Designing an Experiment to Measure the Alert Fatigue of Different Alarm Sounds Using the Physiological Signals

Jeonghyeun Chae[a] and Youngcheol Kang[b]

[a] Department of Architecture and Architectural Engineering., Yonsei University, South Korea
[b] Department of Architecture and Architectural Engineering., Yonsei University, South Korea
E-mail: jh.chae@yonsei.ac.kr, yckang@yonsei.ac.kr

Abstract

This study proposes an experiment to find the most effective alarm sound for controlling alert fatigue. Alert fatigue is the phenomenon that an individual is constantly exposed to frequent alarms and becomes desensitized or loses his attention or focus on the alarm. One of the major causes of struck-by accidents caused by construction equipment is the blind spot. Even though many research studies have developed the alarm system to manage the issue, frequent alarm from construction equipment is inevitable because construction equipment and workers on foot usually work in close range. Hence, the alarm sound that manages alert fatigue effectively can reduce the accident caused by the blind spot. This study proposes an experiment design using three different alarm sounds (complex tone, auditory icons, and self-own name) and three different physiological signals (electroencephalography, electrodermal activity, and event-related potential) to measure alert fatigue quantitatively to compare alert fatigue of each alarm sound. This paper suggests two research hypotheses: 1) different alarm sounds induce different levels of alert fatigue and 2) suggested physiological signals are suitable for measuring alert fatigue. A future study testing these hypotheses can contribute to reducing the accidents related to blind spots, which will eventually contribute to better safety performance in the construction industry.

Keywords – Alert fatigue, Physiological signal, EEG, EDA, Alarm sound, Construction equipment safety

1 Introduction

The construction industry has been known as one of the most hazardous industries. In the U.S., accidents related to equipment are the leading cause of work-related injuries and fatalities in the construction industry [1, 2]. Similarly, statistics and many reports have suggested that the struck-by accident between construction equipment and workers on foot is one major cause of the work-related accident in the construction industry [3, 4]. Teizer et al. (2010) suggested that loss of focus and blind spot are two common hazardous factors in construction equipment. Hence, they recommended to study an alarm system helping equipment operators to recognize possible threats from blind spots promptly [5]. But due to the dynamic circumstances of the construction site, mobile construction equipment and workers on foot frequently work closely at construction sites, which leads to repetitive, frequent, and loud alarm sounds [1, 5].

The authors of this study assumed that managing alert fatigue can contribute to reducing the accidents caused by blind spots. Alert fatigue is the phenomenon of reduced alertness towards the alarm sounds, due to exposure to frequent alarms [6, 7]. As aforementioned, equipment operators' constant exposure to the frequent alarm is inevitable [1, 5]. Such frequent alarms can lead to alert fatigue. Some studies investigated the alarm system of construction equipment [1, 5, 8]. Teizer et al. (2010) suggested the pro-active real-time proximity alarm system using radio frequency remote sensing technology. The system can provide information related to the safety to the equipment operator and workers on foot but cannot manage alert fatigue [5]. Wang and Razavi (2016) used two 4-dimensional models to reduce the rate of false alarms of the recent alarm system. After developing such models, they conducted the simulation and field test to verify the validity of the model [8]. However, even though the reduced false alarm can relate to lowering the rate of alarm, frequent alarm is inevitable. Therefore, the development of the method of managing alert fatigue can help the current alarm system to be more effective for reducing the accidents caused by construction equipment.

This paper presents two hypotheses: 1) alert fatigue is different by an alarm sound and 2) physiological signals (i.e., electroencephalography (EEG), electrodermal activity (EDA), and event-related potential (ERP)) can be useful for measuring alert fatigue.

The main research objective of this study is to develop an experiment design to measure alert fatigue for three different alarm sounds. Alert fatigue will be measured by the physiological signals and behavioral data. Three alarm sounds include a complex tone (which represents the conventional auditory warning), auditory icon, and self-own name (SON). EEG, EDA, and ERP are the physiological signal included in this experiment design. In addition, behavioral data will be collected by measuring the reaction time of the subject to the alarm sound.

By measuring alert fatigue of each alarm sound, it is expected that the result of the experiment can suggest the most effective alarm sound to control alert fatigue. Such a result can contribute to reducing the equipment accidents caused by blind spots, which will lead to better safety performance in the construction industry.

This paper consists of four sections. After the Introduction section, the second section presents the literature review. Definition of alert fatigue and related research studies are presented in this section. Also, the description of the alarm sounds included in the experiment is presented. The third section is about the methodology of the experiment. In addition to how the alarm sound was designed in the experiment, the description of the physiological signals used in the experiment and the suggested experiment design are presented. The final section presents the expected finding and the discussion of the experiment suggested in this study.

2 Literature Review

The literature review section consists of three sub-sections. In the first sub-section, the definition and studies related to alert fatigue are presented. The following sub-section provides three different alarm sounds used in this study. In the final sub-section, the research hypotheses and objective are presented.

2.1 Alert Fatigue

Blackmon and Gramopadhye (1995) discussed decrement of vigilance in the construction industry. Vigilance means the ability to stay focused on a specific stimulus over a long time. Vigilance decrement is human nature that an individual cannot sustain the attention to the specific stimulus for a long period of time due to the intense stimuli or monotonous stimuli. To avoid such an effect, Blackmon and Gramopadyhe (1995) suggested installing the positive feedback device, so that workers around the backing mobile equipment can sustain their attention by keeping refreshing their attention on the equipment [6].

Alert fatigue is closely related to vigilance decrement but there are some differences. The exact definition of alert fatigue is not agreed upon by researchers yet. Edworthy (2012) defined alert fatigue as the phenomenon that occurs due to false alarms, and the tendency of people to adjust their attention and response rate to the alarm by the accuracy of the alarm [9]. The everyday safety tailgate talks of the Cornell university defined safety alarm fatigue as the phenomenon that occurs when an individual or group is constantly exposed to alarms long period of time and becomes desensitized to the alarm [7]. Cash (2009) claimed that alert fatigue is the user-desensitization occurred due to the increasing number of the alert [10]. In this study, alert fatigue is defined as the phenomenon of an individual or group constantly exposed to the frequent alarm and becomes desensitized or loses the attention or focus towards the alarm. When comparing vigilance decrement and alert fatigue, while vigilance decrement deals with various kinds of stimulus, alert fatigue is only related to alarm sound.

There have been several studies investigating vigilance decrement and quantitatively measuring the phenomenon. For measuring vigilance quantitatively, researchers used behavioral data such as reaction time or error rate. The others used physiological signals such as EEG, EDA, and PPG. For example, Jung et al. (1997) measured alertness to the auditory targets during the visual task. They used EEG, reaction time, and error rate to measure alertness, which indicates vigilance [11]. Trutschel et al. (2011) used the PERCLOS (Percentage of Eye Closure) to measure alertness of drivers [12].

Compared to vigilance decrement, there have been a relatively small number of studies about alert fatigue. Furthermore, there has been no research study about measuring alert fatigue quantitatively. Even though Edworthy (2012) suggested the alarm sound design principle for avoiding alert fatigue, there is no study comparing the alarm sound to prove that alert fatigue differs for each different alarm sound [9].

2.2 Alarm Sounds

As mentioned above, this study uses three different alarm sounds to measure and compare the effect of alert fatigue. The alarm sounds being tested in this study are complex tone, auditory icon, and SON.

The complex tone is a sound that consists of multiple sinusoidal components of different frequencies [13]. In this study, the complex tone is used for replacing the conventional auditory warning sounds. Belz et al. (1999) used the complex tone as the representative of the conventional auditory warning sounds [14].

The auditory icons, which was suggested by Gaver (1988), are the types of sound that occur in a threat or hazard situation [15]. Auditory icons are well-known for its learnability and recognition performance [16, 17]. The learnability of an alarm sound means how easily the listener understands the urgency or the detail of the threat. Several studies suggested that auditory icons perform better than the conventional warning system in terms of learnability and recognition performance. Edworthy (2011) suggested that the learnability of auditory icons is better than abstract sound and tonal alarm, and inferior to the speech alarm, as the speech does not require learning process to understand [18]. Cabral and Remjin (2019) suggested the principle of designing auditory icons. They classified the auditory icons into three groups, which are symbolic, iconic, and metaphorical. A symbolic auditory icon is a sound that is generally accepted as the symbol of the event or the threat that does not emulate the sound of the real world. For example, if anyone listens to the siren on the road, the listener will immediately recognize that an ambulance is near. In this case, the siren is the symbolic auditory icon of the ambulance. An iconic auditory icon is a sound related to the physical characteristic of an event. For example, the sound of tire skidding can be used as the alarm sound to alert the driver for the impending crash. A metaphorical auditory icon is a sound in between the iconic and symbolic auditory icon. The sound does not completely emulate the physical aspect of an event but also, it is not a completely random sound. Research suggests that the iconic auditory icon alarms better than the symbolic or the metaphorical auditory icon as the iconic auditory icon did not require the learning process to understand the meaning of the alarm [17]. As previous research studies suggested that auditory icons perform better than the conventional tonal alarm, this study uses auditory icons as one of the new alarm sounds to control alert fatigue.

SON is the sound of a subject's own voice calling his or her own name. SON is one of the self-related stimuli. Self-related stimuli are external stimuli that have a relation with the subject [19]. (e.g., subject's own face, name) Conde et al. (2015) suggested that self-related stimuli induce greater attention than non-self-related stimuli even if the stimuli are task-irrelevant. They tried to explain how such self-related stimuli work. As the self-related stimuli contain more emotional and personal information, therefore the subject will attract more to the self-related stimuli than the non-self-related stimuli. Therefore, greater attention was induced [20]. Also, Tateuchi et al. (2012) reported that as the process of responding to self-own name is based on long-term memory (their name) and neural response, time to realize the threat is shorter than the process of understanding conventional alarm which is based on short-term memory and consisted of multiple steps [21]. As SON can induce more attention than other non-self-related stimuli and the cognitive process is shorter than the other alarm sound, SON is tested to control the alert fatigue in this study.

2.3 Research Objective and Hypotheses

The objective of this study is to design an experiment to test different types of alarm sounds to control alert fatigue. For this, it is important to determine the method of measuring alert fatigue.

As mentioned previously, many research studies measured vigilance decrement and alertness using the physiological signals [11, 12, 22-24]. But there has been no research measuring alert fatigue using the physiological signals. This research suggests a hypothesis that the physiological signals used to measure vigilance decrement can measure alert fatigue, as two concepts are closely related.

Also, as Edworthy (2011) noted, urgency of an alarm can be affected by the acoustic characteristics of the alarm sound [18]. Therefore, this study suggests a hypothesis that alert fatigue differs by alarm sound type.

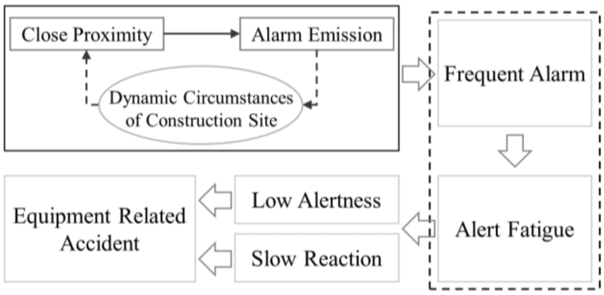

Figure 1. Research model

Figure 1 presents the research flow of this study. The dashed box in Figure 1 indicates the scope of the experiment suggested in this study, which is investigating the relationship between alarm sound and alert fatigue. As aforementioned, due to the circumstances of the construction site, workers on foot and construction equipment frequently work in close range [1, 5]. Also, one of the major obstacles that construction equipment operators facing is the blind spot of the equipment [5]. Therefore, alarm systems warning the operator to prevent accidents have been widely developed. Due to the close working range and the highly developed alarm, the frequent alarm is inevitable. If the operator exposes to alarms frequently, then alert fatigue can occur. Alert fatigue will result in lower alertness towards the alarm, which leads to a longer reaction time. As the alarm system of the construction equipment helps operators to prevent accidents by providing the auditory stimuli that contain the information of the impending accident, lower alertness and longer reaction time can increase the likelihood of the construction equipment-related accidents.

3 Methodology

This section presents how alertness will be measured via a simulated-laboratory experiment. To measure the effect of the alarm sounds on alertness of the construction equipment operators, this study suggests an experiment design that simulates the equipment operator's action. For three alarm sounds, three physiological signals will be used in the experiment to measure alertness. Also, to give the subject a specific circumstance (i.e., driving the equipment or the vehicle), the subject of this experiment will play the driving simulation during the experiment. By conduct the experiment, three physiological data sets, and one behavioral data set are obtained. Through the data process and analysis, the result can indicate which alarm sound is more effective against alert fatigue.

This section comprises four sub-sections. In the first sub-section, details of the alarm sounds were discussed. The second sub-section is about the physiological signals used to measure alert fatigue. In the third sub-section, the preliminary experiment design is presented. Finally, in the last sub-section, a data analysis plan that can be used in the future study is demonstrated.

3.1 Alarm Sounds Design

3.1.1 Complex Tone

To comparing the effect of alert fatigue for different types of alarm sounds, a reference sound is needed. This study uses the complex tone as the reference for the comparison. Belz et al. (1999) used the complex tone as the substitute for the conventional auditory warning sound. In the paper, the authors used the complex tone that consisted of 500, 1000, 2000, and 3000Hz. [14]. This study uses the same complex tone, and the length of the sound varied to match the length of the SON and the auditory icon.

3.1.2 Auditory Icon

Auditory icons should contain information about the imminent threats or danger. This means that the sound of auditory icons should have a relation to the danger it indicates [18]. Gaver (1988) defined an auditory icon as the natural sound that represents threats or object of the alarm. In case that those do not make any sounds, the author suggested using sound effects[15, 16].

In the experiment, the sound of tire skidding will be used as the auditory icon. This sound will alert the subjects and induce them to react. As the subject of the experiment plays the driving simulation, the subject reacts to the tire skidding sound with the action of pressing the brake. The reaction will be ordered and trained before the test, therefore, auditory icons (tire skidding sound) can successfully lead the subject to react. Such a reaction is the simplified simulation of the action of the operator.

3.1.3 Self-Own Name

SON sound is recorded beforehand. Each subject will be asked to visit the lab before the experiment and record the sound of calling their names. During the record session, 20 SON sounds will be recorded. The researchers will investigate each recording session and select the most appropriate sound which satisfies adequate length and clear sound with no noise or clipping sound. After selecting the appropriate SON sound, each sound is processed to match its volume and length to other alarm sounds.

3.2 Physiological Signals

As aforementioned, the physiological signals will be used to measure alert fatigue of three types of alarm sounds tested in this study. As the effect of alert fatigue is decrement of alertness or decrement of attention towards the alarm, this study will measure the alertness level of the subject to measure alert fatigue. If alertness of the subject decreases, it will be considered as alert fatigue. The description of the physiological signals used in this study is presented below.

3.2.1 EEG

EEG is the electrical signal collected from the scalp of the subject. Such a signal is generated by activation of the neurons in the brain [25]. EEG is a widely used signal to investigate activation of the brain [25-27]. EEG signal comprises delta (0.5~4Hz), theta (4~8Hz), alpha (8~13Hz), beta (13~30Hz), and gamma (>30Hz) in frequency domain perspective. Each frequency domain represents different types of brain activity or state of a human body. For example, the delta domain represents the deep sleep state [28].

The experiment will use the alpha and beta frequency domains to measure alertness. The alpha frequency domain has been used to measure alertness of the subject [29-31] as it is related to a relaxed state [32]. Therefore, the decreased alpha value means increasing alertness.

Alertness can also be defined as the state of general wakefulness [29]. Previous research has been proved that the beta frequency domain represents wakefulness [25]. Also, there are research studies that used the beta frequency domain to measure alertness [30, 31]. Therefore, in addition to the alpha frequency, this study will use the beta frequency domain to measure alertness.

To eliminate the possible inter-individual difference of the absolute power of EEG due to the difference of the conduction of the skull and scalp, this study suggests using relative alpha and relative beta data for measuring alertness [33]. Relative EEG data is obtained by dividing the alpha and beta power with the power of the overall frequency band.

The raw EEG signal will be processed with the bandpass filter and ICA (Independent Component Analysis) method to eliminate the intrinsic and extrinsic artifacts [28, 34].

The extrinsic artifacts are occurred due to the noise from the outside of the body. For example, an electric device near the EEG device or the electric node popping noise is classified as extrinsic artifacts. The extrinsic artifacts are eliminated via a bandpass filter as the frequency range of such artifacts is different from the EEG signal [25].

The intrinsic artifacts are the noise from the inside of the body [26]. For example, the EEG device can detect the electrical signal that occurs by the heartbeat. Also, as the EEG device is located at the head of the subject, movement of the eyeball can induce the noise. The bandpass filter cannot eliminate the intrinsic artifacts as the frequency range of the intrinsic artifacts is similar to the range of EEG signals. Therefore, the ICA method is used to eliminate the intrinsic artifacts [26, 28]. The ICA method is a data processing method assuming that raw EEG data can be decomposed to the independent components. Each component is analyzed and classified as artifacts or EEG signals. The artifact component is eliminated, and the EEG signal component remains [28].

The EEGlab software will be used to process raw EEG data. The EEGlab is the open-source program developed by the Swartz center for computational neuroscience at the University of San Diego [35].

After the data processing, the PSD (Power Spectral Density) value of each frequency range can be obtained. By dividing the alpha and beta PSD values with the PSD value of the overall frequency range, the relative alpha and beta value can be calculated.

When comparing the absolute values of the relative alpha and beta values before and after the alarm, if the value decreases, it means alert fatigue is detected [29].

The wireless EEG measuring device, EPOC+ (EMOTIV, USA), will be used to collect EEG data. This device has been widely used for collecting EEG data in previous studies [25-28].

3.2.2 EDA

EDA is the skin conductance signal obtained from the skin surface by placing two electric nodes and passing the small electrical current [36]. The sweating is controlled by the ANS (Autonomic Nervous System), especially, SNS (Sympathetic Nervous System). Under the controlled conditions, sweating is only activated by activation of SNS. Activation of SNS means the body is stimulated [28]. As mentioned previously, alertness means wakefulness of the body. Therefore, an increase of the EDA value can be considered as the alert of a subject [37, 38].

Similar to EEG, raw EDA data should be processed due to the artifacts [36]. The high pass filter and the moving average filter will be used to eliminate the artifacts in raw EDA data. The high pass filter will smooth the EDA signal and the moving average filter will remove the artifacts within the signal [39, 40].

EDA can be decomposed into two components, tonic components (Electrodermal level, EDL) and phasic components (Electrodermal response, EDR). The EDL represents the change of EDA in the long duration. The EDR represents the change of EDA in the short duration and response toward the stimuli [36]. Therefore, as this study will use EDA data to measure alertness that occurs due to the alarm, which is the auditory stimuli, the EDR will be used to measure alertness of the subject.

To decompose processed EDA data, the convex optimization based EDA model (cvxEDA method), sparsEDA, and the continuous decomposition analysis (CDA) will be used [39-43].

After the decomposition stage, EDR data will be obtained. The alertness can be measured by comparing the EDR values before the alarm. If the difference in the EDR values decreases with time, it means alert fatigue is detected with the EDR.

The Empatica E4 wristband, which has been widely used to measure EDA data, will be used for collecting EDA data [28, 40].

3.2.3 ERP

ERP is the time-locked electric potential for an event. ERP means the synchronous activity of a large population of neurons that occurs due to an external or internal event [44]. P300-ERP, which means positive potential evoked after the 300ms from the event, is related to the external stimulus. Research reveals that P300-ERP is related to the auditory stimulus [45]. Therefore, this study will use P300-ERP data to measure alertness of the subject.

As ERP data can be derived from EEG data, processed EEG data will be used to obtain ERP data. The occipital region of the 10-20 system (i.e., O1 and O2) is known to use to measure P300-ERP [46].

If the magnitude of P300-ERP decreases with time, it means alert fatigue is detected.

3.3 Preliminary Experiment Design

3.3.1 Experiment design

The main purpose of the experiment is to simulate the equipment operator's action in the laboratory. Through the experiment in the laboratory, alert fatigue difference by three different types of alarm sounds will be tested by using physiological signals such as EEG, EDA, and ERP.

Figure 2 demonstrates the experiment design. The red objects indicate the physiological signal measuring devices. The red arc on the subject's head is the EEG device (i.e., Emotiv EPOC+). The red line on the wrist of a subject is the EDA device (i.e., Empatica E4). Orange objects indicate the auditory stimulus-related devices. The orange box behind the subject is the speaker that plays the alarm (i.e., the auditory stimulus). The orange rectangle under the table is the pedal used for measuring the reaction time to the auditory stimulus. Blue objects indicate the visual stimulus-related devices. The blue rectangle on the table is the keyboard, which is the input device for the non-target reaction. The vertical rectangle in the figure is the monitor providing the visual stimulus.

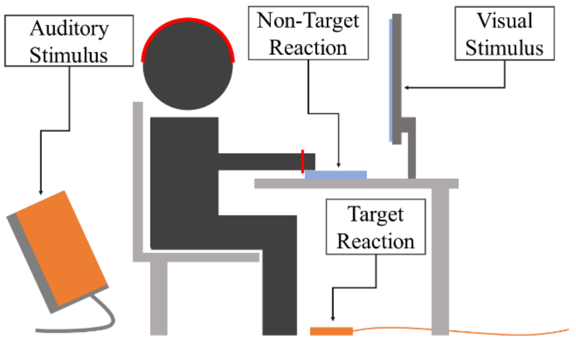

Figure 2. Experiment Diagram

During the experiment, the subject will be exposed to two different stimuli. The first stimulus is the visual stimulus, which is the simple driving simulation. The subject will control the game with the directional key on the keyboard. As the objective of this experiment is to measure alertness of the alarm sound, the visual stimulus is the non-target stimulus. Playing the game with the keyboard is the non-target reaction. This non-target stimulus and non-target reaction are designed to give the subject a specific circumstance, which is driving the equipment or the vehicle. Also, a method of reacting to the target stimulus while focusing on the non-target stimulus is the oddball paradigm, and such a paradigm is widely used to measure alertness to the target stimulus [21, 47]. The second stimulus is the auditory stimulus, which is the alarm sound provided with the speaker while the subject playing the game. Subjects will be instructed in advance to press the button located under the desk with their foot right after detecting the alarm sound. The auditory stimulus is the target stimulus and pressing the button with the foot is the target reaction. Visual and auditory stimuli, and target and non-target reactions are the simplified simulations of the action of the operator of the construction equipment. Hence, through this experiment, alert fatigue of the operator of the construction equipment can be measured indirectly. The subjects' reaction time to push the pedal after they are stimulated by an alarm sound will be measured to collect behavioral data.

3.4 Data Analysis Plan

After collecting processed physiological data, whether or not each physiological data can successfully measure alert fatigue will be tested by comparing those data to behavioral data, the reaction time.

Figure 3. show the expected data analysis process. For every alarm that goes off during the experiment, physiological signals measured before and after the auditory stimulus will be calculated. By comparing those values, alert fatigue can be measured. In addition, by comparing each of the physiological data results to the behavioral data results, feasibility of measuring alert fatigue by different types of physiological signals will be tested. From these comparisons, different effects of alert fatigue by three different alarm sounds will be evaluated.

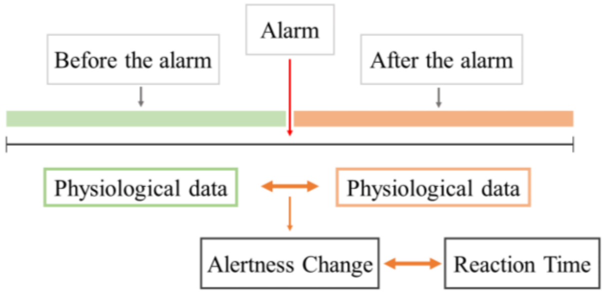

Figure 3. Expected Data Analysis Diagram

4 Expected Findings and Discussion

4.1 Expected Findings

By conducting the experiment, alert fatigue of each different alarm sound can be measured. The effects of SON and auditory icons in terms of learnability or recognition performance have been tested by previous research studies [19,20,23]. Even though learnability and recognition performance are different dimensions from alert fatigue, based on the previous research studies, it can be conjected that alert fatigue occurs from auditory icon and SON is lower than alert fatigue occurs due to the conventional auditory alarm or the complex tone.

In addition, the physiological signals suggested in this study are supported by previous studies that such signals can measure vigilance and alertness successfully [30,33-35,46]. Hence by comparing each physiological data to behavioral data, the authors expect to validate that various physiological data can successfully measure alert fatigue.

4.2 Discussion

4.2.1 Expected Contribution

The expected result of the experiment designed in this study will suggest the most effective alarm sound to control alert fatigue. Knowing such an alarm sound can contribute to improving the performance of alarm systems by providing the method to reduce alert fatigue. This improvement will eventually contribute to reducing accidents caused by the blind spot.

Another contribution of the experiment is to test feasibility of measuring alert fatigue by physiological signals. This result can contribute to the current body of knowledge as no research measures alert fatigue with the physiological signals.

4.2.2 Limitation and Future Study

As the main objective of this paper is to design an experiment that can find the most effective alarm sound against alert fatigue of the operator of the construction equipment, the experiment suggested in this paper tries to simulate the action of the operator. However, the experiment cannot reproduce the circumstance of the operator perfectly. If future study using the experiment successfully investigates alert fatigue, the experiment can be tested on real construction equipment operators with different alarm sounds installed in their equipment. By doing so, the most effective alarm sound for controlling alert fatigue can be verified in a real situation. Such a result can leads to a more sophisticated alarm system design.

ACKNOWLEDGMENT

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy(MOTIE) of the Republic of Korea (No. 20194010201850). This work was also supported by a National Research Korea grant funded by the Korean government (Ministry of Education) (NRF-2021R1F1A1050519).

References

[1] Marks E.D. and Teizer J. Method for testing proximity detection and alert technology for safe construction equipment operation. *Construction Management and Economics*, 31(6):636-646, 2013.

[2] Vahdatikhaki F., El Ammari K., Langroodi A.K., Miller S., Hammad A., and Doree A. Beyond data visualization: A context-realistic construction equipment training simulators. *Automation in construction*, 106:102853, 2019.

[3] Li J., Li H., Umer W., Wang H., Xing X., Zhao S., and Hou J. Identification and classification of construction equipment operators' mental fatigue using wearable eye-tracking technology. *Automation in Construction*, 109:103000, 2020.

[4] United States Department of Labor. Commonly used statistics. On-line: https://www.osha.gov/data/commonstats, Accessed: 13/07/2021.

[5] Teizer J., Allread B.S., Fullerton C.E., and Hinze J. Autonomous pro-active real-time construction worker and equipment operator proximity safety alert system. *Automation in construction*, 19(5):630-640, 2010.

[6] Blackmon R. and Gramopadhye A. Improving construction safety by providing positive feedback on backup alarms. *Journal of construction engineering and management*, 121(2):166-171, 1995.

[7] New York LTAP Center. Safety Alarm Fatigue. Everyday Safety Tailgate Talks On-line: https://www.clrp.cornell.edu/library/SC/Tailgate.html, Accessed: 12/07/2021.

[8] Wang J. and Razavi S. Two 4D models effective in reducing false alarms for struck-by-equipment hazard prevention. *Journal of Computing in Civil Engineering*, 30(6):04016031, 2016.

[9] Edworthy J. Medical audible alarms: a review. *Journal of the American Medical Informatics Association*, 20(3):584-589, 2013.

[10] Cash J.J. Alert fatigue. *American Journal of Health-System Pharmacy*, 66(23):2098-2101, 2009.

[11] Jung T.-P., Makeig S., Stensmo M., and Sejnowski T.J. Estimating alertness from the EEG power spectrum. *IEEE transactions on biomedical engineering*, 44(1):60-69, 1997.

[12] Trutschel U., Sirois B., Sommer D., Golz M., and Edwards D. PERCLOS: An alertness measure of the past. 2011.

[13] Roederer J.G., *Introduction to the Physics and Psychophysics of Music*. 2012: Springer Science & Business Media.

[14] Belz S.M., Robinson G.S., and Casali J.G. A new class of auditory warning signals for complex systems: Auditory icons. *Human factors*, 41(4):608-618, 1999.

[15] Gaver W.W. and Norman D.A., *Everyday listening and auditory icons*. 1988, University of California, San Diego, Department of Cognitive Science and Psychology.

[16] Suied C., Susini P., Misdariis N., Langlois S., Smith B.K., and McAdams S. *Toward a sound design methodology: Application to electronic automotive sound*. 2005. Georgia Institute of Technology.

[17] Cabral J.P. and Remijn G.B. Auditory icons: Design and physical characteristics. *Applied ergonomics*, 78:224-239, 2019.

[18] Edworthy J. Designing effective alarm sounds. *Biomedical Instrumentation & Technology*, 45(4):290-294, 2011.

[19] Rosa C., Lassonde M., Pinard C., Keenan J.P., and Belin P. Investigations of hemispheric specialization of self-voice recognition. *Brain and cognition*, 68(2):204-214, 2008.

[20] Conde T., Gonçalves Ó.F., and Pinheiro A.P. Paying attention to my voice or yours: an ERP study with words. *Biological psychology*, 111:40-52,

2015.

[21] Tateuchi T., Itoh K., and Nakada T. Neural mechanisms underlying the orienting response to subject's own name: An event‐related potential study. *Psychophysiology*, 49(6):786-791, 2012.

[22] Jung T.-P. and Makeig S. *Estimating level of alertness from EEG*. in *Proceedings of 16th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. 1994. IEEE.

[23] Murthy K. and Khan Z.A. Different techniques to quantify the driver alertness. *World Applied Sciences Journal*, 22(8):1094-1098, 2013.

[24] Correa Á., Molina E., and Sanabria D. Effects of chronotype and time of day on the vigilance decrement during simulated driving. *Accident Analysis & Prevention*, 67:113-118, 2014.

[25] Hwang S., Jebelli H., Choi B., Choi M., and Lee S. Measuring workers' emotional state during construction tasks using wearable EEG. *Journal of Construction Engineering and Management*, 144(7):04018050, 2018.

[26] Jebelli H., Hwang S., and Lee S. EEG signal-processing framework to obtain high-quality brain waves from an off-the-shelf wearable EEG device. *Journal of Computing in Civil Engineering*, 32(1):04017070, 2018.

[27] Jebelli H., Hwang S., and Lee S. EEG-based workers' stress recognition at construction sites. *Automation in Construction*, 93:315-324, 2018.

[28] Chae J., Hwang S., Seo W., and Kang Y. Relationship between rework of engineering drawing tasks and stress level measured from physiological signals. *Automation in Construction*, 124:103560, 2021.

[29] Sengupta A., Dasgupta A., Chaudhuri A., George A., Routray A., and Guha R. A multimodal system for assessing alertness levels due to cognitive loading. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 25(7):1037-1046, 2017.

[30] Kamiński J., Brzezicka A., Gola M., and Wróbel A. Beta band oscillations engagement in human alertness process. *International Journal of Psychophysiology*, 85(1):125-128, 2012.

[31] Sun H., Bi L., Chen B., and Guo Y. EEG-based safety driving performance estimation and alertness using support vector machine. *International Journal of Security and Its Applications*, 9(6):125-134, 2015.

[32] Jena S.K. Examination stress and its effect on EEG. *Int J Med Sci Pub Health*, 11(4):1493-7, 2015.

[33] Bronzino J.D., *Biomedical Engineering Handbook 2*. Vol. 2. 2000: Springer Science & Business Media.

[34] Comon P. Independent component analysis, a new concept? *Signal processing*, 36(3):287-314, 1994.

[35] Delorme A. and Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods*, 134(1):9-21, 2004.

[36] Boucsein W., *Electrodermal activity*. 2012: Springer Science & Business Media.

[37] Oken B.S., Salinsky M.C., and Elsas S. Vigilance, alertness, or sustained attention: physiological basis and measurement. *Clinical neurophysiology*, 117(9):1885-1901, 2006.

[38] Kompier M.E., Smolders K.C., van Marken Lichtenbelt W., and de Kort Y.A. Effects of light transitions on measures of alertness, arousal and comfort. *Physiology & Behavior*, 223:112999, 2020.

[39] Choi B., Jebelli H., and Lee S. Feasibility analysis of electrodermal activity (EDA) acquired from wearable sensors to assess construction workers' perceived risk. *Safety science*, 115:110-120, 2019.

[40] Jebelli H., Choi B., Kim H., and Lee S. *Feasibility study of a wristband-type wearable sensor to understand construction workers' physical and mental status*. in *Construction Research Congress*. 2018.

[41] Benedek M. and Kaernbach C. A continuous measure of phasic electrodermal activity. *Journal of neuroscience methods*, 190(1):80-91, 2010.

[42] Hernando-Gallego F., Luengo D., and Artés-Rodríguez A. Feature extraction of galvanic skin responses by nonnegative sparse deconvolution. *IEEE journal of biomedical and health informatics*, 22(5):1385-1394, 2017.

[43] Greco A., Valenza G., Nardelli M., Bianchi M., Citi L., and Scilingo E.P. Force–velocity assessment of caress-like stimuli through the electrodermal activity processing: Advantages of a convex optimization approach. *IEEE Transactions on Human-Machine Systems*, 47(1):91-100, 2016.

[44] Sur S. and Sinha V.K. Event-related potential: An overview. *Industrial psychiatry journal*, 18(1):70, 2009.

[45] Işoğlu-Alkaç Ü., Kedzior K., Karamürsel S., and Ermutlu N. Event-related potentials during auditory oddball, and combined auditory oddball–visual paradigms. *International Journal of Neuroscience*, 117(4):487-506, 2007.

[46] Ekanayake H. P300 and Emotiv EPOC: Does Emotiv EPOC capture real EEG? *Web publication http://neurofeedback. visaduma. info/emotivresearch. htm*, 133, 2010.

[47] Conde T., Gonçalves Ó.F., and Pinheiro A.P. Stimulus complexity matters when you hear your own voice: Attention effects on self-generated voice processing. *International Journal of Psychophysiology*, 133:66-78, 2018.