Knowledge E
Engaging minds

Conference Paper

The Impact of Sleep Deprivation on the Level of Sleepiness, Fatigue, and Stress on Experiment Using Driving Simulator

Rida Zuraida[1], Hardianto Iridiastadi[2], Iftikar Zahedi Sutalaksana[2], and Suprijanto[3]

[1]Faculty of Industrial Technology, Bandung Institute of Technology, Jalan Ganesha 10 Bandung 41032, Indonesia
[2]Ergonomics, Work and Safety Engineering Research Group, Faculty of Industrial Technology, Bandung Institute of Technology, Jalan Ganesha 10 Bandung 41032, Indonesia
[3]Medical Instrument Laboratory, Engineering Physics Program, Faculty of Industrial Technology, Bandung Institute of Technology, Jalan Ganesha 10 Bandung 41032, Indonesia

Abstract

Sleep prior to driving has been discussed widely in fatigue driving research focusing on how it affected driver on duty. This study is intended to compare the impact of prior normal sleep hour and sleep reduction during long-duration driving to subjective sleepiness, fatigue and stress level. To aim this objective, within-subject 2 x 2 experiments was conducted (4 experiments condition). Sleep hour variable consists of ± 4 hours (var11) and ± 8 hours sleep (var12) before driving, and long duration driving consist of non-stop 5 hours driving (var21) ended with 60 minutes rest, and 2.5 hour driving x 2 sessions (var22) with 30 minutes break between session and ended with 30 minutes rest. Driving task conducted in laboratory started at ± 7 am to ± 1 pm using a simulator that set to highway and city route randomly. Thirteen participants were involved in these four experiments, each of them conducted in a different day in random fashion. Karolinska Sleepiness Scale (KSS/scale 1–9) and Visual Analogue Scale (0–10) were applied to rated subjective sleepiness and fatigue level, and saliva amylase was used to measure the participants' stress level that was collected using Cocoro meter nipro. The result showed that sleepiness and fatigue level under sleep reduction condition was relatively higher compared to the normal sleep condition, while saliva amylase test result slightly increases after experiments, but cannot be categorized into stress condition yet. The conclusion is a duration and sleep hours before driving factors were induced fatigue, sleepiness and stress to driver, but lack of sleep has a higher impact compare to driving duration. Further research with another profession may give different results.

Keywords: driving simulator, fatigue from driving, Karolinska Sleepiness Scale, sleep deprivation, stress level

Corresponding Author:
Rida Zuraida
rzuraida@binus.ac.id

Received: 15 May 2018
Accepted: 3 June 2018
Published: 19 June 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICOHS 2017 Conference Committee.

OPEN ACCESS

How to cite this article: Rida Zuraida, Hardianto Iridiastadi, Iftikar Zahedi Sutalaksana, and Suprijanto, (2018), "The Impact of Sleep Deprivation on the Level of Sleepiness, Fatigue, and Stress on Experiment Using Driving Simulator" in *International Conference of Occupational Health and Safety (ICOHS-2017)*, KnE Life Sciences, pages 268–280. DOI 10.18502/kls.v4i5.2559

1. Introduction

Sleepiness related to fatigue become the focus on many fatigue driving studies, and both of them consider as major factors in most road accident cases, which can be caused by sleep deprivation [1–3]. This sleepiness and fatigue during driving can be interpreted as a biological sign that the body needs recuperate [4]. When they combine with time awake and time of day factor, level of sleep propensity may not intolerable and the best countermeasure strategy to prevent from any accidents is sleeping [5]. Despite being aware of sleep need, in many situations, people continue to drive because it's impossible for them to stop, because there is no appropriate parking spot. But in many cases, the driver prefers to continue the journey even they feel fatigue or sleepy. This condition can be a trigger for increasing accident risks that can lead to fatalities. The number of accidents that related to fatigue and drowsiness while driving is still really high in many countries including in Indonesia [6, 7].

Lack of sleep is a common situation, either due to working conditions, social responsibilities or demographic factors [8–12]. Working condition, including workload [13–14] widely discussed as a contributor factor in causing fatigue and sleepiness, especially during monotonous driving [9] and the impact is more severe under sleep deprivation [4]. The risks not only experienced by commercial drivers on duty but also to any worker who driving from home or after work. The cause of sleep deprivation might differ between each profession, but its impact on the increased risk of accidents still remains.

Workload and other factors also induced drivers stress, and this stress can cause the emergence of fatigue [12]. In the long run, it may affect sleep quality which worsens lack of sleep and fatigue [15, 16] and generates a higher sleep propensity. If sufficient sleep hours before next duty is not fulfilled [15], a risk of the accident become greater.

As described earlier, the driver is in a high-risk situation when driving in a sleepy and tired condition. Some factors are more influential to sleep/fatigue level than other [4], and some literatures suggested sleep and task-related factors be considered seriously. the impact of both factors still requires to be explored to increase our understanding, especially for driving jobs.

The previous studies that explore sleepiness and fatigue in driving have been done as a real driving and/or a laboratory study using a driving simulator [2, 3]. It showed that driving simulator research gives similar results for real driving, especially in response ability. The studies reported that sleepiness level is relatively higher compares to real driving [16–18]. Imitation of driving workload by simulator indeed has some limitations such as pressure on safety during driving is less than real driving that may impact on performance variation during experiment [19], but in many conditions applying driving simulator allowed a researcher to minimize the risks that may occur during experiments.

To increase understanding of fatigue, sleepiness, and stress level that may experience by a driver on duty, this study was conducted. The objective is to investigate the differences of sleepiness, fatigue and stress level under normal sleep and restriction sleep hour condition using a driving simulator. It also considers long duration driving situation which being faced by many people who work as the driver. In this study all participant is a commercial driver, and it hopes can yield close results.

2. Methods

To achieve the objective, experiments conducted in the laboratory using a driving simulator. A driving simulator is chosen as an approach since the safety and collection data are a major consideration for the study. The experiment was designed as 2x2, with the two conditions of sleep hour at night before the experiment and two conditions of driving duration. Sleep hour were ± 4 hours and ± 8 hours, while driving duration is 2.5 hours x2 with 30 minutes break between and 30 minutes rest after the second driving session; and non-stop 5 hours with 60 minutes rest after driving finished.

Route at simulator is assigned at modern district consist of highway and city route, vehicles medium density, some intersection with traffic light at city route. All participants followed assignment routes that consist of 10km, the arrangement between assignments ranges from 30–60 seconds, and during highway route, vehicle speed had to maintain 60–80 km/hr. The route can be seen at Figure 1.

A prior session using driving simulator is conducted for all participants until they reach their normal skills in real driving, such as engaged the machine, steering control, read speed information, read machine status, etc. To minimize result caused by individual variability, all participants agreed to not consume caffeine, tea, or other beverage, and they also not allowed to smoke before and during experiments.

2.1. Participants

The number of participants involved in the study was 13 people, all of them are male aged 23–31 years (mean 26.36 ± 4.59), height 169.76cm ± 3.52, and weight 71.69 ± 15.35. All participants have experience as a driver at least 1 year with a relevant driving

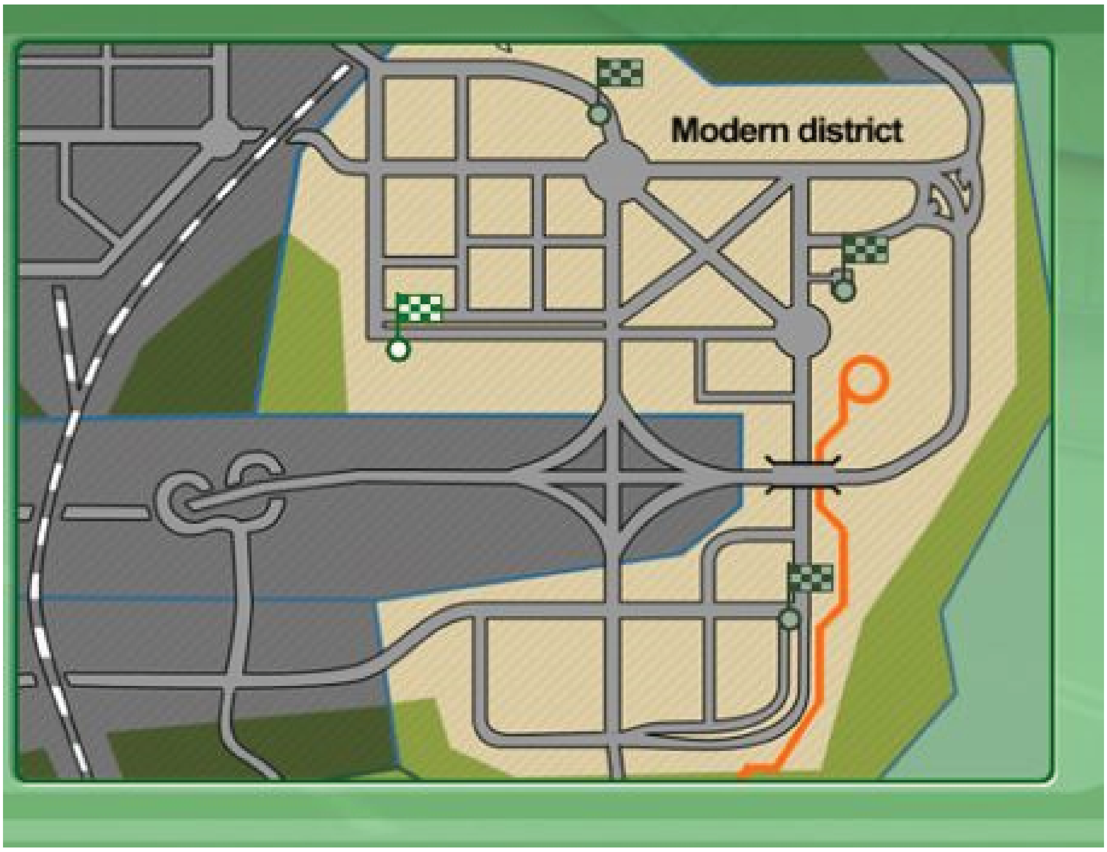

Figure 1: Driving route simulator.

license. Ten of them are part-time driver and using the online application to serve customers while the other three participants are a full-time driver in Taxi Company. The average duration of sleep before the experiment was 4.04 ± 0.29 hours of experiments with sleep reduction condition, and 7.46 ± 0.55 hours for experiments with normal sleep time. The average participant had already awoken 2.5 ± 0.50 hours before the experiment begins at 7 am. The experiment begins between 06:58 and 07:15 am and it finished around 13. All participants have expressed willingness to engage in the experiment and signed informed consent.

2.2. Driving simulator

The study was conducted in a laboratory using a simulator consisting of a set of Logitech G27 series 92 with 3 pedals as driving tools, and a set of PCs equipped with a standard sound system and external speakers and a 32 'HD touchscreen monitor placed in front of the participants as a display. Using City Car Driving v.1.4 as a simulator software, the transmission speed set to manual so participants use all three pedals of the available controls (see Figure 2). The experiments are performed in a room with a temperature of 22^0 Celsius and lighting rate of 215 Lux in average.

Figure 2: Driving simulator equipment.

For the purposes of this study, scenarios assigned to software are daytime with 80 percent vehicle density in freeway routes and other drivers' behavioral levels set to normal (non-aggressive). Car using in this experiment set to a minibus type, the right steering wheel and the left-hand driving path (accordance with conditions in Indonesia).

2.3. Experimental condition

Participants were asked to sleep ± 8 hours for normal sleep condition and ± 4 hours for sleep reduction condition. This study designed as a within-subject experiment and only data from participants who involved in all four experiments is analysis further. Two of experiments conditions conducted under normal sleep condition and two others are under sleep deprivation. Participants involved in driving 2.5 hours with 30 minutes break and continued driving 2.5 hours that ended with a 30-minute rest and non-stop 5 hours driving with 60 minutes rest after finish for both sleep condition.

The experiment begins ± 7 am which ended at 1 pm to eliminate the biological declining due to circadian rhythm during the day [5]. Participants were requested to be in the location for at least 40 minutes before experiments started. After arriving and had some rest about 5 minutes, they interviewed for subjective sleepiness score using KSS (1–9) [20, 21], and fatigue level using VAS with scale 0-10 [20, 21].

Scale in KSS described as follows [18–20]: 1 = very alert, 3 = alert, 5 = neither alert nor sleepy, 7 = sleepy, but no problem to stay awake, 9 = very sleepy, great effort to stay awake, and even numbers (2, 4, 6, and 8) as an intermediate score between odd score.

Scale 0 in fatigue of VAS related to none (fatigue), 5 as moderate fatigue, and scale 10 is worst possible fatigue [22, 23]. Participants also took the stress level test through sampling saliva measured by Nipro Cocoro Meter (Japan) [24, 25]. Other physiological data, blood pressure and body temperature that measured right before and right after driving session, and also brainwave signal during driving are not described here. Participants had breakfast before experiment, experiments were started 5–10 minutes after they finished their meal.

During the experiment, every ten-minute participant asked to rate their sleepiness level, including at a break/rest time. Right before driving (minute 0), minute 70, minute 160, minute 250 and minute to 330 (right after driving session last) they asked to rate their fatigue level. Amylase saliva tests conducted right before experiments, at break time and after of the experiment.

3. Results

3.1. Sleepiness

The effect of prior sleep discussed first is the level of sleepiness. Sleepiness rate can be seen in Figure 3, and sleep rate was higher under sleeping reduction condition (± 4 hours) compared to normal sleeping hours (± 8hours). Surprisingly, the sleepiness level on K2 was 10.4 percent higher compared to K4, but K1, as expected it lower, compare to K3 (26.1%). Table 1 show data on average and comparison test result between experiment condition:

Statistical test conducted to see whether the sleepiness level between experiments condition are exists. Wilcoxon Signed Rank Test applied for two related sample and the result showed that differences were not found for comparison two conditions

Table 1: Sleepiness level comparison test.

	K1	K2	K3	K4
Sleepiness rate (mean, SD)	3.83 ± 0,81	5.91 ±1.11	3.97 ±1,06	5.36 ±0,96
Statistic test result for 2 sample	K1–K2		K2–K3	
	p-value = 0.000*		*p*-value = 0.000*	
	K1–K3		K2–K4	
	p-value = 0.166		*p*-value = 0.001*	
	K1–K4		K3–K4	
	p-value = 0.000*		*p*-value = 0.000*	
Note: K1= normal sleep, driving 2.5 x 2 hrs; K2 = sleep reduction, driving 2.5 x 2 hrs; K3 = normal sleep, driving 5 hrs; and K4 = sleep reduction, driving 5 hrs.				
** = p-value < 0.05.				

Figure 3: Average subjective sleepiness level (KSS 1–9).

under normal sleep (K1–K3). It can conclude that driving duration more affected by the sleepiness level while people under sleep deprived.

3.2. Subjective fatigue level

Fatigue was measured by Visual Analogue Scale (VAS) on a scale of 0–10. Participants rated their fatigue level right before the experiment began, in the middle of the first session (minute ±70), minutes to ±160, minutes to ±250 and minutes to ±330. Fatigue level for each condition showed in Figure 4. Wilcoxon Signed Rank Test for two related samples also conducted and the result can be seen as follow:

Table 2: Fatigue level comparison test.

Mean, SD	**K1: 3.56 ± 1.51**	**K3: 3.58 ± 1.61**
	K2: 4.31 ± 1.34	**K4: 4.82 ± 1.71**
Comparison test result	K1–K2	K2–K3
	p-value = 0.046*	*p*-value = 0.046*
	K1–K3	K2–K4
	p-value = 1.000	*p*-value = 0.157
	K1–K4	K3–K4
	p-value = 0.034*	*p*-value = 0.034*

Note: K1 = normal sleep, driving 2.5 x 2 hrs; K2 = sleep reduction, driving 2.5 x 2 hrs; K3 = normal sleep, driving 5 hrs; K4 = sleep reduction, driving 5 hrs; * = *p*-value < 0.05.

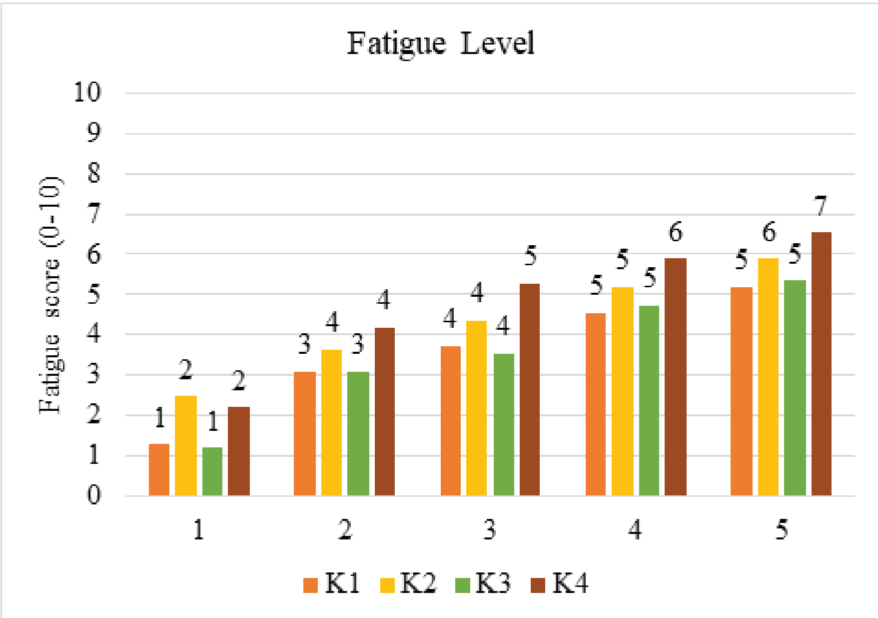

Figure 4: Average Fatigue Level Comparison.

It is shown earlier that comparison between same sleep hours is not statistically different (K1–K3, K2–K4), but it exists for different conditions of sleep hours (KI–K2, K2–K3, K1–K4, K2–K3, K3–K4). This result gives understanding, that not only sleepiness level but also the fatigue level during driving will worsen when people don't have sufficient sleep. A continuing sleep debt might give a worse result than what can see in this study.

3.3. Stress level

Participant saliva amylase data in each experiment can be seen in Table 3.

Table 3: Salivary amylase result test.

	Condition 1 (kU/l)	Condition 2 (kU/l)	Condition 3 (kU/l)	Condition 4 (kU/l)
Before driving (in average)	23.9 ± 30.45	38.2 ± 30.17	32.4 ±26.18	28.3 ±16.15
After (in average)	40.4 ± 21.29	41.5 ±25.98	35.9 ±19.96	31.7 ±14.82
Note: 0–30 = none; 30–45 = somewhat stressed; 46–60 = stress; > 60 = very stressed.				

As can be seen in Table 3, saliva amylase before experiment are categorized into a none-somewhat stress, and after experiment categorized into somewhat stress. The increasing is not really high, but it can be said that driving duration and sleep arrangement hours affected participants stress level. This result may affect by participants occupation background as a driver. The workload and driving length during the experiment may not induce high-stress level for them, even though they agreed the experiment causes sleepiness and fatigue.

3.4. Sleepiness and fatigue comparison

The results of statistical tests showed that there was a significant correlation between sleepiness and driving time (Pearson correlation 0.543, p-value $\leq$ 0.01), fatigue level with driving time (Pearson correlation 0.892, p-value $\leq$ 0.01) and sleepiness and fatigue (Pearson correlation 0.700, p $\leq$ 0.01). See Figure 5 to see the comparison in the graphic.

Sleep reduction was seen to have the most effect on sleepiness for experiment condition 2, the condition at which participants were given a break between driving times. Sleep reduction also affected fatigue level during non-stop 5 hours driving without resting between them. Visually, sleepiness and fatigue level under adequate sleep (conditions 1 and 3) relative lower than with less sleep time. Fatigue levels were consistently increased when sleepiness level increased. Experiment results consistently showed that lack of sleep time has impacted to driver's sleepiness and fatigue level.

While the driving cycle and duration (time on task) has most impact on the level of fatigue and driver's stress level.

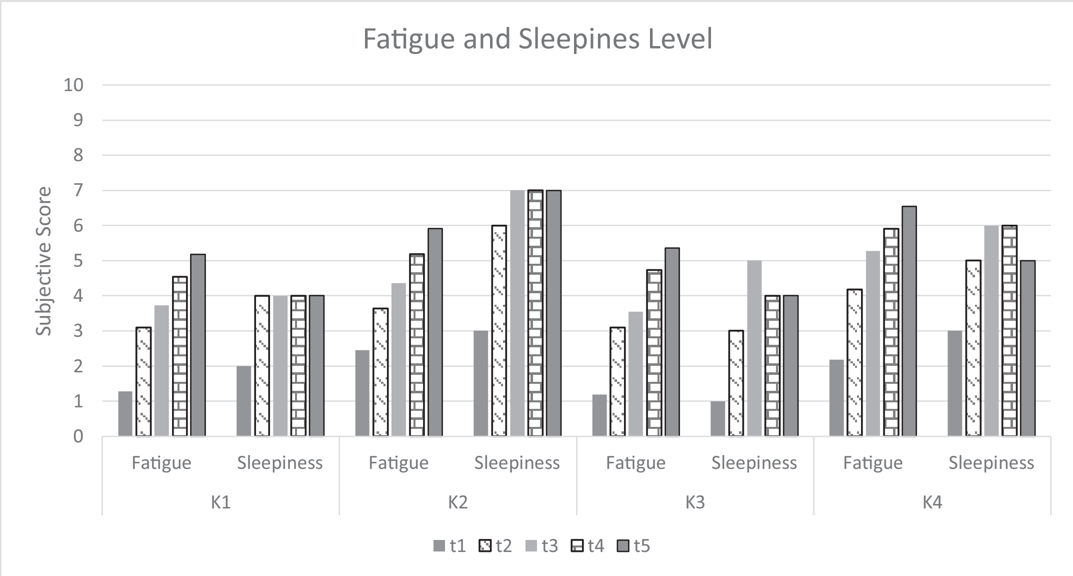

Figure 5: Sleepiness and fatigue level comparison.

4. Discussion

Driving simulator widely uses in driving study, and the result gives many insights for researchers or other parties. Despite its limitations compare to real driving [3, 16, 18], the results as well as in this study can be used to draw conclusions and made a general proposal to mitigate car accidents. Lack of sleep, especially in the previous night before duty should receive serious attention for drivers who will be on duty [24]. An effect of acute sleep debt of fatigue, sleepiness, and stress may different, but the effect estimated more severe. Further research still needed to compare how the condition will affect another profession who drive regularly as well as include other factors that may be more influential such as workload, social-factors, and emotional individual type [12]. Age also play important role and may result a different response to duration and sleep hour that set in the experimental for performance aspect [25], and analysis of fatigue status based on performance need to analysis more carefully for elderly compare to other age group.

5. Conclusions

Sleep reduction together with long duration driving induced higher sleepiness and fatigue level. It also affected stress level, especially for long-duration driving. The break between driving can be considered as a mitigation from fatigue and sleepiness, but further investigation is needed to define an effective break for the driver who under sleep deprivation.

Conflict of Interest

The authors hereby issue a declaration that they have no competing interest in this article.

Funding

This research was supported by Hibah Disertasi Doktor from Directorate General Higher Education Indonesia (2017), the Ministry of Research Technology and Higher Education, contract number 039A/VR.RTT/VI/2017.

References

[1] Akerstedt, T., Ingre, M., Kecklund, G., et al. (2010). Reaction of sleepiness indicators to partial sleep deprivation, time of day and time on task in a driving simulator—The DROWSI project. *Journal Sleep Research*, vol. 19, pp. 298–309.

[2] Baulk, S. D., Reyner, L. A., and Horne, J. A. (2001). Driver sleepiness—Evaluation of reaction time measurement as a secondary task. *Sleep*, vol. 24, no. 6, pp. 695–698.

[3] Philip, P., Sagaspe, P., Moore, N., et al. (2005). Fatigue, sleep restriction and driving performance. *Accident Analysis and Prevention*, vol. 37, pp. 473–478.

[4] Williamson, A., Lombardi, D. A., Folkard, S., et al. (2011). The link between fatigue and safety. *Accident Analysis and Prevention*, vol. 43, pp. 498–515.

[5] May, J. F. and Baldwin, C. L. (2009). Driver fatigue: The importance of identifying causal factors of fatigue when considering detection and countermeasure technologies. *Transportation Research Part F 12*, pp. 218–224.

[6] WHO Report. *Global Status Report on Road Safety 2015*. Retrieved from http://www.who.int/violence_injury_prevention/road_safety_status/2015/en/ (accessed on 20 June 2017).

[7] Puspasari, M., Muslim, E., Moch, B. N., et al. (2015). Fatigue measurement in car driving activity using physiological, cognitive, and subjective approaches. *International Journal of Technology*, vol. 6, no. 6, pp. 971–975.

[8] Connor, J., Whitlock, G., Norton, R., et al. (2001). The role of driver sleepiness in car crashes: A systematic review of epidemiological studies. *Accident Analysis and Prevention*, vol. 33, pp. 31–41.

[9] Garbarino, S., Nobili, L., Beelke, M., et al. (2001). The contributing role of sleepiness in highway vehicle accidents. *Sleep*, vol. 24, no. 2.

[10] Smolensky, M. H., Di Milia, L., Ohayon, M. M., et al. (2011). Sleep disorder, medical conditions, and road accident risk. *Accident Analysis and Prevention*,vol. 43, pp. 533–548.

[11] Di Milia, L., Smolensky, M. H., Costa, G. (2011). Demographic factors, fatigue, and driving accidents: An examination of the published literature. *Accidents Analysis and Prevention*, vol. 43, pp. 516–532.

[12] Useche, S. A., Ortiz V. G., Cendales, B. E. (2017). Stress-related psychosocial factors at work, fatigue, and risky driving behavior in bus rapid transport (BRT) drivers. *Accidents Analysis and Prevention*, vol. 104, pp.106–114.

[13] Sang, Y. and Li, J. (2012). Research on Beijing bus driver psychology fatigue evaluation. *Procedia Engineering*, vol. 43, pp. 443–448.

[14] Da Silva, F. P. (2009) Mental workload, task demand, and driving performance: What relation? *Procedia- Social and Behavioral Science*, vol. 162, pp. 310–319.

[15] Carter, N., Ulfberg, J., Nyström, B., et al. (2003). Sleep debt, sleepiness and accidents among males in the general population and male professional drivers. *Accidents Analysis and Prevention*, vol. 35, pp. 613–617.

[16] Hallvig, D., Anund, A., Fors, C., et al. (2013). Sleepy driving on the real road and in the simulator – A comparison. *Accident Analysis and Prevention*, vol. 50, pp. 44–501.

[17] Meuleners, L. and Fraser, M. (2015). A validation study of driving errors using a driving simulator. *Transportation Research Part F. 29*, pp.14–21.

[18] Dunn, N. and Williamson, A. (2012). Driving monotonous routes in a train simulator: The effect of task demand on driving performance and subjective experience. *Ergonomics*, vol. 55, no. 9, pp. 997–1008.

[19] Ekanayake, H. B., Backlund, P., Ziemke, T., et al. (2013). Comparing expert driving behavior in real world and simulator contexts. *International Journal of Computer Games Technology*, vol. 2013, p. 14, article ID 891431.

[20] Kaida, K., Takahashi, M., Åkerstedt, T., et al. (2006). Validation of the Karolinska sleepiness scale against performance and EEG variables. *Clinical Neurophysiology*, vol. 117, pp. 1574–1581.

[21] Åkerstedt, T. and Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *The International Journal of Neuroscience*, vol. 52, no. 1–2, pp. 29–37.

[22] Putilov, A. A., Donskaya, O. G. (2014). Calibration of an objective alertness scale. *International Journal of Psychophysiology*, vol. 94, pp. 69–75.

[23] Kim, E., Lovera, J., Schaben, L., et al. (2010). Novel method for measurement of fatigue in multiple sclerosis: Real-Time Digital Fatigue Score. *Journal of Rehabilitation Research & Development*, vol. 47, no. 5, pp. 477–484.

[24] Yamaguchi, M., Kanemori, T., Kanemaru, M., et al. (2004). Performance evaluation of salivary amylase activity monitor. *Biosensors and Bioelectronics*, vol. 20, pp. 491–497.

[25] Komada, Y., Asaoka, S., Abe, T., et al. (2013). Short sleep duration, sleep disorder, and traffic accidents. *IATSS Research*, vol. 37, pp. 1–7.

[26] Susilowati, I. H. and Yasukouchi, A. (2016). Variation of driving skill among elderly drivers compared to young drivers in Japan, Kesmas. *National Public Health Journal*, vol. 11, no. 1, pp.1–6.