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Preliminary investigation of sleep-related driving fatigue experiment in Indonesia

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Abstract

Sleep-related driving fatigue has been recognized as one of the main causes of traffic accidents. In Indonesia, experiment-based driving fatigue study is still very limited. Therefore it is necessary to develop a laboratory-based experimental procedure for sleep-related fatigue study. In this preliminary study, we performed a literature review to find references for the procedure and three pilot experiments to test the instruments and procedure to be used in measuring driving fatigue. Three subjects participated, both from experienced and inexperienced drivers. Our pilot experiments were performed on a driving simulator using OpenDS software with brake and lane change test reaction time measurement. We measured sleepiness by using Karolinska Sleepiness Scale (KSS) Questionnaire. The conditions of the experiment were based on illumination intensity as well as pre- and post-lunch session. We found that lane change reaction time is more potential than brake reaction time to measure driving performance as shown by more fluctuating data. Post-lunch seems to induce drowsiness greater than illumination intensity. KSS questionnaire seems non-linear with driving performance data. We need to test further these speculations in the future studies involving a sufficient number of subjects. We also need to compare the effect of circadian rhythm and sleep deprivation on driving fatigue. The use of eye closure and physiological measurement in further study will enable us to measure driving fatigue more objectively. Considering the limitations, more preliminary experiments are required to be performed before conducting the main experiment of driving fatigue.

Keywords: Driving fatigue; sleepiness; experimental procedure; driving simulation.

I. Introduction

Road traffic accident which costs human life has been recognized as an important issue encountered by many countries [1]. The impacts of the accidents are much greater in developing countries where the accidents often take the life of the only income earner in the family [2]. Among the various causes of road-traffic accidents, driving fatigue has been reported to be one of the most common causes [3].

Based on its causes, driving fatigue is classified into sleep-related and task-related fatigue [1][4]. The most common type of driving fatigue is drowsiness, which has been reported to cause accidents in many countries. In the United States, drowsiness was reported to be responsible for around 100,000 crashes annually, which resulted in more than a thousand fatalities, more than seventy thousands people injured and monetary losses of more than USD 10 billion [5]. Drowsiness was responsible for more than a quarter of road fatalities in Germany [5], and between 15 to 20% of traffic accidents in the UK [6]. In Indonesia, around 21% of total traffic accidents recorded by Jasa Marga, an operator of the toll road in Indonesia, were caused by sleepiness [6].

In the longest toll road in Indonesia, Tol Cipali, 140 traffic accidents occurrence were recorded during its inauguration from June 2015 to October 2016 on which drowsiness has been suspected to be the main

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cause, as most of the accidents took place between midnight and early morning [7]. Most drowsiness during driving is caused by lack of sleep before driving or driving at the time when most people usually sleep [8].

In the driving fatigue classification, sleep-related fatigue is caused by the sleep disorder, restriction, and deprivation as well as sleeping related with biological rhythm [1][4]. As reported that most accidents due to drowsiness occurred during the first 45 minutes of driving [8], which was well below driving fatigue due to a prolonged driving duration of three hours [9][10], it can be assumed that drowsiness during driving is more associated with sleep-related fatigue.

Research on driving drowsiness that measured Indonesian subjects was still very few. Our literature review found two studies on driving fatigue. The first study was a field study involved sixteen shuttle service drivers between Bandung-Jakarta using a digital video recorder (DVR) [6]. Only twelve drivers completed the study. The variables measured in the study were eye-blink and microsleep frequency based on video-recorded eye closure and sleepiness incident, pattern and changes based on KSS data.

In the study, the subjects were recorded during prolonged driving tasks of around seven hours without any information about the time set up for the study. We speculated that the study had neglected the effects of environmental aspects such as temperature, humidity, and illumination as well as the effects of circadian rhythm on fatigue, as controlling those aspects is very challenging in a field study. The second study used an OpenDS-based driving simulator that measured reaction time and KSS data from both normal and sleep-deprived condition among twenty-five subjects [11]. The study reported longer reaction time among sleepy drivers. However, the second study did not provide any information about the characteristics of the subjects, the control of the laboratory environment such as temperature, humidity, and illumination, as well as the time set up of the experiment. Both studies did not employ any physiological measurements.

II. Method/material

This article is limited to developing an experimental procedure for sleep-related fatigue study and no other types of inattention. As physiological measurement methods have been published in our previous article [1], in this study, the discussion is limited to driving fatigue experimental procedure, reaction time, and subjective assessment with KSS questionnaire.

A. Literature review on standards and subjective assessment methods

In this study, we focused on primary driving tasks and driver condition and behaviour. We regarded two guidelines for driving performance test from International Organization for Standardization (ISO) and National Highway Traffic Safety Administration (NHTSA), United States of America, as the most widely referred in driving studies [12][13]. The two guidelines provide a very detail information on the experiment procedure based on an extensive database from previous studies. ISO standards provide guidelines for studying lane change test to measure driver inattentiveness [14], which is the most common symptom of driving drowsiness. Daimler also issued a lane change test guidelines [15], underlining the importance of this method for various types of driving simulator studies. Lane change test is also relatively low-cost and easy to use [13]. The low-cost aspect, is very important in applied engineering research, especially in private companies. The applicability of the employed methods should avoid the so-called the “law of diminishing return” without sacrificing the reliability of the results [13]. A low-cost and easy to use method also means that it will be replicable by many researchers with limited resources, especially in developing countries. The adoption of the lane change test in an open source software like OpenDS [16] will allow us to compare the results of our future study with other worldwide studies.

There are various sleepiness scale questionnaires used in sleep-related studies, such as Stanford Sleepiness Scale [17][18][19], Pittsburg Sleep Quality Index [18], Kwansei Gakuin Sleepiness Scale [20], and Karolinska Sleepiness Scale [6][11][21][22][23]. Karolinska Sleepiness Scale (KSS) has been reported to be very sensitive to measure sleepiness level [24], across its different versions [23], applicable for both performance measurement [22] and drivers’ sleepiness level [21]. With regard to driving fatigue studies, KSS is the one that has been used extensively in our references. KSS has been reported to be as sensitive as objective measurement methods using electro-encephalogram (EEG) and electro-oculogram (EOG), and its reliability has also been examined in many studies [24]. There are two types of KSS in English, the modified version is with label on every scale number from 1 to 9 (1 = extremely alert, 2 = very alert, 3 = alert, 4 = rather alert, 5 = neither alert nor sleepy, 6 = some signs of sleepiness, 7 = sleepy, but no effort to keep awake, 8 = sleepy, some effort to keep awake, 9 = very sleepy, great effort keeping awake, fighting sleep), while the original one is with label only on number 1, 3, 5, 7, 9 [23]. The version in Bahasa Indonesia refers to the original version [6], and we used this version in our preliminary experiment.

B. Pilot experiment

The pilot experiment was performed in the Dark Room, Graham Sutherland Building, Coventry University. As shown in Figure 1, the driving simulator used an OpenDS [16] and LCT Sim [14][15] software, and modified game controllers Logitech GT 5 (Logitech International S.A., Switzerland) to provide more realistic driving experience for the subjects. ISO 26022:2010 suggests the minimum resolution for driving simulator display is 1024 × 768 pixel with a refresh rate of 50 Hz [14]. We used 2048 × 1536 pixel for the experiment which is above the minimum standard.

Figure 1. The used driving simulator hardware for the experiment. It combined a driving wheel with pedals and chairs to simulate a real driving set up/experience

Three participants volunteered for the experiment. Two of them were experienced drivers that possess Indonesian driving license (SIM A). One was an inexperienced driver without a driving license. All subjects were in healthy condition and aged in the early 30s. At the earliest stage, we allow the subjects to familiarise with the driving simulator by performing trials for more than 10 minutes.

Initially, two driving tasks were performed, namely lane change test using LCT SIM and reaction test using OpenDS software. Lane change test requires the driver to change lane continuously according to the road signs. The reaction test requires the driver to react to two types of road signs appeared on the gantries, namely brake and lane change sign. The driver should keep driving in the middle lane. For brake reaction test, the driver should push the brake pedal when a red cross appeared on the gantries, then release the brake and push the gas pedal when an auditory cue was given. The lowest speed during braking was 20 km/h and the top speed never exceeded 60 km/h. For lane change reaction test, the driver should change the lane from the middle lane to the lane with a green tick and then return to the middle lane when an auditory cue was given. Brake reaction time was measured from the time of the sign appeared to the maximum brake push. Lane change reaction time was measured from the sign appeared to the time when the vehicle was already in the intended lane.

We decided to use the Open DS-based reaction time test for the pilot experiment after trying the scenario and considering that LCT Sim is more appropriate for lane change test measurement related to secondary task effect. We did not measure secondary driving task such as the use of radio and LCD in this experiment. The first pilot experiment was performed from 1:00 p.m. to 5:00 p.m. Each subject performed five trials, each trial was in 5 minutes. In this experiment, we tried to induce drowsiness upon the subjects by having them driving on a monotonous straight road continuously. The second pilot experiment was performed between 1:30 p.m. and 4:30 p.m. The subjects performed the driving task in eight sessions consecutively to induce drowsiness. In this session, the experiment was under high-intensity illumination when all the lighting in the room were turned on (Figure 2). The third pilot experiment was conducted in the morning, from 10:00 a.m to 12:00 a.m, with the same task procedure of the second pilot experiment, but under low-intensity illumination when all the lighting were turned off (Figure 3). Right after completing every trial session, subjects answered the KSS questionnaire.

C. OpenDS and KSS data processing

The use of OpenDS software allows us to record the reaction time during trials. The data are shown in a bar diagram (Figure 4). The red bar represents brake reaction time and the green bar represents lane change reaction time. The reaction time is in the millisecond. In every session, there were ten data for both brake and lane change test reaction time. Whenever the reaction time was failed to be recorded, the data were excluded from further analysis. Some outliers data in both brake and lane change reaction time test which is more than 10,000 milliseconds were excluded.

Because statistical power analysis is impossible in this preliminary experiment with a small number of subjects [14][25], we did not perform statistical significance analysis. We can assume that the more drowsy the drivers, the longer reaction time and the higher KSS score. All data were input into Microsoft Excel 2010 to be processed into line charts.

Figure 2. The second pilot experiment under high intensity illumination, when the lighting in the room was turned on

Figure 3. The third pilot experiment under low intensity illumination, when the lighting in the room was turned off

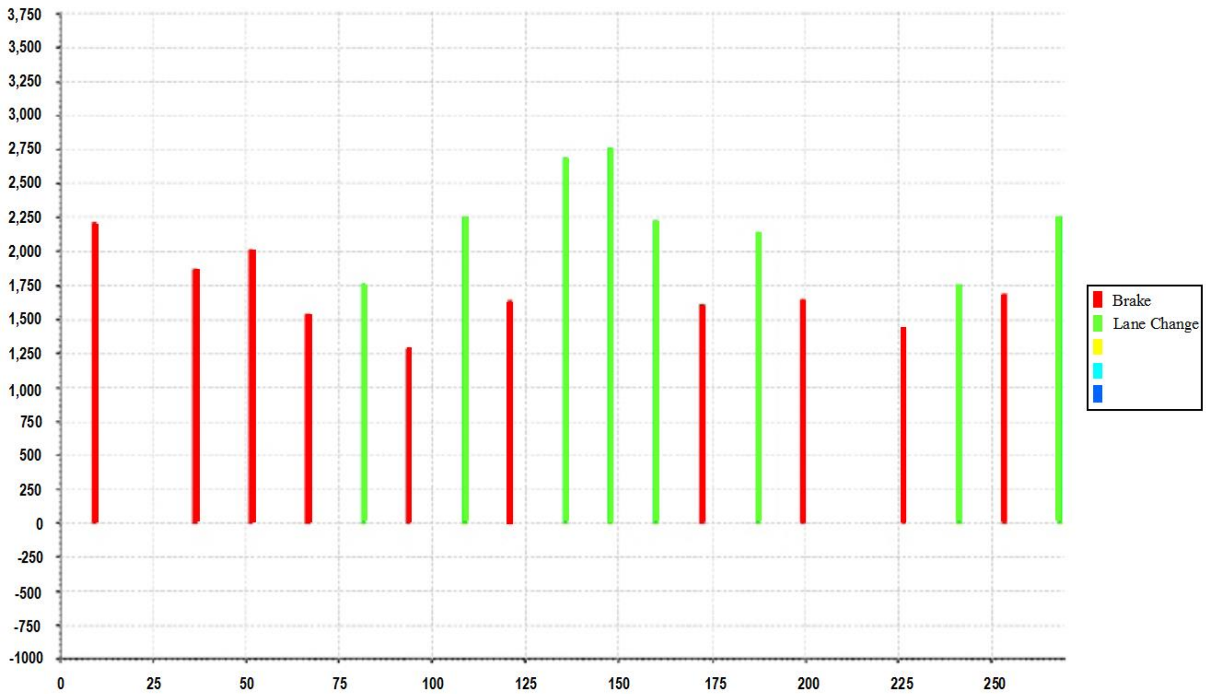

Figure 4. Reaction time data in bar diagram from OpenDS

III. Result and discussion

As this preliminary study only involved a small number of subjects, we cannot perform any deep analysis. This study only describes the possibility that we may record data using the tested methods. The result and discussion section include the description of the pilot experiment results and the improvements necessary for further experiments. We also discuss some assumption to be examined in the further preliminary experiment before conducting the main experiment.

A. Pilot experiment I

In the four trials performed, all the three subjects participated in the first pilot experiment showed slightly but steady increase in brake reaction time from the first to the last trial (Figure 5). As illustrated in Figure 5, the inexperienced driver showed a different trend from the experienced driver in lane change reaction time. While experienced drivers showed increasing lane change reaction time, inexperienced driver, on the contrary, showed slightly lower reaction time at the last trial. This probably represents the effect of learning that has been reported in previous studies [26]. Visually, the lane change reaction time fluctuates more than brake reaction time. We speculate that level of experience has a greater effect on lane change reaction time than brake reaction time.

KSS questionnaire data shows increasing sleepiness in the four trials among subjects (Figure 6). One subject who had experience in answering KSS questionnaire seems to show more steady increase than the other two subjects who responded to the questionnaire for the first time.

B. Pilot experiment II

In the second pilot experiment, only two subjects participated, an experienced driver and an inexperienced driver. As illustrated in Figure 7, the experienced driver showed less fluctuation on brake reaction time than lane change reaction time. Unlike the first pilot experiment, lane change reaction time was found to be the longest not at the last trial, but in the middle (trial 5; 4,177.2 ms). The last trial was found to result in the second longest reaction time (3,692.7 ms).

The data from inexperienced driver also shows more fluctuation in lane change reaction. Similar to the experienced driver, lane change reaction time from the inexperienced driver was also found to be the longest in the middle trial (trial 4; 5,873.5 ms). However, the inexperienced driver did not show an increase in lane change reaction time at the last trial.

As illustrated in Figure 8, KSS questionnaire score shows the increasing level of sleepiness due to the prolonged driving task during the experiment. The pattern of changes in sleepiness level is not the same between both subjects.

The steady increase of sleepiness seems non-linear to the reaction time. We suspect the effect of motivation since the subjects well understood the length of the experiment. The effect of motivation to overcome fatigue has been reported in a previous study [27]. Boredom seems to reach its peak in the middle of the experiment session, whereas near to the end, the motivation of the subjects increases. Therefore, they generate relatively shorter lane change reaction time.

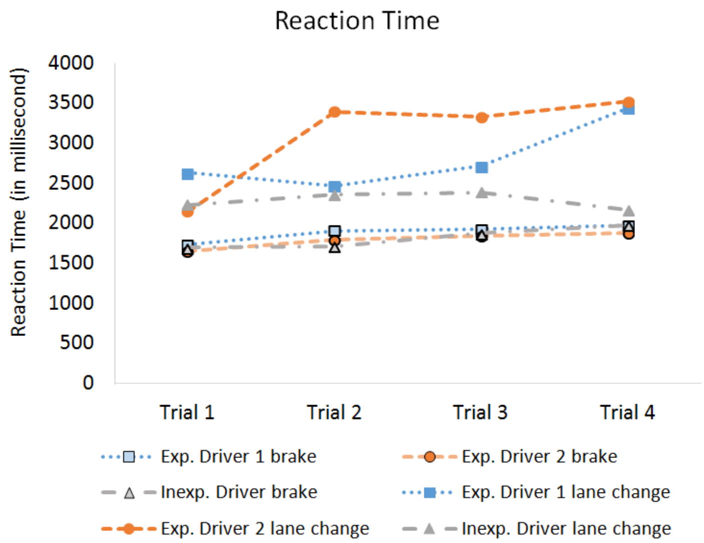

Figure 5. Brake and lane change reaction time of the three subjects in pilot experiment I. Lane change reaction time fluctuates more than brake reaction time

C. Pilot experiment III

The two subjects from the second pilot experiment participated in the third pilot experiment. Experienced driver's data, as observed in the earlier experiments, showed greater fluctuation in lane change reaction time than brake reaction time (Figure 9). Similar to the second pilot experiment under a bright condition, the longest lane change reaction time was observed in the middle trial (trial 5; 2,884.5 ms). However, from the earliest to the last trial, lane change reaction time tends to become shorter.

As found in other data, as illustrated in Figure 9, the inexperienced driver also showed an only slight change in brake reaction time under dark condition. The inexperienced driver showed the longest lane change reaction time at trial 7 (3,981.3 ms). The last trial generated shorter lane change reaction time (2,421.4 ms) than the first trial (3,006.3 ms) and both the 6th (3,013.6 ms) and 7th trials. The fluctuation occurred from the 5th trial to the last trial.

KSS questionnaire data in Figure 10 shows similar tendency with the second pilot experiment, where the level of sleepiness increased after the eight consecutive trials. As found in the earlier pilot experiments, even under the low illumination, the increase of sleepiness level is non-linear to reaction time data. Due to the possibility of increasing motivation near the end of the experiment session, it is necessary to consider to eliminate the provision of the information on the length of the experiment to the subject. A monotonous task with uncertain time will induce boredom and mental fatigue, then the goal to make the subjects fall into drowsiness will be more effective.

During the third pilot experiment, we also tried the use of an eye tracker instrument (Dikablis eye tracker, Ergoneers GmbH, Germany). The most common application of eye tracker is for detecting the area of interest based on gaze movement [28][29][30][31]. Eye movement has been reported to indicate crash risk [28], which is affected by distraction [29], declining visual capacity due to older age [30], and visual field impairment [31]. The eye tracker has two cameras: one records the eye movement (monocular), and the other records the front view of the subject. The eye tracker is able to measure the gaze point which means it may detect the time when the subject take his/her vision away from the road, and the time of eye closure

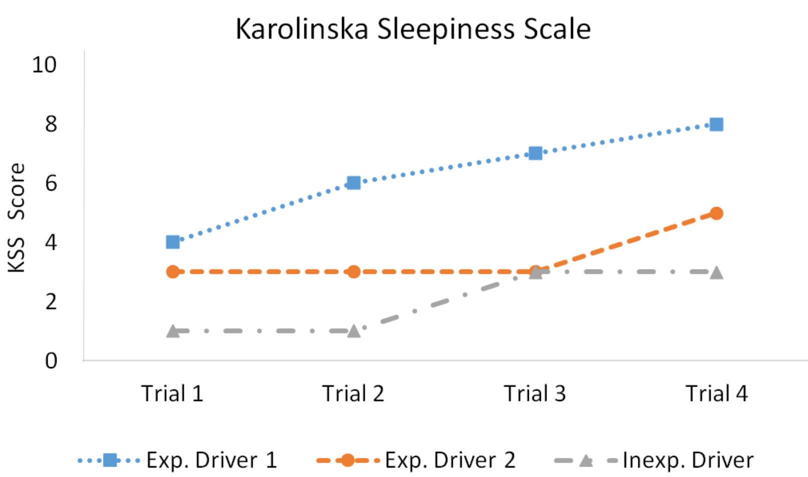

Figure 6. KSS questionnaire score of the three subjects in pilot experiment I

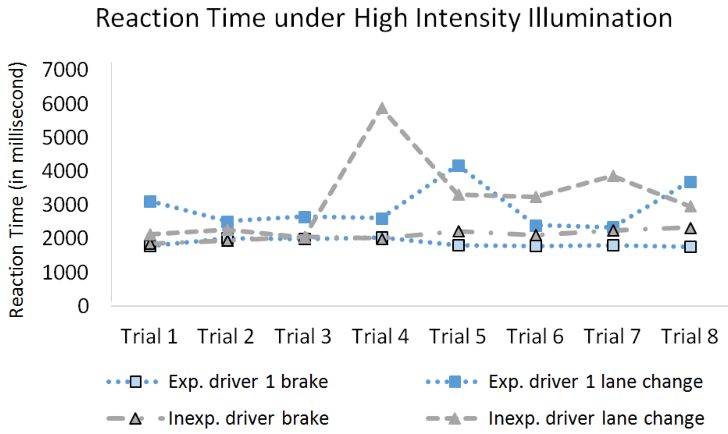

Figure 7. Reaction time data from pilot experiment II. The experiment was conducted at post lunch

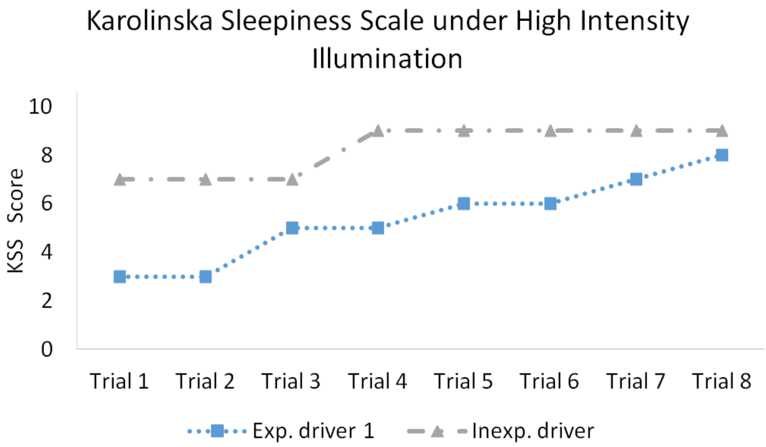

Figure 8. KSS questionnaire score from pilot experiment

which is a common method in drowsiness detection [32][33][34]. However, the eye tracker is relatively expensive and requires training for the operator to be able to use it properly. During the experiment, we had to perform calibration several times. We did not take specific quantitative data from eye tracker measurement during our pilot experiment.

D. Evaluation of pilot experiments

Considering this study is only a very early preliminary experiment, we cannot withdraw a general conclusion to develop a fundamental understanding of driving fatigue. Some assumption needs to be tested in further experiments including the effects of driving experience which is greater on lane change reaction time, the non-linearity of KSS score with driving performance measurement, and the effect of post-lunch which is greater than illumination. We need to test these small findings with a larger number of subjects.

Our pilot experiments were performed with a very limited number of subjects. The previous study suggested that five participants may reveal about 80% of usability problems in a simulated task [13]. Furthermore, many physiological studies employed only six to eight subjects, especially when the task is so demanding and collecting subjects is difficult. ISO standard on lane change test suggests the involvement of at least 16 subjects in finding statistical significance in a within-subject study [14]. Some simulator-based studies even employed more than 50 subjects [35].

The ISO guidelines emphasize that all subjects should have a driving license and it is preferable that all the subjects have a similar level of driving experience and familiarity with the driving simulation task [14]. The guidelines are in line with our speculation on driving experience based on observation. Inexperienced drivers have been reported to be less able in self-measuring their own condition, as such they have become the main target of the road safety campaign [36]. As the KSS form used in Bahasa Indonesia refers to the original version with the label only on number 1, 3, 5, 7, and 9 [6], the inexperienced driver tended to circle those numbers only and pass the numbers without a label.

KSS score shows that regardless of the illumination, the post-lunch experiment session induces greater sleepiness. The reaction time data support this raw assumption in both the experienced and inexperienced drivers. The effect after having meal on post-lunch towards sleepiness during driving has been reported in previous studies [37][38], as worsen performance has been observed [39][40]. In future experiments, we should also measure sleep-related fatigue during driving between midnight and early morning, which has also been reported to greatly induce drowsiness [1][41].

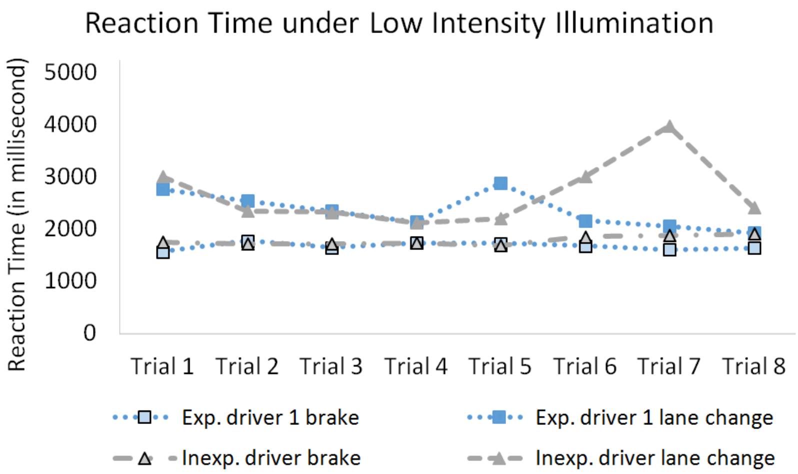

Figure 9. Reaction time data from pilot experiment III. The experiment was conducted at pre-lunch

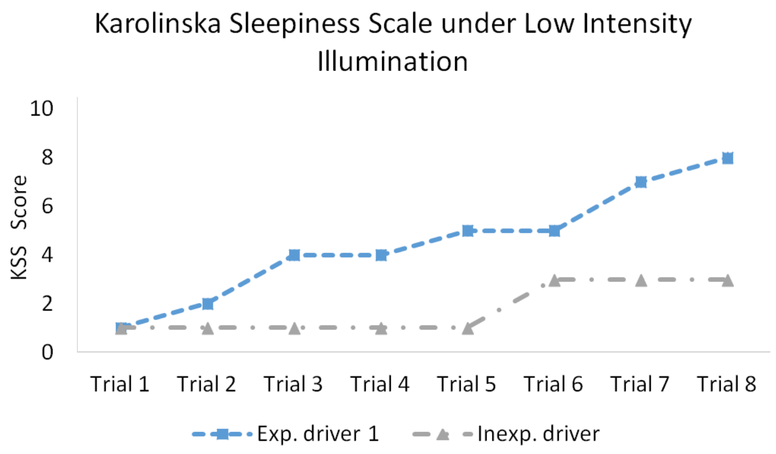

Figure 10. KSS questionnaire score from pilot experiment III

E. Procedure for further experiment

Considering the small number of subjects, there are not many conclusions that can be taken. Additionally, with a very limited number of participants which is only one for each group, there is a very high possibility that the results are limited to the exact person only, and cannot be said the same to other people. As such, further preliminary experiments with a gradually larger number of subjects should be performed. For the further preliminary study, we will involve at least five participants from each group to test the procedure. For the main experiment, we can conclude that the number of subjects should be more than sixteen, with all of them should possess a driving license. In a behavioral study with simple data processing methods, a much larger number up to more than 50 would provide greater significance for the experiment. In the use of physiological measurement methods, such as EEG and electrocardiogram (ECG), with very labouring and time-consuming digital signal analysis, a number of subjects of eight to ten people should suffice.

Compared to the previous study using OpenDS [11], the effects of drowsiness on the longer reaction time is comparable. However, the previous study applied fatigue procedure by depriving subjects of sleeping the night before the experiment. In the future study, we also need to compare the effect of sleep deprivation, lunch, and driving during midnight, to examine which condition produce the worst driving performance.

The use of lane change test can be complemented by performing probe reaction task or peripheral detection task (PDT) [14]. The demand for more realistic driving simulation has brought the complexity of real on-the-road driving into the laboratory study. For example, it is difficult to provide a surprise stimulus continuously, as it would be more predictable. Thus, PDT will provide basic information on subjects the shortest reaction times in various experimental condition. The combination of PDT and driving simulation task will allow us to understand the condition of whole-body coordination, functional potentiality and environmental adaptability in driving. The good understanding of physiological effects of daily activities will provide enough information to design a future system that sustains our biological welfare [42], not only the short term of safety and comfort.

We need to re-evaluate further the effectiveness of KSS both the original and modified version. Previous studies reported that there was no difference between the two versions [23]. The previous study involving OpenDS and KSS reported the non-linearity between the two measurements [11]. On the contrary, the field study measured eye closure and KSS reported the high correlation between the two variables [6]. We also need to evaluate this contradiction in the future studies. The failure to employ an eye tracker in this pilot study made such analysis at the moment is impossible. With regard to eye movements recording, it is possible to use a video camera as replacement of eye tracker [32]. The video camera is cheap and easy to use. However, we may be required to develop and customize the data analysis method.

IV. Conclusion

This preliminary study shows both the limitation and potential of the tested methods, namely lane change reaction time, brake reaction time, and KSS questionnaire. The most significant speculation we formulate based on the experiment is that lunch and circadian rhythm probably has a greater effect on drowsiness than illumination in a simulated driving. We need to test this speculation with a larger number of subjects in the future study. With regard to the previous studies, we need to examine to which extent the effect of circadian rhythm and sleep deprivation in causing drowsiness. The measurement of eye closure apart from KSS is also necessary to confirm the reliability of the subjective analysis. To be able to capture even the slightest change in driver condition, the use of physiological measurement instruments will greatly enhance this type of research. There are various necessary aspects to be tested in various pilot experiments. Such aspects include instruments choice, the procedure to use the instruments and treatment of subjects, and the time of the experiments to meet the required condition. Despite we found that lane change reaction time is probably more representative in fatigue condition than brake reaction time, we still need to develop and try the scenario, as OpenDS allows such thing. To achieve a satisfying experiment procedure that leads to significant results, more pilot experiments need to be performed before the main experiment.

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