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An Analysis of EEG Changes during Prolonged Simulated Driving for the Assessment of Driver Fatigue

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Abstract. Fatigue during driving is the main contributing factor to road accidents. It is influenced by time on task (TOT) and time of day (TOD). Recent electroencephalogram (EEG) research on fatigue assessment has shown a promising result in explaining the fatigue phenomenon. However, different findings exist regarding the best EEG parameters related to fatigue. This study examined EEG changes according to the effect of TOT and TOD and determined the best parameters to distinguish fatigue status. To generate driver fatigue, prolonged driving in the morning and at night in a simulator was conducted. The EEG signal was collected from 28 male participants at frontal and occipital areas. The EEG power (brainwave) was determined from the first and last 5 minutes of the driving task and after a break of 30 minutes. The results of this study showed a general tendency of EEG power changing throughout the driving sessions. However, changes related to fatigue were only found for the night sessions, as confirmed by θ power and the subjective fatigue measurement result. This study showed that TOT (as a factor that induces fatigue) was explained by θ from the frontal area, whereas TOD was differentiated by α, θ, θ/β, $(\theta+\alpha)/\beta$ and $(\theta+\alpha)/(\beta+\alpha)$.

Keywords: *EEG; fatigue; sleepiness; simulated driving; time on task; time of day.*

1 Introduction

Road traffic accidents are a major concern in many industrialized and developing nations. Fatigue among drivers is a prevalent phenomenon and is considered a major contributing factor in many traffic accidents [1]. Fatigued drivers tend to exhibit diminished awareness, resulting in poor judgment in performing tasks in outside environments [2]. Fatigue is also highly associated with reduced cognitive and decision-making performance [3]. Driving is a complex task that can be categorized as a cognitive task rather than a physical task. During driving, driver fatigue is mainly characterized by drowsiness and mental fatigue [4].

According to reports in the literature, physiological changes can be measured as fatigue indicators using both subjective and objective tools [5,6]. The subjective

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tools attempt to capture self-perception of the sleepiness/fatigue level at a certain time based on standardized questionnaires, such as the Karolinska Sleepiness Scale (KSS), the Stanford Sleepiness Scale (SSS), the Epworth Sleepiness Scale (EPS), the Fatigue Visual Analogue Scale (F-VAS), the Fatigue Rating, and the Swedish Occupational Fatigue Index (SOFI) [6-11].

The objective tools involve the use of updated technology to assess fatigue [12]. The technology used records physiological changes to observe fluctuation in fatigue indicators. Among the various approaches available in the literature, electroencephalogram (EEG) is considered an objective and valid method for evaluating fatigue [13-15]. These studies used EEGs in conjunction with several subjective measures to establish the level of fatigue and also as confirmatory test of the EEG results.

It is noteworthy that, to date, research addressing EEG changes as a function of different driving conditions related to fatigue, including comparison of driving during the day (i.e. morning) and at night, is fairly limited. In particular, it remains unclear which parameters can provide a better understanding of fatigue in relation to prolonged driving and time of day. Furthermore, a comparison of EEG signals from different brain areas is needed to understand the results of existing studies related to fatigue. In this study, the occipital (highly related to visual function) and frontal (highly related to cognitive function) brain areas were compared. This study attempted to quantify the changes in EEG parameters during driving with the main objective to determine the best EEG parameters to describe changes in fatigue status. Prolonged driving and time of day (TOD) were used as the independent variables that induce fatigue.

2 Method

2.1 Subjects

Twenty-eight male participants (M ± SD of age 26.36 ± 4.59 years, height 168.56 ± 2.52 cm, and weight 71.69 ± 15.35 kg) were recruited in this experiment. Male participants were chosen because most commercial drivers are male; this strategy was also adopted by Kar, *et al.* [13], Kee, *et al.* [16] and Tanaka, *et al.* [17]. Half of the participants were assigned to morning driving sessions (07:00) and the other half were assigned to night driving sessions (21:00). Each driving session lasted 2.5 h. All participants had a valid driver's license, had been drivers for at least two years, and were familiar with long duration driving conditions. The participants were asked to sleep for approximately 8 h and then wake up in the following morning at around 04:30-05:00. A heavy meal (450-550 kcals) was provided for the participants roughly an hour before the experiment commenced. The number of calories was determined and calculated based on *The Balanced Nutrition Guidelines 2014* from the Indonesian Ministry of Health [18].

The night participants were informed that they were allowed to continue to perform normal activities without taking a nap and were permitted to perform only light physical work during the day. To ensure that the participants followed the instructions, after finishing the meal, all participants were interviewed regarding their daytime activities. If there was an indication that the participant had not followed the instructions, the experiment on that day was canceled and the experiment was rescheduled.

The number of participants (14 participants for each driving session, 28 in total) was considered sufficient for the study according to the value of the effect size $d = 1.25$ with power 0.8, which requires a minimum sample size of 12 [19]. No alcoholic or caffeinated beverages were allowed within 24 h before (and throughout) the experiment. A brief interview and blood pressure measurement were performed to ensure that the participants were fit and ready for the experiment. The systolic blood pressure (SBP) and diastolic blood pressure (DBP) of all participants did not exceed 120/80mmHg during the experiments. Note that the participants provided their written informed consent prior to the experiment and were paid for their time.

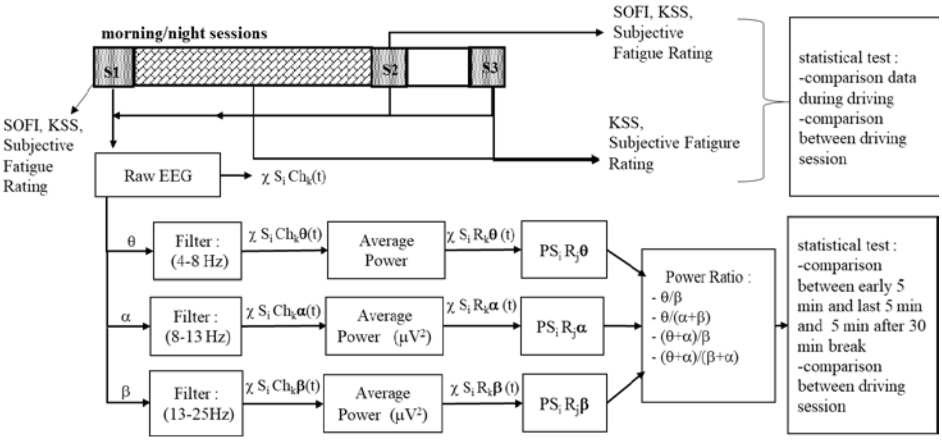
2.2 Tasks Design

The design of this research study involved 150 minutes (2.5 h) of driving for both types of driving sessions (morning and night) to induce fatigue from prolonged driving. The driving duration was considered prolonged when it took at least 120 minutes [20], although other researchers set 150-180 minutes as the prolonged driving threshold [16,21]. The route chosen for this simulation was a loop track comprising of freeways and city streets, as provided by the driving simulation software used, City Car Driving Simulator v.1.4, which is commonly used in driving simulation studies (e.g., Almahasneh, *et al.* [22]). The traffic density was set at 80% and the suggested driving speed was in the range of 40 to 60 km/hour.

The simulator in this study comprised of a set of standard sound systems with an external stereo speaker (Hewlett Packard), which was used to generate the engine sound, and a set of Logitech G27 series 92 steering wheels (USA) with three pedals and manual controls that were integrated with a PC (Intel i7 processor, 4GB of RAM and 2GB of VGA card). The simulator was located inside a room with the temperature set at 22 °C.

2.3 EEG data collection

Electroencephalography or EEG (Emotiv Epoch, USA) was utilized in recording the brain activities during the experiments. The EEG signals were obtained from eight channels for the frontal area and two channels for the occipital area with a sampling frequency of 128 Hz [16]. The EEG signal was recorded during the experiments to minimize the interruption of tasks caused by the EEG installment process; only signals from the first and last 5 minutes of the driving sessions and 5 minutes after the 30-minute break from the driving task were analyzed in this study [23].



Note: S1 = first 5 min, S2 = last 5 min before end, S3 = 5 min after 30-min break, Ch = channel (1-10) ((1 = AF3, 2 = AF4, 3 = F7, 4 = F8, 5 = F3; 6 = F8, 7 = FC5, 8 = FC6, 9 = O1, 10 = O2); $R_{k(1\text{-}2)}$ (1 = Frontal, 2 = Occipital), P = Power Spectral Density; SOFI: Swedish Occupational Fatigue Index, KSS = Karolinska Sleepiness Scale

Figure 1 Data collection and analysis.

The signals (stored in edf. files) were later extracted using eeglab's module in MATLAB (see Figure 1). Each of the EEG signals was band-pass filtered to eliminate undesired signal frequencies below 0.5 Hz and above 32 Hz [24].

Signal decomposition was applied to acquire the 1-minute power spectral density (PSD) values of the θ wave (4-8 Hz), α wave (8-13 Hz), and the β wave (13-25 Hz), which were later converted to dB units. Each brain wave in the form of EEG parameters was represented by the mean value of the 5-min PSDs. Additionally, following Jap, *et al.* [14], the EEG parameters of four ratios of brainwaves (θ/β, θ/(α+β), (θ+α)/β, and (θ+α)/(α+β)) were also analyzed.

2.4 Subjective Data Collection

To augment the EEG measurement, some subjective fatigue and sleepiness tools were applied. The tools were applied to confirm that the driving tasks induced the participants' fatigue. The subjective measurements were SOFI [11], the KSS [7-8], and the subjective Fatigue Rating [9-10]. SOFI was applied to measure the subjective fatigue before and after driving using a scale of 0 = *not at all* to 6 = *very high degree*, with 3 as an intermediary level. Of the five SOFI dimensions, the sleepiness dimension was not measured to avoid repetition of the questions of sleepiness level asked using KSS.

The KSS, as a tool to measure sleepiness, is based on a scale of 1 = *very alert* to 9 = *very sleepy, fighting sleep, an effort to keep awake*, with 5 as a neutral condition [8]; the KSS value was collected before the experiment started and every 10 minutes during the experiments. The Subjective Fatigue rating uses a 0 to 10 scale [10]. In the scale, 0 = *none* and 10 = worst *possible fatigue*, with 5 = *moderate fatigue* as the intermediary level. The data were collected immediately before the experiment started, before the driving task ended, and after participants had a break of 30 minutes.

2.5 Data Analysis

All EEG parameters were tested using repeated measures ANOVA to determine any significant changes between the first 5 minutes, last 5 minutes, and 5 minutes after the 30-minute break from the driving task. Analysis was conducted for each session (morning and night). In addition, a comparison test was conducted between sessions using one-way ANOVA to identify any significant differences.

Data from the subjective tools were used to establish the level of fatigue from EEG parameters changes. To study the effect of duration and TOD of the subjective data result, a Wilcoxon test was used on the score obtained on the SOFI, KSS, and Subjective Fatigue rating scales. A significance level of α = 5% was applied for the tests.

3 Result

3.1 EEG Data Collection

For both sessions, the EEG was observed for changes throughout the driving sessions. In the morning sessions, the three EEG parameters (θ, α, and β wave power) demonstrated an increasing pattern throughout the driving duration. This phenomenon existed for both the frontal and occipital areas. Changes in the θ

wave power appeared to be consistent for both areas (6-7%), whereas changes in the β wave power were only observed for the occipital area (10%). The power ratios from the additional four parameters tended to increase after 2.5 h of driving. However, a slight (3-4%) change occurred only for the frontal area. It is noteworthy that all these changes were not significant, except for the θ/β parameter ($p < 0.05$) from the occipital area (Figure 2).

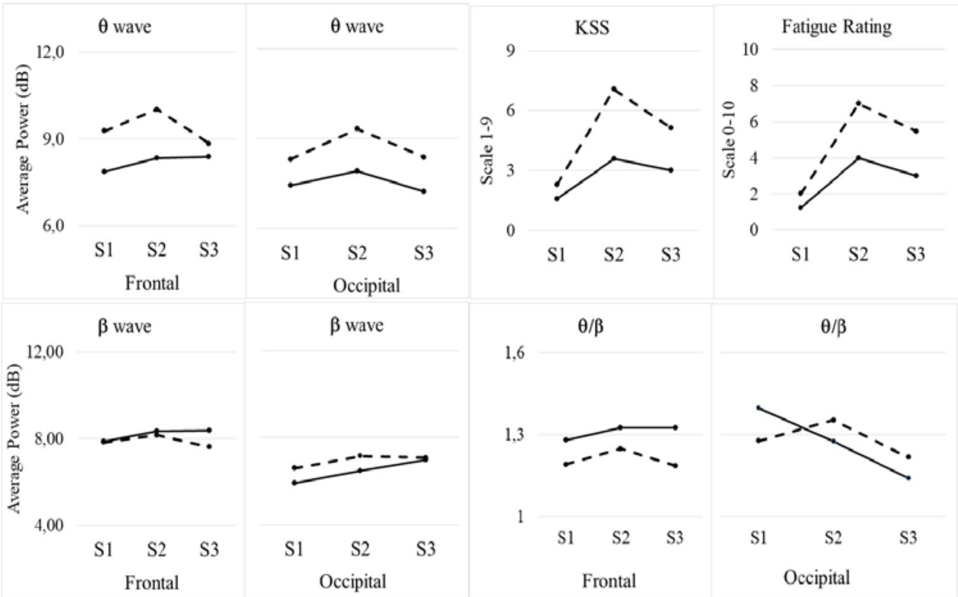


Figure 2 EEG parameters from frontal and occipital areas, and subjective measurements.

The night driving sessions resulted in somewhat different patterns. The β and θ wave power tended to increase for the frontal area (4-8%). For the occipital area, the three waves increased substantially (8-12%), with the greatest changes observed for the θ wave power. For these sessions, the power ratios demonstrated a consistent increase for both areas (1-6%). However, only changes of the θ power from the frontal and occipital area were significant ($p < 0.01$) (Table 1).

Comparisons were also made between the EEG powers of the morning and night driving sessions. Significant changes in the EEG (from the frontal area) were observed for almost all parameters (Table 1). For instance, the differences for the frontal area (for α, β, and θ waves power) were in the order of 18 to 22%. In contrast, changes in the EEG (from the occipital area) were only observed for the α wave ($p < 0.05$) and θ wave ($p < 0.01$). Regardless of the parameters and brain areas, the night driving sessions were generally characterized by greater EEG power.

Table 1 EEG comparison test result (repeated measures ANOVA and one-way ANOVA).

EEG parameter	Morning comparison: Si	Night comparison: Si	Morning & night comparison
Frontal			
- α	$F(2, 26) = 0.486$	$F(2,26) = 0{,}422$	$F(1,76) = 16.173$**
- β	$F(2, 26) = 0.023$	$F(2,26) = 0.333$	$F(1,76) = 14.749$**
- θ	$F(1.408,18.300) = 0.844$	$F(1{,}408, 18.300) = 7.113$**	$F(1,76) = 14.283$**
- θ/β	$F(2,26) = 0.438$	$F(2,26) = 0.811$	$F(1,76) = 5.911$*
- θ/(α+β)	$F(2,26) = 1.349$	$F(2,26) = 1.215$	$F(1,76) = 3.048$
- (θ+α)/β	$F(2,26) = 0.752$	$F(2,26) = 0.331$	$F(1,76) = 4.129$*
- (θ+α)/(β+α)	$F(2,26) = 1.049$	$F(2,26) = 0.936$	$F(1,76) = 4.353$*
Occipital			
- α	$F(2, 26) = 0, 082$	$F(2, 26) = 0.445$	$F(1,76) = 4.338$*
- β	$F(2, 26) = 1.078$	$F(2, 26) = 0.469$	$F(1,76) = 1.080$
- θ	$F(2, 26) = 1.586$	$F(2, 26) = 2.807$*	$F(1,76) = 10.226$**
- θ/β	$F(2, 26) = 3.232$*	$F(2, 26) = 0.965$	$F(1,76) = 1.854$
- θ/(α+β)	$F(2, 26) = 0.940$	$F(2, 26) = 0.569$	$F(1,76) = 1.084$
- (θ+α)/β	$F(2, 26) = 1.491$	$F(2, 26) = 1.083$	$F(1,76) = 2.588$
- (θ+α)/(β+α)	$F(2, 26) = 1.404$	$F(2, 26) = 0.860$	$F(1,76) = 1.272$

Note: * ($p < 0.05$); ** ($p < 0.01$)

3.2 Subjective Fatigue Changes

The result obtained from SOFI suggests that the fatigue level of the participants was increased after the experiment. However, the participants were not yet in a tired condition after driving for 2.5 h, except for those in the night sessions. The average SOFI scores for physical exertion (PD), lack of motivation (LM), lack of energy (LE), and physical discomfort (PD) after the experiment for the morning sessions were 0.52 ± 0.63, 0.48 ± 0.52, 0.75 ± 0.84, and 1.04 ± 1.15, respectively, i.e. all below 3, whereas for the night sessions, the average SOFI scores for PD, LM, LE, and PD were 1.65 ± 1.33, 3.02 ± 1.49, 3.73 ± 1.05, and 3.00 ± 1.07, respectively. These results demonstrate that the morning sessions resulted in significantly increased scores ($p < 0.05$) only for the LE and PD dimensions, whereas the night sessions resulted in significantly increased scores for all dimensions ($p < 0.05$).

The second subjective set of data accompanying the EEG result is the subjective sleepiness of KSS. This study showed that the KSS scores generally increased throughout the driving sessions. The average final scores after the driving tasks were approximately 3.6 for the morning sessions and 7.1 for the night sessions (scale 1-9), with only the night sessions corresponding to sleepiness level greater than 5 (neither alert nor sleepy). There were no differences with respect to the level of subjective sleepiness (KSS scores) of the morning sessions, but a difference was found ($p < 0.05$) for the night sessions. Similar to the SOFI result, this KSS score showed that fatigue had not occurred yet after driving in the morning, whereas the opposite results were observed for the night driving sessions. After resting for 30 minutes, the KSS scores during 5 minutes of driving decreased to approximately 3 for the morning sessions and 5 for the night sessions.

Similar to the KSS scores, the Subjective Fatigue rating also indicated an increasing trend throughout the driving duration, with no observed differences between the initial ratings from the morning. At the end of the session, an average rating of 4 and 7 (scale 0-10) was observed for the morning and night driving sessions, respectively, with only the night sessions categorized as sessions in which fatigue occurred. The 30-minute break resulted in lower fatigue scores: 25% for the morning sessions and 22% for the night sessions.

Based on these subjective results, the significant EEG changes at the night session and the differences between EEG parameters between the morning and night sessions were related to fatigue. This participants' fatigue condition was confirmed by the increasing KSS and the Subjective Fatigue rating score.

4 Discussion

The findings of study demonstrate that several EEG parameters tend to increase marginally throughout a 2.5 h driving duration. The driving tasks result in a substantial increase in the level of sleepiness and perceived fatigue, particularly for night driving.

With respect to the PSD of the EEG parameters, significant changes were only observed for the θ/β parameter (for the morning sessions) and the θ parameter (for the night sessions). It seems that the duration employed in the experiment might have been inadequate for providing more substantial effects. These changes were not always consistent across brain areas. Changes in the θ/β parameter were observed from the occipital area, whereas an increase in θ power was found from the frontal and occipital area. The latter, in particular, was also reported by Trejo, *et al.* [25], a phenomenon that may indicate acute fatigue [26]. Although the increases in θ and β power in this study were only marginal, these phenomena have also been reported in several other studies (e.g. Otmani, *et al.* [26] and Tanaka, *et al.* [27]). The power of brainwave changes observed from the frontal and occipital areas could indicate an increase in mental fatigue [25]. Note that increases in α and θ power that are simultaneously observed with a decrease in β power have been used to indicate intense fatigue, resulting in a marked decrease in awareness [28]. An increase in β power at the beginning of a cognitive task has been interpreted as increased mental demand [29]. The findings of this study, however, do not indicate substantial changes in β power.

It is worth mentioning that there is no agreement in the literature regarding which brain waves (and which brain areas) provide consistent changes. For example, a decrease in α power could also indicate fatigue. Such an increase has been reported by Trejo, *et al.* [24], although the signals were obtained from the parietal area. As indicated by Tanaka, *et al.* [27], inconsistent changes in the α power could actually indicate different subjective feelings (sleepiness or fatigue). Changes in EEG parameters as a function of fatigue have been reported by Craig, *et al.* and Ma, *et al.* [29,30] and, to some extent, are in line with the results of this study. The results of this study, however, are in contrast to those reported by Jap, *et al.* [14] and Puspasari, *et al.* [31]

Another important finding here is the fact that the power of all EEG parameters for the night driving sessions was substantially greater than those obtained from the morning driving sessions. This difference is particularly true for the brainwave power obtained from the frontal brain area. For the brainwaves from the occipital area, greater power was only found for the α and θ waves.

It should be noted that it is somewhat difficult to determine whether the results mentioned above are associated with TOD (circadian) effects [32] or with the fact that the drivers were awake for a substantially longer duration (time awake factor). A report by Williamson, *et al.* [4] indicated the role of both factors in relating fatigue and safety. From this study, the result confirmed the findings of a prior research in which the brain changes significantly as a person becomes fatigued. Furthermore, in determining the best EEG parameters related to fatigue, the research indicated that the θ waves obtained from the frontal lobe changed significantly according to the effect of driving duration. The impact of the time of day, although it may be influenced by other factors, is indicated by significant changes of the α and θ waves at the frontal and occipital areas. Other significant changes were found in the β power, θ/β, $(\theta+\alpha)/\beta$, and $(\theta+\alpha)/(\beta+\alpha)$, but only in the frontal area. These results were similar to the results of the study by Jap, *et al.* [16] regarding the use of brainwave ratios obtained from the frontal area.

5 Conclusion

The objective of this study was is to examine the changes in EEG activity in order to obtain the best EEG parameters related to fatigue. By considering prolonged driving duration and TOD as independent variables that induce fatigue, it was concluded that both morning and night driving tasks for 2.5 h only result in marginal EEG changes. The driving tasks, however, were sufficient in producing an increased level of sleepiness and fatigue. It is also concluded that night driving is characterized by substantially greater EEG power, particularly for the frontal area. A synchronization process due to lack of light during night sessions may have affected the change in θ wave power compared to during the morning sessions, and this same process could also increase the participants' fatigue level.

The EEG parameters that changed significantly over the driving time were the θ wave from the frontal and occipital areas during night sessions, and θ/β from the occipital area during morning sessions. The θ wave power changes also explain the effect of TOD together with the other four EEG parameters (α, θ/β, $(\theta+\alpha)/\beta$, $(\theta+\alpha)/(\beta+\alpha)$. In this study, the consistent changes of θ and θ/β indicate that the use of these two parameters to detect fatigue is more promising than the use of the other EEG parameters. Results from comparison between different areas of the brain have frequently been discussed; however, less discussed is the frontal area, which is suggested as the most suitable brain area from which to obtain EEG data related to fatigue.

6 Study Limitations

Based on the study result, more than 2.5 h of driving is required to trigger severe driver fatigue (see the result of the morning sessions). However, a promising result of this study is that the θ and θ/β powers are more sensitive toward driver fatigue changes compared to other EEG parameters.

References

[1] Zhang, G., Yau, K.K.W., Zhang, X. & Li, Y., *Traffic Accidents Involving Fatigue Driving and Their Extent of Causalities*, Accident Analysis and Prevention, **87**, pp. 34-42, 2016.

[2] Tyagi, R., Shen, K., Shao, S. & Li, X., *A Novel Auditory Working-Memory Vigilance Task for Mental Fatigue Assessment,* Safety Science, **47**, pp. 967-972, 2009.

[3] Yanli, M.A., Lou, Y. & Wang, Y., *Road Traffic Accidents Model and Its Application Based on Driver's Self-mistakes*, Journal of Transportation

System Engineering and Information Technology, **10**(4), pp.101-105, 2010.

[4] Williamson, A., Lombardi, D.A, Folkard, S., Stuts J., Courtney, T.K. & Connor, J.L., *The Link between Fatigue and Safety*, Accident Analysis and Prevention, **43**, pp. 498-515, 2011.

[5] Philips, R.O., *A Review of Definitions of Fatigue – And a Step Towards a Whole Definition*, Transportation Research Parf F, **29**, pp. 48-56, 2015.

[6] Shahid, A., Shen, J. & Shapiro, C., *Measurement of Sleepiness and Fatigue*, Journal of Psychosomatic Research, **69**(1), pp. 81-89, 2010.

[7] Kaida, K., Takahashi, M., Åkerstedt, T., Nakata, A., Otsuka, Y., Haratani, T. & Fukusawa, K., *Validation of the Karolinska Sleepiness Scale Against Performance and EEG Variables*, Clinical Neurophysiology, **117**, pp. 1574-1581, 2006.

[8] Pauly, L. & Shankar, D., *Detection of Drowsiness based on HOG Features and SVM Classifiers*, Proceedings of IEEE International Conference on Computer Graphics, Vision, and Information Security (CGVIS), 2015.

[9] Binoosh, S.A., Mohan, G.M. & Bijulai, D., *Assessment and Prediction of Industrial Workers' Fatigue in an Overhead Assembly Job*, South African Journal of Industrial Engineering, **28**(1), pp. 164-175; 2017

[10] Kim, E., Lovera, J., Schaben, L., Melara, J., Bourdetta, D. & Whitham, R., *Novel Method for Measurement of Fatigue in Multiple Sclerosis: Real-time Digital Fatigue Score*, Journal of Rehabilitation Research & Development, **47**(5), pp. 477-484, 2010.

[11] Ahsberg, E., Gamberale, F. & Gustafsson, K., *Perceived Fatigue after Mental Work: an Experimental Evaluation of a Fatigue Inventory*, Ergonomics, **43**(2), pp. 252-268, 2000.

[12] Dawson, D., Searle, A.K. & Paterson, J.L., *Look Before You (S)leep: Evaluating the Use of Fatigue Detection within a Fatigue Risk Management System for the Road Transport Industry*, Sleep Medicine Review, **18**(2), pp. 1-12, 2014.

[13] Kar, S., Bhagat, M. & Routray, A., *EEG Signal Analysis for the Assessment and Quantification of Driver's Fatigue*, Transportation Research Part F, **13**, pp. 297-306, 2010.

[14] Jap, B.T., Lal, S. & Fischer, P., *Comparing Combination of EEG Activity in Train Drivers during Monotonous Driving*, Expert Systems with Application, **38**, pp. 990-1003, 2011.

[15] Al-Shargie, F.M., Tang, T.B., Badrudin, N. & Kiguchi, M., *Mental Stress Quantification using EEG Signals*, International Conference for Innovation in Biomedical Engineering and Life Science, pp. 15-19, 2105.

[16] Kee, S., Tamrin, S.B.M. & Goh, Y., *Driving Fatigue and Performance among Occupational Drivers in Simulated Prolonged Driving*, Global Journal of Health Science, **2**(1), pp. 167-177, 2010.

[17] Tanaka, M., Shigihara, Y., Funakura, M., Kanai, E. & Watanabe, Y, *Fatigue-Associated Alterations of Cognitive Function and Electroencephalographic Power Densities*, PLoS One, **7**(4: e34774); pp. 1-5, 2012

[18] Ministry of Health Republic of Indonesia, *The Balanced Nutrition Guidelines 2014*, accessed from http://gizi.depkes.go.id/download/pedoman%20gizi/pgs%20ok.pdf, 2014. (23 March 2018)

[19] Maxwell, S.E. & Delaney, H.D., *Designing Experiments and Analyzing Data a Model Comparison Perspective (2nd edition)*, Lawrence Erlbaum Associates, New Jersey, 2004.

[20] Cardoso, M., Fulton, F., Callaghan, J.P., Johnson, M. & Albert, W., *A pre/post Evaluation of Fatigue, Stress and Vigilance amongst Commercially Licensed Truck Drivers Performing a Prolonged Driving Task*, International Journal of Occupational Safety and Ergonomics, pp. 1-11, 2018.

[21] Falou, W.E., Duchene, J., Grabisch, M., Hewson, D., Longoren, Y. & Lino, F., *Evaluation of Driver Discomfort During Long-duration Car Driving*, Applied Ergonomics, **34**, pp. 249-255, 2003.

[22] Almahasneh, H., Chooi, W., Kamel, N. & Malik, A.S., *Deep in Thought while Driving: an EEG Study on Drivers' Cognitive Distraction*, Transportation Research part F, **26**, pp. 218-226, 2014.

[23] Chai, R., Naik, G.R., Nguyen, T.N., Ling, S.H., Tran, Y., Craig, A. & Nguyen, H.T., *Driver Fatigue Classification with Independent Component by Entropy Rate Bound Minimization Analysis in an EEG-based System*, IEEE Journal Biomedical and Health Informatics, **21**(3), pp. 715-724, 2017.

[24] Schwilden, H., *Concepts of EEG Processing: from Power Spectrum to Bispectrum, Fractals, Entropies and All That*, Best Practice & Research Clinical Anesthesiology, **20**(1), pp. 31-48, 2006.

[25] Trejo, L.J., Knuth, K., Prado, R., Rosipal, R., Kubitz, K., Kochavi, R., Matthews, B. & Zhang, Y., *EEG-Based Estimation of Mental Fatigue: Convergent Evidence for a Three-State Model*, Proceeding of the 3rd International Conference, 2007.

[26] Boksem, M.A.S., Meijman, T.F. & Lorist M.M., *Effects of Mental Fatigue on Attention: an ERP Study*, Cognitive Brain Research, **25**, pp. 107-116, 2005.

[27] Otmani, S., Pebayle, T., Roge, J. & Muzet, A., *Effect of Driving Duration and Partial Sleep Deprivation on Subsequent Alertness and Performance of Car Drivers*, Physiology and Behavior, **84**, pp. 715-724, 2005.

[28] Eoh, H.J., Chung, M.K. & Kim, S.H., *Electroencephalographic Study of Drowsiness in Simulated Driving with Sleep Deprivation*, International Journal of Industrial. **35**(4), pp. 307-320, 2005.

[29] Craig, A., Train, Y., Wijesuriya, N. & Nguyen, H.T., *Regional Brain Wave Activity Change Associated with Fatigue*, Psychophysiology, **49(**4), 574-82, 2012.

[30] Ma, J., Gu, J., Jia, H., Yao, Z. & Chang, R., *The Relationship between drivers' Cognitive Fatigue and Speed Variability during Monotonous Daytime Driving*, Frontiers in Psychology, **9**, Article No. 459, pp. 1-9, 2018.

[31] Puspasari. M.A., Iridiastadi, H., Sutalaksana, I.Z. & Sjafruddin, A., *Effect of Driving Duration on EEG Fluctuations*, *International Journal of Technology*, **6**, pp. 1089-1096, 2017.

[32] Radun, I. & Radun, J.E., *Convicted of Fatigue Driving: Who, Why and How?* Accident Analysis and Prevention, **1**, pp. 869-87, 2009.