The Usefulness of Neurobehavioral Task as Driver's Fatigue Detection Technology

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ABSTRAK

Kelelahan merupakan kontributor signifikan terhadap kecelakaan kendaraan bermotor. Tujuan dari penelitian ini adalah untuk mengevaluasi penggunaan tugas neurobehavioral, seperti Psychomotor Vigilance Task (PVT) dan Stroop Test, sebagai teknologi pendeteksi kelelahan pengemudi kendaraan bermotor. Dua belas peserta laki-laki (M ± SD; 35, 58 ± 3, 58 tahun) diminta untuk mengemudi selama 6 jam dan dua sesi (Bandung - Bekasi dan Bekasi - Bandung). Hasil menunjukkan bahwa tugas neurobehavioral mungkin berguna untuk mendeteksi kelelahan pengemudi kendaraan bermotor, khususnya menggunakan tiga parameter, yaitu rata-rata dari kecepatan respons (PVT-M), jumlah lapses (#L), dan Reaction Time for Correct Answer (RTCA). Skor kelelahan mental dari Swedish Occupational Fatigue Inventory (SOFI) memiliki korelasi yang signifikan dengan parameter tersebut. Pemeriksaan rutin pada pengemudi (yaitu sebelum, selama, dan setelah tugas) menggunakan tugas neurobehavioral dapat meningkatkan dampak implementasi Fatigue Risk Management System (FRMS) di Indonesia. Pada studi ini juga disimpulkan bahwa PVT, sebagai alat ukur standar dapat digantikan oleh alat ukur lainnya yaitu Stroop Test.

Kata kunci: *: kelelahan, mengemudi, sistem manajemen risiko kelelahan, tugas neurobehavioral*

ABSTRACT

Fatigue is a significant contributor to motor-vehicle accidents and fatalities. The purpose of this study was to evaluate the use of neurobehavioral task (i.e. Psychomotor Vigilance Task (PVT) and Stroop Test) as fatigue detection technology of motor-vehicle drivers. Twelve male participants (M ± SD; 35.58 ± 3.58 years) were asked to drive 6-hour long into 2 trip (Bandung – Bekasi and Bekasi – Bandung). Results showed that neurobehavioral task may be useful to detect the fatigue of motor vehicle's driver, specifically using this three parameters, i.e. mean of response time (PVT-M), total lapses (#L), and Reaction Time for Correct Answer (RTCA). Mental fatigue score from Swedish Occupational Fatigue Inventory (SOFI) had a significant correlation with those parameters. Regular check for drivers (i.e. before, during, and after the duty) using neurobehavioral task may improve the impact of Fatigue Risk Management System (FRMS) implementation in Indonesia. Furthermore, PVT, as the gold standard of application using this approach, may be replaced by a shorter test, such as Stroop Test.

Keywords: *driving, fatigue, fatigue risk management system, neurobehavioral task.*

1. Introduction

The level of traffic accidents involving land transportation modes in Indonesia remains high. This may be caused by several factors, namely people, facilities and infrastructure [15]. Based on the results of traffic accident and road transport investigations conducted by the National Transportation Safety Committee (NTSC) in 2016, the human factor caused 69.7% of accidents. Fatigue is a significant contributor to motor-vehicle accidents and fatalities of human factor [9]. According to Griffith and Mahadevan [11], the term fatigue is used to describe the condition and experience of feeling tired and fatigued. Based on research conducted by Williamson et al. [18], it is proven that there is a relationship between fatigue with work performance and safety. A decrease in performance due to fatigue can be identified by several symptoms, i.e. decrease in speed, error, or failure of someone in responding. Fatigue also increases the risk of accidents. Fatigue may cause disruption of one's focus to stimuli that are relevant to his work. Therefore, it is important to prevent fatigue, especially for modern motor vehicles drivers.

Efforts to prevent fatigue in driving work can be done by developing a Fatigue Risk Management System (FRMS) [6]. FRMS is used to minimize the potential hazards that may appear due to fatigue [8]. According to Balkin et al. [2], the ideal FRMS is a multi-component system so that it can comprehensively describe fatigue conditions. Dawson et al. [6] divides fatigue risk management into 5 levels. Level 1 is made so that someone can rest and sleep adequately. Level 2 focuses on minimizing sleep deprivation. Level 3 is symptoms of fatigue's detection system. Level 4 is made to prevent the consequences caused by fatigue. Level 5, accidents due to fatigue, is prevented by applying levels 1 to 4. In general, FRMS in Indonesia only reach level 1 and level 2. These are manifested in the form of Hours-of-Service (HoS) regulations to limit the word duration and set a minimum amount of rest during work. The drive of motor vehicle in Indonesia must rest for 30 minutes after 4 hours of non-stop driving. This is mentioned in Undang-Undang (UU) No. 22/2009 concerning Road Traffic and Transport. However, in reality, the application of this regulation is not enough to prevent accidents due to fatigue. Drivers have a tendency to underestimate the effects of fatigue, so they often ignore the fatigue that arises and continue driving when getting sleepy [12]. In addition, until now there has been no specific effort to guarantee the application of the HoS. Although drivers and transport service providers have followed these regulations, the number of land transportation accidents is still relatively high. Therefore, it requires the application of FRMS level 3 in the transportation system in Indonesia.

Fatigue detection technology can be divided into 3 groups, i.e. continuous operator monitoring, performance based monitoring, and fitness-for-duty tests [6]. Based on its characteristics, one of the advantages of the fitness-for-duty test fatigue detection technology group, compared to other groups, is that it does not interfere with the main work, and is relatively easy to learn. There are 2 approaches that can be used in fitness-for-duty tests, including pupillometry and neurobehavioral performance approaches. The pupillometry approach measures a person's performance based on pupil size and reactivity. To use pupillometry, special equipment such as Fitness Impairment Tester (FIT) is needed. The neurobehavioral performance approach does not require special equipment. Neurobehavioral is a behavioral performance related to the central nervous system, especially in cognitive function [13]. Cognitive functions regulate one's attention or alertness [16]. Vigilance can be interpreted as an activity of maintaining or keeping things in mind with mental work and high concentration [10]. The amount of workload can encourage fatigue [18]. To measure the amount of workload, it can be used to test one's performance through assigning tasks that require attention and coordination between the eyes and hands, or also called neurobehavioral tasks. Some measuring devices that use neurobehavioral tasks include Psychomotor Vigilance Task (PVT) [4] and Stroop Test [19].

Psychomotor Vigilance Task (PVT) is a tool that measures a person's response time to a particular stimulus. PVT-192 is the first PVT developed to measure the effects of sleep deprivation by David F. Dinges and John W. Powell in 1985 [7]. Currently there have been many software applications that apply the PVT-192 principle. One of the most widely used PVT software uses visual stimuli in the form of black and white images with a chessboard-like pattern. The emergence of this stimulus is random, with a distance between stimuli of 2 to 10 seconds. The way PVT works is similar to PVT 192, where participants must press the button on the left mouse as quickly as possible after the stimulus appears on the computer screen. Reaction Time (RT) recorded is the difference between the time the stimulus appears and the time the response is given to the stimulus. Stroop Test is a cognitive test that is used to measure one's performance [19]. Basically, Stroop Tes give stimuli in the shapes of words and colors [5]. The words in the Stroop Test are the names of colors, like green, red, and so on. Each of these words will appear in a certain color, both colors that match the word and other colors. Participants can respond according to the colors that appear. For example, participants must give a red response when the stimulus word that appears is "GREEN", but colored red [14]. The response can be given in the form of mentioning the right answer, or pressing a particular button, depending on the tool used.

Research related to fitness-for-duty tests in detecting fatigue and measuring a person's work readiness has been developed in many other countries, both using neurobehavioral tasks and pupillometry. There are only a few research related to fatigue, especially in driving work on the highway and toll roads in Indonesia. The characteristics of fatigue due to driving activities are influenced by demographic factors and road conditions (Di Milia et al., 2011). Therefore, this study aims to examine the use of neurobehavioral tasks as a fatigue detection tool in the FRMS of land transportation system in Indonesia.

2. Methods

Participant

This experiment involved 12 male participants aged 30 to 40 years (M ± SD; 35.58 ± 3.58 years). In addition, participants had driving license for a minimum of 3 years (M ± SD; 17.33 ± 3.67 years). Each participants was also a professional driver with a minimum 3 years driving experience (M ± SD; 18.08 ± 4.18 years) and a minimum average distance at 5000 kilometers (KM) per year (M ± SD; 7220 ± 1416 KM). Participants were physically and mentally healthy at the time data collected, did not have a sleep disorder, and did not have a history of serious illness. Participants in this study were all morning type. Determination of this type is done using the Morningness-Eveningness Questionnaire (Jankowski, 2012). Participants were required to follow several rules related to data collection, such as not consuming certain foods or drinks in a certain period of time, other than those permitted by researchers. In addition, based on the experiments of Lerman et al. (2012), participants were also required to sleep for at least 7 hours the night before the measurement was done (M ± SD; 7.52 ± 0.54 hours). Participant's activities while driving were also restricted, such as the prohibition to listen to the radio and communicate intensively with researchers. In addition, participants must follow the rules set by the researcher. Participants received compensation at the end of the research, in the form of money (Rp. 250,000/experimental session).

Experimental Design

In general, this experiment was categorized as field experiment. It aimed to determine the impact of independent variables on the real system and determine the interactions and relationships between observed variables. In this experiment, the within-subjects model was used, with the variable used was driving duration. This factor affects the workload a person receives while driving [18]. In this experiment, measurements were done at certain durations to determine the effect of duration on fatigue.

The dependent variable in this experiment was the parameter value of Psychomotor Vigilance Task (PVT) and Stroop Test. Several PVT parameters included the average response speed (PVT-M), an average of 10% of the longest responses (PVT-L), and an average of 10% of the fastest response (PVT-S) [7]. In addition, PVT also counted the number of lapses or stimuli that get a response with a reaction time (RT) of more than 500 milliseconds (#L). The response speed was obtained through equation (1) as follows [4]; [3]:

$$1/RT = \frac{1000}{RT}\left(\frac{1}{ms}\right) \tag{1}$$

The Stroop Test only had one parameter that was Reaction Time for Correct Answer (RTCA), or the average response time of the correct answer. In this experiment, there were several variables that are fixed so that they did not affect the relationship between the independent variables and the dependent variables, including the sex and age of the participants, the time and place of data collection, travel route, duration of sleep, and consumption of alcohol, caffeine, and nicotine. There were also variables that were uncontrollable in this study, namely the physical and psychological conditions of the participants.

Procedure

Participants must drive a car that was provided, start from Bandung to Bekasi, then return to Bandung. There are 6 times data retrieval during the experiment. Each of them represents a condition after driving with a certain duration. The 1st point is the 0 hour driving duration. This point can be used to determine whether a participant's condition is appropriate for driving or not, by comparing it against the baseline. The 2nd point is a condition that one's has been driving for 80 minutes. The 3rd point represents 150 minutes driving duration. The 5th point is used to measure participant's condition after driving for 270 minutes. Last point represents the condition after driving for 360 minutes. The 4th point is used to measure the effect of giving a 15-minute break to the parameters of the measuring instrument.

In addition, baseline data was needed from each participant. Baseline data is data obtained when participants are physically and mentally healthy, had adequate sleep (both in quality and quantity), and felt focused (not under the influence of alcohol or illegal drugs). This condition was in line with rules mentioned in article 106 paragraph (1) of Undang-Undang (UU) No. 20 published on 2009 concerning Road Traffic and Transportation.

Data and Analysis

Data processing was performed using descriptive statistics and inference. Descriptive statistics was used to determine the characteristics of participants, such as the average, standard deviations, minimum values, and maximum values of participants' general data. Through the use of box plot, the pattern of fatigue of each participant could be described.

Statistical inference is used to test hypotheses and see the interrelationships between parameters. In this experiment, the statistical inference test used was non-parametric statistics. This was used because the amount of data processed is less than 30 and does not meet normal assumptions [17]. Some of the tests used in this study were Friedman test and the Wilcoxon test. The Friedman test was used to find out whether or not an average of each of six measurement points have differences, while the Wilcoxon test was used to know the difference between the baseline and other measurement points. In addition, this test was used as a Post Hoc test on parameters that have a significant difference between the six measurements points from the Friedman test's results. Post Hoc Test is used to determine which pair of measurement points cause the differences.

Correlation test was used in this study to determine whether or not there was a relationship between the parameters used. Correlation test was done using the Spearman's rho test. If the two parameters had a relationship, then the value of the correlation coefficient (*r*) ranges between -1 and 1, where the value of 1 indicates perfect correlation, and the value of 0 indicates no correlation between the 2 parameters tested [17]. Correlation coefficient with a positive sign indicated a unidirectional correlation, while the negative sign indicated the unidirectional correlation. P-value used in each of these tests was 0.05.

3. Results

Data collected in this study consisted of participant general data, Psychomotor Vigilance Task (PVT), and Stroop Test. This study used 5 parameters, i.e. (a) 4 parameters of PVP consisting of PVT-S (average of 10% fastest response), PVT-M (average response speed), PVT-L (average of 10 % late responses), and #L (number of lapses, i.e. stimuli that get a response with time> 500 milliseconds) and (b) a parameter of Stroop Test called RTCA (Reaction Time Correct Answer; the amount of time from the correct response divided by the number of correct responses). Based on the Friedman test's results, it was found that there are 3 parameters that have a significant difference between the 6 measurement points, namely PVT-M, #L, and RTCA. The data pattern of each parameter is shown in Fig.1.

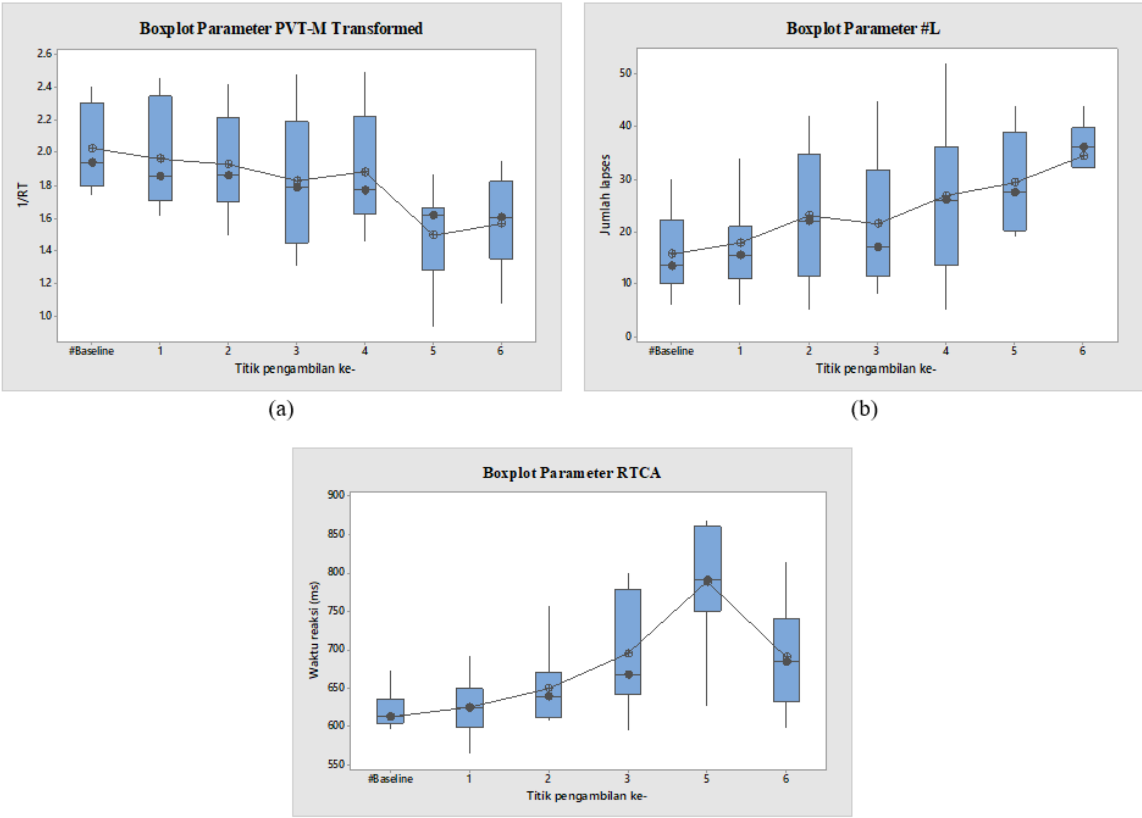

Figure 1. Data plot (a) PVT-M; (b) #L; (c) RTCA

To determine which pair caused the significant differences on Friedman test, the Post-Hoc test was performed using the Wilcoxon test. In general, there are significant differences in the sample pairs for each parameter. Most of the parameter's values on 5th point of measurement differ significantly from other points. In addition, the Post Hoc test's results showed that parameters PVT-M, #L, and RTCA at each pair of points have significant difference at the 3rd and 5th point of measurements.

Correlation test result between all parameters is shown in Fig. 2. Based on the value of the correlation coefficient (r) in Fig. 2, in this study there were 2 types of correlations, i.e. strong and weak correlations. The strong correlation was shown in the relationship between PVT-M and #L. The other two parameters were weakly correlated with RTCA.

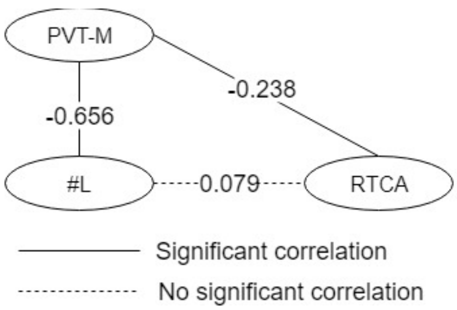

Figure 2. Correlation between all parameters

This correlation test was also used to compare the results of measurement of fatigue from subjective measuring instruments and all of the neurobehavioral task's result. The subjective fatigue measurement tool used was the Swedish Occupational Fatigue Inventory (SOFI) questionnaire. The results of this correlation test are shown in Table 1.

Table 1. Recapitulation of correlation tests between neurobehavioral task parameters and SOFI dimensions

SOFI Dimension	**Correlation coefficient (S/NS*)**		
	PVT-M	**#L**	**RTCA**
S	-0.521 (S)	0.273 (S)	0.506 (S)
LE	-0.546 (S)	0.523 (S)	0.252 (NS)
LM	-0.292 (S)	0.152 (NS)	0.322 (S)
PE	-0.072 (NS)	0.252 (S)	0.274 (S)
PD	0.059 (NS)	0.076 (NS)	0.528 (S)

*S: Significant; NS: Not Significant (p = 0.05)

The results (Table 1) show that all SOFI dimensions, i.e. sleepiness (S), lack of energy (LE), lack of motivation (LM), physical exertion (PE), and physical discomfort (PD), have significant differences between points the measurement. Based on the results, the parameters PVT-M, #L, and RTCA had a significant correlation with sleepiness. Compared to LE, PVT-M and #L parameters have a significant correlation, while LM correlate significantly with PVT-M and RTCA. Physical fatigue's dimensions of SOFI, i.e. PE and PD, correlate only with RTCA.

4. Discussion

The main finding of this study is that neurobehavioral task can be used to identify fatigue as long as there is baseline data for each parameter. Based on the data patterns of the four parameters in Fig. 1, it appears that participants experience a decrease in performance as the duration of driving increases. In general, this decrease in performance is characterized by an increase in response time (RT), which causes a decrease in the value of the PVT-M parameter and an increase in RTCA, % Miss, and #L. According to Kosmadopoulos et al. [13], an increase in RT is an indicator of a decrease in alertness. In addition, this study also proves that vigilance is an excellent indicator of measuring driver fatigue. This vigilance is influenced by the workload one receives, especially mental workload [16]. Based on the research of Williamson et al. [18], workload is a factor causing fatigue. The higher the workload a person receives, the greater the fatigue one experiences.

Dawson et al. [6] states that Psychomotor Vigilance Task (PVT) is a gold standard for fatigue detection using the neurobehavioral task approach. Stroop Test only correlates significantly with PVT-M parameter. In addition, each measuring instrument measures different basic operations of vigilance. There are 5 basic operations, i.e. orientation, searching, multi-target tracking, filtering, and monitoring multi-action [16]. These five basic operations are a basic component of neurobehavioral tasks. The first three operations are the stimulus selection process, while the other 2 operations include the response selection process.

The PVT and Stroop Test can also be compared by the duration required to take the test. The faster the test time, the better the tool to use, as long as the test results can represent fatigue well. Stroop Test requires the shortest duration when compared with the two other measuring devices, which is 2 minutes. With this duration, Stroop Test is able to give pretty good results. The ability of the RTCA (Reaction Time for Correct Answer) compared to PVT's parameters can also be seen from the pattern of data in Fig.1. There were similarities to the PVT-M parameter as well as the strong correlation to the dimensions of mental fatigue in the Swedish Occupational Fatigue Inventory (SOFI). However, based on a comparison of the baseline values, the results of the Stroop Test measurements were not in line with the results of the PVT's parameters measurements. For Stroop Test, there was significant differences in all points, except for the 1st point of measurements. This was because the Stroop Test is relatively harder than PVT.

In addition, the respond method can also affect the measurement results. PVT software used in this study needs a mouse to response the stimuli. The use of a mouse can reduce the accuracy of the response time due to the transmission time of the signal from the mouse to the computer where the software is installed. This caused a bigger RT, so the measured time is not the actual RT. As for the Stroop Test software used in this study, responses were given using the keyboard which may reduce the transmission time.

Based on discussion above, it can be inferred that both tools have some differences. However, there are some similarities too in several aspects. The complete comparison between PVT and Stroop Test is shown in Table 2.

Table 2. PVT versus Stroop Test

	PVT	*Stroop Test*
Duration test	5 minutes	2 minutes
Vigilance's basic operations	1. Orientation 2. Searching	1. Searching 2. Multi-target tracking 3. Filtering
Responding method	Respons pada *software* PVT yang digunakan dalam penelitian ini diberikan dengan menggunakan *mouse.*	Respons pada *software Stroop Test* yang digunakan dalam penelitian ini diberikan dengan menggunakan *keyboard.*
Correlation to SOFI	1. PVT-M correlates with S, LE, and LM, with r value -0.521, -0.546, and -0.292. 2. #L correlates with S and LE, with r value 0.273 and 0.523.	RTCA correlates with S dan LM, with r value 0.358 and 0.306.
Usefulness in fatigue detection	PVT is used in many research related to fatigue. PVT classified as the gold standard in fatigue measurement using neurobehavioral task [1]. Research on transportation field mostly use this tool [6]; [13]	Stroop Test has many use in healthcare field, i.e. to measure one's performance related to nerve system and behaviour (Barwick dkk., 2012). Stroop Test has many use in measuring mental fatigue (Smith dkk., 2016). This tool rarely used in transportation field research.
Correlation to PVT	-	RTCA correlate significantly with PVT-M with r value -0.238.
Comparison to *baseline*	1. PVT-M has differences on 5th and 6th point of measurements compared to baseline. 2. #L differ in 4th, 5th, and 6th, compared to baseline.	RTCA differs significantly in all points, except for 1st point.

The results of this study can be used to refine the Fatigue Risk Management System (FRMS) of land transportation system in Indonesia, especially at levels 1, 2 and level 3. According to Balkin et al. [2], the ideal FRMS is a multi-component system so that it can comprehensively describe fatigue conditions. Fatigue is a complex phenomenon, so it cannot be handled or identified by only one type of indicator [1].

At level 1, efforts are made to ensure that a person can get adequate rest and sleep. As for level 2, an approach is taken to ensure that the approach at level 1 is actually implemented, so that someone gets enough rest. The approach used in Indonesia to implement level 1 and level 2 is Hours-of-Service (HoS), which is a maximum work duration. According to the relevant law, the limit of driving duration in a day for motor vehicle is 8 hours, which every 4 hours is accompanied by a 30 minutes break. Based on results of this study, fatigue possibly appear in the after 2.5 hours long driving. A 15 minutes break can have a pretty good effect on driving performance. Furthermore, rest can be accompanied by several other treatments. In this study, treatments given were eating snacks and drinking water. According to Gimeno et al. [9], consumption of food or drinks can have a better influence on the process of restoring conditions during the resting period. However, this study cannot provide suggestions for refinement on level 1 and level 2.

Implementation of FRMS at level 3 can be done by checking the driver's condition related to fatigue regularly, before and several times during the period of duty (driving), using any objective measuring tool, such as neurobehavioral task. This may ensure the driver to drive safely and minimize the risk of accidents due to fatigue. To build a system that can detect fatigue with a neurobehavioral task, a reference value is needed to determine a person's condition whether be able to drive safely or not. One of the reference values may be used is baseline score, or the value of a measuring instrument measured when participants are in prime condition or full of concentration, as arranged in UU.

This study had several limitations. Due to the limitation of physiological measuring instruments use outside the laboratory, this study could not use it to compare physiological fatigue measurement's results with the measurement results of neurobehavioral task. In addition, some of these measuring instruments can interfere the driving activities, because it must be attached to the participant's parts of body.

Another limitation was that measurement of neurobehavioral task was not done in a completely isolated place where no outside disturbances (i.e. noise, temperature, and visual disturbances) could affect the participant's focus while doing the test. This occurred due to the limited access of public facilities and infrastructures to provide a soundproof place with a minimal interference, as in laboratory. Participants do the neurobehavioral task tests on the 2nd row of passenger seat so that participant's feel comfortable, undisturbed, as well as minimize the interference of irrelevant stimuli while completing the tests.

This study only used one treatment of break that is 15-minutes break. This study's result may not be used to refine the FRMS level 1 and 2. Limited budget is the reason for this limitation in experimenting with other types of resting treatment. To do this, several groups of participants were needed where each group must have a statistically adequate number.

This study also ignored to the influence of internal factors (i.e. age and sex) during the test. In addition, this study did not use several types of routes and time to see the effect on the workload felt by the driver. This is due to budget limitation. Therefore, these factors served as control variables in this study.

Conclusion

Neurobehavioral task was found to be a potential fatigue detection tool, especially in the PVT-M parameter (average response speed), #L (number of lapses or number of responses with time over 500 milliseconds), and RTCA (Reaction Time for Correct Answer; average response time with correct answers). This result was obtained based on 3 main indicators, namely the parameter value of the measuring instrument, the comparison to the baseline, and the correlation with the dimensions of subjective fatigue measurement's result.

The first indicator and the second one gives the same results which is identifying the presence of fatigue at the 5th measurement point (after 270 minutes driving). Moreover, the third indicator shows that there is a significant correlation with the dimensions of mental fatigue for all parameters used.

The best neurobehavioral task measurement can be done by PVT. However, Stroop Test has good potential to substitute PVT because it requires a shorter duration and use a more accurate response method. This results may be used to refine the level 3 of Fatigue Risk Management System (FRMS) of land transportation system in Indonesia which used to check driver's condition related to fatigue regularly, before and several times during the period of duty (driving), by using objective measuring tools, such as neurobehavioral task, where each driver has previously been measured the baseline data used as a reference value. This is done to ensure the driver can drive safely and minimize the risk of accidents due to fatigue.

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