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Correlation between Driver Subjective Fatigue and Bus Lateral Position in a Driving Simulator

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Abstract
Background: Driver fatigue as a leading cause of death in the transportation industry can impair the driving performance in long-distance driving task. Studies on the links of driver subjective fatigue and the bus lateral position are still an exploratory issue that requires further investigation. This study aimed to determine the correlation between the driver subjective fatigue and the bus lateral position in a driving simulator.
Methods: This descriptive-analytical research was conducted on 30 professional male bus drivers participated in a two-hour driving session. The driver subjective fatigue was assessed by the Fatigue Visual Analogue Scale (F-VAS) at 10-min intervals. Simultaneously, the performance measures of lane drifting as the mean and standard deviation of the bus lateral position (SDLP) were calculated during the simulated driving task. Descriptive statistics and the Spearman correlation coefficient were used to describe and analyze the data.
Results: Fatigue levels had an increasing trend as the time-on-task of driving increased. Time-on-task of driving had the greatest effect on the fatigue self-evaluation ($r = 0.605$, $p < 0.0001$). The results showed a significant correlation between fatigue self-evaluation and bus lateral position ($r = 0.567$, $p < 0.0001$).
Conclusion: As the time of driving increased, driving performance was affected adversely, as shown by the increase in the SDLP. Even so, the effect of individual differences on driving performance should not be overlooked. This work concludes that predicting the state of a driver fatigue based on the group mean data has some complications for any application.
Keywords: driving performance, driver fatigue, lane position

1. Introduction

1.1. Background

Drivers' inability to maintain a proper lane position because of inattention, fatigue, or drowsiness is one of the main causes of accidents. The National Highway Traffic Safety Administration (NHTSA) has estimated that, in the U.S. in 2005, about 28% of traffic accidents that resulted in death were due to crashes that involved Running-off-Roadways (ROR) crashes (1). Clearly, fatigue and drowsiness can lead to the deterioration of the driver's performance, and this can cause various errors and increase the risk of accidents. Nilsson et al. (1997) posited that fatigue was a major cause of drivers' errors (2). Human error is a major contributor in 85% of crashes, and lack of consciousness has been identified as the single most important factor in accidents caused by human error. Sleepiness, fatigue, and road monotony may decrease the driver alertness level (3). Driving performance over time usually requires more cognitive than physical effort (4). Continuous consciousness, selective attention, complicated decision making, and sometimes automatic motor-perceptual control skills are instances of cognitive functions. According to Miller and Mackie (1980), long hours of continuous driving and monotonous driving at night and in the early hours of the morning lead to a decrease in driving performance (5). In addition, Adkins (1964) found that changes in the arousal level caused by the circadian rhythm can cause performance variations (6). In contrast, driving while fatigued is associated with the worsening of performance. It is notable that at lower levels of fatigue,

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the decrease in physiological arousal, slow motor and sensory functions, and the impaired processing of information also can diminish the driver's ability to respond in emergency or unusual situations (7).

1.2. Statement of the problem

Driver fatigue, as a direct or contributing factor in road accidents, is defined as a feeling of sleepiness caused by long periods of driving, monotonous roads, bad weather, or personal characteristics. Mental fatigue related to time on cognitive tasks can somehow influence driving performance because of drowsiness and the duration of monotonous driving (8-10). In a survey, Venelle et al. (2010) found that 20% of drivers suffer from severe sleepiness during the day and that 12% experience microsleep at least once a month during driving (11). Seven percent of the drivers had a drowsiness-related accident and 18% had near misses. Since maintaining the vehicle properly in the lane is the highest degree of a steady task done by a driver, it can be an important and sensitive measure of driver fatigue (12, 13). Vehicle-based performance measures can provide useful information about the driver's behavior. Some researchers have studied driving performance through steering wheel movements (14), and lateral position of the vehicle (15). Several authors have correlated drivers' alertness levels to driving performance. One study showed that time-on-task can significantly decrease drivers' alertness and driving performance (10). Long hours of driving, inadequate sleep, and other cumulative factors let the sleep-deprived drivers cross the white line on the right side of the road and commit other errors (16, 17). In fact, steady driving offers little visual stimulation, causing drivers to become sleepy, resulting in their making more mistakes while driving (13). Detecting the driver fatigue by analyzing biological signals is very challenging (18), because the same changes do not occur in all biological signals based on drivers' different fatigue levels. For instance, electroencephalography (EEG) and electrooculography (EOG) can be used as reference laboratory standards. Many researchers including Akerstedt and Gilberg (1990), Lal and Craig (2001), Eoh, Chung and Kim (2005), Yang, Lin and Bhattacharya (2010), and Simon et al. (2011) have used EEG as an effective indicator of driver fatigue (19-23). However, these electrode-based methods are not suitable for application on actual roadways. The major problems involved in these methods are poor resistance to various environmental conditions (such as moisture and high temperature), lack of comfort, and the short lifetime of the electrode sensors that are used. In contrast to the electrode-based methods, performance-based measures, such as steering wheel angle and lateral position of the car are more suitable for discovering drivers' states of fatigue. Besides, according to Krajewski et al. (2009), these systems are inexpensive, non-intrusive, robust, and do not distract the driver (24).

1.3. Objective

Since methods for dealing with fatigued drivers are still in the exploratory phase, the aim of this study was to determine the correlation between driver mental fatigue and bus lateral position in a simulated task.

2. Material and Methods

2.1. Research design and study setting

This descriptive-analytical study was conducted on healthy, professional, male, urban bus drivers selected from Beihaghi and the eastern, southern, and western intercity bus terminals in Tehran, Iran. The subjects were invited formally to take part in a driving simulated task at Khaje Nasir Toosi University of Technology during the summer of 2014. The experiments were performed from 9:00 A.M. to 12:00 P.M. or from 2:00 P.M. to 5:00 P.M. to control the possible influence of circadian rhythm since these time periods have similar circadian rhythms (25).

2.2. Sampling and participant selection

Thirty professional, male, urban bus drivers voluntarily participated in this study. All drivers held valid driving licenses (with at least two years' driving experience). They had no history of mental illness or brain injury, and they did not have any sleep disorders. The subjects were asked to refrain from caffeinated drinks or any other drugs and to avoid smoking 12 hours before the study. In the study, food and sleep diary logs were prepared for a week before the test began.

2.3. Instrument and data collection

In this study, a bus driving simulator was used to evaluate mental fatigue in a calm controlled room with a fixed temperature and illumination conditions. The virtual-reality technique enables the drivers to interact directly with the virtual environment instead of responding passively to audiovisual stimulants (26). A bus driving simulator, i.e., Akia BI 303, was designed and developed in the Mechatronic Department of Khaje Nasir Toosi University of Technology. The driving simulator had a mobile platform with three degrees of freedom (pitch, roll, and surge), the driver's cabin, which included a speedometer, engine speed in RPM, real accelerator and brake pedals, a steering wheel, automatic gear buttons, and virtual rear-view and side mirrors. In this study, a 70-km virtual road was designed and simulated as a loop. The virtual road was an approximately straight highway with the least fatigue-inducing side components and curvatures. The sampling rate of the simulator's data ranged from 90 to 350 Hz. The linear interpolation was used to convert the sampling rate to 100 Hz. Then, the distance between the center of the bus and the sideline at any moment during the drive was calculated and saved as the simulator output. The Epworth Sleepiness Scale (ESS) was used to assess the sleep prepotency of drivers before the experiments were initiated. The drivers evaluated their own fatigue levels subjectively (fatigue self-evaluation) at 10-min intervals using a 10-point Fatigue Visual Analogue Scale (F-VAS) (1 for completely alert and 10 for extremely fatigued). The subjects had to drive on a highway for two hours at a constant speed of 110 km/hr while keeping the bus in the proper lane on the driving simulator. The driving task continued until the subject deviated from the lane or went off the road.

2.4. Research ethics
This research was approved by the Ethics Committee approval at the Tehran University of Medical Sciences and Health Services. All participants provided signed informed consent forms.

2.5. Statistical analyses
In this research, the Spearman correlation coefficient was used to study the correspondence between subjective fatigue (F-VAS) and driving performance (as measured by the mean and standard deviation of the bus lateral position).

3. Results
3.1. Participants' demographic characteristics
The mean age of the drivers was 45.33 (± 9.3). Ninety percent of the drivers were married and 26.7% were smokers. Half of smokers smoked fewer than 10 cigarettes per day. Sixty percent of the drivers reported that they had driven while they were sleepy. More than half of drivers (53.3%) engaged in weekly exercise. About 3.3% of the drivers had a primary school educational level, 50% had finished primary school, 43.3% had high school diploma, and 3.3% had graduated from college. The participants' other characteristics are presented in Table 1.

Table 1. Participants' demographic characteristics

Participants	Mean	Standard deviation
Age (year)	45.33	9.34
Driving experience (year)	25.23	2.07
Intercity bus driving experience (year)	14.73	1.79
Driving (days/week)	5.70	0.26
Driving (hour/day)	8.18	0.29
Maximum driving time without rest (hour)	2.94	0.28
Resting time between travels (hour)	22.92	0.28

3.2. Findings from the fatigue self-evaluation with the F-VAS scale
The drivers reported their fatigue levels subjectively from 1 to 10 at 10-min intervals based on the F-VAS scale. The F-VAS score of less than 4 in the first 10 minutes of driving progressed by a steep upward trend to 7 at the 50th minute of the session. The F-VAS score continued to increase but at a lower rate to 7.5 at the 80th minute of driving. The fatigue self-evaluation had a slight descending trend (F-VAS=7.3) during the 9th 10-min interval, but it resumed its upward trend at the 100th minute of driving, reaching 7.7. In the last two 10-min sections of driving, we observed a descending trend in the drivers' subjective fatigue, which ended at 6.9 at the 120th minute.

3.3. Findings of driving performance
The mean of the lateral position (MLP) and the standard deviation of the lateral position (SDLP) of the bus at the 10-min intervals are presented in Figures 1 and 2, respectively. Figure 1 shows that, as the time-on-task of driving increases, the mean of changes in the lateral position (MLP) of the bus increases. The changes had an increasing trend until 60 minutes of driving. During the section 7 of driving, MLP had a descending trend, but it increased again during the next 10-min period. The mean lateral position of the bus had a downward trend during the time period from 80 to 100 minutes, but it increased again during the next time period. This measure decreased in the final 10 minutes. Figure 2 indicates that the SDLP increased until the 70th minute of driving. Then, SDLP decreased

from 70 to 90 minutes and increased again during the 10th section (100 min) of driving. SDLP had a descending trend during the two final sections of the driving session (110 and 120 min).

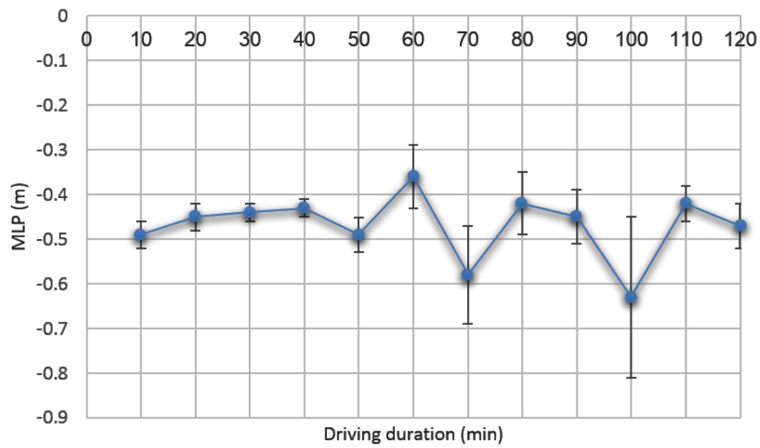

Figure 1. Mean change in lateral position (MLP) while the bus drivers were driving using the simulator

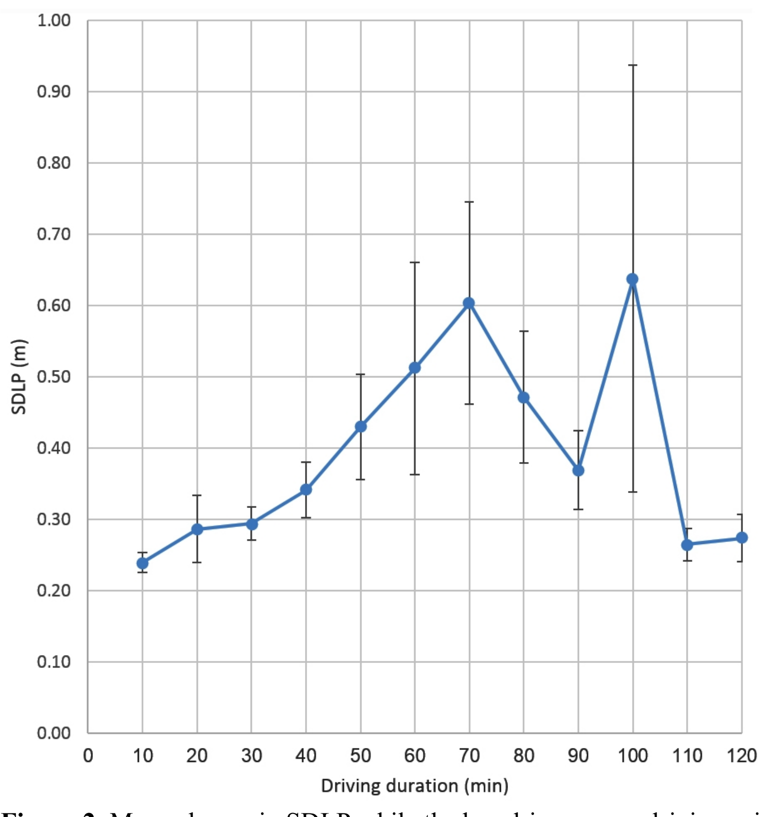

Figure 2. Mean change in SDLP while the bus drivers were driving using the simulator

3.4. Correlation between subjective fatigue and the bus driver's performance

The study showed the time-on-task of driving as the most influential factor on subjective fatigue ($r = 0.605$, $p < 0.0001$). However, we found a weak, but significant, correlation between the fatigue self-evaluation and the bus's MLP ($r = 0.162$, $p = 0.009$), while there was a strong, significant correlation between the F-VAS and the SDLP in the intercity bus drivers ($r = 0.567$, $p < 0.0001$). A closer look at the raw data indicated that there were some individual differences between the drivers concerning subjective fatigue and driving performance. For example, driver No. 11 stated his fatigue level was 3 (mild fatigue) during the entire 120 minutes of driving. As it appears in

Table 2, by removing driver No. 11 from the analysis, a stronger correlation was observed between the time-on-task of driving and fatigue self-evaluation in the intercity bus drivers (r = 0.683, p < 0.0001). Another worthwhile point was the opposing results obtained from driver No.19 concerning the reverse correlation between time-on-task of driving and MLP (r = -0.769, p = 0.003). More detailed results about driver No. 19 were illustrated in Table 2 and Figure 3 showing the correlations between the time-on-task, fatigue self-evaluation, MLP, and SDLP of the bus.

Table 2. Correlation coefficients and significant levels of time-on-task of driving, F-VAS, the bus's MLP and SDLP for the intercity bus drivers and driver No. 19

Spearman correlation	MLP (p value)	SDLP (p value)	F-VAS (p value)
Time-on-task	0.035 (0.581)	0.283** (0.0001)	0.683** (0.0001)
Time-on-task (for driver No. 19)	-0.769** (0.003)	0.867** (0.0001)	0.944** (0.0001)
MLP	1.000 (-)	0.087 (0.174)	0.154* (0.015)
MLP (for driver No. 19)	1.000 (-)	-0.566 (0.055)	-0.681* (0.015)
SDLP	0.087 (0.174)	1.000 (-)	0.532** (0.0001)
SDLP (for driver No. 19)	-0.566 (0.055)	1.000 (-)	0.866** (0.0001)

*Correlation is significant at 0.05; **Correlation is significant at 0.01

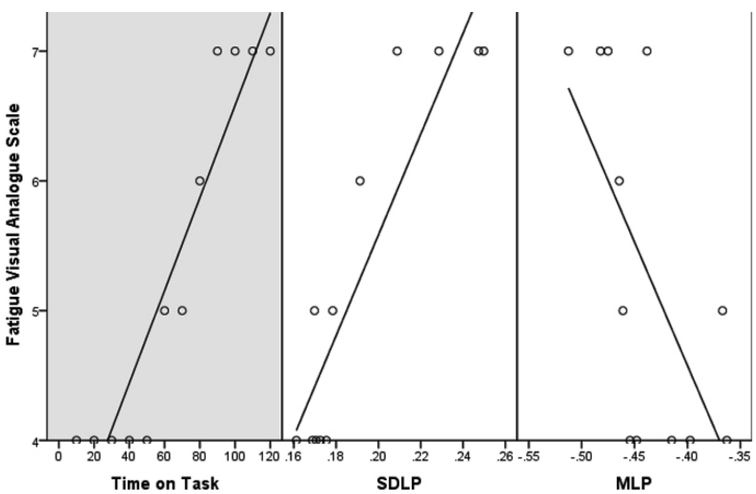

Figure 3. Distribution of fatigue self-evaluation and time-on-task (left), SDLP (middle) and MLP (right) in intercity bus driver No. 19

4. Discussion

This paper presented the correlation between drivers' subjective fatigue measured by F-VAS and the bus lateral position calculated as MLP and SDLP in a simulated driving task.

4.1. Fatigue self-evaluation

The findings suggested the F-VAS score of less than 4 in the first 10 minutes of driving progressed to 7.5 at the 80th minute of driving. The fatigue self-evaluation had some fluctuations during the rest of the driving and showed a downward trend in the last two 10-min intervals of driving. One reason for this variation may be the falls in the number of drivers driven up to two hours. This means that most of the drivers had driven the simulator 80 minutes or less. In other words, because of fatigue or hitting to the guardrail, the drivers had to stop the assigned driving task. Second, the mental alertness of the drivers was changing with time, and the drivers experienced different periods of fatigue, alertness, and microsleep for various reasons. However, the average fatigue self-evaluation had an increasing trend, and, by increasing the time-on-task of driving, the fatigue level also was increasing. Other researchers also have confirmed the effect of increasing time-on-task on driver fatigue (14, 17). Drivers must be vigilant constantly, and their ability to do so is sensitive to the effects of fatigue-related time-on-task.

4.2. Driving performance

In general, our findings showed that as the time-on-task of driving increased, the mean of changes in the lateral position (MLP) of the bus increased. The reason for the observed variations in the MLP between 70 minutes until the end of the driving task may be due to the stopping of the experiment by most of the drivers after 70 to 80 minutes, because they reached their highest levels of fatigue and experienced the worst driving performance at these times. Research on the effects of time-on-task on driving performance has produced contradictory results, which may have been related to imperfections in the methods that were used (27). Some studies have determined the effect of time-on-task on rested drivers after just 40 minutes in a driving simulator (14). However, most studies have used SDLP as a better performance measure (12, 28, and 29). The findings of the survey also showed that, as the time-on-task of driving increased and the fatigue level increased, SDLP of the bus also increased. Similarly, in a study by Anund et al. (2011), SDLP and Karolinska Sleepiness Scale (KSS) increased with time-on-task (30). Recent evidence suggests that, in rested drivers, the number of line crossings, the changes in the lateral position, and the small movements of the steering wheel gradually increased during simulated driving tasks (16). This implies that the time-on-task of driving might merely impair the driving performance. Jackson et al. (2011) reported that fatigue can affect driving skills by increasing the frequency, amplitude, and variability of errors (27). For example, in lane drifting, fatigue can increase the number of drifts from the centerline, the distance of the drifts from the centerline, and the variability in the ability of the driver to keep the vehicle properly located in the lane. In the study of Wylie et al., driver sleepiness was detected by the off-line review of recorded video images (31). They inferred that the SDLP is a valid indicator of driving performance and that sleepiness causes an increase in lane tracking variations. The researchers also concluded that, since the drivers change their behavior in response to the road environmental conditions, it is necessary to consider individual differences while using the lateral position of the vehicle for detecting driver sleepiness. Prior research has reported inconsistencies in the study of fatigue-related time-on-task on the driving performance. Traffic studies conducted by Philip et al. (2005) showed that rested subjects had no significant impairment in driving performance during a 10-hour period, which was divided into 105 minutes of driving with 15-30 minute breaks (32). In this study, SDLP continued to increase up to 70 minutes of driving. After that, it decreased until the driving time reached 90 minutes, and, in the next 10 minutes (100 minutes of driving), it increased with a large standard deviation. This measure decreased during 100 to 110 minutes and showed no changes at 120 minutes of driving. As mentioned earlier in this paper, the reason that changes appeared during 70 to 120 minutes of driving probably occurred because of the drivers who stopped the test after 70 to 80 minutes of driving. However, differences in driving skills also may cause these variations.

4.3. Association between the driver's subjective fatigue and the bus's lateral position

In this study, we found a strong, significant correlation between the fatigue self-evaluation of the drivers and the SDLP of the bus. Recently, a few researchers have reported good agreement between sleepiness and driving impairment (33-35). Wylie et al. also found a correspondence between the driver sleepiness and lane tracking variability (31). A simulator study by Peters and Kloeppel showed that, as the driver's sleepiness increases, the variance of the lateral position of the car increases (36). It is important to note that the lateral position of a car changes according to the traffic conditions on the adjacent lanes as well as in response to road conditions. Therefore, these issues should be considered when using this measure. The findings of this study indicated that there were significant differences among the drivers with respect to the association between mental fatigue and SDLP; as an illustration, driver No. 11 reported that his fatigue level was constant (3, mild fatigue) throughout the entire 120-min period. However, other evidence provided clues about the driver's tiredness. Other studies have also reported the inadequacy of the existing fatigue self-assessment techniques. Some researchers have posited that drivers are not good evaluators of their own momentary levels of fatigue and that they overestimate their alertness levels (4, 14). Ingre et al. (2006) showed that, while the KSS score increases, the SDLP measure (in meters) increases and blink duration takes longer (12). This correspondence was observed for all of the subjects in their study. However, many individual differences also were observed. While predicting outcomes based on any individual, these differences should be considered. The authors noted that the individual differences are complicated and the mechanisms that result in these differences are still unknown. The individual differences may be the result of careful driving or driving skills in general. The SDLP was calculated based on the average of 20 participants. However, in some drivers, SDLP did not exceed 0.25 m, even for a KSS score of 9. In their experiments, significant differences were found with the correlation test that was based on a person-to-person analysis. They assumed that there may be a curvilinear relationship between KSS and SDLP, with a further increase in SDLP at the higher levels of KSS. This conclusion agrees well with previous research concerning subjective and objective sleepiness, and it shows that serious behavioral and physiological changes do not occur until drivers reach a relatively high level of sleepiness (KSS > 7) (19).

4.4. Limitations of the study

This research had some limitations that should be noted. One limitation was that SDLP depends on external factors, such as lighting, weather, and road markings. Another limitation is the microsleep that occurs when a driver is driving on a straight road and goes to sleep for a few seconds without changing the vehicle's lateral position. Such events are undetectable by a device based on the lateral position of a car (37). A significant problem still exists in the real-time detection of the lateral position of a car. In summary, some studies have reported that vehicle-based measures are poor predictors of sleepiness-related performance errors. In addition, the use of alcohol or drugs can affect the SDLP. In other words, the vehicle-based performance measures are not specific to sleepiness (29).

5. Conclusions

The findings of this study indicated that the time-on-task of driving can be a critical factor in developing mental fatigue. However, driving over time affects the driving performance and increases SDLP, but one should not ignore the effects of individual differences on driving performance. This shows the importance of using reliable methods in preventing the onset of fatigue in drivers. The use of lane-tracking devices for preventing fatigue and drowsiness still has some significant limitations and requires further research. Finally, using a performance measure, such as SDLP, as a fatigue countermeasure device should be validated and tested experimentally in future research.

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Conflict of Interest:

There is no conflict of interest to be declared.

Authors' contributions:

All authors contributed to this project and article equally. All authors read and approved the final manuscript.

References

1) National Highway Traffic Safety Administration. Traffic safety facts 2005. U.S. Department of Transportation, Washington. Available from: www-nrd.nhtsa.dot.gov/Pubs/TSF2005.PDF
2) Nilsson T, Nelson TM, Carlson D. Development of fatigue symptoms during simulated driving. Accid Anal Prev. 1997; 29(4): 479-88. doi: 10.1016/S0001-4575(97)00027-4. PMID: 9248506
3) Gruyer D, Rakotonirainy A, Vrignon J. Data combination using belief theory to assess driver's vigilance, in Proc. Australasian Road Safety Research, Policing and Education, Wellington, New Zealand, November 2005
4) Brown ID. Driver fatigue. Hum Factors. 1994; 36(2): 298-314. doi: 10.1177/001872089403600210. PMID: 8070794
5) Miller JC, Mackie RR. Effects of irregular schedules and physical work on commercial driver fatigue and performance. In: Oborne DJ, Levis JA (eds.), Human Factors in Transport Research: Academic Press, New York. 1980; 1: 127-33.Available from: http://trid.trb.org/view.aspx?id=249687
6) Adkins S. Performance, heart rate, and respiration rate on the day-night continuum. Percept Mot Skills. 1964; 18: 409-12. http://dx.doi.org/10.2466/pms.1964.18.2.409. PMID: 14166031
7) Mascord DJ, Heath RA. Behavioral and physiological indices of fatigue in a visual tracking task. J Saf Res. 1992; 23(1):19-25. doi: 10.1016/0022-4375(92)90036-9
8) Otmani S, Roge J, Muzet A. Sleepiness in professional drivers: effect of age and time of day. Accid Anal Prev. 2005; 37(5): 930-7. doi: 10.1016/j.aap.2005.04.011. PMID: 15919047
9) Papadelis C, Chen Z, Kourtidou-Papadeli C, Bamidis PD, Chouvarda I, Bekiaris E, et al. Monitoring sleepiness with on-board electrophysiological recordings for preventing sleep-deprived traffic accidents. Clin Neurophysiol. 2007; 118(9): 1906-22. doi: 10.1016/j.clinph.2007.04.031. PMID: 17652020
10) Sze SK, Tamrin SBM,Goh YM. Driving Fatigue and Performance among Occupational Drivers in Simulated Prolonged Driving. Global J Health Sci. 2010; 2(1): 167-77. doi: 10.5539/gjhs.v2n1p167
11) Vennelle M, Engleman HF, Douglas N, Douglas NJ. Sleepiness and sleep-related accidents in commercial bus drivers. Sleep Breath. 2010;14(1): 39-42. doi: 10.1007/s11325-009-0277-z. PMID: 19588178

12) Ingre M, Akerstedt T, Peters B, Anund A, Kecklund G. Subjective sleepiness, simulated driving performance and blink duration: examining individual differences. J Sleep Res. 2006; 15(1): 47-53. doi: 10.1111/j.1365-2869.2006.00504.x. PMID: 16490002
13) Liu CC, Hosking SG, Lenne MG. Predicting driver drowsiness using vehicle measures: Recent insights and future challenges. J Safety Res. 2009; 40(4): 239-45. doi: 10.1016/j.jsr.2009.04.005. PMID: 19778647
14) Thiffault P, Bergeron J. Monotony of road environment and driver fatigue: a simulator study. Accid Anal Prev. 2003; 35(3): 381-91. doi: 10.1016/S0001-4575(02)00014-3. PMID: 12643955
15) De Waard D, Brookhuis KA. Assessing driver status: a demonstration experiment on the road. Accid Anal Prev. 1991; 23(4): 297-307. doi: 10.1016/0001-4575(91)90007-R. PMID: 1883469
16) Otmani S, Pebayle T, Roge J, Muzet A. Effect of driving duration and partial sleep deprivation on subsequent alertness and performance of car drivers. Physiol Behav. 2005; 84(5): 715-24. Doi: 10.1016/j.physbeh.2005.02.021. PMID:15885247
17) Philip P, Taillard J, Klein E, Sagaspe P, Charles A, Davies WL, et al. Effect of fatigue on performance measured by a driving simulator in automobile drivers. J Psychosom Res 2003; 55(3): 197-200. doi: 10.1016/S0022-3999(02)00496-8. PMID: 12932791
18) Punsawad Y, Aempedchr S, Wongsawat Y, Parnichkun, M. Weighted-Frequency Index for EEG-based Mental Fatigue Alarm System. International Journal of Applied Biomedical Engineering (ijabme). 2011; 4(1): 36-41. DOI:10.13140/RG.2.1.2714.5765
19) Akerstedt TF, Gillberg M. Subjective and objective sleepiness in the active individual. Int J Neurosci. 1990;52(1):29-37. doi: 10.3109/00207459008994241. PMID: 2265922
20) Eoh HJ, Chung MK, Kim SH. Electroencephalographic study of drowsiness in simulated driving with sleep deprivation. Int J Ind Ergon. 2005; 35(4): 307-20. doi: 10.1016/j.ergon.2004.09.006
21) Lal SK, Craig A. A critical review of the psychophysiology of driver fatigue. Biol Psychol. 2001; 55(3):173-94. doi: 10.1016/S0301-0511(00)00085-5. PMID: 11240213
22) Yang G, Lin Y, Bhattacharya P. A driver fatigue recognition model based on information fusion and dynamic Bayesian network. Inform Sci. 2010; 180(10): 1942-54. doi: 10.1016/j.ins.2010.01.011
23) Simon M, Schmidt EA, Kincses WE, Fritzsche M, Bruns A, Aufmuth C, et al. EEG alpha spindle measures as indicators of driver fatigue under real traffic conditions. Clin Neurophysiol. 2011; 122(6): 1168-78. doi: 10.1016/j.clinph.2010.10.044. PMID: 21333592
24) Krajewski J, Sommer D, Golz M, Trutschel U, Edwards DJ. Steering Wheel Behavior Based Estimation of Fatigue. 5th International Driving Symposium on Human Factors in Driving Assessment, Training and Vehicle Design. Driving Assessment 2009, pp. 118-124. Big Sky, MT, USA, June 2009 Available from: http://trid.trb.org/view.aspx?id=918391
25) Craig A, Tran Y, Wijesuriya N, Boord P. A controlled investigation into the psychological determinants of fatigue. Biol Psychol. 2006;72(1):78-87. doi: 10.1016/j.biopsycho.2005.07.005. PMID: 16137817
26) Chin-Teng L, Ruei-Cheng W, Sheng-Fu L, Wen-Hung C, Yu-Jie C, Tzyy-Ping J. EEG-based drowsiness estimation for safety driving using independent component analysis. IEEE Trans Circ Syst Fund Theor Appl. 2005; 52(12): 2726-38. doi: 10.1109/TCSI.2005.857555
27) Jackson P, Hilditch C, Holmes A, Reed N, Merat N, Smith L. Fatigue and Road Safety: A Critical Analysis of Recent Evidence. London: Department for Transport: 2011 No. 21.
28) Oron-Gilad T, Ronen A, Shinar D. Alertness maintaining tasks (AMTs) while driving. Accid Anal Prev. 2008; 40(3): 851-60. doi: 10.1016/j.aap.2007.09.026. PMID: 18460351
29) Sahayadhas A, Sundaraj K, Murugappan M. Detecting Driver Drowsiness Based on Sensors: A Review. Sensors. 2012; 12(12): 16937-53. doi: 10.3390/s121216937. PMID: 23223151, PMCID: PMC3571819
30) Anund A, Ahlstrom C, Kecklund G, Akerstedt T. Rumble strips in centre of the lane and the effect on sleepy drivers. Ind health. 2011; 49(5): 549-58. doi: 10.2486/indhealth.MS1247. PMID: 21804273
31) Wylie CD, Miller JC, Mitler MM, Mackie RR, Shultz T. Commercial motor vehicle driver fatigue and alertness study: technical summary. Technical report. U.S. Department of Commerce, National Technical Information Service, Alexandria, Virginia 22312, 1996 Nov 1996. Report No.: 9724. Available from: http://trid.trb.org/view.aspx?id=479029
32) Philip P, Sagaspe P, Moore N, Taillard J, Charles A, Guilleminault C, et al. Fatigue, sleep restriction and driving performance. Accid Anal Prev. 2005; 37(3): 473-8. doi: 10.1016/j.aap.2004.07.007. PMID: 15784201
33) Horne JA, Reyner LA. Sleep related vehicle accidents. BMJ. 1995; 310(6979): 565-7. doi: 10.1136/bmj.310.6979.565. PMID: 7888930, PMCID: PMC2548939

34) Maycock G. Sleepiness and driving: the experience of heavy goods vehicle drivers in the UK. J Sleep Res. 1997;6(4):238-44. doi: 10.1111/j.1365-2869.1997.00238.x. PMID: 9493523
35) Neville KJ, Bisson RU, French J, Boll PA, Storm WF. Subjective fatigue of C-141 aircrews during Operation Desert Storm. Hum Factors. 1994; 36(2): 339-49. doi: 10.1177/001872089403600213. PMID: 8070797
36) Peters RD, Kloeppel E, Alicandri E, Fox JE, Thomas ML, Thorne DR, et al. Effects of Partial and Total Sleep Deprivation on Driving Performance. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 1995; 39(14): 935. doi: 10.1177/154193129503901410
37) Kircher A, Uddman M. Sandin J. Vehicle Control and Drowsiness. Swedish National Road and Transport Research Institute; VTI Meddelande 922A; 2002. Available from: http://62.119.60.72/sv/publikationer/pdf/fordonskontroll-och-trotthet.pdf