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THE IMPACT OF ROAD COMPLEXITY ON THE PSYCHOPHYSIOLOGICAL LOAD EXPERIENCED BY CAR DRIVERS USING ELECTROENCEPHALOGRAPHY (EEG) MEASUREMENT OF BRAINWAVES

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SUMMARY

Background: A driver's mental and physical states while driving on hazardous roads significantly determine the incident of traffic accident. The objectives of this paper are to analyze the impact of road complexity on the psychophysiological load experienced by drivers through the use of Electroencephalography (EEG). Three conditions were examined through driving simulation, namely motorway, rural road, and city road.

Material/ Methods: The data were collected from three respondents (drivers) who had different driving experiences, including < 3 years, 3 to 5 years, and > 5 years. Besides, each respondent would go through two tests with different situations: a normal situation and interfered situation (noises). The tool used was Emotive EPOC neuroheadset with 5 channels (electrode) which represent brain parts, such as the frontal (AF3 and AF4), temporal (T7 and T8), and parietal/occipital Pz.

Results: The simulation test results show that the beta signal for the motorway road situation in the occipital lobe, which functioned as visual, is more dominant compared to electrodes in other parts. Meanwhile, data from the rural road and the city road indicate a strong signal of emotions and visuals. In addition, based on the metrics performance result, the drivers' level of stress reached its highest on the city road, as much as 45, followed by the rural road = 44 and the motorway = 42. While for the concentration index, the city road achieved 47, the rural road = 50 and the motorway = 53.

Conclusions: EEG can be used as the basis for drivers performance assessment within different road situations so that the alert system for drivers can be engineered better.

Key words: Electroencephalography (EEG), driving complexity, driving stress, safe driving.

BACKGROUND

The a driver's mental and physical states are vital and are even often the cause of traffic accidents. One instance of causes is exhaustion and drowsiness [1]. Many factors also contribute to the rate of accidents on roads, for examples: the condition of the vehicle, driving experiences, age, gender, traffic infrastructures, hazards, the driver's level of concentration, alcohol, the speed of the car, and external interferences upon driving. Jim Horne and Louise Reyner [2] state that over 20% of serious traffic accidents in Great Britain were caused by driver fatigue (drowsiness). According to Khizar Azam et al. [3], the rate of traffic accidents with a similar cause on motorway lanes in Pakistan is more than 28%. Moreover, based on statistics, the tendency as seen in the number of traffic accidents caused by factors of physical fatigue and the driver's mental state represents quite a high value.

The number of traffic accidents in Indonesia can be considered as very high with a total of 105,374 accidents in 2017. According to Ambarwati et al. [4], drivers aged 17-22 years old dominate in these types of traffic accidents. Fuller R [5] argues that the level of driving ability and driving experience are essential in reducing the rate of traffic accidents. Fastenmeir and Gstalter [6] in their research point out that to avoid risks, there are three main aspects: the driver, the car, and the environmental situation. Generally, there are three types of road condition situation, namely motorways, rural roads, and city roads. The environmental situation includes straight track, meandering track, slopes, junction, the number of hazards, and the traffic density. Naiwala P. Chandrasiri et al. [7] conducted an experiment to examine the impact of the main road condition on a meandering track using a machine learning approach. Bhise, V. D [8] stated that the drivers' workload is divided into two: these being the driving task and non-driving task. Driving tasks are the activities drivers do to drive the vehicle, such as setting the accelerator, hitting the brake, steering, and other controls (e.g., the windshield, mirrors). Non-driving tasks are the drivers' activities aimed at supporting the primary function of driving, for instances setting the AC, audio/video, phone, drink, and many more. The factors of driving tasks and non-driving tasks influenced on the drivers' mental and physical states, which potentially cause genuine fatigue.

The relationship between the drivers' physical and mental states is essential to monitor in order to prevent traffic accidents. Sugiono et al. [9, 10] in his research investigated the drivers' mental and physical loads by measuring the subjective assessment using the NASA TLX questionnaires for the 3 different road conditions, such as motorways, rural roads, and city roads. The objective measurement is conducted through the heart rate (HR) parameter and heart rate variability (HRV). Electroencephalography (EEG) is a very suitable tool to assess the psychological and psychophysiological state of drivers. An EEG test while driving is a good method of measurement since it records the correlation between the drivers' physical and mental states, driving behavior, and the road conditions [11]. EEG will record the brain activities along the drive through several electrodes which are attached to the drivers' heads. Some researches have utilized EEG to investigate psychological condition, mood, and level of anxiety resulting from their fatigue. Collaboration among the information from the EEG, heart rate, and NASA TLX becomes an essential input in constructing an alert system for safe driving.

THEORY

Fatigue and Stress upon Driving

Fatigue is a condition wherein someone feels tired physically and/or mentally in doing their activities within a variety of time periods, targets, and work environments. According to Mississauga [12], fatigue is a process whose causes decrease the rate of safety, capacity, or even performance as the effect of work-related activities. Meanwhile, the Workplace Safety & Health Council (WSH Council) [13] states that the types of fatigue are categorized into two types: these being are physical fatigue (reduction in the ability to work manually) and mental fatigue (a decrease in the level of concentration and alertness).Continuing fatigue, whether physically or mentally, would lead to an overwhelming level of stress for the worker and eventually lowers their performance. Fatigue in driving activities can also cause health problems both directly and indirectly. Directly, it can disturb the driving performance, such as:

- Driving focus and alertness to interruption
- Quick and accurate decision-making abilities
- Structured and analytical thinking
- Understanding the chronological order of an event
- Emotion control
- Maintaining the level of alertness
- Recognizing hazards in traffic
- Understanding complex situations
- Coordinating

Stress is a part of mental disorder in daily life. It can be defined as a situation where one feels uncomfortable, has anxiety, and is pressured either physically or mentally. Stressors (events or conditions in the surroundings) which influenced the ability/capacity/skill can be the main trigger of stress. Psychophysiological measurement would combine stress assessment from the physiological and psychological aspects of a human through brain wave records, such as using Electrocardiogram (ECG). According to Ahmad Rauf Subhani et al. [14], stress is a physiological and psychological response toward threatening situations which needs to be adjusted in the hemostasis imbalance caused by the general alarm in homeostasis. The weakness of this method is that there are still many noises which have to be treated further and also the method is not quite practical. Luis Montoro et.al [14] states that a number of drivers do not admit the presence of stress due to a lack of training and awareness about driving in traffic. An empirical study conducted by Ge, Y et al. [15] has found factors related to stress to be an effective predictor of dangerous driving behavior. This behavior can disrupt the driving performance causing more mistakes in driving, violation of traffic regulations, and increasing the risks of an accident. The density and complexity of the main road can have an impact on the drivers' psychological and physiological health, namely irritability, heart attack risk, heartbeat irregularities and spikes in blood pressure. The Driving Behaviour Inventory – General Driver Stress questionnaire can be used to measure the drivers' level of stress; this consists of 16 items [16].

Electroencephalographic (EEG)

The human brain is a vital part of anatomy as the central nervous system is constructed of 100 billion neurons. Generally, it has central control over human physical motions, behavior, and also bodily functions as well as maintaining blood pressure within one's body and much more. Broadly, the human brain can be divided into 4 parts (see Figure 1a) including the big brain (cerebrum), small brain (cerebellum), the brain stem, and the limbic system. Cerebrum has functions which allow humans to possess logic, the ability to think, learn languages, planning, and decision-making. Besides, it also control the motor functions of the human body. The big brain (Figure 1b) consists of the frontal lobe, parietal lobe, temporal lobe, and occipital lobe. The frontal lobe functions to make a human able to argue, able to do activities and move, cognition, able to plan things, problem-solving, make a judgment, cultivating creativity within humans, control over feelings, control over sexual behavior and general linguistics ability. The parietal lobe functions to enact as a sensor toward certain feelings, for instances being oppressed, pressures, touch response, and pain. The temporal lobe has the function of enabling man to hear, grasp and define information and also be able to process language in the form of sound. The occipital lobe functions to coordinate visual stimulation.

Meanwhile, the small brain or cerebellum is the part of the brain located at the back of the head, close to the tip of the upper neck. The functions of the cerebellum include: to regulate automatic motions and to maintain balance. Another part of the brain is the brain stem, which is located inside the human skull or at the base cavity of the human head. The brain stem has an elongated shape up to the bone marrow. Its functions are to adjust man specifically in breathing, body

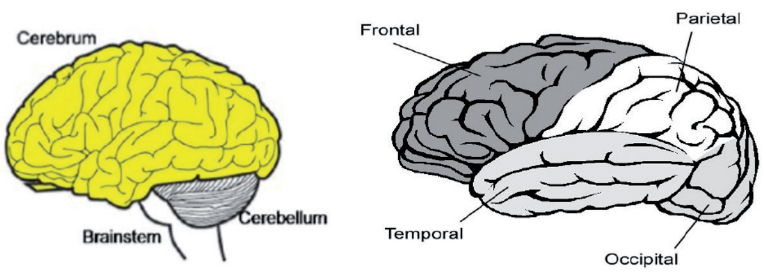


Fig. 1. a. Parts of the human brain [17], b. Cerebrum: frontal, parietal, temporal and occipital [18]

temperature, heartbeat, digestion, and to control a human's reflex movements. The last part of the brain is the limbic system which is in the middle brain. Its components include the hypothalamus, thalamus, hippocampus, limbic cortex and also the amygdala. It has functions related to the hormone testosterone, controlling homeostasis, creating senses like thirst and hunger, stimulating the desire for sex, stimulating feelings of being happy, organizing the body's metabolism and arranging long-term memory.

Neurons, which consist of soma, dendrite, and axon, function to forward electrochemical signals of sensory stimulation to the central nerve (sensory) and take impulses from the central nerve to the muscles (motoric). The electroencephalogram (EEG) is an installation tool that can record the strength of the electrochemical signal presence in the brain. In the process of an EEG recording, it can be implemented through an invasive and non-invasive way. EEG is constructed by a number of electrodes which are placed at certain points in accordance with the systemic pattern 10-20 to the scalp surface [19]. The voltage created by neurons are varied depending on a human's mental, emotional, and psychological states. EEG was chosen due to its rapid, complex pattern, and real-time recording [20]. Because of the small electrode voltage fluctuation, an amplifier was needed to read the sine waves formed. Commonly, the voltage formed has an amplitude of between 0.5μV - 100μV or 100 times smaller compared to the signal formed by the electrocardiogram (ECG) from the heartbeat. The studies on brain signal characteristics were actually started a long time ago, one of them being from Adrian and Matthews in 1934, who found that a brain signal will form a well-ordered oscillation around the frequency of 10 – 12 Hz and is known as alpha rhythm [21].

Brain signals are generally divided into 4 kinds (see Figure 2) based on the frequency recorded by electrodes adhered to the human scalp, including [20]: beta waves (>13 Hz), alpha waves (8-13 Hz), theta waves (4-8 Hz), and delta waves (0.5-4 Hz). Delta waves are brain waves which were formed when a human sleeps soundly. They are slow waves, brain waves with a low frequency being very mild, and systematic like drum beats. These waves are generated in the deepest meditation and dreamless sleep. Delta waves suspend external consciousness and are the source of empathy. Healing and regeneration are also stimulated in this condition, that is why a very deep restorative sleep is essential in a healing process. Theta waves are experienced by humans during light sleep or meditation. They will rise when someone is experiencing emotional stress due to frustration or disappointment. Theta brain waves happen the most often during sleep but also dominantly happen during deep meditation. Theta is the gateway to learn, remember, and intuition. In these waves, our senses are drawn from the external world and focused on internal signals. This is a condition which is often experienced in a glance the moment we wake up or fall asleep. In theta waves, we are in a dream; vivid imaging, intuition, and information from outside the man's normal consciousness. Alpha waves happen during the moment of waking up and during resting moments without any thoughts in mind. Alpha brain waves

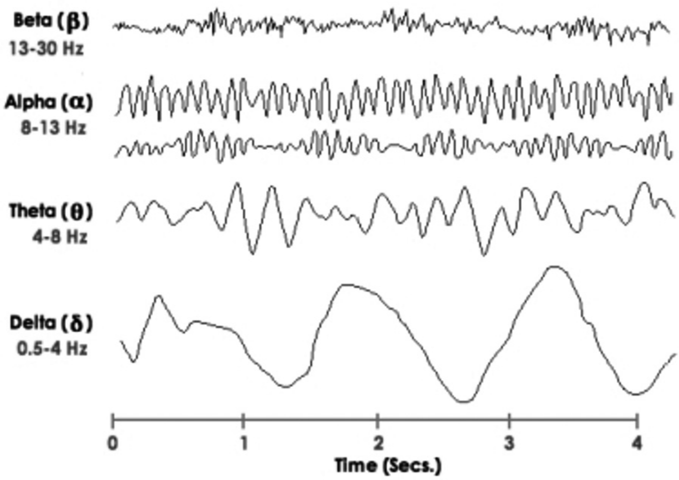


Figure 2. Four kinds of normal brainwave in the electroencephalogram (EEG) [22]

are dominated by the condition of a calm mind and in certain meditative conditions. Alpha is the resting condition for the brain. They help in coordinating the mental state thoroughly, calmness, alertness, and mind/body integration and study. Beta waves are brain signals generated by human activities which involve thoughts over specific things. They dominate a human's consciousness in a normal situation when it is being directed to cognitive tasks from the external world. Beta are 'quick' activities, present when man is alert, attentive conditions which include problem-solving, judgment, decision-making, or focused mental activities. Therefore in the case of driving activities, which are full of thought, the level of stress is included in this kind of waves.

EEG shows a good correlation with mental pressure in terms of alpha waves suppression and theta waves increase. Alpha waves are more active in occipital and frontal lobes areas. These waves are related to the brain's laziness. Thus, in stress-free condition, when the brain is not doing any activity, alpha waves are dominant. In a situation full of pressure, the decrease in the alpha waves strength indicates a shift in the underpressure response. Beta waves show varied behavior with different frequencies in different parts of the brain, and the strength in the theta waves rises under exposure to stress and mental tasks.

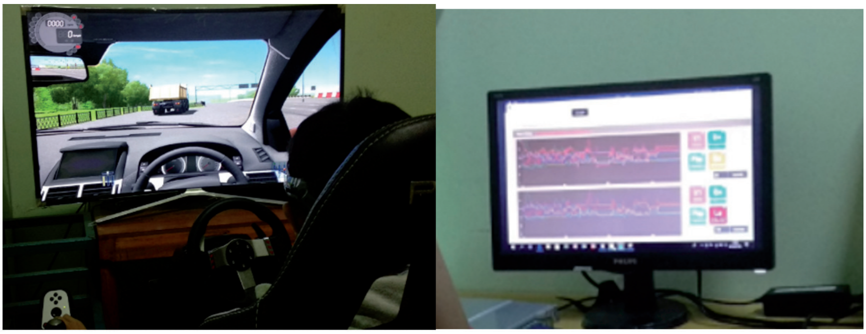
METHODOLOGY

This research is aimed at recording brain signals which picture the drivers' psychophysiological load in relation to the complex situation of different roads, namely city roads, rural roads, and motorways. This recording of brain signals was conducted using electroencephalogram (EEG), the type of Electroencephalography (EEG) which provides a way where we can access and record nerve activities required to detect the emotional condition. Generally, EEG temporally records brainwaves in certain electrodes [23]. The use of brain electrical activities as an indication of emotions has become more popular since it does not require physical efforts from the user. For the last few years, EPOC has been used more and more in numerous fields of study. An EPOC can detect the thoughts, feelings, and expressions of the user by seizing the brainwaves generated by the user itself. The waves received through the headset were then transferred to a computer through a wireless dongle USB. The electrodes in an EPOC must be dampened by a salt solution, which also acts as the disinfectant, provided in the EPOC kit. The data were constantly gathered by EPOC. Afterward, the data were then changed into digital data transmitted wirelessly into the dongle USB. The post-recording software known as Emotiv EmoEngine exposed the Emotive detection results to API Emotiv and Emotiv panel control. The panel control showed the battery level, the waves quality, and status of the system. It also provided Graphical User Interface (GUI) to EmoEngine through API Emotiv and demonstrated the EmoEngine's ability. The EmoEngine also provided options of built-in detection suites, including Expressiv, Affectiv, and Cognitiv suites.

In this research, the recording of brain signals used the recording tool Emotiv Channel 5 as seen in Picture 3a. The first step is to assure that the electrodes were lubricated with an intermediate liquid to enable it to read signals optimally. Then the electrodes were placed upon the respondents' heads, specifically on the scalp, therefore hair must be considered as a barrier factor. These electrodes worked with the Emotiv 5 channel and were functioning at a number of points on the forehead: points AF 3 and AF 4, on the temples points T7 and T8, and on the rear head at point Pz (see Figure 3b). The color green marks the electrodes ready to be used by delivering good signals, the color black indicates there was no signal while the color orange indicates there were brain signals, though weak ones.

After setting up the EEG – electrodes, the next step is preparing the driving test in the driving simulation with modifications of the vehicle properties, foot pedal, gear lever just like as in real conditions. A 52-inch LCD TV screen was used to picture the road condition faced. Drivers could adjust the driving seat to

Picture 3. a. Brain signals recording emotiv tool, b. Positions of electrodes according to brain structure



Picture 4. The implementation of measuring the drivers' mental load with the ECG and the process of data observation conducted during the test

make it more ergonomic. The simulator software gave flexibility to the researcher to set the density and hazards that the drivers would encounter.

In the simulation, the respondents (drivers) would drive through 3 different road conditions, such as city roads, rural roads, and motorways. The respondents' driving experiences were varied, including < 3 years, 3 to 5 years, and > 5 years. For the motorway, the interruptions were very minor, while the city road produced a high density and other hazards would appear more often with a setting score of 60%. This was designed in order to replicate the driving situation in the metropolitan cities of Indonesia. To assure proper results in research data collection, the replication was done by 3 measurements for each road condition. There were two types of conditions experienced by the drivers which are normal and stress conditions (there were hazards along the route) the likes of thoughts to hurry due to the time limit, telephone interruptions, and other noises. The recording was started by opening Testbench™ software. The recording could be in a resting state or under any stimulation depending on the needs, the data saving could be implemented by clicking the button 'save data' which was positioned on the nottom left-hand side. Checking the signals in the frequency domain can be done by using the Fast Fourier Transformation (FFT) by clicking the FFT icon on the Testbench™ software display. Windowing FFT can be applied through the following methods: Hanning, Hamming, Hann, Blackman, and Rectangle.

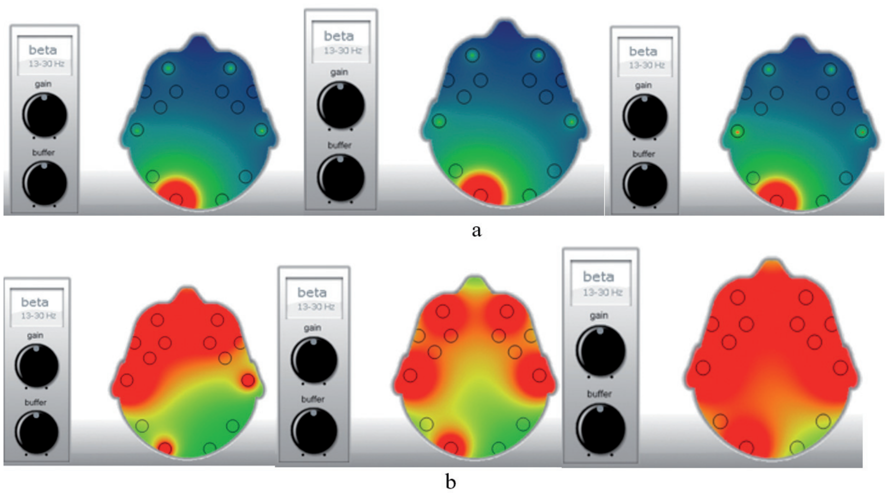
RESULTS

Analysis of the psychophysiological load experienced by car drivers under two different conditions, that is with and without distractions (noises), while driving through a rural road, city road, and motorway lanes, was measured according to the recording of non-invasive EEG Emotive 5 channels. The generated brainwaves consist of delta waves (< 4 Hz),), theta (4–7 Hz), alpha (7–13 Hz) dan beta (13–39 Hz). The EEG recording results of 3 drivers were compared with the same treatment. Each treatment was conducted three times, therefore the total running driving simulator = 54 measurements (3 replication, 3 types of road complexity, 3 respondents, 2 driving conditions). Below is the explanation of the measurements taken on the three types of complexity for the test tracks.

EEG Test on a motorway track

Motorways are a transportation route which gives flexibility to drivers to concentrate more on their driving because external distractions or hazards are pretty minor. There are no street-crossers, no stopping vehicles etc. According to the EEG measurement (see Picture 5), it can be seen that there is a slightly noticeable shift in signal strength on every event during the drive along a motorway lane. All electrodes actively take turns to give a signal to point AF3 and AF4, to the sides of point T7 and T8, and to the rear head of point Pz. As shown on the topography, the different brain areas correlate with different brain functions. Each electrode on the head scalp was positioned near to a certain brain center, AF3 and AF4 are near the center of consciousness and motor planning, T7 and T8 are for drivers' emotions and auditory, while Pz is the area of the primary visual in the brain function. Based on Picture 5a, it can be acknowledged that for the condition prevalent on this motorway lane, the brain activities are centralized on the electrode Pz, which means the Occipital/parrietal lobe is very dominant. Thus, it can be interpreted that the activity was the processing of visual data into information for drivers in an attempt to maintain their performance.

Compared to normal driving conditions, the presence of brain signals when hazards are encountered (noise) will generate a bigger voltage of brain signals. This can be seen by comparing what happens between Picture 5a and Picture 5b for all the points of the electrode either within the perspective of brain conscious activeness, the drivers' emotions, or the brain visual. Overall, it can be concluded that on the conditions of the motorway lane, drivers encountering noises will con-



Picture 5. Print screen of EEG Emotive 5 Channels on the motorway, 1st replication, and 1st driver; a. normal condition, b. encountering interference during the drive

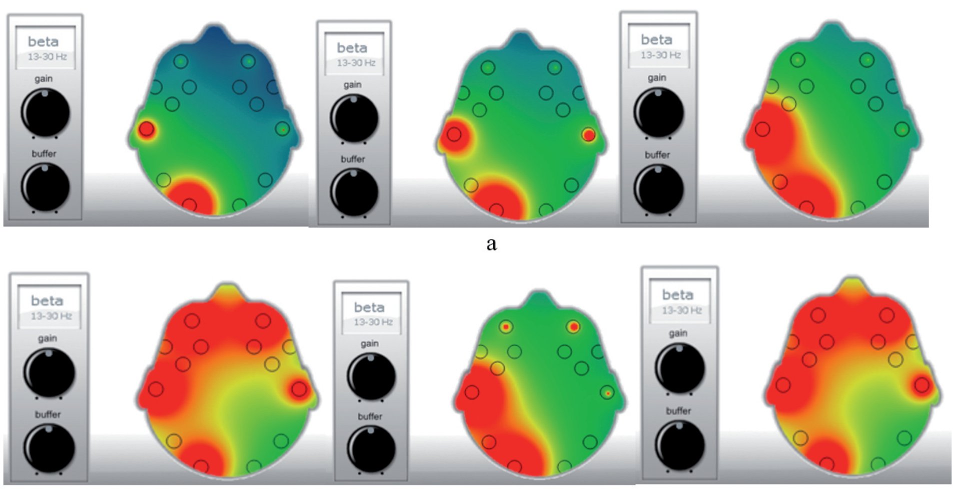
centrate on thought and hearing. While the visual is not really dominant, the fluctuation depends on the condition of the main road. Furthermore, according to the performance metrics Emotiv will experience a gradual increase between normal and stress conditions due to those interferences experienced during the drive.

EEG Test on a rural road

Picture 6a is a print screen display on the contour of EEG from respondent no. 1 in replication 1 on the lane of a rural road. In comparison to the signal strength of drivers on the motorway lane, drivers on the rural road generated stronger signal energy for all the points of the electrode. Yet, in more details, the signal strength in this track within some measurements show that electrodes T7 and T8 have a high rate of activeness compared to those on the motorway. It can be concluded that brain activity on a rural road is the temporary part for **memory** in driving rules and a part for **visual** to interpret the driving situation. Meanwhile, the stress condition given to drivers on the rural road has an increase in every point of the electrode of the brain signals recording. Being almost similar to normal condition, the active points in the stress condition are the front and side parts of the brain, the red side of the brain is not really dominant (the visual part), see Picture 6b.

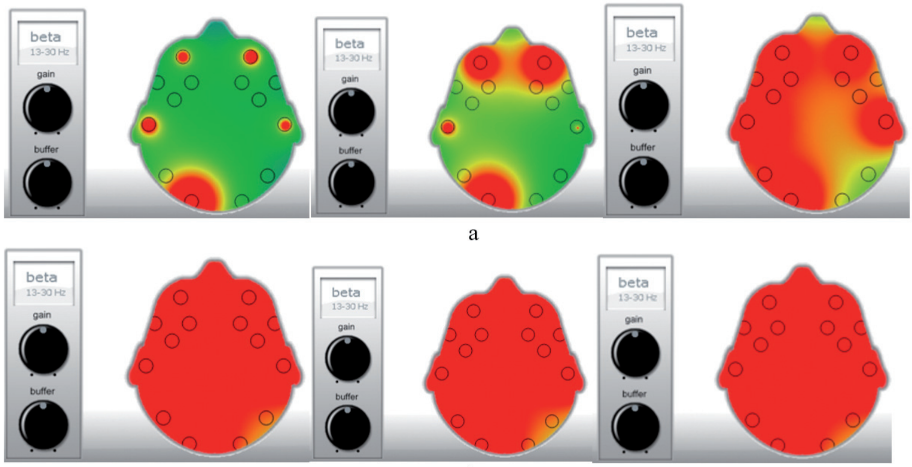
The EEG Test on a city road

A city road with its characteristically more complex lanes, many hazards, and rules of driving surely generates different perceptions and mental loads compared to the ones generated on the lanes of motorways and rural roads. As seen in Picture 7a and 7b, it can be understood that electrodes create stronger energy than other tracks. From the colors of the electrodes, it is shown that all electrodes have an active role in encouraging the drivers' performance. The brain functions



b

Figure 6. Print screen of EEG Emotive 5 Channels on a rural road, 1st replication, and 1st driver; a. normal condition, b. encountering interference during the drive



a

b

Figure 7. Print screen of EEG Emotive 5 Channels on a city road, 1st replication, and 1st driver; a. normal condition, b. encountering interference during the drive

simultaneously in understanding the visual condition of the track to be utilized as the basis of an action plan that needs to be decided on by the drivers. Thus, in this condition of the track, the role of the electrodes Pz, AF3, and AF4 is very dominant. while for the brain function of memory, it is almost the same with the conditions prevalent on the rural road (T7 and T8). For stress condition, Picture 7b vividly depicts the significant heightening of the brain signal energy, wherein it is the highest compared to other experiments. In addition, Picture 7b in its details may be understood as showing that driving on the lanes of a city road requires the most optimum of brain functions in terms of thinking ability, emotion, and visualization in driving. On average, the brain works more optimally in visualization, to observe the more complex conditions occuring on the route.

EEG Performance Metrics

EEG performance matric with Emotiv tools can be displayed in some dimensions, these being: engagement, excitement, interest, relaxation, stress, and focus. The engagement is the current level of the respondents' immersion. The focus is the measurement of the respondents' constant attention toward one specific task. It maintains the depth of attention as well as the frequency which distracts the respondents' attention in between the tasks. The high rate of distraction is an indication of poor focus and interference. Interest is the rate of reluctance toward the respondents' current activities. A score of low interest shows a strong reluctancetowards certain tasks, the high-interest score represents a strong affinity to the tasks, while mid-range score indicates that the respondents are interested in or are not interested in the activities. The interests are related to the respondents' excitement toward the current tasks. Relaxation is the measurement of the respondents' ability to turn themselves off and let them take a rest from the intense concentration. A trained meditator would achieve a very high relaxation score. Stress is a measurement of the respondents' rate of comfort with the current task. A high level of stress can be caused by the inability to accomplish a difficult task, feeling overwhelmed and afraid of the negative consequences of failing the task requirements. Commonly, low to medium level of stress can increase the productivity, while a high level of stress tends to destruct and potentially cause long-term consequences for the respondents' health and welfare.

The graphics in Picture 9 a and b depicts the difference in the average performance metrics for categories of stress and focus levels while driving through normal condition and a condition with noise (interference) on 3 different lanes. For the levels of stress, there is a sequential value increase among the motorway, the rural road, and the city road. This is in line with the measurement results using heart and subjective NASA TLX methods. On the contrary, for the levels of focus, there is a sequential decrease started from the motorway, rural road, and city road, as the lowest. The condition of the drivers' experiencing of interferences will significantly heighten the levels of stress and will lower the drivers' alertness ability. Specifically, the level of alertness on the city road has a very significant decline on the performance metrics scores, here as much as 20.

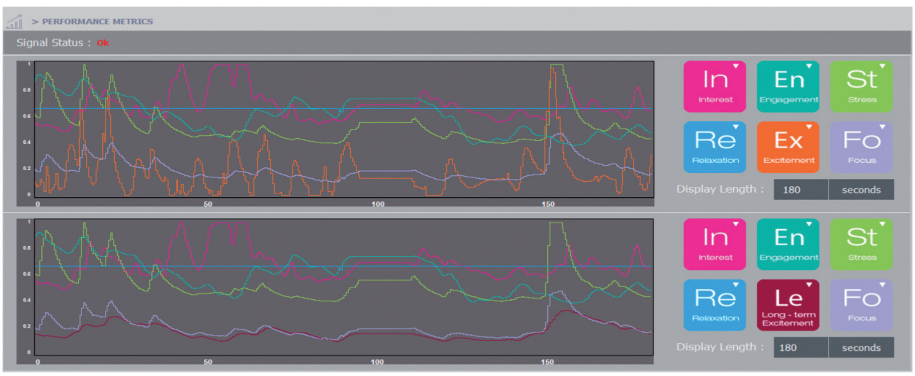
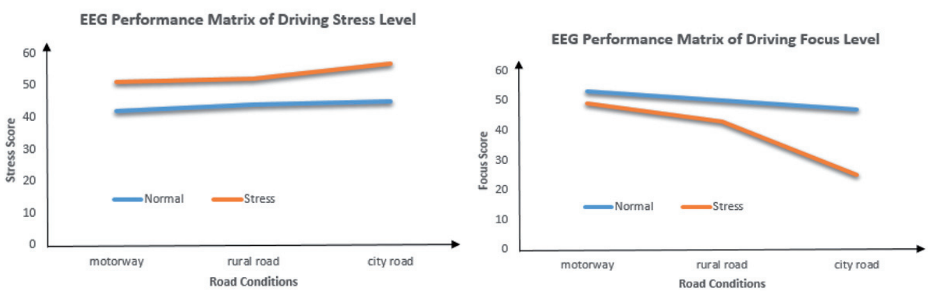


Figure 8. An example of performance metrics as a result of EEG Emotive 5 Channels measurement, 1st replication, and 1st driver in stress condition driving through a city road



Gigure 9. A comparison of the stress level and focus level in 3 different lane conditions on the drivers' situation with and without interference

DISCUSSION

The complexity of the lane situations will increase the drivers' level of stress related to maintaining their driving performance. In this research, the increase in anxiety, the increase in efforts, and the increase in interference will strengthen the brain signal strength for all kinds of waves, especially beta waves, and in agreement with the statement made by Lal S.K.L. and Craig A. (2002) [24]. This research suggests that when beta waves occur actively during a lengthy period of time with strong brain signal wave energy, the period of rest, according to microgenetic theory of brain functioning [25] must be considered before the subject gets tired. The continuous condition will cause an increase in mental stress and potentially has consequences for the decline in driving ability and often causes traffic accidents.

CONCLUSION

Based on the results of brain signal measurement, it can be stated that Eeg can be used optimally to picture the levels of drivers' mental stress. The difference in lane-situation complexitywill generate different values, wherein the city road has the highest level of stress followed by the rural road and the motorway. EEG is able to show the way drivers' brain functions in coping with difficulties in traffic, either relating to the visual, decision making, hearing, or responding toward environmental interference. The results of the experiment indicate that interferences such as a telephone ringtone and the thought to rush due to the time limit are very significant in affecting the jump in brain signal strength, thus a level of stress and physical fatigue occur faster. To enhance the production of a safe driving alarm, the combination between information of NASA TLX, heart rate, and brainwaves is essential to be considered for any input system to be constructed.

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