Fatigue from driving – a comparison between morning and afternoon tasks

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Abstract— Various studies have linked the effects of time-of-day on fatigue, as indicated by performance decrement and increased risks of error. Such is the phenomena in the transportation industry, in which higher accident rates occur at certain times of day. This study examined driver’s fatigue following morning (E1) and afternoon (E2) driving tasks performed using a driving simulator. Nine male university students (aged 20-22 years old) participated in this study, and were asked to drive for 60 minutes (in random fashion) between 9-11 am and 3-5 pm in a very dense traffic conditions. Fatigue was assessed by measuring changes in blood pressure, heart rate, salivary amylase, and ratings of sleepiness and fatigue. Findings from this study generally indicated that driving for 60 minutes was sufficient in inducing fatigue phenomenon. It also confirm the relationship of sleepiness with fatigue driving, and other physiological changes during experiment. Furthermore, driving in late afternoon could result in greater increase in fatigue when compared with the same tasks performed during morning hours. This study suggests taking times of day into consideration when managing and scheduling driving jobs.

Keywords— Driver fatigue, time-of-day, sleepiness, KSS

I. INTRODUCTION

Fatigue is still an interesting area to investigate, and various topics such as its causes, mechanisms, evaluation methods, and the effects on performance and safety are still open for discussion. In Indonesia, fatigue has been linked to many road accidents. The data show that there are nearly 32,000 accidents involving motor vehicles annually in 2012, resulting in 15% fatalities as higher number over the past 10 years [1].

In transportation, area where a road safety in being everyone's concern, accident cause by fatigue drive government to formulate a regulation related to working hours, driving duration and break time. In Indonesia the road accident is still very high and enhances understanding about driver fatigue is needed.

Though the road transport regulation to prevent fatigue for driving job is available in Indonesia, there is no formal study on how many accidents are caused by fatigue. In many countries, as reported by Radun and Radun [2], official statistics regarding fatigue-related accidents are missing because only some of them are reported. Nevertheless, police reports generally indicate fatigue and human error as major factors. A number of studies also mention fatigue (and sleepiness) as an important factor associated with many road accidents [3].

Driver fatigue and sleepiness can be caused by sleep- and task-related factors. Sleep-related factors include sleep deprivation or time of day (circadian rhythms). Examples of task-related factor are workload during or before driving, including primary and secondary tasks carried out by the driver [4]. High workload can cause excessive fatigue; in contrary, low workload can lead to monotonous situations that are associated with fatigue and sleepiness. Both conditions can cause a decrement in attention and/or driving performance [5].

In the transportation industry, work in shifts is a common practice. It is common to start driving in the morning hours or in the afternoon. The latter time, however, could mean that an individual has already been up (or performing activities) for a number of hours before doing the assigned job.
In some studies, differences in the time of day have been noted to contribute to fatigue [6] and are associated with reduced performance in driving [7]. Additional factors that are also important include the number of sleep hours in the preceding nights [8] [9]. Investigating these factors can help in understanding how each of (or groups of) the factors actually affects the intensity of fatigue and sleepiness during driving jobs.

Several literatures propose indicators and parameters that can be used to evaluate fatigue, including changes in heart rate, brain wave, muscle movement, eye blinks, and biochemical status [10] [11] [12]. These indicators are often simultaneously used with subjective tools, such as motivational and behavioral change, sleepiness and stress level, or perception of performance [13]. In driving, evaluating fatigue by utilizing certain technology is sometimes too difficult for practical reasons [2] and, therefore, the use of subjective tools is more preferable (and often used as a primary measurement tool). Subjective technique may include simple Visual Analogue Scale (VAS), or in the form of more complex sets of questionnaires [13].

As mentioned earlier (and also reported in a number of studies [7] [14]), driving jobs performed under different times of day is associated with differences in fatigue levels. The effects, however, have not been widely quantified. Moreover, it may influence levels of stress and, to some extent, could affect the quality of working life [15]. The aim of this study was to investigate if driving in different times of the day resulted in differences in fatigue and sleepiness. Since stress may also accompany fatigue and sleepiness while driving, relevant indicator of stress was also measured.

II. METHOD

A. Participants

A total of nine male university students (aged 20-22 years old) were recruited in the study. Their average sleep duration at night is 5.7 hours in the previous 5 days. All participants had a driver’s license and had driving experience for at least a year. They received training on driving in a simulator, and were allowed to practice until they were familiar with the simulator. All provided their informed consent prior to the experiment.

B. Simulator

Driving task was performed in a driving simulator equipped with a car seat, a steering wheel, gas pedal, brake pedal, clutch, and turn signal (Logitech G29). The software used was City Car Driving Simulator v.1.4. It allowed to drive in the city and/or highway road with various weather and time setting (day or night) conditions. Choices of different traffic densities and driver behaviors (normal to aggressive) were also available. A computer display was placed right in front of the car seat that displayed virtual driving environments.

C. Experiment Procedure

Each participant was requested to drive in two different (randomly assigned) sessions. The morning session was from 09:00 AM to 11:00 AM, while the afternoon session was from 14:00PM to 16:00PM. The tasks involved driving for one hour, during which the average speed was 25 km/hr. There were circumstances where driving stopped for a few minutes due to traffic jam. During experiment simulator software sets to day time with city route and highway scenario, 80% traffic density, and clear weather (no rain, cloud or fog). This scenario is apply for both.

Participants allowed to do their normal activity before the experiment. The room temperature was around 22.5°C and light intensity in a constant rate at 215 Lux. Before the experiment, whole procedure and instruction was explained to all participants. They also asked to rate their fatigue level subjectively 1-10 scale, 1 for having no feeling tired at all and 10 for feeling very tired and really need to stop the activity and have a rest.

Fig.1. Blood pressure measurement, driving in simulator, and salivary amylase test
Participant’s sleepiness scale was rated using Karolinska Sleepiness Scale/KSS (1-9) as one of validate instrument to measure self report fatigue or sleepiness [6]. Researcher explain the interpretation of each scale to participants, and asked which is suited to the conditions of participants, such as 1 for extremely alert, 9 for very sleepy, great effort to keep awake.

Blood pressure was measured using automatic wrist blood pressure monitor Omron-HEM 6200, and salivary amylase tested using nipro cocoro meter. Number sleep hour at night before the experiment is also documented. The driving task performed on the simulator for 60 minutes without a break under city and highway road environment. A participant asked to try their best to avoid car accidents during the experiment, and they didn't allow talking or discussed with the researcher. After driving task finished, all tests also carried out.

D. Analysis

Collected data was analysed repeated measurment ANOVA to see whether the differences exist between morning and afternoon task, and between before and after experiment. Correlation analysis also conducted to examine how each data correlated to fatigue subjective score using simple regression linear. Both statistical analysis is used as basis to explain how fatigue driving experienced in the morning and in the afternoon.

E. Boundary of study

This study design as within subject experiment. All participant. The design is chosen because within the subject is believed can is have more power and can reduce error variance associated with individual differences. To minimize the carryover effect, experiments conducted in random fashion. Research variable that investigates in this study are change of biochemical condition represent by salivary amylase and physiology aspect measure by automatic wrist blood pressure monitor after the experiments. Other variables that also include in these experiments are perceived fatigue and sleepiness.

III. RESULT

A comparison sleepiness level before and after each experiment from nine participant (E1 = in the morning, and E2= in the afternoon) show at Fig.2. It can be seen sleepiness each participant increased after 60 minutes driving session for both experiments. The lowest sleepiness scale before experiments is 3 (alert) and the highest is 5 (neither alert nor sleepy). Sleepiness score after the experiment is 2 (very alert) as the lowest one and 8 as the highest (sleepy, some effort to keep awake). The average increasing in the E1 is 2 levels and 3 levels in the E2. Furthermore, analysis on the KSS data revealed a significant result that driving 60 minutes affected to increasing KSS score for both experiments (p 0,05), the increasing was between 20%-50%.

On the Fig.3, fatigue scores each participant as a result of E1 and E2 (before and after) can be found. At present in the graphic below (Fig 3.) all participants reported an increasing level of fatigue after experiments. The highest increasing was experienced in E2, it raised 4 levels (participant 9). On average, fatigue level scores increase 2 points for both experiments. To be considered, self-fatigue rate before the experiment is higher in the E2 compare to E1. Additionally, analysis on the data yield p value 0.05, and confirm the differences in fatigue level after 60 minutes driving for both experiments (10 %-30%).
Correlation analysis between sleepiness level (KSS score) and the fatigue subjective score is generated coefficient correlation of 0.45. It can be concluded that sleepiness sufficiently correlated with driving fatigue.

The measurement result of salivary amylase shows at Fig. 4. below. In line with the result of two measurement mentioned above, salivary amylase was increased. Salivary amylase is experiencing signs of stress [16], and it proposed as one of fatigue biomarker index [12] [17].

As can be seen in Fig. 4. salivary amylase of five participants was higher after the driving session finished (6.2%-8.1%). Although further analysis showed the increasing is not significant, the driving session induced this phenomenon and stress is suggested to use along with other measurement in fatigue evaluation.

Further analysis is conducted to see whether the correlation between subjective fatigue score is available. Through simple regression, linear, correlation coefficient between two data is 0.213. This correlation is categorized as weak correlation, although both data give consistency results when comparisons between morning and afternoon conducted.

Other physiology measurement also conducted in this research, a blood pressure (diastolic and systolic) measurement and heartbeat. Interesting results show by diastolic and systolic data, they tend to decrease in E1 and the increase in E2. Blood pressure level showed a slight decline in E1 (3.7%) and a slight increase in E2 (7.3%). But, blood pressure after E2 is 5.1% higher than the value in E1, even though the value before E2 is 6.3% lower than E1. This pattern happened to 60% data on blood pressure of participants. What have to take in consideration, in the afternoon (E2) the result may also affect by time awake as compounding factors compare to E1. Data on blood pressure and heartbeat show in Fig.5 and Fig. 6.
The correlation coefficient measurement also carried on blood pressure, and it reveals that the value is higher compared to salivary amylase. The coefficient correlation of systolic between systolic and fatigue score is 0.322. Although systolic has stronger relationships, diastolic has a weaker relationship to subjective fatigue score, the coefficient is 0.13.

Correlation analysis between heartbeat and subjective fatigue score is 0.42. It can be concluded that heartbeat change has a significant correlation with fatigue. The correlation analysis showed that sleepiness level, systolic data, and heartbeat have a higher correlation coefficient compare to salivary amylase and diastolic data. This result confirms physiology change can be use to evaluate fatigue from driving. In addition, correlation analysis also carried out between each data. The result showed only correlation coefficient of salivary amylase and heartbeat is needed to be considered (0.375). The other has r value smaller than 0.002.

IV. DISCUSSION

The aim of this study was to investigate if driving in different times of the day resulted in differences in fatigue and sleepiness, and also stress level. This investigation demonstrates that 60 minutes driving induce an increasing those three aspects level either in the morning or in the afternoon. It also confirms that the differences are significant for fatigue and sleepiness level, although driving duration about 60 minutes.

The increasing level consistently experienced by all participants after the experiment, except for the salivary amylase test result (5 out of 10 participants). On the other hand, although blood pressure and heartbeat suggested as a fatigue indicator [18], measurement in this study didn’t show conclusive result compare to fatigue and sleepiness level. Other objective tools i.e EEG should consider in the further experiment to support the obtained result [10]. Compounding factor also might have effect to the result, as mention above circadian and time awake also can impact fatigue risk [7].

It should be noted that an increased risk of fatigue also related to lack of sleep in addition to duration (workload) and time of day. In this study traffic high density cause participant has to stop for a few minutes due to traffic jam. This condition more close to task-related factors rather to sleep-related factors [4], despite that the level of sleepiness, increased after the experiments, and some participants reported a needed to sleep during afternoon session. In this condition, rest and sleep is more suitable as a countermeasure to reduce fatigue compared to the stimulus.

Based on findings in this research, it is clearly shown that driving time along with the workload as the design of this study has an effect on driver’s fatigue. Some physiology data also show promising coefficient correlation with fatigue subjective score. As mention by earlier research, fatigue is caused by different factors [11] [16] and time of day, workload (in this study include duration, traffic density and rate design) also mention in many studies [7] [11] [18]. Furthermore, driving in late
afternoon could result in a greater increase in fatigue when compared with the same tasks performed during morning hours. This study suggests taking times of day into consideration when managing and scheduling driving jobs.

In safety aspect, although driving in an hour has induced fatigue, fatigue was believed to be a nonlinear [19]. It means further research is still needed to define fatigue driving in longer work hour. However, relevant research about effect of driving hour to safety show that higher accident and incident most likely to be higher when driver has insufficient break, driving is more than 4 hours, or total driving hour in a day is longer than 10 hr [20]. Fatigue countermeasures for this condition is short break or nap especially if homeostatic factors is involved [21].

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[1] Indonesian Statistics Bureau, 2013

BIography

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