conduct advanced physical ergonomics and neuroergonomics research on an assembly workstation. The motivation for writing the paper can be found in the fact that it is necessary to measure the muscular and brain activity of operators when performing monotonous and repetitive activities at an assembly workstation in order to identify ergonomic risks that may occur during the execution of assembly activities and tasks.

THE SPECIFICS OF ASSEMBLY ACTIVITIES ON TRADITIONAL WORKSTATIONS

In the fourth industrial revolution, safety and ergonomics at work have a crucial role in organizations. Application of advanced technologies of the Industry 4.0 (I4.0) era fundamentally changes the way of performing assembly activities on traditional assembly workstations through intelligent connectivity and advanced automation. Industry 5.0 brings workers back into the production processes and pays special attention to the human-centric approach.

It is of particular importance that assembly workstations and tools necessary for the implementation of work activities be adapted to the needs of workers in order to improve their safety and health – to reduce work-related injuries and illnesses, create a safer and more pleasant work environment, and improve the physical and mental well-being of workers. If the workstations are not ergonomically designed, in addition to the appearance of musculoskeletal disorders due to mental fatigue, the probability of injuries at work also increases, which further results in a decrease in productivity and worker satisfaction (Gerr et al., 2014).

The application of ergonomic principles to assembly workstations contributes to occupational injury reduction and improves the health of workers (Gerr et al., 2013). Ergonomic design of workplaces is one of the most important prerequisites for improving production processes and creating a more efficient, safer, and more comfortable workplace (Cimino et al., 2009).

Furthermore, performing monotonous, repetitive movements at high speed in awkward body positions increases the strain on the tendons, muscles, and nerves of the hands, the joints of the forearm muscles, and neck muscles, which further increases the risk of MSDs. Numerous studies have shown that MSDs in the wrists and hands are associated with repetitive manual work (Barr, Barbe, & Clark, 2004; Hansson et al., 2000). According to Mehta (2016), psychological factors at work can have a significant impact on the development of MSDs in workers.

MSDs have negative consequences in working environments given that they cause absenteeism, disability, increased replacement costs (Maakip et al., 2017), and reduced efficiency and productivity (Matos and Arezes 2015). Jones and Kumar (2004) pointed out the fact that musculoskeletal disorders represent 32% of the total costs in the organization and cause 40% of the total loss of time in the organization compared to other occupational and work-related diseases.

Manual assembly activities are an example of repetitive tasks involving the manual handling of low loads at high frequency. Therefore, during assembly activities, workers experience excessive mental and physical effort, fatigue, and discomfort. Also, fatigue and mental strain negatively affect productivity (Finnsgård et al., 2008). Due to the inability to maintain attention for a longer period of time, injuries may occur at work.

In particular, workers who perform assembly activities at a workstation are constantly exposed to cognitive stress. This is caused primarily by the large amount of information that workers receive when performing assembly activities consisting of a large number of components and parts that need to be handled. Hanson and Brolin (2011) pointed out that if there are different variations of components and parts (which are combined into the final product), the complexity of the work increases to a great extent, and this has a significant negative impact on the operator's mental state (Lindblom, Thorvald, 2014). During the manual assembly of components and parts, workers sometimes repeat the same operation several times during the work shift, which negatively affects their concentration and attention (Fisherl, 1993). Cognitive load negatively affects workers' attention and reasoning ability (Rabby et al., 2019). In some situations, workers fail to stay alert due to a decrease in attention span (Spath and Braun, 2021).

METHODOLOGY

A detailed review of scientific research papers showed that most of the works that focus on operators who perform manual repetitive tasks of assembling parts and components were mainly based on determining the correct position of the body in order to eliminate the incorrect positions and prevent the occurrence of MSDs (Leider et al., 2015). Less attention is paid to cognitive and perceptual aspects (Fish et al., 1997). According to Wiegmann and Shappell (2001), timely detection of attention deficits could contribute to the prevention of dangerous situations and injuries at work.

Jung and Makeig (1994) showed that the vigilance of workers during the performance of tasks that require an increased concentration of workers can be investigated using brain waves. Parasuraman (2003) pointed out the importance of understanding brain processes in workers. Electroencephalography (EEG) is one of the most common methods for assessing the cognitive state of the operator (Hohnsbein et al., 1998). Bakshi (2018) detected the cognitive workload of 28 subjects through EEG. Moreover, several authors conducted neuroergonomics tests of brain activity during the manual assembly of a hose. Other studies identified the relationship between cognitive load and changes in the EEG signal (Antonenko et al., 2010; Brouwer et al., 2015; Mijović et al., 2015; Charles and Nixon, 2019).

EEG signals are directly correlated with mental demands experienced during the task (Brookings et al., 1996). The captured EEG signals are analyzed to identify their features by fusing them to define the overall brain activity. They enable direct measurement of brain activity in real-time (Gramann et al., 2011). Moreover, they can estimate the quantitative assessment of alertness levels, which requires expensive computational signal processing (Correa et al., 2014; Zhang et al., 2017). The main advantage of EEG is the possibility of objective measurement (as opposed to subjective methods of self-assessment) of workers' attention in real-time (Mijović et al., 2016).

In industrial scenarios, EEG is widely used to assess the cognitive state and mental workload of workers (Infantolino and Miller, 2014). Foong et al. (2019) used EEG to identify the drowsiness of 29 subjects. Numerous studies evaluated the measurement of cognitive load via the EEG signal (Fasth-Berglund, Stahre, 2013; Scalera et al., 2020).

On the other hand, EMG is the most popular and commonly used method for detecting the occurrence and development of muscle fatigue (De Luca, 1997; Freitas et al., 2019). EMG signals represent neuromuscular activities of the human body. They are used to monitor workers' muscle condition and find the maximum lifting load, lifting height, and the number of repetitions that the workers are able to handle before experiencing fatigue, all for the purpose of avoiding overexertion (Gevins et al., 1995).

EMG ergonomics applications are the most widely and successfully used in industry for real-time fatigue monitoring, musculoskeletal risk assessment, and assisted handling devices. EMG is the most commonly used tool in many research papers (He, Zhu, 2017). In contrast to the subjective methods of measuring muscle activity, EMG is characterized by objectivity and reliability. The study of EMG signals can help assess functions at the muscle level and at the level of the nervous system, which controls the muscles.

Bosch et al. (2007) showed EMG manifestations of muscle fatigue of the trapezius muscles during normal (8-hour) and extended (9.5-hour) working days involving light manual work. Bennie et al. (2002) also simulated 8h-hour working days using EMG measurements.

Another study (Björklund et al., 2000) focused on the effect of a repetitive low intensity task to fatigue on shoulder position sense. Molinari et al. (2006) assessed the changed spectrum of the EMG signals when fatigue occurred during dynamic muscle contraction. Dingwell et al. (2008) pointed out the relation between localized muscle fatigue and changes in muscle movement.

CASE STUDY

In the experiment, muscle and brain activity was monitored in real-time during the performance of repetitive and monotonous assembly activities. The main goal of monitoring muscle activity in the neck is to determine the load and strain of the neck muscles in order to examine the frequency of neck pain and the onset of the first symptoms of MSDs. Muscle activity was monitored by placing EMG sensors on the trapezius muscles on the subject's neck on the left and right sides (Savković et al., 2022). Brain activity was monitored in order to examine the subject's mental fatigue and, on the basis of the obtained data, determine when attention and concentration decrease (Savković et al., 2022). An EEG cap with electrodes was placed on the subject's head in order to monitor brain activity.

Three master's degree students of the Faculty of Engineering, all of them male, aged between 19 and 21 and between 165 and 190 cm tall, participated in the research. All subjects were right-handed and participated in the study voluntarily. The laboratory where experimental research was carried out is air-conditioned and the microclimatic conditions were under control.

The experiment consisted of two sessions between which the subjects had a 15-minute break. Before the experiment started, the respondents were given detailed instructions on how they should perform the assembly activities. Before the beginning of the first session of the experiment, the subjects listened to a relaxing track for 5 minutes. After receiving the information and listening to the music, the respondents started the work operation by taking the wires and the metal structure after the sound signal. After that, the subjects were supposed to place the wires inside the metal structure according to the instructed pattern, following the instructions they received via a screen, which was at their eye level and at a distance of about half a meter.

After placing the wire at the instructed position on the metal structure, the subjects were supposed to press a button on the screen as a sign that they had completed the operation. This step was repeated several times during the experiment. After the completion of the entire operation, the respondents moved on to the next work operation. They were told that if they made a mistake while assembling the wires, they should disregard the product and continue assembling another product so that they could keep performing the activity.

At the end of operation simulations, the complete product was dismantled and the components were returned to the containers in which they were located.

At the end of the experiment, an oral interview was conducted with the respondents. They answered questions related to the complexity of the task they were performing and the physical and mental fatigue they felt during the experiment, and they were given the opportunity to make their own suggestions.

An innovative EEG system was used to design and conduct the neuroergonomics experiment. The SMARTING wireless EEG system (mBrainTrain, Serbia) was used for EEG signal acquisition. This device has the ability to record EEG signals with a sampling frequency of 500 Hz and a 24-bit data resolution. The SMARTING EEG amplifier (85x51x12mm, 60g) was connected to a 24-channel EEG cap in the occipital region of the head using an elastic band. The connection between the amplifier and the computer was made using a Bluetooth connection.

For EMG measurements, the muscleBAN (PLUX Wireless Biosignals, Portugal) was used. This wearable wireless (Bluetooth or Bluetooth Low Energy data transmission) device combines a single-channel EMG sensor, triaxial accelerometer and magnetometer and in that way enables real-time acquisition with up to 16-bit resolution at up to a 1000 Hz sampling rate.

RESULTS AND DISCUSSION

The experiment involved using an EEG system with 24 channels, which were recorded during the entire experiment on the subjects. Only three channels were suitable for further analysis (Figure 1). The signals value is represented as an analog-to-digital conversion value represented in 16 bits. This value hasn't got a physical unit but represents scaled voltage of EEG voltage.

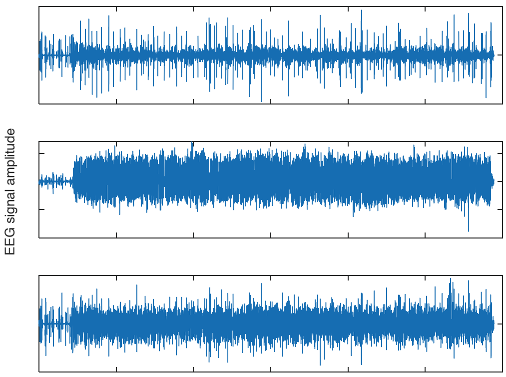

Figure 1. EEG signal amplitude over time

The first step in signal processing was filtering, in order to obtain the corresponding frequency bands. These bands were delta up to 4 Hz, theta from 4 to 8 Hz, alpha from 8 to 13 Hz, beta from 13 to 30 Hz, and gamma from 30 to 100 Hz. The banded signals were now more suitable for further processing (Figure 2).

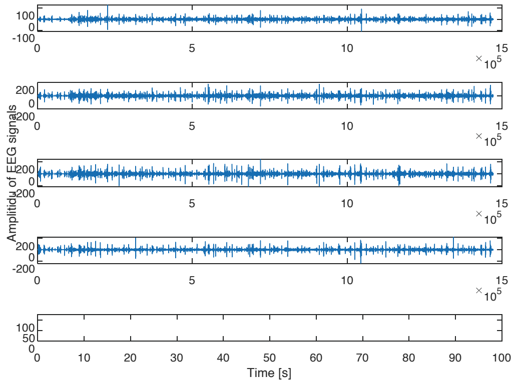

Figure 2. EEG signals for different bands

The following step in EEG signal processing was to calculate the spectra in the frequency domain using a Fourier transform (Figure 3).

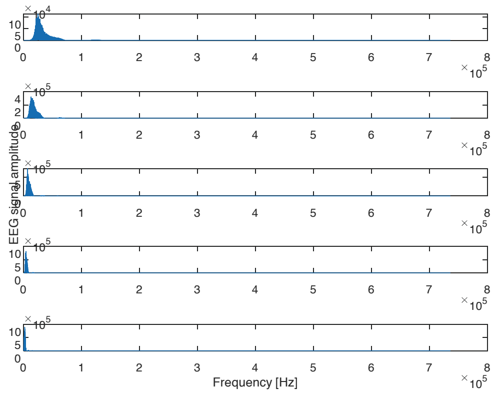

Figure 3. Spectra of one EEG channel for different bands

The EMG signals recorded simultaneously with EEG and the amplitude variation for both sessions of the experiment are shown in Figure 4.

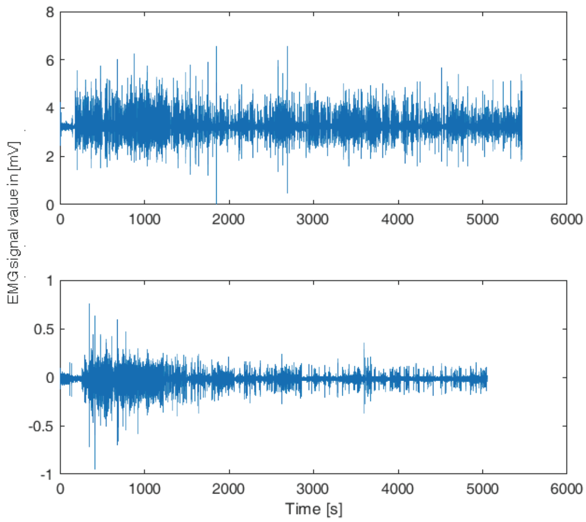

Figure 4. EMG signals in [mV] for both sessions of the experiment during time

Based on the low number of the subjects' experimental results, it can be concluded that EMG data is suitable for classification between both sessions of the experiment. This is because it is easy to notice the difference in signal patterns between the sessions. As a measure of similarity, cross-correlation can be used for EEG and EMG signals, respectively. This fact allows the provision of ergonomic information about a subject according to recorded signals. Owing to improvements in artificial intelligence methods and tools, it is possible to improve the quality of this information and to draw conclusions that would not be possible by using standard deterministic models.

CONCLUSION

Modern organizations strive to improve traditional workstations where workers perform repetitive, monotonous, and tedious assembly activities and to improve the safety and health of operators performing these activities by reducing work injuries and occupational diseases and improving physical and psychological health and worker satisfaction. The improvement of traditional workstations poses a major challenge for modern industrial systems.

Performance of repetitive manual assembly activities at traditional non-ergonomically designed workstations is widespread in many modern manufacturing systems.

This paper presented the results of monitoring the muscle and brain activity of respondents who perform assembly activities for a long period of time in an improper body position, in order to determine the ergonomic risks to the workers are exposed to.

It can be concluded that it is possible to use EEG and EMG signals for the purpose of classification and connection with ergonomic performance. The next step in the research should be to create a data set of signals for both sessions of the experiment and then develop a model for predicting the ergonomic characteristics of a specific subject, which will be a part of future research.

It can also be concluded that the appearance of mental fatigue and a decrease in concentration in all three subjects occurred during the second session, which coincides with the answers by the subjects in the oral interview, which was conducted immediately after the experiment. During the interview, the respondents stated that they began to feel mental fatigue and a decrease in concentration during the second session, more precisely in the middle of the second session.

On the basis of the data obtained using EEG and EMG, a new collaborative workstation was proposed in which a poka-yoke device was installed. The new workstation is aligned with ergonomic and lean principles and is adapted to the individual characteristics, capabilities, skills, and limitations of the operator. At the proposed workstation, workers will perform activities within the golden zone where, on the one hand, their productivity and efficiency are at the highest and, on the other hand, occupational diseases and injuries are reduced to a minimum due to the elimination of unnecessary bending and stretching of the worker's body.

REFERENCES

Antonenko, P.D., Paas, F., Grabner, R.H., & Gog, T.V. (2010). Using Electroencephalography to Measure Cognitive Load. *Educational Psychology Review, 22*, 425-438.

Barr, A.E., Barbe, M.F., & Clark, B.D. (2004). Work-related musculoskeletal disorders of the hand and wrist: epidemiology, pathophysiology, and sensorimotor changes. *The Journal of orthopaedic and sports physical therapy, 34 10*, 610-27.

Bakshi, V.K. (2018). Towards Practical Driver Cognitive Workload Monitoring via Electroencephalography.

Bennie, K. J., Ciriello, V. M., Johnson, P. W., Dennerlein, J. T. (2002). Electromyographic activity of the human extensor carpi ulnaris muscle changes with exposure to repetitive ulnar deviation. *European Journal of Applied Physiology,* 88(1-2), 5-12.

Björklund, M., Crenshaw, A. G., Djupsjöbacka, M., Johansson, H. (2000). Position sense acuity is diminished following repetitive low-intensity work to fatigue in a simulated occupational setting. *European journal of applied physiology, 81(5),* 361-370.

Bosch, T., de Looze, M. P., van Dieën, J. H., (2007). Development of fatigue and discomfort in the upper trapezius muscle during light manual work. *Ergonomics, 50(2),* 161-177.

Brookings, J.B., Wilson, G.F., & Swain, C.R. (1996). Psychophysiological responses to changes in workload during simulated air traffic control. *Biological Psychology, 42*, 361-377.

Brouwer, A., Zander, T.O., van Erp, J.B., Korteling, J.E., & Bronkhorst, A.W. (2015). Using neurophysiological signals that reflect cognitive or affective state: six recommendations to avoid common pitfalls. *Frontiers in Neuroscience, 9.*

Charles, R., Nixon, J. (2019). Measuring mental workload using physiological measures: A systematic review. *Applied ergonomics, 74*, 221-232.

Cimino, A., Curcio, D., Longo, F., & Mirabelli, G. (2009). Improving workers' conditions within industrial workstations.

De Luca, C. J. (1997). The use of surface electromyography in biomechanics. In Journal of Applied Biomechanics, 13(2), 135–163.

Dingwell, J.B., Joubert, J. E., Diefenthaeler, F., Trinity J. D. (2008) Changes in muscle activity and kinematics of hi1ghly trained cyclists during fatigue, *IEEE Trans. Biomed. Eng. 55,* 2666-2674.

Ellegast, R. Assessment of Physical Workloads to Prevent Work-Related MSDs; Institute for Occupational Safety and Health of the German Social Accident Insurance: Berlin, Germany, 2016.

Fasth-Berglund Å., Stahre J. (2013), Cognitive automation strategy for reconfigurable and sustainable assembly systems, Assem. Autom., vol 33, pp. 294-303.

Finnsgård, C., Medbo, L., Wänström, C., Neumann, W.P., (2008). The impact of materials exposure on the conditions at the workstation

Fish, L.A., Drury, C.G., & Helander, M.G. (1997). Operator-specific model: An assembly time prediction model. *Human Factors and Ergonomics in Manufacturing & Service Industries, 7*, 211-235.

Fisherl, C.D. (1993). Boredom at Work: A Neglected Concept. *Human Relations, 46*, 395 - 417.

Foong, R., Ang, K.K., Zhang, Z., & Quek, C. (2019). An iterative cross-subject negative-unlabeled learning algorithm for quantifying passive fatigue. *Journal of Neural Engineering, 16*.

Freitas, R.C., Alves, R.L., Filho, A.G., Souza, R.E., Bezerra, B.L., & Santos, W.P. (2019). Electromyography-controlled car: A proof of concept based on surface electromyography, Extreme Learning Machines and low-cost open hardware. *Comput. Electr. Eng., 73*, 167-179.

Garcés Correa, A., Orosco, L., & Laciar, E. (2014). Automatic detection of drowsiness in EEG records based on multimodal analysis. *Medical engineering & physics, 36 2*, 244-9.

Gerr, F., Fethke, N.B., Anton, D., Merlino, L., Rosecrance, J., Marcus, M., & Jones, M.P. (2014). A Prospective Study of Musculoskeletal Outcomes among Manufacturing Workers. *Human Factors: The Journal of Human Factors and Ergonomics Society, 56*, 178 - 190.

Gevins, A.S., Leong, H.M., Du, R., Smith, M.E., Le, J., DuRousseau, D.R., Zhang, J., & Libove, J. (1995). Towards measurement of brain function in operational environments. *Biological Psychology, 40*, 169-186.

Gramann, K., Gwin, J.T., Ferris, D.P., Oie, K.S., Jung, T., Lin, C., Liao, L., & Makeig, S. (2011). Cognition in action: imaging brain/body dynamics in mobile humans. *Reviews in the neurosciences*.

Hanson, R., Brolin, A. (2011). A comparison of kitting and continuous supply in in-plant materials supply. *International Journal of Production Research, 51*, 979 - 992.

Hansson, G., Balogh, I., Ohlsson, K., Pålsson, B., Rylander, L., & Skerfving, S. (2000). Impact of physical exposure on neck and upper limb disorders in female workers. *Applied ergonomics, 31 3*, 301-10.

He, J., Zhu, X., Combining Improved Gray-Level Co-Occurrence Matrix With High Density Grid for Myoelectric Control Robustness to Electrode Shift (2017). *IEEE Trans. Neural Syst. Rehabil.*, *25*, 1539-1548.

Hohnsbein, J., Falkenstein, M., & Hoormann, J. (1998). Performance differences in reaction tasks are reflected in event-related brain potentials (ERPs). *Ergonomics, 41 5*, 622-33.

Infantolino, Z.P., Miller, G.A. (2014). Psychophysiological Methods in Neuroscience.

Jones, T., & Kumar, S. (2004). Six years of injuries and accidents in the sawmill industry of Alberta. International Journal of Industrial Ergonomics, 33(5), 415-427.

Jung, T., Makeig, S. (1994). Estimating level of alertness from EEG. *Proceedings of 16th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2*, 1103-1104 vol.2.

Leider, P.C., Boschman, J.S., Frings-Dresen, M.H., & van der Molen, H.F. (2015). Effects of job rotation on musculoskeletal complaints and related work exposures: a systematic literature review. *Ergonomics, 58*, 18 - 32.

Lindblom, J., Thorvald, P. (2014). Towards a framework for reducing cognitive load in manufacturing personnel.

Maakip, I., Keegel, T., & Oakman, J. (2017). Predictors of musculoskeletal discomfort: A cross-cultural comparison between Malaysian and Australian office workers. *Applied ergonomics, 60*, 52-57.

Matos, M., & Arezes, P.M. (2015). Ergonomic Evaluation of Office Workplaces with Rapid Office Strain Assessment (ROSA). *Procedia Manufacturing, 3*, 4689-4694.

Mehta, R.K. (2016). Integrating Physical and Cognitive Ergonomics. *IIE Transactions on Occupational Ergonomics and Human Factors, 4*, 83 - 87.

Mijović P., Ković V., Mačužić I., Todorović P., Jeremić B., Milovanović M., Gligorijević I. (2015), Do Micro-Breaks Increase the Attention Level of an Assembly Worker? An ERP Study, *Procedia Manufacturing*, 3, pp. 5074-5080.

Mijović P., Ković V., De Vos M., Mačužić I., Todorović P., Jeremić B., Gligorijević I. (2016), Towards Continuous and Real-Time Attention Monitoring at Work: Reaction Time versus Brain Response. *Ergonomics*, pp. 1-41.

Molinari, F., Knaflitz, M., Bonato, P., Actis, M. V. (2006), Electrical manifestations of muscle fatigue during concentric and eccentric isokinetic knee flexion-extension movements. *IEEE Trans. Biomed. Eng. 53,* 1309-13016.

Parasuraman, R. (2003). Neuroergonomics: Research and practice. *Theoretical Issues in Ergonomics Science, 4*, 20 - 5.

Rabby K. M., Khan M., Karimoddini A., Jiang S. X. (2019), An Effective Model for Human Cognitive Performance within a Human Robot Collaboration Framework, Proceedings of the 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC), Bari, Italy, pp. 3872-3877.

Savković, M., Caiazzo, C., Djapan, M., Vukićević, A. M., Pušica M, Mačužić, I. (2022), Development of Modular and Adaptive Laboratory Set-Up for Neuroergonomic and Human-Robot Interaction Research. *Front Neurorobot*.

Scalera L., Giusti A., Vidoni R., Di Cosmo V., Matt D. T., Riedl M. (2020), Application of dynamically scaled safety zones based on the ISO/TS 15066:2016 for collaborative robotics, Int. J. Mech. Control, vol. 21, pp. 41-49.

Spath, D., Braun, M. (2021). HUMAN FACTORS AND ERGONOMICS IN DIGITAL MANUFACTURING. *Handbook of Human Factors and Ergonomics*.

Wiegmann, D.A., Shappell, S. (2001). A Human Error Analysis of Commercial Aviation Accidents Using the Human Factors Analysis and Classification System (HFACS).

Zhang, X., Li, J., Liu, Y., Zhang, Z., Wang, Z., Luo, D., Zhou, X., Zhu, M., Salman, W., Hu, G., & Wang, C. (2017). Design of a Fatigue Detection System for High-Speed Trains Based on Driver Vigilance Using a Wireless Wearable EEG. *Sensors (Basel, Switzerland), 17*.

ACKNOWLEDGEMENTS

This research paper has been financed by the European Union's H2020 research project under the Marie Sklodowska-Curie Actions Training Network Collaborative Intelligence for Safety Crytical Systems (Grant Agreement ID: 955901).

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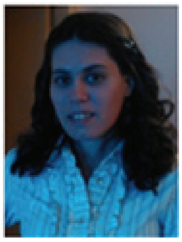

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