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ORIGINAL ARTICLE

THE MENTAL WORKLOAD AND ALERTNESS LEVELS OF TRAIN DRIVERS UNDER SIMULATED CONDITIONS BASED ON ELECTROENCEPHALOGRAM SIGNALS

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ABSTRACT

It was suggested by most researchers that train drivers' workload and alertness levels attribute to train accidents. The main objective of this study is to determine the significant patterns of mental workload and alertness levels of train drivers with respect to the conditions. The data are collected from simulation experiments on 15 professional train drivers. The simulation experiments are performed under three driving conditions (i.e. daytime, rainy daytime and rainy night) using a train driving simulator set. Electroencephalogram (EEG) signals are collected from six significant points on the body of the subjects. It is found that the mental workload of the train drivers tends to be high during rainy night driving condition and sleepiness occurs which is indicative of low vigilance. The beta amplitude increases under rainy night driving condition which may be attributed to viewing difficulties while driving in the dark. The results reveal that there is a significant different between each session (p = 0.042) especially with the pattern for rainy night driving. It is also observed that there is lower mental workload among the train drivers, which indicates that the train drivers are detached from their work.

***Keywords**: Train drivers; mental workload; alertness; Electroencephalogram; simulated experiment*

INTRODUCTION

Accidents and system failure still occur due to faulty interactions between humans and machines. There are several contributors to accidents such as poor track conditions, faulty machinery and human error. According to Jap et al.[1], almost 75% of all train accidents are attributed to human error. Many solutions have been implemented over the years such as improving railway infrastructure and upgrading systems. The ergonomics approach has received much attention in recent years since human skills and capabilities while handling train devices and machines play a vital role in the prevention of catastrophic incidents. Various fields including human working environment in industries have improved after the findings of ergonomics studies are used as a guidelines [2, 3]. It is deemed necessary that a study focused on the working conditions of train drivers is carried out in order to investigate the scenarios and problems which will lead towards incidents and accidents.

Furthermore, night driving is an unfavourable driving condition for certain groups of people. In general, drivers of transportation vehicles are exposed to various forms of condition and environment while driving. For example, the weather may change unexpectedly. However, the drivers need to go on with their journey regardless of its distance and environmental conditions. Conflicting weather such as rain complicates the work of drivers which can cause accidents due to varying road conditions. According to Kilpeläinen et al.[4], rain is one of the adverse weather conditions which can be considered as a cause of an elevated risk of traffic accidents in northern Europe and northern America. It is therefore necessary for drivers to acquire simple strategies to tackle the demands imposed while driving in adverse environments. According to Lee and Triggs[5], an increase in environmental complexity during driving affects peripheral stimuli detection. It has been shown that an increase in brain waves is correlated with an increase in task loads [6, 7].

This may be due to visual inadequacy as well as human factors such as sleepiness and fatigue.Several studies concluded that train drivers are especially fatigued during night shifts [8, 9, 10]. Austin and Drummond[10] found that drivers tend to fall asleep while driving at night. This is clearly dangerous not only to the drivers but also passengers.

It can be seen that the mental workload of drivers is closely linked with their alertness levels. Changes in mental workload result in changes in alertness levels [11]. In land transportation, drivers with high mental workloads suffer from reduced alertness, diverted attention and inadequate time for information processing[12]. Alertness can be defined as the mental state of aroused awareness[13] and thus decreased alertness is a state of reduced awareness. Alertness and constant attention to the environment are related to a number of primary brain processes and are linked with psychological constructs.

There are several contribution factors which affect the alertness levels of drivers. Prolonged work duration may result in boredom among train drivers[14]. An increase in driving duration is a significant factor which decreases the alertness levels of drivers[11]. There is nothing more frustrating than sleep deprivation and thus the amount of sleep affects a worker's alertness levels. Impaired alertness may occur due to sleep debts which consequently affect a person's reaction time, concentration, judgement and decision-making abilities[14]. Nocturnal driving also affects the alertness of drivers. It is known that there are two particular times which will cause physiological decrement in alertness levels (i.e. afternoon and night) [11]. It has been reported in a number of studies that the alertness levels of professional drivers decrease at night, which will jeopardize their work performance [9, 15].

Owing to the importance of understanding the relationship between mental workload, alertness levels and driving conditions, the main objective of this study is to conduct an empirical investigation which identifies the significant patterns of mental workload and alertness levels of train drivers with regards to different conditions. It is propose that the findings presented in this study can be utilized to establish efficient work schedules and better working environment for the train drivers. Thus, a broader sense of ergonomics can be applied which ensures a good balance between the organization as a whole, its people, working practices and technology.

METHODS

Participants

A total of 15 participants participated in this study and they are all male train drivers with aged between 24 and 48 years (mean age: 40 years). The participants all possess a valid train driving licence. None of the participants have a history of serious illnesses and are free of medications which would otherwise prevent compliance to the subject requirements and affect the physiological measures. The participants read and signed the consent form prior to the experiments.

Experimental Apparatus

A modern train driving simulator (Mitsubishi Electric Advance, Japan) was used for the experiments. A MP150 system (Figure 1) equipped with Acq*Knowledge*® 4.0 software was used to monitor and record the brain signals, filter the data automatically and remove the Electrooculogram (EOG) artefacts in the signals. The stretchable electrode cap (CAP100C) assists in securing 19 embedded tin electrodes to each participant's head. A video camera was used to record the activities throughout the experiments and affirm the data obtained at a particular time.

Figure 1: Photograph of the MP150 system

Experimental Setup

The experiments were carried out at Keretapi Tanah MelayuBerhad (KTMB) which they provided a room specifically for the experiments, which consists of a computer-based train driving simulator (Mitsubishi Electric Advance, Japan). The simulation route displayed on the screen is the exact train route in Malaysia and shows the real environment which the train is driving in since the software was developed based on real-life scenarios. The train driver interacts with the simulator using the keyboard, mouse and buttons on the simulator hardware including a multi-functional speed hand-operated control. The top view of the experimental setup is shown in Figure 2.

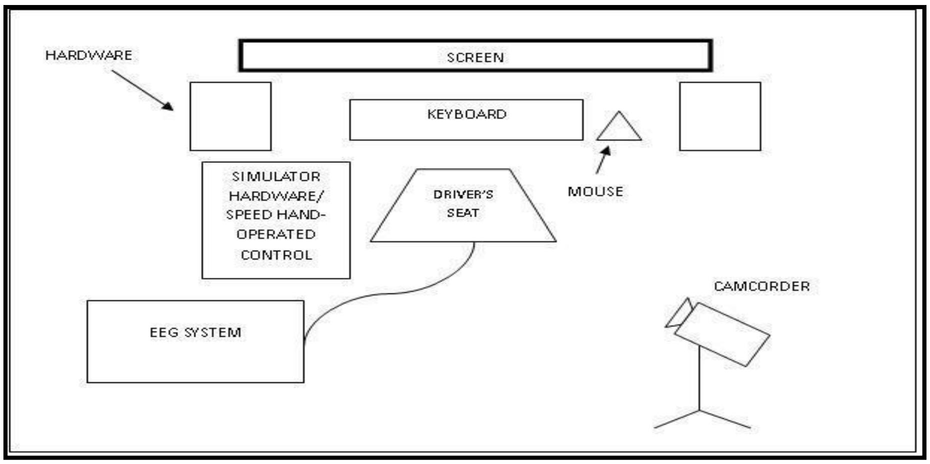

Figure 2: Top view of experimental setup

Experimental Procedure

The initial procedure before the simulation experiments involves collecting the participants' demographic data. Three driving conditions were chosen based on a survey carried out previously from part of this study regarding the most critical train driving conditions (Daytime; Rainy day; Rainy night). The participants were instructed to complete 60 minutes of monotonous train driving sessions. A repeated measurement design was used with a 5-minute break after each session. The participants were given a few minutes to familiarize with the controls and experimental setup used to perform the train driving task. During the monotonous driving sessions, the electroencephalogram (EEG) and electrooculogram (EOG) data were collected using the MP150 system and BIOPAC set. The EEG signals were acquired from six locations of electrodes (i.e. F_Z, P_Z, O_1, O_2, P_3 and P_4) based on the international 10–20 montage [16] with an electronically linked earlobe reference, as shown in Figure 3. EOG recordings were collected by placing the electrodes above and below the eye on the right side of the participant's face, as shown in Figure 4.

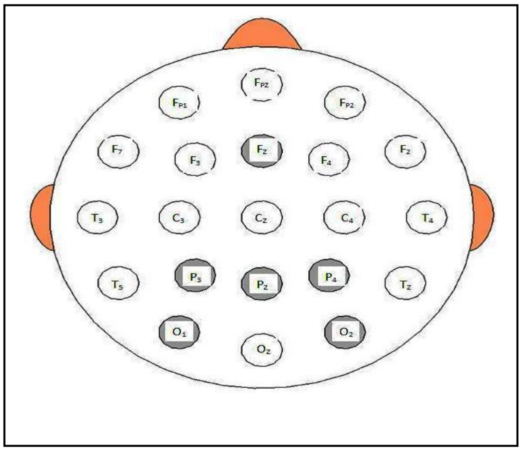

Figure 3: EEG electrode placement

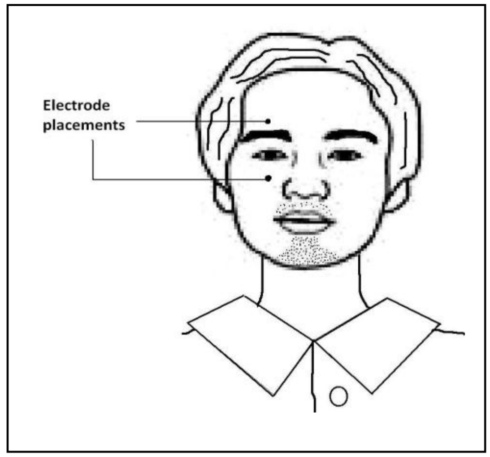

Figure 4: Electrode placement above and below the right eye for EOG recording

Analysis

There are two types of analysis carried out in this study, namely, signal and statistical analysis. AcqKnowledgesoftware was used for signal analysis. The first 120-second interval of the physiological signal from the beginning of each period was excluded from the analysis in order to eliminate drifts. The remaining duration was then segmented into six equal time intervals in order to observe the variations in EEG activity during the driving sessions. Since EEG data contain noise and eye movement artefacts[17], EOG data were used to remove the noise and eye movement artefact as a measure of the blink interval. Fast Fourier transform (FFT) analysis was used to extract and estimate for each time interval as the data were smoothed using 100% Hanning window. The alpha (8-12Hz) and beta (13 – 30 Hz) frequency bands were extracted for each driving condition as well as participants. It shall be noted that this study focuses only on the selected measurement channels (which means that the frequency was calculated for all participants and the mean was determined. Statistical analysis was then carried out to determine the output of the data derived from the EEG software analysis. Friedman Test was used to determine if there is a significant difference between the alpha and beta power data between the three driving conditions.

RESULTS

Demographic Data

A total of 15 male train drivers participated in the experiments. The participants are all healthy without a history of serious illnesses. The mean age of the subjects is 40 ± 6.9 years. The number of years of working experience varies among train drivers, with a mean value of 14 ± 6.1 years.

EEG Mean Alpha Power: Comparison of Mean Alpha Power between Three Driving Conditions

One of the objectives of this study is to determine if there is a significant difference in the mental workload of train drivers between driving conditions. The EEG data is analysed with regards to the alpha power since the alpha power is associated with mental workload. It is found that driving cndition has a significant effect on the EEG mean alpha power (8-12 Hz). The mean value for each subject is extracted from the raw EEG data and plotted into a graph. The variation of mean alpha power with respect to time for channel F_ZP_Z for three driving conditions is shown in Figure 5, and it can be observed that the mean alpha power initially decreases initially, followed by an increase towards the end of the driving session for daytime driving condition. The variation of mean alpha power is less apparent for rainy day condition, whereas the mean alpha power first increases from the first to second time interval, followed by a decrease between the second and third time intervals while driving in rainy night condition.

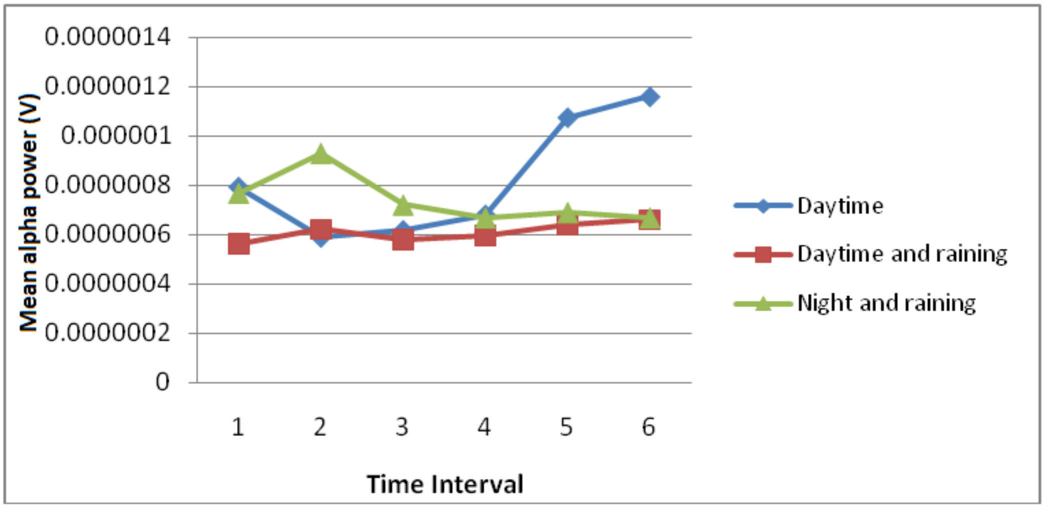

Figure 5: Variation of mean alpha power with respect to time for channel F_ZP_Z for three driving conditions

Comparison is also made on the mean alpha power between three driving conditions (Table 4). It can be observed that the difference in mean alpha power for signal F_ZP_Z is statistically significant, where x^2 (2) = 6.333, *P* = 0.042. This indicates that the mental workload of the train drivers is highly dependent on the driving condition, especially when driving in rainy night condition.

Table 4: Difference in mean alpha power between three driving conditions for each measurement channel obtained from Friedman Test

Measurement Channel	Chi-Square	Asymp. Sig.
F_ZP_Z	6.333	0.042*
O_1O_2	3.000	0.233
P_3P_4	4.333	0.115

EEG Mean Beta Power: Comparison of Mean Beta Power between Three Driving Sessions

The beta power of the EEG data is then analyzed since it is associated with alertness levels. The mean beta power is extracted from the raw EEG data and plotted into a graph. The variation of mean beta power with respect to time for channel P_3P_4 for three driving conditions is shown in Figure 6, and it can be observed that there is a pronounced increase from the first to third time interval, followed by a decrease between the third and fourth time intervals for daytime driving condition. The mean beta power signal then increases again towards the end of the driving session. The trend differs significantly however for rainy day driving condition, whereby the signal first decreases between the first and second time intervals and remains constant between the second and fourth time intervals. The mean beta power then increases towards the end of the driving session. In contrast, the mean beta power signal is rather unstable for the rainy night driving condition, whereby the signal fluctuates throughout the driving session and the value is highest at the end compared to others.

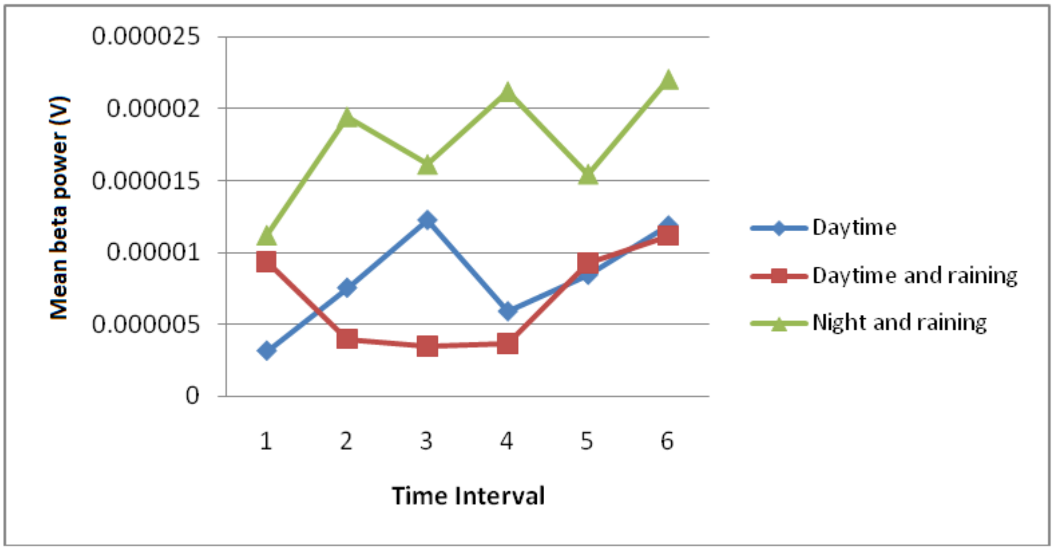

Figure 6: Variation of mean beta power with respect to time for channel P_3P_4 for three driving conditions

The mean beta power signals for the three driving conditions are compared (Table 5). It can be seen that the difference in mean beta power signal for channel P_3P_4 is statistically significant, where x^2 (2) = 6.333, P = 0.042. This indicates that the mean beta power signal for this channel strongly depends on driving session. It is apparent from result that only channel P_3P_4 shows a significant difference between driving conditions. This reflects that the alertness levels of the train drivers vary depending on the driving conditions.

Table 5: Difference in mean beta power between three driving conditions obtained from Friedman Test

Measurement Channel	Chi-Square	Asymp. Sig.
F_ZP_Z	4.333	0.115
O_1O_2	2.333	0.311
P_3P_4	6.333	0.042*

DISCUSSIONS

Mental Workload of Train Drivers

Comparison has been made with regards to the three driving conditions and it is found that the difference in mean alpha power for channel F_ZP_Z is significant (p = 0.042), which indicates that the alpha activity differs depending on the type of mental workload imposed on the train driver. This observation agrees with the results of Ryu and Myung [18], whereby the value of alpha varies in accordance with task difficulty levels. The train drivers tend to feel calmer towards the end of Session 1 (daytime driving condition), which explains the increase in alpha activity. It is expected that the train drivers will be more relaxed towards the end of the driving session since they have reached their destination. However, the results contradict the findings of Myrteket al.[19], in which that the workload component is higher at the ‘start’ and ‘braking’ modes. The different may because they used a real driving situation in their experiments.

Alertness Patterns of Train Drivers

The beta power activity is analysed to examine the alertness patterns during train driving experiments. A significant difference in beta activity is observed for channel P_3P_4. It can be seen from Figure 6 that the beta activity is rather unstable for Session 3 (rainy night driving condition) compared to the other driving sessions. Since channel P_3P_4 contributes to perception and differentiation[20], the train drivers may be experiencing confusion in perceiving their surroundings while driving in rainy night driving condition, which consequently affects their alertness levels. The result shows variations of beta activity which has been associated with instability of the drivers' condition and performance [21, 22]. In addition, a reduction in beta waves is a clear sign of weariness and sleepiness among people [23].

Effects of driving conditions on mental workload and alertness

It is evident from the EEG results that the alpha power signal is most significant for Session 3 (rainy night driving condition). The mean alpha power decreases between the second and third time intervals for all measurement channels in Session 3, which indicates that the mental workload of the train drivers increases after six minutes of driving. Drivers with high mental workloads suffer from reduced alertness, diverted attention and inadequate time for information processing [12].

Night driving has been confirmed to induce sleepiness [11, 24]. In this study, it is found that the percentage difference between daytime and rainy night driving is 37%, even at the initial period of the experiments. A low mental workload can cause boredom which will divert the driver's attention to other things [14, 25]. It is extremely dangerous if the train driver feels drowsy in the actual working environment such that the train driver dozes off while driving. It is therefore necessary for the management to devise an appropriate work schedule to enable train drivers arrange their sleeping hours before checking in for work. According to Budi et al. [26], there is a distinct relationship between railway accidents and locomotive crew while they are on duty. The availability of an efficient work schedule will enhance the motivation of train drivers to perform their tasks, which will enable them to provide excellent service for the organization. An efficient work schedule is vital to increase the motivation and satisfaction of workers [27].

It shall be highlighted that safety factors need to be taken into consideration and therefore measures can be taken to overcome the pitfalls of rainy night driving. The results in this study indicate that the train drivers may be experiencing viewing difficulties while driving in rainy night condition and this problem can be alleviated by making modifications in the train design. For example, an infrared camera can be installed in the front of the cabin in order to improve visibility, particularly at blind spots. In addition, providing sufficiently bright lighting in front of the cab will enable train drivers to view the route from at least 1 mile ahead. This in turn, will help train drivers are able to address potential problems or dangers quickly, especially during night shifts and rainy days. According to Barney et al. [28], the braking distance of a train depends on the speed of the train when the brakes are applied. Thus, the train drivers will be able to react quickly by braking the train if they are able to detect potential dangers ahead.

CONCLUSION

The mental workload and alertness levels of 15 professional train drivers have been investigated by simulation experiments in this study. In general, it can be concluded that there are significant patterns for mental workload and alertness levels of train drivers driving in rainy night condition. The mental workload of the train drivers increases by 37% in rainy night driving condition relative to daytime driving condition. The results show that the mental workload of the train drivers increases after six minutes of driving in rainy night condition. In addition, the results show that the train drivers may be having viewing difficulties while driving in rainy night condition. It is therefore crucial for train drivers to be more alert while driving in such conditions as it is dangerous and risky in terms of safety. The findings obtained in this study can be used as basis to devise improvement strategies on the current railway transportation system in Malaysia as well as design working environments which will enhance safety and reduce the risk of potential accidents which have been attributed to inappropriatemental workload and alertness levels.

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