Title
Time of day, time of sleep, and time on task effects on sleepiness and cognitive performance of bus drivers

Permalink
https://escholarship.org/uc/item/46p5k5tc

Journal
Sleep and Breathing, 26(4)

ISSN
1520-9512

Authors
Maghsoudipour, Maryam
Moradi, Ramin
Moghimi, Sara
et al.

Publication Date
2022-12-01

DOI
10.1007/s11325-021-02526-6

Peer reviewed

Published in final edited form as:
Sleep Breath. 2022 December ; 26(4): 1759–1769. doi:10.1007/s11325-021-02526-6.

Time of day, time of sleep, and time on task effects on sleepiness and cognitive performance of bus drivers

Maryam Maghsoudipour[1,2], **Ramin Moradi**[2], **Sara Moghimi**[3], **Sonia Ancoli-Israel**[4], **Pamela N. DeYoung**[1], **Atul Malhotra**[1]

[1]Department of Medicine, University of California, San Diego, La Jolla, CA, USA

[2]Department of Ergonomics, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran

[3]Department of Neurobiology, University of California, San Diego, La Jolla, CA, USA

[4]Department of Psychiatry, University of California, San Diego, La Jolla, CA, USA

Abstract

Purpose—Optimal cognitive performance might prevent vehicle accidents. Identifying time-related circadian and homeostatic parameters having an impact on cognitive performance of drivers may be crucial to optimize drivers' performance.

Methods—In this prospective study conducted on bus drivers, two drivers alternated driving during a 24-h round trip and were accompanied by an interviewer. Each driver was tested using Karolinska Sleepiness Scale (KSS) and the reversed digit span Wechsler Working Memory test before the start of his shift and then every 6 h during a "work/driving" day. Psychomotor Vigilance Task (PVT) was assessed before and after the journey. Linear mixed model was used to explore the factors affecting cognitive performance and sleepiness in univariate and multivariate analysis.

Results—Among 35 bus drivers, the effect of time of day on working memories was statistically significant ($p = 0.001$), with the lowest working memory scores at 04:00 am (± 1). The highest score of subjective sleepiness was also at 04:00 am (± 1). The time on task parameter affected sleepiness significantly ($p = 0.024$) and sleepiness was significantly associated with decreased working memory. Psychomotor Vigilance Task reaction time mean and the number of minor lapses were significantly increased after the journey, which suggested decreased vigilance. In multivariable analysis, a longer interval between the beginning of working hours and testing time

---

Maryam Maghsoudipour mamaghsoudipour@health.ucsd.edu.

Code availability Not applicable.

Declarations

Ethics approval The study has been approved by the ethics committee of the University of Social Welfare and Rehabilitation Sciences and has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All participants gave their informed consent prior to their inclusion in the study.

Consent to participate The participants gave written consent prior to their inclusion in the study.

Consent for publication The participants gave written consent for the publication of the study prior to their inclusion in the study.

Conflict of interest None of the authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper. Dr. Malhotra is funded by the NIH. He reports income related to medical education from Merck and Livanova. ResMed provided a philanthropic donation to UC San Diego.

(B (95% CI) = 15.25 (0.49 to 30), $p = 0.043$) was associated with higher (i.e., slower) PVT reaction time mean.

Conclusions—These results suggest that optimizing bus drivers' working schedules may improve drivers' sleepiness and cognitive performance and thus increase road safety.

Keywords

Working memory; Sleepiness; Driver; Shift work; Cognition

Introduction

Road accidents have an impact on population health although, often neglected by policymakers [1]. Global status reports on road safety have shown that road accidents are the second leading cause of death among 15 to 29 years old [2]. Several studies have demonstrated that sleep deprivation and night-time driving with the resulting sleepiness affect driver performance negatively and are considerable contributors to road accidents [3, 4]. Sleepiness increases the risk of motor vehicle accidents and should be evaluated while assessing the fitness for driving [5]. A study by Connor et al. found that driving between 2 and 5 am can increase accident risks fivefold, and sleepiness can increase the risk by eight times the initial level [6]. In a survey in the USA, 16.5% of fatal event accidents were reported to be related to drowsy drivers [7]. Sleep deprivation is not only dangerous for ordinary drivers but perhaps even more so for professional drivers who spend much more time on the road. In a study assessing the city bus drivers, severe sleepiness was common among the drivers and severe sleepiness was correlated with fatigue-related safety risks, such as near-crashes [8]. In a simulated driving study, sleep loss resulted in significantly increased subjective sleepiness and subjective workload but change detection accuracy was not significantly affected by sleep loss [9]. Another study revealed that decreasing the driving time (2-h versus 8-h sessions) decreased the rate ratio of inappropriate line crossings [10].

Due to homeostatic sleep drive, even in non-sleep deprived individuals, fatigue and sleepiness gradually increase throughout the day, as the time on task and time of wakefulness increase. In addition, cognitive resources deplete over time, increasing the possibility of human error [11–13]. Moreover, the mismatch between the schedule of job tasks and circadian rhythms aggravates sleepiness and fatigue [14, 15]. Homeostatic sleep drive and non-optimal mental performance increase the possibility of errors, but it is not clear to what extent these factors explain the incidents or accidents [16, 17].

Several components are contributing to optimal mental performance. Working memory, a principal aspect of cognitive performance, consists of temporary saving and manipulating information. Working memory is the core of cognitive ability and a powerful predictor of mental and rational reasoning abilities. Working memory is an important component of cognitive performance, and regular performance depends on it [18].

Psychomotor Vigilance Task (PVT) is an identified tool and a significant predictor of cognitive aspects of driving performance in the literature [19, 20]. Psychomotor vigilance impairment may be a key to cognitive impairment, in particular, when sleep-deprived [21]. The increased response variability that characterizes sleep loss is due to a reduced level of stability in physiologic processes maintaining wakefulness [22]. Drowsiness and vigilance fluctuations can strongly impact driving performance [23]. In previous studies, PVT was promising for the evaluation of cognitive impairment based on sensitivity and correlations with driving impairment [24].

In this study, we assessed bus drivers' characteristics, shift work parameters, and task-related variables to evaluate the effects of time of day, time of sleep, and time on task on cognitive performance and sleepiness of drivers. We sought to test the hypothesis that a combination of (a) time of day factors, (b) homeostatic drive, and (c) time on task parameters would influence the drivers' performance. Our goal was to understand the associations between these three categories of parameters with sleepiness, working memory, and psychomotor vigilance of the drivers.

Methods

Participants

This study was a descriptive-analytical prospective study performed on bus drivers (mean age = 40.3 years; SD = 9.6). The participants were recruited from a road travel company in Iran. All participants were male shift-work drivers, driving the route between cities Tehran and Sanandaj (490 km apart).

Inclusion criteria were as follows: (1) at least 1 year of long-distance bus driving experience; (2) a valid medical certificate (i.e., confirming they have been evaluated by medical experts and approved); (3) bus driving in Tehran-Sanandaj route. Exclusion criteria were as follows: (1) age older than 60 years; (2) the history of any sleep or psychiatric disorder indicated by the participant; (3) unwillingness to participate; (4) a positive score from Berlin questionnaire indicating increased risk of obstructive sleep apnea syndrome; (5) currently use of any medication that could potentially affect diurnal vigilance and sleepiness of the participant; and (6) drug abuse by the participant.

Written informed consents were obtained from all participants after explaining the procedure. The Ethics Committee of the University of Social Welfare and Rehabilitation Sciences approved all protocols and methods described adhered to the tenets of the Declaration of Helsinki (approval number of USWR.REC.1392.105).

Design

The study was a within-subject design. The driving route was the same for all drivers to decrease potential confounding factors. Two drivers were assigned for each round trip (of Tehran-Sanandaj). The drivers were free to decide the timing of their shifts in that 24-h period, and they were supposed to switch off to another during the trip. A researcher accompanied the drivers for 24 h on every round trip. KSS and WAIS-R working memory were recorded once before the journey and then every 6 h (repeated measurements). Each episode of testing was performed in a 2-h span-time, to make it possible to assess the driver after the driver-switch or after the driver woke up from his nap. PVT was assessed before the start of the journey and at the end of the journey (only two times).

Assessments

Epworth Sleepiness Scale—The Epworth Sleepiness Scale (ESS), an 8-item questionnaire, is a simple and inexpensive measure for subjective evaluation of daytime sleepiness. ESS scores of 11–24 represent increasing levels of excessive daytime sleepiness [25, 26]. Sadeghniat et al. performed the assessment of psychometric features of ESS for the Iranian population [27]. We analyzed the stability of ESS in the present study and calculated the Cronbach's alpha as 0.77.

Karolinska Sleepiness Scale—Karolinska Sleepiness Scale (KSS) measures the subjective level of sleepiness at a particular time during the day. On this scale, subjects indicate which level best reflects the psycho-physical state experienced in the last 10 min. This is a 9-point scale (1 = extremely alert, 3 = alert, 5 = neither alert nor sleepy, 7 = sleepy – but no difficulty remaining awake, and 9 = extremely sleepy – fighting sleep). We used the modified KSS that contains one other item: 10 = extremely sleepy, falls asleep all the time [28]. KSS is used to measure sleepiness in the short term with high reliability [29].

Berlin Questionnaire—Berlin questionnaire consists of 11 questions with three parts. It is designed to identify people with high risk of obstructive sleep apnea (OSA). This questionnaire focuses on symptoms of sleep apnea, including snoring, daily sleepiness, obesity, or high blood pressure. Questions are categorized into three groups and examine the patient's respiratory interruption probability. The result of the assessment places the patient in one of two categories of either high risk of obstructive sleep apnea or low risk of obstructive sleep apnea [30]. Amra et al. verified the reliability and validity of the Persian version of the questionnaire. The stability was 0.7 according to the Cronbach's alpha [31]. In our study, calculated Cronbach's alpha for the Berlin questionnaire was 0.7.

Wechsler Adult Intelligence Scale Revised—Wechsler Adult Intelligence Scale-Revised (WAIS-R) consists of combined tests. Each test is used individually and each of them measures different domains of intelligence capabilities. One of the subtests of Wechsler Adult Intelligence Scale-Revised is a reverse digit span memory test. This subtest assesses the person's ability to remember and repeat audible information in the correct order. It includes a two-step process. First, the subject should capture the information completely; this step requires attention and encryption. Second, the participant must correctly remember the information, consider the sequence, and attempt to repeat them. The reversed digit span memory test from the Wechsler Adult is used to determine the capabilities of working memory in healthy adults. The results are defined as Wechsler Working Memory Score. The score has a high stability and validity [18, 32, 33].

Psychomotor Vigilance Task—Psychomotor Vigilance Task (PVT) measures behavioral alertness and neurobehavioral consequences of sleep loss [34].

Procedure

Drivers attended the briefing session, signed the informed consent, and completed the Berlin questionnaire. The drivers whose Berlin questionnaires' results were positive were excluded from the study. Demographics were collected including age, working experience, weekly working hours and different working shifts, amount of daily caffeine use, and education level.

On the day of trial, all drivers filled out sleep diaries for the previous week and their last 48 h of sleep summary before the beginning of their shift or the start of the journey. Also, the drivers' baseline sleepiness was evaluated using the ESS. WAIS-R, KSS, and PVT were tested before the start of the work shift. As mentioned above, working memory and KSS were tested repeatedly, every 6 h. PVT was assessed again at the end of the journey. During the journey, if a participant was driving, the assessments were repeated after the driver switched roles with the other driver. Moreover, the drivers had permission to sleep when not driving, and reassessment was performed after awakening. Each episode of testing was performed in a 2-h span-time (every 6 h ± 1). For each test, the time features (time of day, time on task, and time of sleep) and the temporal characteristics related to nap time (during the journey), the sleep time, and the time span between beginning of the journey and the tests were all recorded. Thus, every driver was tested at least four times (WAIS-R and KSS) during the 24-h journey; these four time periods included as follows: 04:00 am (± 1 h) or early morning, 08:00 am (± 1 h) or late morning, 02:00 pm (± 1 h) or afternoon, and 10:00 pm (± 1 h) or nighttime.

The PVT was administered two times, just before the beginning of the journey and at the end of the journey with time features and the temporal relation to sleep features of each PVT test recorded.

Statistical analysis

All statistical analysis was done at a confidence level of 95% using SPSS version 21.0 for Windows (SPSS Inc., Chicago, IL, USA). Each variable was inspected visually for normality with frequency histograms and quantile–quantile plots and was tested formally with the Shapiro test. Descriptive statistics of normally and nonnormally distributed continuous variables were reported as mean (standard deviation) and median (interquartile range [IQR]), respectively; frequencies and proportions were reported for categorical variables.

The change across time of the WAIS-R score and the KSS score was assessed with a linear mixed model for repeated measures. Subject ID was included as a random effect to account for individual differences. All parameters were included in a mixed model analysis. Factors associated with Wechsler Working Memory score, KSS score, and PVT parameters were evaluated using univariate analysis (time and subject ID were considered to be random effects). We readjusted the models with probable confounders that were borderline significant predictors ($p < 0.1$ of measurement magnitude in univariate models) to adjust for the effect of these variables. Our sample size with type 1 error of 0.05 had 87% power to detect a 0.5 score change in KSS score assuming a standard deviation of 0.9 score during the trip.

Results

The study sample consisted of 35 drivers. Three drivers were excluded from the research: two because of high risk of OSA (Berlin questionnaire) and one due to reluctance to participate. All participants were male. The mean (SD) age of the subjects was 40.3 years (9.6) with the range of 28 to 58 years. Table 1 shows the clinical and demographic information for the subjects included in the study. The mean (SD) of body mass index was 26.3 (3.4) with the range of 18 to 33 kg/m^2. The mean (SD) ESS of the drivers was 6.4 (2.7) (range: 2–16) with 12.5% of drivers scoring above 10 suggesting excessive daytime sleepiness (Table 1).

The mean KSS and Wechsler working memory scores of drivers at different time periods are presented in Fig. 1. The mean KSS scores were highest in the early morning compared to the late morning, afternoon, and night-time (*p* value = 0.001). Likewise, the lowest Wechsler Working Memory measurements were found in the early morning compared to the late morning, afternoon, and night-time (*p* value = 0.001) (Fig. 1).

The main factors (time of sleep, time on task, and time of day) associated with Wechsler Working Memory score are presented in Table 2. The effect of fatigue and time on task on working memory were assessed using the number of drivers' round trips per week and the interval between the beginning of working hours and test time, respectively (Tables 2 and 3). The number of drivers' round trips per week negatively affected their working memory (Table 3).

There was no association between Wechsler Working Memory score and the temporal relation to sleep (before or after sleep nap). We did not find any significant difference among Wechsler Working Memory scores, at various interval times between waking up to performing Wechsler test (Table 2). Wechsler Working Memory scores of the drivers were negatively associated with the KSS score (*B* (95% CI) = − 1.26 (− 1.78 to − 0.74), *p* value = 0.001). In other words, increased sleepiness was associated with a decrease in working memory (Table 2).

There was no association found between the sleep hours of test day, the mean total sleep time (TST) of two previous days, the average total sleep time, sleep patterns (interrupted or persistent), and the Wechsler Working Memory score (Table 2).

The effect of time of sleep, time on task, and time of day on KSS score is presented in Table 4. The greater interval between the beginning of the working hours and the testing time was linked to a higher KSS score (*B* (95% CI) = 0.03 (0 to 0.06), *p* value = 0.024). The KSS scores were significantly higher in the early morning compared to the other three time periods. However, in a multivariate mixed model analysis, we did not find any association between sleep hours (on test day), the mean TST of two previous days, the sleep patterns (interrupted or persistent), and KSS score in our study subjects (Table 4).

Univariate and multivariate linear mixed models were also used to examine the association between the personal and demographic features and the Wechsler Working Memory Score and KSS scores (Table 3). Educated drivers had higher sleepiness scores (*B* (95% CI) = 1.13

(0.13 to2.13) and *p* value = 0.029). The Wechsler Working Memory score and the KSS had a significant reverse relationship (*B* (95% CI) = − 0.16 (− 0.23 to − 0.1) and *p* value = 0.001) (Table 3).

The comparison between PVT parameters, before and after the journey, is presented in Table 5. Compared to before the start of the shift, mean reaction time (RT) increased significantly after the journey (*p* value = 0.003), and number of lapses (i.e., RT > 500 ms) also increased significantly (*p* value = 0.000). False start (percentage) was not significantly different (before and after the journey) (Table 5).

Effects of time of sleep, time on task, time of day, and demographics on mean reaction time (PVT) are shown in Table 6. The procedure (before/after the journey) had significant effect on the mean reaction time (*p* value = 0.001). The interval between wake up and test showed a significant effect when not adjusted (*p* value = 0.049) but was not significant (*p* value = 0.364) after adjustment for repeat. Although in univariable analysis, the interval between the beginning of working hours and testing time (*p* value < 0.001) and time of day (nighttime) was associated with lower mean reaction time (*p* value = 0.040), the *p* value did not reach statistical significance after adjusting for the repeat. On the other hand, the lower Epworth Sleepiness Scale and education were associated with higher mean reaction times, before and after adjustment for the repeat (*p* value = 0.025, and *p* value = 0.089, respectively) (Table 6).

In multivariable analysis, longer intervals between the beginning of working hours and testing time (*B* (95% CI) = 15.25 (0.49 to 30), *p* value = 0.043) and having high school diploma (*B* (95% CI) = 170.94 (6.82 to 335.06), *p* value = 0.041) were associated with greater mean PVT reaction time (Table 6).

Discussion

These results add to the literature in several ways. First, we observed a prevalence of sleepiness of 12.5% based on the Epworth Sleepiness Score among bus drivers in Iran. Second, the time of day was a critical factor in determining self-reported sleepiness and working memory. Time of day was not a significant predictor of PVT (mean reaction time), when adjusted for repeat (before/after the journey). Third, we found that time on task (defined by the time from start of the shift to the time of assessment) was predictive of subjective sleepiness (based on KSS), and longer reaction time (on PVT), but not affecting working memory. In contrast, the number of round trips (as a metric of fatigue or depletion of cognitive resources) was predictive of impaired working memory. Fourth, in our study, working memory was negatively correlated with sleepiness.

The literature regarding professional drivers and their performance has shown somewhat different results about sleepiness. Prior studies have shown highly variable results with the prevalence of sleepiness (based on ESS) ranging from 1.1. to 50% in different countries [35–38]. This variability in prior reports likely reflects the subjective nature of the ESS, the incomplete exclusion of OSA in prior studies, and the variability in chronic partial sleep deprivation in different settings. In a large sample study (> 30,000 individuals) in the USA, "very short" and "short" sleep durations, defined as ≤ 5 and 6 h, respectively, were associated with drowsy driving. “Short” sleepers and “very short” sleepers experienced drowsy driving, regardless of whether they rated their sleep as always sufficient. This association persisted even in participants who reported “no insufficient” sleep at all in the past month [39]. In our study, we used sleep diaries as well as the Epworth Sleepiness Score (ESS) to assess baseline levels of sleepiness.

In this study, Wechsler working memory scores of the drivers were significantly lower in the early morning compared to the other time periods. Additionally, the sleepiness of the drivers was worst in the early morning based on KSS. Some researchers have shown that the working memory performance curve is either parallel or delayed compared to the core body temperature curve and, as a result, the lowest in the early morning [40]. Another study, in line with ours, recorded electroencephalography and subjective ratings of sleepiness. In this prior study, night driving demonstrated significant effects on subjective sleepiness and electroencephalographic indicators of sleepiness [41]. We identified a relationship between the KSS and working memory suggesting that diurnal fluctuations in sleepiness could contribute to cognitive impairment. The time of day effect was shown to be significant on PVT mean reaction time before adjustment. Although after adjustment for repeat (before/after the journey), the impact of time of day was no longer significant. As the second PVT was measured after 24 h and at the end of the journey, adjustment for repeat (before/after the journey) means adjustment for the parameter of time on task. It suggests that the effect of “time on task” on PVT mean reaction time was so strong that after adjustment, the “time of day” effect was ignorable. In addition, we assessed the effect of fatigue on working memory by assessing the number of the drivers’ round trips per week. The number of drivers’ round trips per week showed a significant negative effect on working memory score, a finding consistent with previous studies [42, 43].

Unlike some prior reports, we did not find any relationship between time on task parameters (the interval between the beginning of working hours and testing time) and the working memory score [44], although we found significant associations between time on task and PVT mean reaction time. In a study performed by Findley et al., the researchers compared the loss of attention with time on task in healthy participants and patients with disorders of excessive sleepiness. Vigilance decrements with time on task reflect the increasing instability of the waking state. They demonstrated the vulnerability of potentially sleepy patients to decrements of neurobehavioral performance over time in tasks that require sustained attention and timely responses, both of which are crucial components in safe driving performance [45]. Moreover, there are more studies showed untreated obstructive sleep apnea (OSA) severely interferes with attention capacity [46, 47], and untreated patients with OSA are at increased risk for motor vehicle accidents [48, 49]. Excessive daytime sleepiness (EDS) is a major concern with obstructive sleep apnea (OSA) [50]. According to literature, OSA and related EDS have impacts on vigilance and motor vehicle accident risks. However, uncertainty prevails regarding the relative importance of OSA severity (determined by the apnea–hypopnea frequency per hour) and the degree of sleepiness in determining accident risk [51]. Hence, we excluded apnea patients from our participants. Depressive symptoms are also positively correlated with insomnia symptoms and the risk for OSA [52]. In addition, a literature search on OSA, depression, and EDS demonstrated the relationship of EDS and depression and revealed that the duration of CPAP is crucial for improving EDS and depressive symptoms in patients with OSA [50]. To eliminate the effects or interactions of depression and sleepiness, we also excluded the participants with major depression disorders.

There was no association between time of sleep parameters and working memory score of the drivers. This result is consistent with the results of a previous study that investigated the recovery benefits of a nap during simulated night shifts [53]. However, according to our results, a longer interval between the beginning of working hours and testing time resulted in higher KSS scores.

We found a negative relationship between subjective sleepiness and working memory. The findings are consistent with other studies that found similar relationships [54, 55]. We did not find any association between subjective sleepiness and PVT mean reaction time. It seems that KSS after the journey was not a sign for sleep deprivation, and it was lower than expected at the fourth assessment of KSS at the end of the shift, so the last KSS was not associated with PVT performance at the end of the shift. A previous study revealed a significant increase in reaction time after 24 h of sleep deprivation [56]. The PVT performance after the journey was worse than the first one (before the journey), and we can explain it as a sign of sleep deprivation as in previous studies, although the KSS was not as high as expected. Moreover, Lim et al. demonstrated in their study that sleep deprivation resulted in late responses and the increase of the errors of commission of PVT [55].

In this study, there was a significant association between a higher level of education and higher scores of sleepiness (KSS). Also, the higher education (high school diploma) compared to lower education (under high school) showed a significant association with worse cognitive performance (higher PVT reaction time) after the journey. Higher KSS scores of those drivers with high school diploma might explain this finding.

Although numerous investigations have addressed the impact of sleep on quality of life, few have specifically addressed their potential deleterious effects on driving performance and road incidents [57]. In a survey by European Sleep Research Society, the most frequently perceived reasons for falling asleep at the wheel were poor sleep in the previous night (42.5%) and poor sleeping habits in general (34.1%) [58]. Also, it has shown that driving events are exacerbated by an interaction between circadian phase and duration of wakefulness or homeostatic processes [59]. Joint assessment of time on task, time of day, and sleep time may reflect the joint actions of the circadian and homeostatic factors on sleep pressure and vigilance, which might increase the probability of motor vehicle accidents. So, our findings might be instructive to present a larger image of the problem and be helpful to understand the multi-dimensional solution.

From an analytical perspective, our data have considerable strengths including a real-world setting, not using simulators. However, we acknowledge some limitations as well. First, the sample size was small, even though it was a real-world study. Second, we used questionnaires for the evaluation of sleepiness and sleep apnea. Therefore, the data used in this investigation may reflect recall bias. We used the Berlin questionnaire to exclude the apnea patients from our study. The Berlin Questionnaire is a validated screening tool for OSA, but polysomnography (PSG) remains the gold standard for diagnosis of OSA and is preferred in confirmatory studies. Also, objective assessment of sleep duration, sleep stage distribution, and sleep fragmentation with polysomnography would be useful as they could contribute to sleepiness and sleepiness was one of our primary outcomes. Although we did not evaluate our participants with PSG in this project, it would be helpful in future studies. Despite these limitations, we do believe we can draw some important conclusions and provide motivation for further studies.

Conclusion

Time of day was the most important predictor of working memory compared to time on task and time of sleep. Time on task had a significant effect on PVT performance and sleepiness. Sleepiness was significantly associated with lower working memory.

Public transportation is considered critical, as the safety of the passengers is related to the proper function of the system. The results of the present study may impact the health policies on road to reduce the number of accidents. We support interventional studies to determine the optimal drivers' schedules to optimize the drivers' performance and increase road safety.

Data availability

All our data and analyses are available.

References

1. Bastida JL, Aguilar PS, González BD (2004) The economic costs of traffic accidents in Spain. J Trauma 56(4):883–8 (discussion 888–9) [PubMed: 15187757]
2. Kapp C (2003) WHO acts on road safety to reverse accident trends. Traffic accidents kill 1.26 million people each year; 2nd leading cause of death among those aged 15–29. Lancet 3(9390):1125
3. Lowrie J, Brownlow H (2020) The impact of sleep deprivation and alcohol on driving: a comparative study. BMC Public Health 20(1):980 [PubMed: 32571274]
4. Fritz J et al. (2020) A chronobiological evaluation of the acute effects of daylight saving time on traffic accident risk. Curr Biol 30(4):729–735.e2 [PubMed: 32008905]
5. Bioulac S et al. (2017) Risk of motor vehicle accidents related to sleepiness at the wheel: a systematic review and meta-analysis. Sleep 40(10):28958002
6. Connor J et al. (2002) Driver sleepiness and risk of serious injury to car occupants: population based case control study. BMJ 324(7346):1125 [PubMed: 12003884]
7. Tefft BC (2012) Prevalence of motor vehicle crashes involving drowsy drivers, United States, 1999–2008. Accid Anal Prev 45:180–186 [PubMed: 22269499]
8. Anund A et al. (2016) Factors associated with self-reported driver sleepiness and incidents in city bus drivers. Ind Health 54(4):337–346 [PubMed: 27098307]
9. Filtness AJ et al. (2020) Sleep loss and change detection in simulated driving. Chronobiol Int 1(11):1430–1440
10. Sagaspe P et al. (2008) Extended driving impairs nocturnal driving performances. PLoS ONE 3(10):e3493–e3493 [PubMed: 18941525]
11. Balkin TJ et al. (2002) The process of awakening: a PET study of regional brain activity patterns mediating the re-establishment of alertness and consciousness. Brain 125(Pt 10):2308–2319 [PubMed: 12244087]

12. Reteig LC et al. (2019) Sustaining attention for a prolonged period of time increases temporal variability in cortical responses. Cortex 117:16–32 [PubMed: 30925309]
13. Greenlee ET, DeLucia PR, Newton DC (2019) Driver vigilance in automated vehicles: effects of demands on hazard detection performance. Hum Factors 61(3):474–487 [PubMed: 30307760]
14. Vetter C et al. (2015) Aligning work and circadian time in shift workers improves sleep and reduces circadian disruption. Curr Biol 25(7):907–911 [PubMed: 25772446]
15. Wong LR, Flynn-Evans E, Ruskin KJ (2018) Fatigue risk management: the impact of anesthesiology residents' work schedules on job performance and a review of potential countermeasures. Anesth Analg 126(4):1340–1348 [PubMed: 29049076]
16. Pettersson K et al. (2019) Saccadic eye movements estimate prolonged time awake. J Sleep Res 28(2):e12755 [PubMed: 30133045]
17. Gupta S, Kumar P, Yuga Raju G (2021) A fuzzy causal relational mapping and rough set-based model for context-specific human error rate estimation. Int J Occup Saf Ergon 27(1):63–78 [PubMed: 30775954]
18. Lefebvre CD et al. (2005) Assessment of working memory abilities using an event-related brain potential (ERP)-compatible digit span backward task. Clin Neurophysiol 116(7):1665–1680 [PubMed: 15908268]
19. Bartolacci C et al. (2020) The influence of sleep quality, vigilance, and sleepiness on driving-related cognitive abilities: a comparison between young and older adults. Brain Sci 10(6):327
20. Huffmyer JL et al. (2020) Impact of caffeine ingestion on the driving performance of anesthesiology residents after 6 consecutive overnight work shifts. Anesth Analg 130(1):66–75 [PubMed: 31274603]
21. Jackson ML et al. (2013) Cognitive components of simulated driving performance: sleep loss effects and predictors. Accid Anal Prev 50:438–444 [PubMed: 22721550]
22. Durmer JS, Dinges DF (2005) Neurocognitive consequences of sleep deprivation. Semin Neurol 25(1):117–129 [PubMed: 15798944]
23. Bartolacci C et al. (2020) The influence of sleep quality, vigilance, and sleepiness on driving-related cognitive abilities: a comparison between young and older adults. Brain Sci 10(6):327
24. Jongen S et al. (2015) Sensitivity and validity of psychometric tests for assessing driving impairment: effects of sleep deprivation. PLoS One 10(2):e0117045
25. Johns MW (1991) A new method for measuring daytime sleepiness: the Epworth sleepiness scale. Sleep 14(6):540–545 [PubMed: 1798888]
26. Johns M, Hocking B (1997) Daytime sleepiness and sleep habits of Australian workers. Sleep 20(10):844–849 [PubMed: 9415943]
27. Sadeghniiat Haghighi K et al. (2013) The Epworth Sleepiness Scale: translation and validation study of the Iranian version. Sleep Breath 17(1):419–426 [PubMed: 22327509]
28. Akerstedt T, Gillberg M (1990) Subjective and objective sleepiness in the active individual. Int J Neurosci 52(1–2):29–37 [PubMed: 2265922]
29. Gharagozlou F et al. (2013) Investigating EEG alpha variations for mental fatigue detection on car driving simulator. Iran-J-Ergon 1(1):5–13
30. Netzer NC et al. (1999) Using the Berlin Questionnaire to identify patients at risk for the sleep apnea syndrome. Ann Intern Med 131(7):485–491 [PubMed: 10507956]
31. Amra B et al. (2013) Validation of the Persian version of Berlin sleep questionnaire for diagnosing obstructive sleep apnea. Int J Prev Med 4(3):334–339 [PubMed: 23626891]
32. Kaufman AS, Lichtenberger EO, McLean JE (2001) Two- and three-factor solutions of the WAIS-III. Assessment 8(3):267–280 [PubMed: 11575620]
33. Moradi AR et al. (2012) Overgeneral autobiographical memory recollection in Iranian combat veterans with posttraumatic stress disorder. Behav Res Ther 50(6):435–441 [PubMed: 22542534]
34. Basner M, Dinges DF (2011) Maximizing sensitivity of the psychomotor vigilance test (PVT) to sleep loss. Sleep 34(5):581–591 [PubMed: 21532951]
35. Perez-Chada D et al. (2005) Sleep habits and accident risk among truck drivers: a cross-sectional study in Argentina. Sleep 28(9):1103–1108 [PubMed: 16268379]

36. de Pinho RS et al. (2006) Hypersomnolence and accidents in truck drivers: a cross-sectional study. Chronobiol Int 23(5):963–971 [PubMed: 17050211]
37. Baulk SD, Fletcher A (2012) At home and away: measuring the sleep of Australian truck drivers. Accid Anal Prev 45(Suppl):36–40 [PubMed: 22239929]
38. Krishnaswamy UM, Chhabria MS, Rao A (2016) Excessive sleepiness, sleep hygiene, and coping strategies among night bus drivers: a cross-sectional study. Indian J Occup Environ Med 20(2):84–87 [PubMed: 28194081]
39. Maia Q et al. (2013) Short and long sleep duration and risk of drowsy driving and the role of subjective sleep insufficiency. Accid Anal Prev 59:618–622 [PubMed: 23973762]
40. Lewandowska K et al. (2018) Would you say “yes” in the evening? Time-of-day effect on response bias in four types of working memory recognition tasks. Chronobiol Int 35(1):80–89 [PubMed: 29111783]
41. Sandberg D et al. (2011) The characteristics of sleepiness during real driving at night–a study of driving performance, physiology and subjective experience. Sleep 34(10):1317–1325 [PubMed: 21966063]
42. Berthie G et al. (2015) The restless mind while driving: drivers’ thoughts behind the wheel. Accid Anal Prev 76:159–165 [PubMed: 25697452]
43. Lowe CJ, Safati A, Hall PA (2017) The neurocognitive consequences of sleep restriction: a meta-analytic review. Neurosci Biobehav Rev 80:586–604 [PubMed: 28757454]
44. Basner M et al. (2008) Effects of night work, sleep loss and time on task on simulated threat detection performance. Sleep 31(9):1251–1259 [PubMed: 18788650]
45. Findley LJ, Suratt PM, Dinges DF (1999) Time-on-task decrements in “steer clear” performance of patients with sleep apnea and narcolepsy. Sleep 22(6):804–809 [PubMed: 10505827]
46. Büttner A, Randerath W, Rühle KH (2000) The driving simulation test “carsim” for assessing vigilance. Effect of driving practice and other factors in health subjects and in patients with sleep apnea syndrome. Pneumologie 54(8):33844
47. Büttner A, Randerath W, Rühle KH (2003) Two simulation programs to measure continuous attention in obstructive sleep apnea syndrome. Pneumologie 57(12):722–728 [PubMed: 14681743]
48. Ayas N et al. (2014) Obstructive sleep apnea and driving: a Canadian Thoracic Society and Canadian Sleep Society position paper. Can Respir J 21(2):114–123 [PubMed: 24724150]
49. Strohl KP et al. (2013) An official American Thoracic Society Clinical Practice Guideline: sleep apnea, sleepiness, and driving risk in noncommercial drivers. An update of a 1994 Statement. Am J Respir Crit Care Med 187(11):125966
50. Zhang D et al. (2021) Excessive daytime sleepiness in depression and obstructive sleep apnea: more than just an overlapping symptom. Front Psychiatry 12:710435
51. Bonsignore MR et al. (2021) European Respiratory Society statement on sleep apnoea, sleepiness and driving risk. Eur Respir J 572:2001272
52. Jermann F et al. (2021) Quality of life and subjective sleep-related measures in bipolar disorder and major depressive disorder. Qual Life Res
53. Centofanti SA et al. (2016) The impact of short night-time naps on performance, sleepiness and mood during a simulated night shift. Chronobiol Int 33(6):706–715 [PubMed: 27077524]
54. Naismith S et al. (2004) Neurobehavioral functioning in obstructive sleep apnea: differential effects of sleep quality, hypoxemia and subjective sleepiness. J Clin Exp Neuropsychol 26(1):43–54 [PubMed: 14972693]
55. Lim J, Dinges DF (2008) Sleep deprivation and vigilant attention. Ann N Y Acad Sci 1129:305–322 [PubMed: 18591490]
56. Dixit A, Mittal T (2015) Executive functions are not affected by 24 hours of sleep deprivation: a color-word stroop task study. Indian J Psychol Med 37(2):165–168 [PubMed: 25969601]
57. Smolensky MH et al. (2011) Sleep disorders, medical conditions, and road accident risk. Accid Anal Prev 43(2):533–548 [PubMed: 21130215]
58. Gonçalves M et al. (2015) Sleepiness at the wheel across Europe: a survey of 19 countries. J Sleep Res 24(3):242–253 [PubMed: 25581328]

59. Mulhall MD et al. (2019) Sleepiness and driving events in shift workers: the impact of circadian and homeostatic factors. Sleep 42(6)

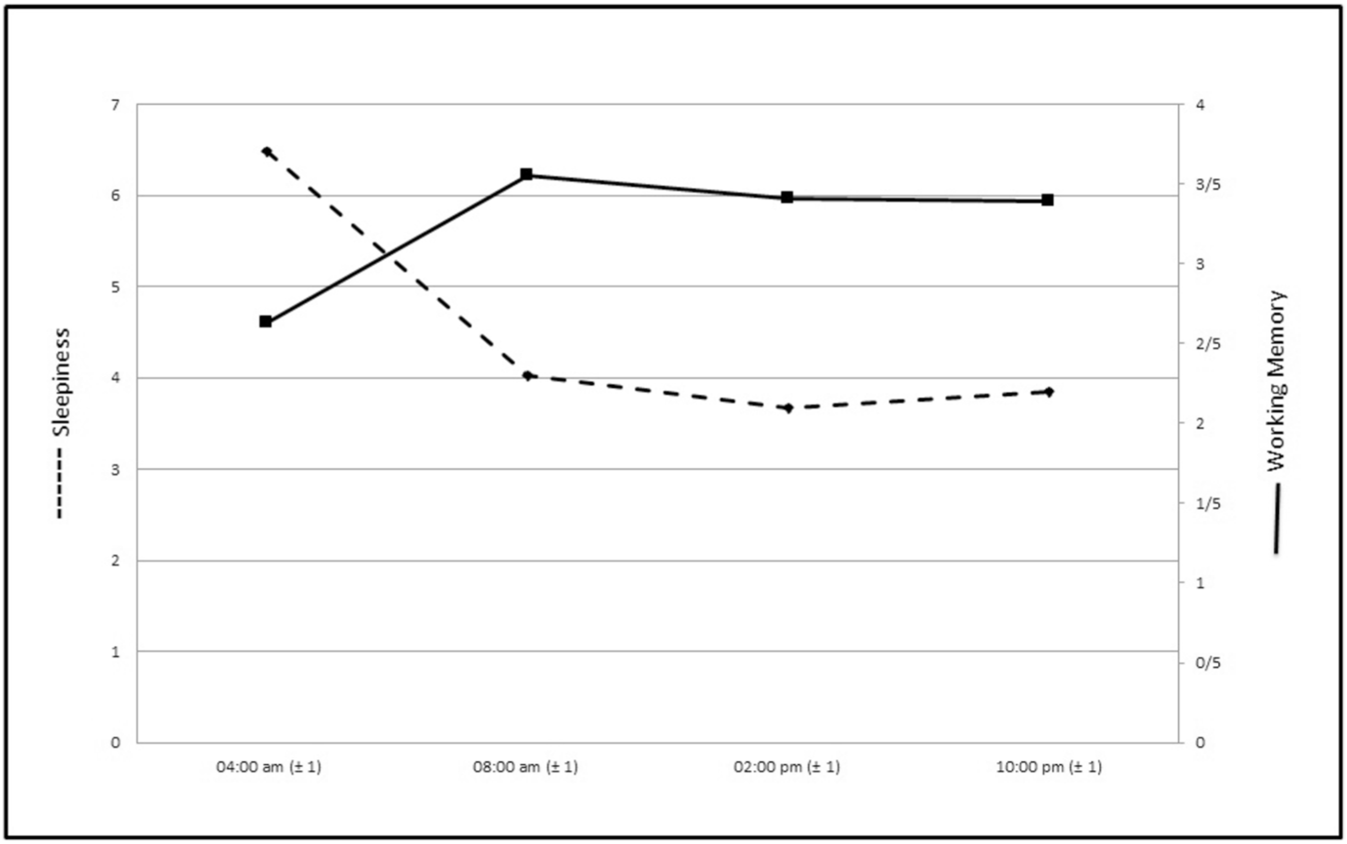

Fig. 1.

Comparing the mean values of sleepiness and working memory, at four periods of time (N = 35)

Table 1

Demographic features of the drivers ($n = 35$)

Variables	Value
Age, years	40.3 ± 9.6 (range: 28–58)
Weight, kg	81.6 ± 11 (range: 55–105)
Height, m	1.75 ± 0.063 (range: 1.65–1.92)
Body mass index (BMI)	26.3 ± 3.4 (range: 18–33)
Exercise time per week, min	0 (0, 100) (range: 0–360)
Marriage duration, years	13 (3, 26) (range: 0–33)
Education level number (%)	
Under the high school diploma	18 (51.4)
High school diploma	15 (42.9)
Academic	2 (5.7)
Marital status number (%)	
Married	30 (85.7)
Single	5 (13.3)
Smoking number (%)	
Smoker	16 (45.7)
Non-smoker	19 (54.3)
Accident history number (%)	
With a history	6 (17.1)
Without a history	29 (82.9)

Data expressed as the mean ± SD and median (interquartile range [IQR]) for normally and nonnormally distributed continuous variables, respectively. Frequencies and proportions are reported for categorical variables

Table 2

The effect of time of sleep, time on task, and time of day on Wechsler Working Memory score

Variable	Unadjusted		Adjusted	
	Regression coefficient (confidence interval)	***p*-value**	**Regression coefficient (confidence interval)**	***p*-value**
Effect of time of sleep on working memory				
The temporal relation of the test to sleep (before sleep versus after sleep)	− 0.57 (− 0.31–1.46)	0.202	− 0.05 (− 1.18–1.08)	0.929
Normal TST (normal versus abnormal)	0.03 (− 0.81–0.87)	0.946	1.47 (− 3.32–0.39)	0.115
Interrupted or persistent sleep (persistent versus interrupted)	0.63 (− 0.25–1.51)	0.155	1.56 (− 1.34–4.46)	0.276
The interval between waking up and taking the test	0.03 (− 0.08–0.14)	0.567	0.03 (− 0.12–0.17)	0.719
Mean TST of two previous days	− 0.04 (− 0.36–0. 28)	0.801	− 0.18 (− 0.75–0.4)	0.536
Sleep hours at 24 h of test day	0.15 (− 0.15–0.46)	0.312	− 0.13 (− 0.69–0.42)	0.625
Subjective sleepiness (KSS)	− 1.4 (− 1.73–(− 1.08))	**0.001**	− 1.26 (− 1.78–(− 0.74))	**0.001**
Effect of time on task on working memory				
The interval between the beginning of working hours and testing time	− 0.02 (− 0.09–0. 05)	0.523	0.02 (− 0.07–0.1)	0.65
Effect of time of day on working memory				
Time of taking tests at day and night (reference: early morning 04:00 am ± 1)				
Late morning (08:00 am ± 1)	2.68 (1.66–3.7)	**0.001**	2.77 (1.49–4.04)	**0.001**
Afternoon (02:00 pm ± 1)	2.65 (1.63–3.67)	**0.001**	2.7 (1.53–4.07)	**0.001**
Night (10:00 pm ± 1)	3.22 (2.24–4.2)	**0.001**	3.34 (2.14–4.55)	**0.001**

Bold font *p*-value highlights significance

Abbreviation: *TST*, total sleep time (per 24 h a day); we assumed Normal TST > 6 h; *KSS*, Karolinska Sleepiness Scale

Table 3

The effect of personal and demographic features of drivers on working memory (Wechsler score) and subjective sleepiness (Karolinska Sleepiness Scale)

Variable	**Unadjusted**		**Adjusted**	
	Regression coefficient (confidence interval)	***p*-value**	**Regression coefficient (confidence interval)**	***p*-value**
Effect on working memory (Wechsler score)				
The total time of driving the present bus	− 0.08 (− 0.35−0.19)	0.545	− 0.01 (− 0.29−0.26)	0.927
The number of drivers’ round trips per week	− 0.54 (− 1.01−(− 0.07))	**0.025**	− 0.72 (− 1.53−0.09)	0.079
Number of smoking per day	0.02 (− 0.04−0.02)	0.353	0.04 (− 0.04−0.13)	0.314
Number of cups of tea consumed per day	− 0.01 (− 0.05−0.04)	0.799	− 0.01 (− 0.79−0.43)	0.548
ESS score	0.00 (− 0.15−0.16)	0.952	0.14 (− 0.25−0.53)	0.461
Education (reference: under high school diploma)				
High school diploma	0.56 (− 0.24−1.37)	0.165	0.1 (− 1.98−2.19)	0.919
Academic	2.16 (0.49−3.83)	**0.012**	− 0.24 (− 3.52−3.04)	0.882
Effect on subjective sleepiness (KSS)				
Time period of driving the present bus	0.00 (− 0.02−0.02)	0.718	− 0.04 (− 0.1−0.02)	0.180
The number of drivers’ round trips per week	0.12 (− 0.09−0.34)	0.261	0.13 (− 0.12−0.39)	0.283
Number of smoking per day	0.00 (− 0.03−0.02)	0.685	0.12 (− 0.07−0.31)	0.212
Number of cups of tea consumed per day	0.01 (− 0.11−0.13)	0.925	0.03 (− 0.05−0.11)	0.450
ESS score	0.02 (− 0.05−0.09)	0.598	− 0.02 (− 0.14−0.1)	0.987
Working memory (Wechsler score)	− 0.26 (− 0.32−(− 0.2))	**0.001**	− 0.16 (− 0.23−(− 0.1))	**0.001**
Education (reference: under high school diploma)				
High school diploma	0.00 (− 0.38−0.38)	0.993	0.11 (− 0.53−0.74)	0.729
Academic	0.01 (− 0.78−0.8)	0.976	1.13 (0.13−2.13)	**0.029**

Bold font *p*-value highlights significance

Abbreviations: *ESS*, Epworth Sleepiness Scale; *KSS*, Karolinska Sleepiness Scale

Table 4

The effect of time of sleep, time on task, and time of day on subjective sleepiness (Karolinska Sleepiness Scale)

Variable	**Unadjusted**		**Adjusted**	
	Regression coefficient (confidence interval)	***p*-value**	**Regression coefficient (confidence interval)**	***p*-value**
Effect of time of sleep on subjective sleepiness				
The temporal relation of the test to sleep (before sleep versus after sleep)	− 0.45 (− 0.82–(− 0.08))	**0.016**	− 0.11 (− 0.48–0.27)	0.574
Normal TST (normal versus abnormal)	0.17 (− 0.22–0.55)	0.384	0.37 (− 0.2–0.94)	0.195
Interrupted or persistent sleep (persistent versus interrupted)	0.07 (− 0.34–0.48)	0.723	− 0.64 (− 1.53–0.25)	0.154
The interval between waking up and taking the test	− 0.03 (− 0.07–0.02)	0.283	0.09 (− 0.07–0.03)	0.391
Mean TST of two previous days	0.02 (− 0.12–0.16)	0.78	0.00 (− 0.18–0.18)	0.998
Sleep hours at 24 h of test day	− 0.07 (− 0.2–0.07)	0.321	− 0.08 (− 0.25–0.09)	0.345
Effect of time on task on subjective sleepiness				
The interval between the beginning of working hours and testing time	0.03 (0.0–0.06)	**0.057**	0.03 (0.0–0.06)	**0.024**
Effect of time of day on subjective sleepiness				
Time of taking tests at day and night (reference: early morning 04:00 am ± 1)				
Late morning (08:00 am ± 1)	− 1.32 (− 1.71–(− 0.93))	**0.001**	− 0.88 (− 1.34–(− 0.4))	**0.001**
Afternoon (02:00 pm ± 1)	− 1.58 (− 1.76–(− 1.19))	**0.001**	− 1.3 (− 1.76–(− 0.85))	**0.001**
Night (10:00 pm ± 1)	− 1.5 (− 1.88–(− 1.13))	**0.001**	− 0.8 (− 1.26–(− 0.34))	**0.001**

Bold font *p*-value highlights significance

Abbreviation: *TST*, total sleep time (per 24 h a day); we assumed Normal TST > 6 h

Table 5

Comparison of PVT parameters, before and after the journey

Variable	PVT parameters Before	PVT parameters After	*p*-value
Percentage of false start [*]	0.9 ± 1.4	1.3 ± 1.9	0.370
Mean reaction time (ms)	493.7 ± 188.3	715.4 ± 332.4	**0.003**
Number of lapses [**]	24.9 ± 21.3	57.6 ± 35.1	**0.000**
Sum of minor part of lapses [***] (ms)	674.6 ± 358.8	852.1 ± 387	0.089

Bold font *p*-value highlights significance

[*] False start: reaction to a false stimulus which has not happened

[**] Lapses (i.e., reaction time) > 500 ms

[***] Sum of the times above 500 ms (of lapses)

Table 6

Effect of time of sleep, time on task, time of day, and personal and demographic features on mean reaction time of PVT in univariate, adjusted for repeat, and multivariable analysis

Variable	**Unadjusted**		**Adjusted (multivariable)**	
	Regression coefficient (95% CI)	***p*-value (adjusted for repeat)**	**Regression coefficient (95% CI)**	***p*-value**
Effect of time of sleep on mean reaction time of PVT				
Before/after	221.68 (85.21, 358.14)	**0.001**	−	−
Normal total sleep time (normal versus abnormal)	− 6.32 (− 162.1, 149.47)	0.937 (0.931)	−	−
Interrupted or persistent sleep (persistent versus interrupted)	14.64 (− 148.39, 177.66)	0.860 (0.848)	−	−
The interval between waking up and test	− 19.34 (− 38.65, − 0.04)	**0.049** (0.364)	− 16.1 (− 36.66, 4.45)	0.125
Mean TST of two previous days	− 17.6 (− 78.62, 43.41)	0.572 (0.535)		
Sleep hours at 24 h of test day	26.86 (− 31.34, 85.05)	0.366 (0.333)	−	−
KSS score	44.95 (− 32.41, 122.31)	0.255 (0.859)	−	−
Effect of time on task on mean reaction time of PVT				
The interval between the beginning of working hours and testing time	16.35 (7.51, 25.2)	**< 0.001** (0.444)	15.25 (0.49, 30)	**0.043**
Effect of time of day on mean reaction time of PVT				
Time of taking tests at day and night (reference: early morning 04:00 am ± 1)				
Late morning (08:00 am ± 1)	− 186.51 (− 466.51, 93.49)	0.192 (0.693)	− 104.34 (− 395.91, 187.23)	0.483
Afternoon (02:00 pm ± 1)	− 94.93 (− 342.42, 152.56)	0.452 (0.736)	46.99 (− 194.52, 288.5)	0.703
Night (10:00 pm ± 1)	− 304.55 (− 560.15, − 48.94)	**0.020** (0.565)	29.12 (− 314.75, 372.99)	0.868
Effect of personal and demographic features on mean reaction time of PVT				
The number of drivers’ round trips per week	−60.33 (− 146.26, 25.59)	0.201 (0.169)	−	−
Number of smoking per day	1.35 (− 7.51, 10.21)	0.765 (0.751)	−	−
Number of cups of tea consumed per day	− 18.33 (− 64.26, 27.6)	0.434 (0.402)	−	−
ESS score	− 26.55 (− 51.72, − 1.37)	**0.039 (0.025)**	− 4.64 (− 42.39, 33.12)	0.810
Education (reference: under high school diploma)				
High school diploma	147.86 (− 1.88, 297.61)	**0.053 (0.036)**	170.94 (6.82, 335.06)	**0.041**
Academic	160.2 (− 137.28, 457.68)	0.291 (0.254)	197.84 (− 79.44, 475.12)	0.162

Bold font *p*-value highlights significance

Abbreviations: *TST*, total sleep time; *KSS*, Karolinska Sleepiness Score; *PVT*, Psycho-motor Vigilance Test; *ESS*, Epworth Sleepiness Scale