

Keywords: driving; fatigue; sleepiness; Psychomotor Vigilance Task; Swedish Occupational Fatigue Inventory; Karolinska Sleepiness Scale

Hardianto IRIDIASTADI*, Ibrahim ABDURRAHMAN,
Maya PUSPASARI, Herman Rahadian SOETISNA
Faculty of Industrial Technology, Institut Teknologi Bandung
Ganeca 10, Bandung, West Java, Indonesia 40132
*Corresponding author. E-mail: hiridias@vt.edu

FATIGUE AND SLEEPINESS DURING LONG-DURATION DRIVING: A PRELIMINARY STUDY AMONG INDONESIAN COMMERCIAL DRIVERS

Summary. Fatigue and sleepiness are two major factors that have been reported to contribute to road crash and accidents in Indonesia. Fatigue among commercial drivers is probably a common phenomenon, particularly during long-duration driving. This study aimed at characterizing fatigue and sleepiness during long-duration driving. Nine commercial drivers were recruited in this field study and were requested to drive a multi-purpose vehicle for three trips back and forth between two major cities. Each trip was completed within 4 hours, with about 3 to 3.5 hours of continuous driving (and 0.5 to 1 hour of rest). Fatigue was assessed by utilizing the Psychomotor Vigilance Task (PVT), which was administered for 5 minutes immediately following the completion of each trip. A video camera was employed to capture blink frequency, and for each trip, this measure was determined during 5 minutes after two hours of driving. Subjective ratings were also collected during the task and included the Swedish Occupational Fatigue Inventory (SOFI) and the Karolinska Sleepiness Scale (KSS). The results of this study demonstrated a consistent increase in the blink rate and subjective measures of fatigue. A significant association was also found between the blink rate and SOFI measures, indicating an association between those objective and subjective measures. Although not statistically significant, there were also changes in PVT parameters associated with driving duration. However, no significant association was found between PVT parameters and the subjective measures. This study found that a minimum of six hours of intermittent driving was adequate in inducing fatigue and sleepiness, despite the seemingly sufficient amount of rest break. Based on the findings of this study, it is suggested that long-duration driving be limited to a maximum of 12 hours, and that a minimum of 30 minutes of rest be provided after 3 to 4 hours of driving. This finding should be used as a basis for scheduling drivers and for finding the appropriate intervention strategy for mitigating fatigue and sleepiness risks during prolonged driving tasks.

1. INTRODUCTION

Road safety is considered a very serious issue in Indonesia. There were 109,215 accidents involving motor vehicles in 2018 [1], and between 2014 and 2018, this figure increased by roughly 3.3% per year. The accidents in 2018 resulted in 29,472 fatalities and 130,571 injuries. The direct cost associated with these accidents was roughly in the order of 15 million US dollars. The Ministry of Transportation indicates that the potential economic and social cost per year is greater than 16 billion US dollars.

Based on road accident reports, the Indonesian National Transportation Safety Committee pointed out fatigued and careless drivers as two of several major factors in road accidents [2]. Fatigue (and sleepiness) has also been cited in a number of studies as a factor that plays an important role associated with many road accidents. The work of Williamson and colleagues [3] also highlighted a causal link between fatigue and poor performance and safety.

Fatigue and sleepiness can also be linked to factors associated with sleep or tasks [4]. According to this study, fatigue can be sleep-related in nature, such as when a driver is sleep deprived, or can also be related to the time of day. Additionally, fatigue can be influenced by the characteristics of the tasks being performed. Both excessive and less than optimal workload could have adverse effects on driving performance. The latter condition, in particular, often results in monotony and is associated with sleepiness. Driving continuously for long periods of time has also been cited as a major factor that contributes to fatigue and sleepiness [5, 6].

In Indonesia, working for long hours is a common phenomenon for commercial drivers. This can be found among truck and bus drivers. During national holidays, for instance, it is not uncommon for them to work for up to 20 hours, although separated by major breaks [5]. A similar phenomenon can also be found among taxi drivers who start working early in the morning (e.g., at 5:00 am) and return to their pool in the evening (typically past 11:00 pm). Their work roster is usually two consecutive workdays, followed by one day off.

Another job requiring long-duration driving is when operating a shuttle service, which is one of the most common modes of public transportation between two major cities. Unfortunately, many road crashes (resulting in fatalities and injuries) for this type of transportation have been reported in the media. Formal investigations have been carried out by the Indonesian National Transportation Safety Committee, which noted fatigue and sleepiness as a major factor that contributes to the accidents [2].

This was a preliminary study that sought to assess degrees of fatigue and sleepiness among shuttle service drivers using objective and subjective indicators. This was a field experiment, in which the drivers performed their typical actual driving tasks while several measures were taken in real time. It was expected that the findings from this study could be used as a basis for managing fatigue among shuttle service drivers and, moreover, for determining the optimal mitigation strategy.

2. MATERIAL AND METHODS

A total of nine male commercial drivers (with at least 5 years of driving experience) were recruited in this study. They all had a driver's license and were adequately paid to participate in this study. They provided their consent before participating in this study and were free to withdraw their participation without any penalty. Their mean age (standard deviation) was 35.9 (5.6) years, with a height and weight of 165.2 (5.4) cm and 63.7 (8.1) kg, respectively. This study had been approved by the Ethical Research Committee of the Directorate General of Higher Education, the Indonesian Ministry of Education.

A field experiment that mimicked the jobs of a real shuttle service driver was created, in that the drivers were asked to drive a multi-purpose vehicle for three trips, back and forth, between two major cities in Indonesia (a one-way distance of approximately 180 km). The first trip started at around 07:00 AM, while the last trip was completed at around 06:00 PM. Most of the driving was performed on toll roads and, depending on the traffic, each trip was typically completed within 3 to 3.5 hours. Four hours were allotted for each trip; the drivers, therefore, had roughly 0.5 to 1 hour of break (in an air-conditioned room) between two consecutive trips. The drivers were not allowed to eat or drink (except water) throughout the duration of each trip. Lunch or snacks were provided during the breaks. If needed, they were also allowed to have a short nap during the breaks. Note that each driver was requested to have at least eight hours of good sleep before participating the next morning.

Fatigue and sleepiness associated with the driving tasks were assessed by examining changes in four dependent measures. Eye-blink frequency [7] was determined by calculating the average frequency (approximately) during 5 minutes after two hours of continuous driving in each trip. A baseline frequency was determined by using the third 5-minute segment from the first trip. For this

purpose, a video camera was installed on the dashboard that continuously recorded the face of the drivers. The calculation of eye-blink frequency was done manually after the experiment was completed.

The Psychomotor vigilance task (PVT) was also used in this study for evaluating fatigue and sleepiness. This test was administered before the first trip and immediately following each trip. During this test, a driver was asked to respond to a computer-generated stimulus (a square) that was randomly (between 2 and 10 s) and briefly displayed. For each presentation, the driver was supposed to respond as quickly as possible by pressing the space-bar key on the computer. The PVT is a sensitive measure and represents human performance [8]. The task has also been utilized in many fatigue studies [9]. A number of PVT parameters were used in this study [10], including the mean reaction time (PVT-M), 10% fastest (PVT-F) and the number of lapses (a response greater than 500 ms or PVT-L). Two additional measures were collected, including the Swedish Occupational Fatigue Inventory or SOFI [11] [12] and the Karolinska Sleepiness Scale or KSS [13]. Both techniques employed a set of questionnaires and, thus, are subjective in nature. These two measures were collected immediately after administering the PVT.

Due to the relatively small sample size, the non-parametric Kruskal–Wallis test was used for determining differences in changes in fatigue measures across the three trips. The Spearman rho test was used for measuring the correlations among the various dependent variables. Considering the nature of this study, a $p < 0.1$ was considered significant for all statistical tests.

3. RESULTS

An analysis of the results from Table 1 shows that there are differences in the fatigue and sleepiness measures between the three trips. Across the nine drivers, the mean (SD) blink frequency at the initial phase of the trip was 26.3 (9.0) blinks per minute (bpm), followed by a substantial increase in the blink rate throughout the duration of the driving task. At the end of the third trip, the mean (SD) blink rate was 38.7 (13.3), an increase of about 47% compared to the initial condition. With respect to reaction times collected using PVT, the average (SD) of the mean (PVT-M) and 10% fastest (PVT-F) at the beginning of the experiment were 350.1 (46.6) and 282.6 (40.9) ms, respectively. These measures increased to 380.1 (52.0) and 305.1 (41.3) ms, respectively, a change of roughly 8 to 8.6%. The initial average (SD) number of lapse (PVT-L) was 4.1 (6.6) and increased to 7.2 (6.2).

In this investigation, SOFI was administered via a standardized questionnaire. Across dimensions, the drivers generally rated roughly zeroes at the beginning of the experiment. At the end of the third trip, mean ratings of 1.1 to 2.6 were reported for these dimensions. The level of sleepiness was assessed via the use of the Karolinska Sleepiness Scale (KSS). The mean KSS scores indicated a fairly consistent increase: from about 2.5 at the beginning of the first trip to roughly 3.8 at the end of the third trip. Only two of the drivers reported a final KSS greater than or equal to “6”.

The non-parametric Kruskal–Wallis test was used for determining differences in changes in fatigue measures across the three trips. The results of this analysis for the grouping factor “trips” are shown in Table 2. The results of the calculation presented in table 2 show that, at the adopted level of significance of the test $p < 0.1$, the differences observed in the fatigue and sleepiness measures are statistically significant for blink rate, SOFI, and KSS. For all the measures of PVT, however, the changes in median were not significant ($p = 0.232 - 0.435$). Pairwise comparison of the Kruskal–Wallis test shows that significant differences were found when comparing the blink rate at the beginning of the trip vs. the third trip ($p < 0.032$) and the first trip vs. the third trip ($p < 0.040$). For all SOFI dimensions, significant differences were revealed between every reported rating from the beginning of the experiment to the end of the third trip. ($p < 0.000-0.839$). Significant differences were found when comparing KSS ratings between the beginning of the first trip vs. the second trip ($p < 0.062$), between the first trip vs. the third trip ($p < 0.018$) and between the first trip vs the third trip ($p < 0.036$).

Also of interest in this study were the correlations among various dependent variables, which were measured using Spearman rho. Generally, satisfactory correlations were found among the different PVT or SOFI measures. Blink rate somewhat negatively correlated with PVT-Mean, PVT-Fastest and

PVT-L ($\rho=0.229-0.355$, $p<0.05$) and significantly correlated with SOFI-PE and SOFI-LE ($\rho=0.427-0.478$, $p<0.01$), while a moderate correlation was found between blink rate and SOFI-PD and SOFI-LM ($\rho=0.322-0.366$, $p<0.05$). This indicates associations between objective (blink rate) and subjective indicators (SOFI) for fatigued individuals in this study. Satisfactory correlation was found between SOFI Lack of Energy and KSS scores ($\rho=0.668$, $p<0.01$), SOFI Physical Discomfort and KSS scores ($\rho=0.479$, $p<0.01$), and SOFI Lack of Motivation and KSS scores ($\rho=0.652$, $p<0.01$).

Table 1

Descriptive statistics for the three trips

Fatigue & Sleepiness Measures	Trip	Mean	Std. Deviation	Minimum	Maximum	Range	Variance
Blinkrate	0	26.3111	9.03209	9.50	38.70	29.20	81.579
	1	27.0222	9.48180	10.20	38.60	28.40	89.904
	2	34.8222	12.81540	11.00	51.00	40.00	164.234
	3	38.6889	13.28838	14.20	57.80	43.60	176.581
PVT mean	0	350.1167	46.61141	313.46	466.47	153.01	2172.624
	1	353.8200	43.73230	295.50	445.75	150.25	1912.514
	2	367.8867	39.44235	301.95	421.56	119.61	1555.699
	3	380.1122	52.02642	315.46	486.59	171.13	2706.748
PVT Fastest	0	282.6300	40.91954	236.28	377.78	141.50	1674.409
	1	289.6011	34.79614	240.48	358.80	118.32	1210.772
	2	294.9744	33.53871	248.88	357.98	109.10	1124.845
	3	305.1344	41.28556	253.04	396.67	143.63	1704.497
PVT Lapse	0	4.1111	6.62277	0.00	21.00	21.00	43.861
	1	4.1111	5.10990	0.00	17.00	17.00	26.111
	2	5.0000	3.77492	1.00	9.00	8.00	14.250
	3	7.2222	6.22049	2.00	20.00	18.00	38.694
SOFI Lack of Energy	0	.1556	.27889	0.00	.80	.80	.078
	1	.9333	.55678	.20	2.00	1.80	.310
	2	1.9111	.93333	.40	3.40	3.00	.871
	3	2.5333	1.19583	.40	3.60	3.20	1.430
SOFI Physical Exertion	0	.2667	.28284	0.00	.80	.80	.080
	1	.4222	.29059	0.00	.80	.80	.084
	2	.8889	.63333	.40	2.40	2.00	.401
	3	1.0889	.42557	.40	1.60	1.20	.181
SOFI Physical Discomfort	0	.2222	.39299	0.00	1.20	1.20	.154
	1	.8667	.87178	0.00	2.60	2.60	.760
	2	1.4889	1.25742	0.00	4.00	4.00	1.581
	3	2.0222	1.40870	0.00	4.60	4.60	1.984
SOFI Lack of Motivation	0	.2000	.28284	0.00	.80	.80	.080
	1	.8667	.60828	.20	1.80	1.60	.370
	2	1.3778	.96667	.20	2.80	2.60	.934
	3	1.4667	.88882	.20	2.60	2.40	.790
KSS	0	1.6667	.86603	1.00	3.00	2.00	.750
	1	2.1111	1.45297	1.00	5.00	4.00	2.111
	2	3.3333	1.80278	1.00	6.00	5.00	3.250
	3	3.7778	2.10819	1.00	7.00	6.00	4.444

4. DISCUSSION

This study aimed at evaluating fatigue and sleepiness during long hours of driving commercial vehicle. The findings of this study demonstrated that a driving task for 10 hours (including 30-60 min.

breaks in between trips) clearly induced fatigue. Blink frequency increased nearly 50%, while an 8 to 9% performance decrement (indicated by increased PVT measures) was associated with this driving task. In some measures, the second trip (task duration of about 4–8 hours) also resulted in a substantial increase in fatigue measures. Associations between all these subjective and objective indicators for fatigued individuals have been reported in the literature [14, 15], in line with the majority of the findings in this study. In this study, however, blink frequency somewhat negatively correlated with the mean PVT, but this relationship needs to be investigated further.

Table 2

Results of the Kruskal–Wallis KW test of equality of fatigue measures for the three trips (Grouping factor: trip)

Fatigue measures	Value of the KW test statistic	<i>p</i> -value	Differences
Blinkrate	6.613	0.085	Yes
PVT mean	3.817	0.282	No
PVT Fastest	2.732	0.435	No
PVT Lapse	4.288	0.232	No
SOFI Lack of Energy	22.217	0.000	Yes
SOFI Physical Exertion	16.614	0.001	Yes
SOFI Physical Discomfort	11.625	0.009	Yes
SOFI Lack of Motivation	13.763	0.003	Yes
KSS	8.155	0.043	Yes

Driving for long hours (greater than 3 - 4 hours) was found to be characterized by degraded performance. Wang and Pei [16] noted that reduced driving performance appeared after 2 hours of driving, and more severely after 4 hours of driving continuously. This degradation in performance may include different cognitive functions, such as attention, reactions, operating ability and perception. Several studies have used steering error and lateral position, and other parameter related directly to driving performance [14, 15, 17]. Evaluations using secondary task measurements also showed similar results during extended driving time [14].

Despite these differences, the evidence here suggests that long-duration driving indeed results in fatigue, sleepiness and degraded performance. Since the shuttle service between cities is widely prevalent in Indonesia, this implies that there is a considerable level of safety risk for this mode of transportation. Consequently, driver scheduling should be done with great care, and certain types of fit-for-duty evaluation scheme should also be in place.

While fatigue and sleepiness can be easily perceived and experienced, measurement of these phenomena can be somewhat difficult, which requires the use of several indicators concurrently. The use of eye (and eye lid) responses, in particular, seems attractive since eye behavior can be seen as a direct manifestation of sleepiness. These measures have been applied and discussed in a number of fatigue studies [7, 18 - 20].

This study found that the blink rate was relatively sensitive to task duration and, hence, could be used as a potential indicator of fatigue. It was found here that the blink rate generally increased throughout the experimental sessions. The average blink rate during the first 4-hour trip was around 26 blinks/min, while toward the end of the third trip, this figure increased to nearly 39 blinks/min. In their study, Schleicher and colleagues [20] noted that an increase in blink rate was indicative of increased drowsiness. During severe drowsiness, however, a reduction in blink frequency could occur despite an increase in sleepiness, thus, creating a U-shaped pattern. It was hypothesized that at this phase, an individual may start to stare, and an increase in blink duration could also be observed. The latter indicator, however, was not measured in this study [20]. It should be noted that a decrement in blink frequency could also suggest a decline in task vigilance. The work of McIntire et al. [21], for instance, demonstrated a decrement in vigilance during short-duration tasks. Their results suggest that blink

frequency is a potentially sensitive measure, but since this frequency can change in both directions, the interpretation should be done with care.

Based on psychomotor vigilance task (PVT) parameters, this study demonstrated that performance during long-duration driving deteriorated substantially. This is in accordance with another study that PVT changes are related to the time spent in performing the task [9]. In this investigation, all PVT parameters consistently changed throughout the duration of the driving task. A difference of about 8 to 9% was observed for all parameters, except for the number of lapses. Note that it was somewhat difficult to ensure that changes in PVT measures were merely due to task duration since the last trip was conducted closer to evening time. Worse performance could also be influenced by circadian cycle [22].

There are two critical questions associated with the use of PVT parameters in assessing fatigue from long-duration driving. First, it is not known whether there are normative or baseline values with respect to PVT parameters (e.g., mean reaction time). In the past, the test was based on analogue counters. Today, many studies rely on computer-based systems, including the use of tablets or smart phones [23]. Differences in technologies (and protocols) can be associated with different PVT values and, thus, establishing normative values can be fairly difficult (if not impossible). Comparisons of PVT values against the baselines were probably the more appropriate approach in interpreting changes in PVT associated with fatigue development.

Second, when does fatigue start? Or, what percentage of PVT changes constitutes moderate or severe fatigue? The work of Baulk et al. [14] showed that PVT measures were not sensitive in indicating fatigue during daytime shift work [24]. There was only a minimal decrease in performance (2%), while better performance was also observed concurrently. In contrast, consistent performance decrement was observed (~10%). The latter figure was similar to that observed in the present study. Based on PVT measures, Dorrian and colleagues [25] demonstrated that a consistent decline in performance was observed only after eight hours of experiment. An approximately 4% change was found after 12 hours, and a tenfold decline after 24 hours [25]. We would suggest that a reduction of performance of about 10% is likely indicative of fatigue. Still, it is not known at what percentage of PVT changes fatigue starts. It is also suggested here that changes in the order of 5% - 10% are indicative of moderate fatigue.

This study employed two common subjective measures, with the hope that the results could complement those supplied by the noted more objective techniques. Scores obtained from SOFI and KSS indicated a consistent increase in fatigue and sleepiness. However, associations between subjective and objective measures in this study were only found between SOFI and blink rate, whereas no significant association was found between the objective measures and KSS. This should be investigated further. There are a number of practical implications that can be derived from this research. First, this type of job is definitely tiring, and task duration of up to 10 hours is very likely to result in substantial changes in fatigue indicators. It is unfortunate that jobs requiring one to drive for more than 10 - 16 hours a day are not uncommon in Indonesia. These include trailer truck or interstate coach drivers. Many taxi companies in major cities even allow their drivers to work for up to 18 - 20 hours for several consecutive days. The condition is exacerbated by relatively short sleep durations and poor sleep quality. Generally, Indonesians would have to wake up as early as 04:00 A.M. for their morning prayers, which consequently limits the amount of sleep. In addition, many commercial drivers do not have comfortable bedroom, both in their homes and at work. The latter phenomenon, however, needs further investigations.

Second, even within the 12-hour work duration limit, a rest period of 30 to 60 minutes should be allotted following continuous driving of roughly 3 hours. This recommendation is in accordance with the findings of other studies [16]. Finally, signs of sleepiness were present even after driving for a few hours. Since this could be associated with low-level stimulus while driving on monotonous road conditions such as highways [4], a strategy should be developed that allows for optimal driving workload by reducing the monotonous condition. Previous research has shown that monotonous work is harmful, while moderate sleep is good for vigilance at work [26]. This strategy may include a randomly presented auditory stimulus that should be responded to by the driver, or any of the Alertness Maintaining Tasks (AMT) techniques suggested by Oron-Gilad [27].

Also, there are governmental institutions and stakeholders (e.g., The Ministry of Transportation or The Ministry of Commerce) that govern or are responsible for such shuttle service (or similar) businesses. Together with the company management, they are all responsible for providing a safe public transportation system. However, laws and government regulations that address fatigue and safe work among commercial drivers are relatively minimal (and are very seldom enforced). The findings of this study can be used as an input for improving relevant national laws and regulations with respect to a reliable and safe public transportation system in Indonesia.

5. CONCLUSION

In conclusion, this study has demonstrated that fatigue and sleepiness do exist during long-duration driving. It is interesting that, generally, all measures used in this study changed consistently throughout the task duration. However, there seems to be some dissociation between subjective and objective measures of fatigue. Practical implications drawn from this study are that driving intermittently for 12 hours is definitely fatiguing, and is associated with marked performance decrements. Rest periods of 30 – 60 minutes should be provided after 3 hours of driving, but this does not necessarily guard against cumulative fatigue. In this study, it is suggested that long-duration driving be limited to a maximum of 12 hours, and that a minimum of 30 minutes of rest be provided after 3 to 4 hours of driving. The results of this study can also be used as a means to schedule drivers' rosters.

Acknowledgement

The authors gratefully acknowledge the Directorate of Higher Education of Indonesia (DIKTI) for funding this research. The authors would also like to express their gratitude to Mrs. Rida Zuraida and Mr. Putra Alif Ramdhani Yamin for the review and suggestions given during the preparation of the manuscript.

References

1. Subdirector of Transportation Statistics. *Land Transportation Statistics*. Jakarta: BPS Statistics Indonesia. 2018.
2. Indonesian National Transportation Safety Committee (KNKT). *Kecelakaan Tunggal Mobil Elf E-7548-Pb Terguling di Jalan Raya Subang Ciater Kabupaten Subang Provinsi Jawa Barat*. 2019. Final Report KNKT.18.03.04.01.
3. Williamson, A. & Lombardi, D.A. & Folkard, S. The link between fatigue and safety. *Accident Analysis and Prevention*. 2011. Vol. 43. P. 498-515.
4. May, J.F. & Baldwin, J.L. Driver fatigue: The importance of identifying causal factors. *Transportation Research*. 2009. Vol. 12. Part F. P. 218-224.
5. Zurika, A. *An evaluation of fatigue among interstate bus drivers*. Master's thesis. Bandung: Bandung Institute of Technology. 2012.
6. Sitalaksana, I.Z. & Pratama, G.B. & Yamin, P.A.R. & Soetisna, H.R. The Effects of Food and Drink Intake to Driving Performance: a Systematic Review. *Transport Problems*. 2019. Vol. 14(1). P. 5-12.
7. Cruz, A.A.V. & Garcia, D.M. & Pinto, C.T. Spontaneous eye blink activity. *Clinical Science*. 2011. Vol. 9. No.1. P. 29-41.
8. Drummond, S.P. & Bischoff-Grethe, A. & Dinges, D.F. & Ayalon, L. & Mednick, S.C. & Meloy, M.J. The neural basis of the psychomotor vigilance task. *Sleep*. 2005. Vol. 28. P. 1059-1068.
9. Basner, M. & Mollicone, D. & Dinges, D.F. Validity and sensitivity of a brief psychomotor vigilance test (PVT-B) to total and partial sleep deprivation. *Acta Astronautica*. 2011. Vol. 69. P. 949-959.

10. Loh, S. & Lamond, N. & Dorrian, J. & Roach, G. & Dawson, D. The validity of psychomotor vigilance task of less than 10-minute duration. *Behaviour Research Methods, Instruments, & Computers*. 2004. Vol. 36. P. 339-346.
11. Ahsberg, E. *Perceived Fatigue Related to Work*. Stockholm: National Institute for Working Life. 1998.
12. Ahsberg, E. & Gamberale, F. & Gustafsson, K. Perceived fatigue after mental work: an experimental evaluation of a fatigue inventory. *Ergonomics*. 2000. Vol. 43. No. 2. P. 252-268.
13. Horne, J. & Reyner, L. Vehicle accidents related to sleep: a review. *Occupational and Environmental Medicine*. 1999. Vol. 56. P. 289-294.
14. Baulk, S.D. & Biggs, S.N. & Reid, K.J. & van den van de Heuvel, C.J. & Dawson, D. Chasing the silver bullet. Measuring driver fatigue using simple and complex tasks. *Accident Analysis and Prevention*. 2008. Vol. 40. P. 396-402.
15. Philip, P. & Sagaspe, P. & More, N. & Tailard, J. & Charles, A. & Guileminault, C. & Bioulac, B. Fatigue, sleep restriction and driving performance. *Accident analysis and Prevention*. 2005. Vol. 37. P. 473-479.
16. Wang, L. & Pei, Y. The impact of continuous driving time and rest time on commercial drivers' driving performance and recovery. *Journal of Safety Research*. 2014. Vol. 50. P. 11-15.
17. Gastaldi, M. & Rossi, R. & Gecchele, G. Effects of driver task-related fatigue on driving performance. *Procedia-Social and Behavioral Sciences*. 2014. Vol. 111. P. 955-964.
18. Ahlstrom, C. & Nyström, M. & Holmqvist, K. & Fors, C. & Sandberg, D. & Anund, A. & Kecklund, G. & Åkerstedt, T. Fit-for-duty test for estimation of drivers' sleepiness level: Eye movements improve the sleep/wake predictor. *Transportation Research*. 2013. Vol. C26. P. 20-32.
19. McClelland, L.E. & Pilcher, J.J. & Moore, D.D. Oculomotor responses as predictors of performance during sleep deprivation. *Aviat. Space Environ. Med.* 2010. Vol. 81. P. 833-842.
20. Schleicher, R. & Galley, N. & Briest, S. & Galley, L. Blinks and Saccades as Indicators of Fatigue in Sleepiness Warnings : Looking Tired? *Ergonomics*. 2008. Vol. 51 No.7. P. 982-1010.
21. McIntire, L.K. & McKinley, R.A. & Goodyear, C. & McIntire, J.P. Detection of vigilance performance using eye blinks. *Applied Ergonomics*. 2014. Vol. 45. P. 354-362.
22. Kline, C.E. & Durstine, J.L. & Davis, J.M. & Moore, T.A. & Devlin, T.M. & Youngstedt, S.D. Circadian rhythms of psychomotor vigilance, mood, and sleepiness in the ultra-short sleep/wake protocol. *Cronobiology International*. 2010. Vol. 27. No. 1. P. 161-180.
23. Kay, M. & Rector, K.I. & Consolvo, S. & Greenstein, B. & Wobbrock, J.O. & Watson, N.F. & Kientz, J.A. PVT-touch: Adapting a reaction time test for touchscreen devices. In: *Proceeding of 7th International Conference Pervasive Computing Technologies for Healthcare (PervasiveHealth)*. 2013.
24. Baulk, S.D. & Fletcher, A. & Kandelaars, K.J. & Dawson, D. & Roach, G.D.A. Field study of sleep and fatigue in a regular rotating 12-h shift system. *Applied Ergonomics*. 2009. Vol. 40. P. 694-698.
25. Dorrian, J. & Rogers, N.L. & Dinges, D.F. Behavioural alertness as assessed by psychomotor vigilance performance. *Sleep Deprivation: Clinical Issues. Pharmacology, and Sleep Loss Effect*. 2004. P. 39-70.
26. Sallinen, M. & Harma, M. & Akila, R. & Holm, A. & Luukonen, R. & Mikola, H. & Muller, K. & Virkkala, J. The effects of sleep debt and monotonous work on sleepiness and performance during a 12-h dayshift. *Journal Sleep Research*. 2004. Vol. 13. P. 285-294.
27. Oron-Gilad, T. & Ronen, A. & Shinar, D. Alertness maintaining task while driving. *Accident Analysis and Prevention*. 2008. Vol. 40. P. 851-860.