Effect of Auditory Response Test on Indonesian Drivers' Alertness

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***Abstract*—Drowsiness or sleepiness while driving has been known as a cause of driver alertness decrement and has been a concern in transportation system for years. Much research has been conducted to study factors affecting alertness. Some concluded that secondary task while driving may increase alertness, whereas others informed that any other task besides driving itself might interfere with driver concentration. This study proposed an in-vehicle response test system as secondary task in driving system to maintain driver alertness status.**

Eight professional drivers were involved as participant in a set of laboratory experiment. They drove a set of driving scenario in a car simulator. The alertness status was monitored by four-channel electroencephalograph, whilst response tests were conducted using a tailor-made apparatus. This apparatus emits alarm signals, in random-time interval or fixed-time-interval. Subjects had to give response by pushing a button when signal occur. Statistical analyses were performed to analyze the effect of each of the two types of signals.

Results of this study showed that driver alertness level could be well maintained by the two response test systems. Results also suggested that compared to fixed-time-interval response test, random-time-interval response gave better performance in maintaining alertness. If applied inside a vehicle along with a sleepiness detection system, this response test would decrease sleepiness on wheel occurrence through maintaining the driver alertness level. It is expected that the results of this study supports government effort to reduce traffic accident from the human aspect.

***Index Terms*—alertness, auditory, response test, electroencephalograph, simulator**

I. Introduction

FIGURES on traffic accident in Indonesia seems to show an alarming situation. It was increasing significantly, even for the comparison of the number of traffic accident to number of vehicles operated. Data shows that during 2004-2008, the number of accident involving car-vehicle increased about 31.43%, while accident involving bus and truck increased 28.29% and 34.60% respectively [1].

Impairment of alertness while driving is considered as one of the main cause of those accidents, particularly on highways. This factor has been documented along with other dangerous behaviors leading to traffic accident while driving such as drinking, speeding, distracted driving, using a cell phone while driving, using illegal drugs while driving, and novice driver [2] [3]. Moreover, it is estimated that sleep related accidents as the effect of alertness decrement accounted for about 15–20% of traffic accidents on urban roads and motorways in the United Kingdom [4]. Data from the United State showed that impairment of alertness is responsible for 1–3% of highway crashes and about 96% of crashes involving passenger vehicles [5]. In Indonesia, a 2006 report mentioned that, there were 41 cases out of 194 traffic accident cases on the highways related to distraction in drivers' alertness in 2006 [6].

Based on the above reports, it can be stated that impairment of alertness while driving could eventually cause substantial losses, including human lives and vehicle damage. Therefore, the problem should be taken seriously and as its consequence, an extensive effort to maintain alertness should be considered. This research was conducted for that purpose i.e., to study driver's alertness as a response to auditory stimulus.

Previous research in Cognitive Ergonomics showed that auditory activity is closely related to alertness. The most common behavior in driving activity is listening to the radio and increasing its volume when sleepy/fatigue. However, some studies showed that this might not an effective solution, since instead, driver could be more sleepy [7]. Another type of auditory activity stimulus is the use of warning signal or alarm, which are considered to be more effective in alerting the drivers.

However, the issue that an additional auditory activity might interfere with the primary task i.e. driving arises. Therefore, the challenge in this study is to design auditory stimulus to provide secondary task which is able to maintain drivers' alertness without distraction from the driving task itself.

This study proposed a warning signal as the auditory activity, and referred to as a response test. This test was in Visual Basic programming language and run in a set of personal computer which is connected to an audio speaker and a push-button apparatus to function as an interface between subject and the test equipment. While driving, driver would hear warning sign from the speaker and was asked to push the button. Fig. 1 shows the proposed application of this response test.

II. Methods

A laboratory experiment was carried out to analyze the effect of this response test application on drivers' alertness. Alertness was observed by electroencephalograph (EEG), since this was the most valid measurement on human physiological system [8].

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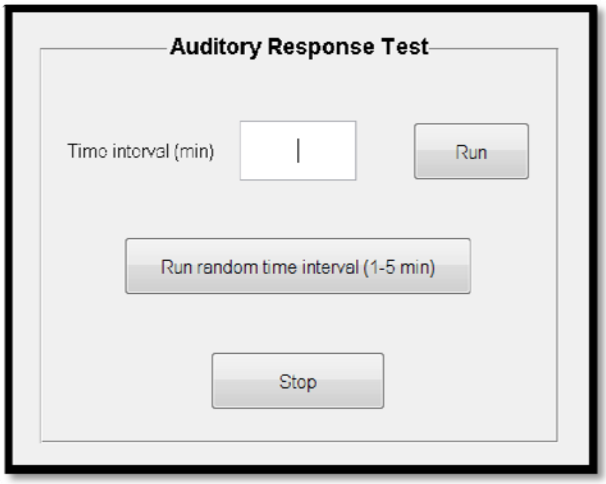

Fig. 1. Interface of proposed auditory response test.

A. Driving Simulation

A driving simulator was used in this experiment to represent real driving activity. It was built in the Laboratory for Work System Design and Ergonomics, at Bandung Institute of Technology. The hardware system used Logitech G-25™ set of pedal, steering wheel, and six-transmission gearshift. A set of personal computer, audio system, and projector were also utilized. The software system represented Indonesian highway situations, built by 3D Game Studio®. A loop route of driving was applied, with urban and suburban areas on each side of the driving route, marked by skyscraper buildings and woods, consecutively. The interface of this simulator is shown in Fig. 2.

Fig. 2. Interface of the driving simulator.

B. Alertness Measurement

Drivers' alertness level was observed by four gold electrodes of BioGraph Infiniti EEG. The standard 10-20 system was applied in attaching electrodes to frontal (Fz), central (Cz), parietal (Pz), and occipital (Oz) area of the brain, the areas which are considered to be highly correlated with human alertness and cognitive system [9] [10]. Each of those electrodes was referenced and grounded to the ear lobe. The sampling frequency applied was 256 Hz.

C. Response Test Application

Two types of response test were tested: one with random time interval (one, two, three, four, or five-minute intervals) and another with three-minute intervals of occurrence. Counterbalancing method was applied to minimize bias from the sequence of response test activity. This response test was played at 82 dB, while the environment was maintained stable at 70 dB range of sound. Reaction time of each warning signal occurrence was also measured to give further analysis on drivers' alertness. The increase in time taken to respond to the auditory stimulus (reaction time, RT), decrease in response speed (1/RT), and increase in lapses (responses $\geq$ 500 ms) were computed as these parameter were associated with decreasing alertness [11].

D. Participants

Eight male aged between 21 and 28 years old (with a mean of 23.5 years old) performed as subjects in this test. However, only six of them complete the test. All of them had more than one year experience in driving car-vehicle. Before the experiment, they were informed on the experiment procedure, their rights, obligation etc, and were asked to fill and sign a consent form. Each participant drove the simulator for one hour, consisted of half hour of random response test and another half hour of 3-minute response test.

E. Data Processing

Raw data from BioGraph Infiniti EEG were exported into text document file (.txt). Further computation was conducted in Power Spectral Density (PSD) analysis by Fast Fourier Transform method using MATLAB 2009a. PSDs data were analyzed for 27 minutes period for each of response test types.

PSD method was applied to gain theta (4-8 Hz), alpha (8-13 Hz), and beta (13-20 Hz) energy level [12]. Combination of the spectral power in these frequency bands were used to get computation of the $(\alpha+\theta)/\beta$ index, which was associated with decreasing of alertness [13] [14]. PSDs of four brain areas were averaged for the next computation.

PSDs data were also computed for several time segments to get better description on any effect of response test on driving time. Each segment represents alertness level after a response test was applied.

Several statistical tests were conducted in order to find out any effect of those two response test types over the driving time. Two-sample t-test was applied to explain the effect of different response test type on alertness level. A two-way ANOVA for within-subject design (response test type × time segment) were then computed on $(\alpha+\theta)/\beta$ index of alertness.

III. Result and Discussion

Examples of EEG data recorded is shown in Fig. 3, whereas Fig. 4 and Fig. 5 show examples for PSD data of first participant on Fz, Cz, Pz, and Oz, respectively for the 3-minute-interval and the random-interval response test.

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In the slope analysis, alertness data showed negative slope of $(\alpha+\theta)/\beta$ index over the period. This condition means that drivers became more alert after several minute of response test application.

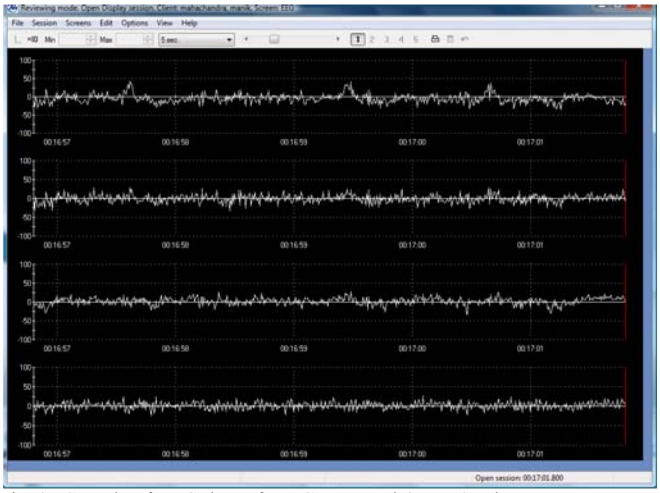

Fig. 3. Sample of EEG data of Fz, Cz, Pz, and Oz on 3-minute response test.

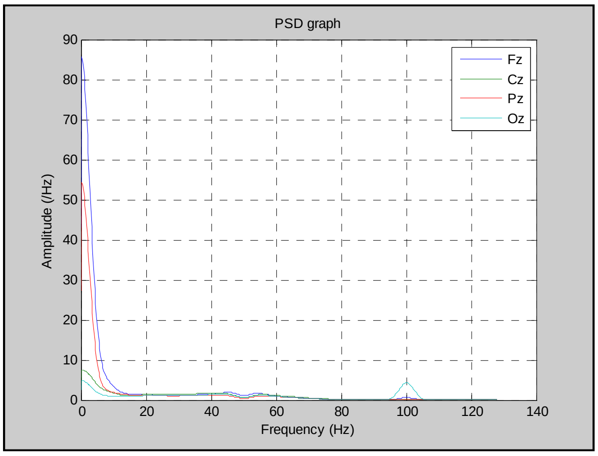

Fig. 4. Sample of PSD graph of 3-minute interval response test.

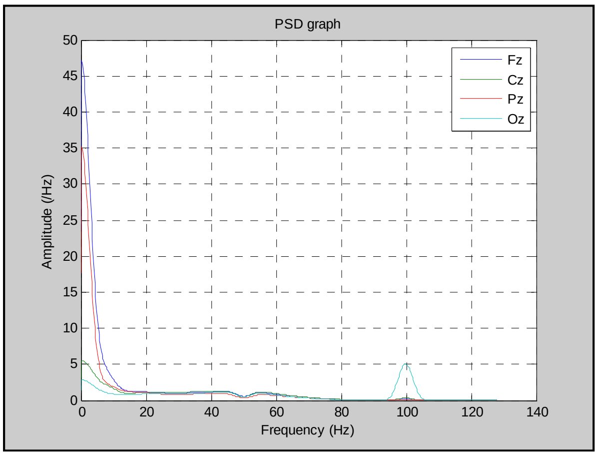

Fig. 5. Sample of PSD graph of random interval response test.

Fig. 6 shows an example of $(\alpha+\theta)/\beta$ index data of the 3-minute-interval and the random-interval response test. As stated before, lower $(\alpha+\theta)/\beta$ index mean a more alert situation of drivers. The random-interval response test, however, showed lower indices than the 3-minute-interval response test (random = 9.234, 3-minute = 9.748). This concludes that the random-interval response test able to maintain drivers' alertness better than the 3-minute-interval response test. Another participant also performed similar data.

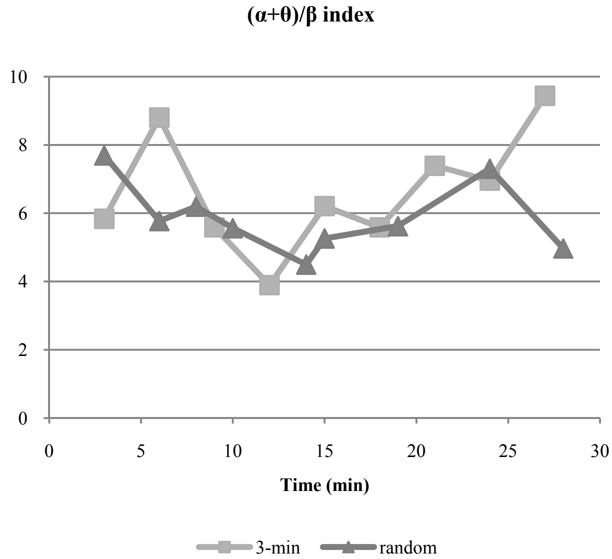

Fig. 6. Example of alertness [$(\alpha+\theta)/\beta$ index] of participant #1.

However, statistical analysis using two-sample t-test analysis failed to show significant difference on alertness level between those two types of response test ($t = -0.63$, $p = 0.557$). This fact shows that a random-time-interval distraction on drivers monotonous condition perhaps lead to a similar result, compared to a fixed-time-interval distraction. On the other hand, this similar condition also indicates that both response test types could give similar performance in alertness maintaining task. Moreover, we still have to make sure that the alertness level was really well maintained over the response test application.

Further analyses were conducted for the first and last time segment of each participant. This two time segments represent driver alertness condition in the early application of response test and after several minute of response test application, respectively. The two-sample t-test showed that alertness level between the two time segments were not significantly different, either for 3-minute response test ($t = 0.57$, $p = 0.585$) or random interval response test ($t = 0.39$, $p = 0.715$).

This result shows that drivers perform similar alertness level in both situations (in the early application and after several minute of response test application). This also concludes that alertness level could be well maintained, since there were no significant alteration of $(\alpha+\theta)/\beta$ index along the period.

Further analysis was conducted to analyze type and time segment effect of response test application on alertness level. Table 1 presents the ANOVA result. The two types of response test gave similar effect on drivers' alertness ($F_{1/5} = 0.05$, $p = 0.831$). This alertness level were also similar over the period ($F_{8/40} = 1.39$, $p = 0.231$), either in the 3-minute-interval response test or in the random-interval response test. This result concludes that both proposed response test method could maintain drivers' alertness along the driving time.

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TABLE I
EFFECT OF RESPONSE TEST TYPE AND TIME SEGMENT ON ALERTNESS

Source	df	SS	E(MS)	F	p
Between					
Subject (S)	5	594.921			
Within					
Response test type (R)	1	0.147	0.147	0.05	0.831
RxS	5	13.632	2.911		
Time segment (T)	8	15.501	1.938	1.39	0.231
TxS	40	55.877	1.397		
RxT	8	4.210	0.526	0.37	0.928
RxTxS	39	54.942	1.409		
Total	106	738.960			

IV. CONCLUSION

This study concludes that the response test could maintain drivers' alertness level during the period of its application in the driving simulator. Result also suggests that a random-interval response test gave better performance in drivers' alertness maintenance, rather than the fixed-time-interval response test (3-minute interval for this study). It is hoped that this study could be followed by a study on its application i.e., the practical use of auditory stimulus as proposed here as part of efforts to minimize traffic accident in Indonesia.

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