A Novel Approach to Road Accident Mitigation through Determination of Time to Rest on Monotonous Roads

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Abstract - Human errors caused by fatigue is the major cause of traffic accident on highways, especially in the monotony environment. The primary factor that leads to fatigue is sleep deprivation which causes drowsiness. When driving in a monotonous environment (containing highly repetitive, predictable stimuli), drowsiness can worsen with driving duration. This problem can be overcome by taking a break (rest) when fatigue arises while driving. The aim and novelty of this study is to determine time to rest while driving, with regard to the impact of circadian rhythm and sleep restrictions. The subjects in this study are classified as morning and afternoon types. They experienced two sleep restriction treatments - less than 5 hours, and 5 to 7 hours the night before the experiment. Subjects were asked to drive using a driving simulation for 40 minutes in a monotonous road while measuring the level of drowsiness through EEG. The results of this study recommended to rest before the 26th minute if the subject sleeps less than 5 hours, and before the 31st minute if the subject sleeps 5 to 7 hours.

Keyword - fatigue, monotony, drowsiness, time to rest, sleep deprivation, sleep restriction, circadian rhythm

I. INTRODUCTION

The World Health Organization (WHO) stated that approximately 1.2 million people die from road accidents, 50 million people suffer injuries each year and one person dies every 25 seconds [1][2]. According to the WHO’s data, in 2012, deaths worldwide for people aged 19 to 29 years old were mostly due to road accidents, followed by suicide and HIV / AIDS [1]. The WHO’s report in 2015 also stated that people aged 15 to 44 years old dominate the global traffic mortality rate of 59% [3].

Road accidents can be caused by human factors, vehicles, and the environment - including road conditions [4]. Of all these factors, the biggest cause of road accidents (up to 93%) is human error [5]. One of the main causes of human error when driving is fatigue, which is the cause of 60% of accidents [6]. 16 to 23% of road accidents in the UK are related to fatigue experienced by drivers [7]. Another studies said 20-30% of deaths on roads in New South Wales, Australia, were caused by fatigue [8]. Therefore, it is necessary to mitigate the risk of accidents due to driver fatigue in order to reduce the number of road accidents.

Fatigue is caused by three main factors – circadian influences, sleep homeostasis factors of sleep loss and time since last sleep, and specific types of task characteristics, which lead to deteriorating performance [9]. The condition of a drowsy driver due to sleep deprivation is a sign of fatigue and it cannot be ignored. Sleep deprivation leads to fatigue which worsens reaction time, perceptual abilities and cognitive abilities [10]. Drowsiness due to sleep deprivation had an impact on deteriorating work performance and require sustained attention.

Increased driver’s drowsiness can be caused by road conditions that tend to be straight, monotonous and have little traffic [11]. Another study also found that drowsiness contributed to 23% of accidents that occurred on deserted and monotonous roads [12]. Driving on a monotonous road caused passive fatigue, which is fatigue due to the demands of driving itself [13] [14]. Monotonous roads affected the driver's psychological condition through reducing the level of vigilance and alertness of the driver [13] [15], impaired driving performance [16], contributing to physical and mental fatigue and increasing the risk of accidents [9]. Monotony is generally defined as an objective task-related characteristic that is associated with an environment that is unchanging or that change in a repetitive or predictable way [17].

One way to overcome impaired performance due to fatigue is rest [9]. Fatigue caused by work could be overcome by improving how to do the work but fatigue caused by sleep deprivation can only be overcome by rest or sleep [18]. Rest is not always accomplished by sleeping, but can be achieved by stopping work for a short period [9]. Based on the relationship between drowsiness, performance degradation and rest, this study aimed to determine the time required to rest for the driver to overcome the degradation on driving performance due to drowsiness caused by sleep restriction and monotonous road conditions. A further aim was to reduce the risk of road accidents due to drowsiness.

II. LITERATURE REVIEW

Studies that have been performed previously showed that fatigue could interfere with, or damage, the person's driving performance [9]. Fatigue decreased attention, response and...
the ability to assess the condition of the surrounding environment so that decision making was inaccurate and led to accidents, especially in risky working conditions [19]. Fatigue also reduced alertness, slowed response time, caused difficulties in making decisions, and increased errors [20].

Fatigue became a major contribution associated with the accidents, injuries, and death. It was caused by three main factors, namely the time of day (associated with circadian rhythm), homeostasis factors of sleep loss and time since last sleep, and task-related factors (task characteristics or conditions) [9]. These three factors caused fatigue that led to the impaired performance of the driver. The relationship between fatigue and safety is shown in Fig. 1.

One indication of fatigue is drowsiness (or sleepiness in Fig. 1) which can cause a person to fall asleep. When the driver had difficulty to wake up (drowsy) then he also had difficulty to pay attention or focus on driving, especially during monotonous driving conditions. This leads the driver to react slowly and might cause him to miss the information he needs from the environment [21]. In long-duration driving conditions, the majority of drivers reported slow reaction, poor performance when changing speed and steering, and driving too slowly when tired [22] [23]. One cause of drowsiness is sleep deprivation, which is exacerbated by monotonous road conditions while driving. In some studies, rest can be a solution to overcome drowsiness [9] [24].

Rest significantly affected the occurrence of accidents in driving, by up to 83% compared to those who did not rest [24]. Rest was not always defined by sleep, but also by a pause from work [9]. Time to rest must be adjusted according to the nature and type of work, duration of sleep, circadian rhythms, and environmental factors such as temperature, noise, etc. By resting, our body has the opportunity to restore the energy that was used previously.

A 15-minute rest after driving for 2 hours and at least 30 minutes after driving for 4 hours was suggested to mitigate fatigue [25]. The duration of rest could be divided into several parts, with the same total time if the rest is done at once [26]. The total recommended rest time is 1.5 hours for driving 8 to 9 hours. For more than 9 hours driving, there was no research that determines the total time of rest required. Another study used rest periods ranging from 15 minutes to 2 hours, divided into 3 parts, with the total driving time observed for 11 hours [24]. Nevertheless, from the literature review that has been done, so far there has been no research that determines the required time to rest, especially for drivers who had experienced sleep deprivation and driving on monotonous roads.

III. MATERIALS AND METHODS

Eight young healthy male subjects volunteered for the present study in response to advertisements displayed at local universities. The subjects were between the ages of 18 and 25 (M= 21.8, SD= 2.6) years. The subjects were nonsmokers, did not regularly consume excessive quantities of caffeine (<350 mg/day), did not consume alcohol, and exercised regularly. In addition, they reported no history of health or sleep problems, did not habitually nap, and had not undertaken shift work or transmeridian travel in the past month. All of the subjects gave their written, informed consent.

Before starting the study, the subjects filled the Morningness-Eveningness Questionnaire Self-Assessment (MEQ-SA) to find out their circadian type. There were 4 subjects with morning type and 4 subjects with evening type. On the night before the study, each subject had two pre-conditions for duration of sleep i.e less than five hours, and between 5 to 7 hours. As can be seen in Fig. 2, all of the subjects were required to attend at the laboratory at 08.45 a.m. Before using a driving simulator, levels of drowsiness (sleepiness) for each subject were measured subjectively using the Karolinska Sleepiness Scale (KSS). During driving on monotonous roads, subjects used the electroencephalograph (EEG) to measure the level of drowsiness based on brain wave activity (Fig. 3). Electroencephalograph (EEG) is one of the measuring instruments used for the continuous monitoring of fatigue - a technology that continuously monitor the correlation of physiological condition with fatigue during work [6].

IV. RESULTS AND DISCUSSION

The output of EEG was a graph which reflects the continuous movement of brain waves from time to time. The results were processed to obtain a value or a number that can be understood by using the MATLAB R2009a software. There were 16 connections attached to the scalp (Fig. 4), which consisted of 14 measuring points and 2 points of reference (CMS and DRL). In this study, there were eight points (frontal lobus) of measurement used (AF3, F7, F3, FC5, FC6, F4, F8, and AF4). The frontal lobus was selected because a high level of brain activity takes place in this part and this lobus controls cognitive activity.
The data from the EEG recording were then filtered into 4-30Hz. Data was filtered to throw waves with frequencies that are not needed or outside the 4-30 Hz frequency. Furthermore, the data were analysed by grouping the frequency adjustments based on the three components of the frequencies used in the study i.e theta (4-8 Hz), alpha (8-13 Hz) and beta (13-30 Hz). Results of the EEG recordings were divided into several observation points. In this study, experiments were conducted for 40 minutes and were divided into 40 observation points, where each point represents a 1-minute observation time of the experiment. The block division experiment aimed to see the changes that occur in all respondents to the observation time. The next stage is to calculate the ratio value using Equation 1 [27].

\[
\text{theta (θ)} + \text{alpha (α)} \over \text{beta (β)}
\]

(1)

The ratio calculation was calculated for all treatments and for each observation point, as well as to the average value of each wave for the 40-minute experiment. The mean ratio of 40 observation points was used for ANOVA and the rate per minute was used for determination time to rest (see Table 1).

Analysis of Variance used in the study was a split plot design (mixed design ANOVA). Both factors used in the study were circadian rhythm factors (evening type and morning type) and sleep duration (less than 5 hours and between 5 to 7 hours on the night before the study). The response was the level of drowsiness (ratio), as seen from the value of the mean ratio of 40 observation points. The entire ANOVA test was performed at a 95% confidence level (α = 5%). Based on the data from Table 1, ANOVAs indicated that sleep duration \([F(1,6) = 10.8266, p < 0.05]\) had significant effects on the level of drowsiness. However, the circadian rhythm type \([F(1,6) = 0.0126, p < 0.05]\) and their interaction \([F(1,6) = 1x10^{-5}, p < 0.05]\) did not significantly affect the level of drowsiness.

### Table 1. Mean Ratio of Drowsiness Level for 40-Minute Experiments

<table>
<thead>
<tr>
<th>Subject</th>
<th>Circadian Rhythm Type</th>
<th>Drowsiness Level (Ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sleep duration &lt; 5 hours</td>
</tr>
<tr>
<td>2</td>
<td>Evening</td>
<td>1.1737</td>
</tr>
<tr>
<td>4</td>
<td>Evening</td>
<td>1.3706</td>
</tr>
<tr>
<td>1</td>
<td>Evening</td>
<td>1.2739</td>
</tr>
<tr>
<td>3</td>
<td>Evening</td>
<td>1.3649</td>
</tr>
<tr>
<td>5</td>
<td>Morning</td>
<td>1.4195</td>
</tr>
<tr>
<td>8</td>
<td>Morning</td>
<td>1.2844</td>
</tr>
<tr>
<td>7</td>
<td>Morning</td>
<td>1.1612</td>
</tr>
<tr>
<td>6</td>
<td>Morning</td>
<td>1.2947</td>
</tr>
</tbody>
</table>

#### A. Sleep Diary and Karolinska Sleepiness Scale (KSS)

A sleep diary and the Karolinska Sleepiness Scale (KSS) were filled prior to driving. A sleep diary is useful for checking the quantity of sleep of the participants on the night before the data collection is done. The objective is to determine whether or not the quantity (duration) of sleep is according to predetermined schedule. This is done by giving the subjects questions when they began to sleep on the night before the experiment and when they woke up in the morning. Based on the data that have been collected, it can be concluded that all sleep durations the night before the study met the requirements and were in accordance with the schedule that has been made.

The Karolinska Sleepiness Scale (KSS) is useful for checking the level of drowsiness shortly before driving. The KSS is a subjective drowsiness (sleepiness) level measurement with a grading scale of 1 (highly alert) to 9 (very sleepy). The KSS will be filled by the subject each time data retrieval is done. Based on the results of KSS that
have been collected, it can be concluded that subjects who slept less than five hours on the night before study gave the assessment KSS higher scale than those who had slept between 5 and 7 hours.

A comparison of the results from the KSS with the brain wave measurements performed by EEG, showed that they are similar or aligned. The EEG showed that subjects who slept less than five hours had a level of drowsiness greater than those who slept between 5 to 7 hours.

B. Determine Time to Rest

The first step in determining time to rest is to calculate the mean ratio of each point (minute) of observation for all treatments. Mean ratio is divided into two categories, i.e mean ratio for a sleep duration of less than five hours and between 5 to 7 hours. Based on the results of ANOVA, the circadian rhythm does not affect the level of drowsiness. Therefore, whether a subject is in the category of morning or evening type, will not affect the level of drowsiness.

Time to rest is determined by calculating the percentage change from the mean ratio per minute to be able to see changes in the level of drowsiness experienced by subject every minute. An increase in the percentage of mean ratios shows a change in drowsiness conditions experienced by the subject. The higher this percentage, the greater the changes in drowsiness level. This also indicates a deteriorating performance that leads to accident. Change in the percentage of drowsiness level can be seen in Fig. 5 and Fig. 6.

As shown in Fig. 5, the highest percentage increase for a sleep duration of less than 5 hours occurs at the 26th minute (13.55%) so that a rest time is recommended after 25 minutes of driving (if only based on the highest percentage increase). Nevertheless, the percentage also increases quite high at the 15th (10.85%) and 18th (9.51%) minute. This indicates that subjects who sleep for less than 5 hours can potentially experience changes in drowsiness level that are quite drastic even at the driving duration which occurs for only 15 minutes. This should be a serious concern for the driver if he will drive in a state of sleep deprivation (less than 5 hours of sleep duration) and monotonous road conditions.

At 5 to 7 hours sleep duration (Fig. 6), the highest percentage increase in drowsiness occurs at 31st minute (12.67%). It can also be seen that before 31st minute, there is a fairly high increase in the percentage of sleepiness at 24th minute (9.13%). It is recommended that time to rest should be done in the 30th minute or previously. However, the percentage increase in drowsiness during a sleep duration of 5 to 7 hours is still lower than for a sleep duration of less than 5 hours. This is in accordance with the hypothesis and theory which states that sleep deprivation will make the level of drowsiness higher. Again, this emphasizes the importance of time to rest earlier (15 minutes) in sleep deprivation conditions compared to adequate sleep conditions (5 to 7 hours).

V. CONCLUSION

Time to rest is one alternative solution to minimize the risk of accidents due to a decrease in performance of drivers who have sleep deprivation and drive on monotonous roads. The results of the study showed circadian rhythm had no effect on drowsiness levels, nevertheless sleep duration had a significant effect. Circadian rhythms that have no effect on drowsiness levels may be caused by the small number of subjects involved in this study. However, from the results of the measurement of drowsiness level it can be concluded that for a sleep duration of less than 5 hours, time to rest should be carried out in the first 15 minutes of driving or no later than the 25th minute. At 5 to 7 hours of sleep, time to rest can be done at the 30th minute or earlier.

REFERENCES


