International Journal of Technology 14(5) 1039-1048 (2023)
Received April 2021 / Revised June 2021 / Accepted October 2021

International Journal of Technology

http://ijtech.eng.ui.ac.id

Fatigue Among Indonesian Commercial Vehicle Drivers: A Study Examining Changes in Subjective Responses and Ocular Indicators

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Abstract. Fatigue from driving is a risk factor in many road traffic accidents and the association between task duration and fatigue, in particular, has been a subject of research interest. Fatigue (and sleepiness) seems to plague many Indonesian commercial drivers whose jobs involve long-duration driving, but this issue is still rarely quantified and investigated. This study aims to characterize fatigue from long-duration driving, with a special interest in the use of eye-blink indicators. A total of 12 male commercial drivers participated in this study, in which they had to drive for about two sessions of 2.5 hours of actual driving tasks on a highway, separated by 15 minutes of rest. Subjective response to fatigue and sleepiness was obtained by employing Karolinska Sleepiness Scale (KSS), while several eye-blink parameters (blink duration, blink frequency, percent of eye closure, and micro-sleep) were analyzed offline via a continuous recording of the subject's facial characteristics throughout the driving task. The findings of this study demonstrated that driving for roughly 2.5 hours did not result in undue fatigue. However, an additional driving task of the same duration yielded excessive fatigue, despite the 15-minute rest period given between the two trips. All eye-blink parameters were closely correlated with subjective measures, although more consistent changes were shown by the blink duration. It was concluded here that prolonged driving, as part of a professional job, is closely associated with undue fatigue that represents a road safety risk factor.

Keywords: Eye-blink parameters; Fatigue; Karolinska sleepiness scale; Prolonged driving; Sleepiness

1. Introduction

Road traffic safety has been a very important issue in Indonesia. A report by the Indonesian National Bureau of Statistics (2018) shows a consistently increasing trend of road accidents. A total of more than 109,000 accidents was reported in 2018, an increase of roughly 85% compared to the data in 2008. About 20,000 people were killed in traffic accidents in 2008, while the number was nearly 29,500 in 2018. The latter demonstrates roughly three to four people were killed in road traffic accidents per hour, a statistic that cannot be taken lightly. Direct financial (material) loss in 2018 was estimated to be more than Rp 213 billion (~USD 15 million), not to mention other substantial economic and social loss among those who are affected by the accidents.

While research addressing motor vehicle crashes has been relatively scarce, authorities

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doi: 10.14716/ijtech.v14i5.4856

(such as the Indonesian National Transportation Safety Committee) have pointed out that fatigue and sleepiness are the key contributing factors. These factors have been indicated in most road crashes investigations involving commercial buses and trucks. Though the number is not exactly known, fatigue has also been reported in a good percentage of crashes involving minivans used as shuttle services between major cities. Such services are a very common mode of public transportation in addition to railway.

Among several relevant human-factors aspects, fatigue has been frequently cited to play a major role in traffic accidents. The relationship between fatigue and safety have also been addressed in the literature (Williamson *et al*., 2011). Three major factors are closely associated with the development of fatigue, including time of day, time awake, and task-related factors (Williamson *et al*., 2011), while demographic aspects as contributing factors have also been suggested in the literature (Di-Milia *et al*., 2011). Fatigue is believed to be a complex phenomenon (Caldwell *et al*., 2019), and no widely accepted definition is currently available. Williamson *et al*. (2011) define fatigue as a need for recuperative rest, with factors including time on task, sleep homeostasis, and time of day, believed to play a major role to fatigue development. Di-Milia *et al*. (2011) suggests an array of potential endogenous as well as exogenous variables that may be linked to the development of fatigue.

As described previously, fatigue (and sleepiness) is likely to be prevalent among shuttle service drivers. It is not uncommon for drivers of these shuttle to operate the vehicle for four trips in a day, which accumulates to 16 hours of driving (with approximately 30 - 60 minutes of rest between trips). Consequently, the drivers experience lack of sleep that also affecting its quality. Most of them have to operate long commute where rest periods are short and uncertain. Self-reported sleepiness often tends to be bias (Sallinen *et al*., 2020), which put the driver and passengers at higher risk of road crashes. The aim of this study is to investigate the level of fatigue and sleepiness among shuttle service drivers. It was hypothesized that the driving job would result in moderate to high level of fatigue; a phenomenon that the company might not be aware of. The findings of this study could be used as a strategy to mitigate fatigue as a road safety risk factor.

2. Methods

2.1. Participants

Twelve male drivers aged 30-40 participated in the experiment (mean age 35.6 ± 3.58 years old). They were compensated for their participation in the experiment. They were experienced drivers with legitimate driving license for at least 3 years (mean 17.33 ± 3.67 years) and had at least 3 years of driving experience (mean 18.08 ± 4.18 years), with mileage driven more than 5,000 km in the past year (means 7,220 ± 1,416 km). The participants were recruited and selected rather purposively from several shuttle service companies in Bandung, Indonesia. The age bracket selected represented a large percentage of commercial (shuttle service) driver population with adequate year of driving experience. All of them were morning type people, had normal vision or corrected-to-normal vision (using contact lenses or glasses), and had no health problems. In addition, all participants were used to consume drinks containing caffeine, both tea and coffee. A large portion of the participants (83.3%) were active smokers and none of the participants consumed alcohol and/or illegal drugs.

A night before the experiment, participants reported that they had a sufficient amount of sleep (7-8 hours) (mean 7.52 ± 0.54 hours). Prior to conducting the experiment, they filled out a profile data questionnaire, signed a data confidentiality agreement, and signed a consent form. Ethical approval for the research protocol was granted by the Institutional Ethics Review Board prior to data collection.

Before the experiment began, participants were prohibited from consuming certain foods or drinks for a certain period of time, other than those permitted by the researchers. During the experiment, participants were prohibited from listening to the radio or communicating intensively with the researchers. Participants were not allowed to wear sunglasses or dark-coloured glasses because they could interfere with the eye-blink data collection. Based on the pre-driving self-report, all participants had confirmed to be physically and mentally healthy, did not consume alcohol within 24 hours before the experiment, and did not consume caffeine within 4 hours prior to the experiment.

2.2. Experimental Procedure

Each participant drove a car from the city of A to the city of B (first session) and back to A (second session) with a total duration of roughly six hours. Each driver started the task at 8 a.m.; the morning shift was chosen to represent common, light to moderate workload (as opposed to a greater workload while driving during night-time). After arriving in B, participants received a 15-minute break before leaving for A. The selection of the route was based on the traveling duration (more than 150 minutes) according to Falou *et al.* (2003), monotonous road conditions (toll roads), as well as low and high traffic densities which represent low and high workloads (May and Baldwin, 2009; Gimeno, Cerezuela, and Montanes, 2006). Before driving, participants filled out a questionnaire regarding sleep conditions and other conditions related to drowsiness before driving. This was done to ensure they were ready for the experiment, and no prior adverse conditions (such as lack of sleep) interfered with the results. Participants also reported their subjective assessment of sleepiness using Karolinska Sleepiness Scale/KSS (Akerstedt *et al.*, 2014). The KSS was used to capture the participant's subjective experience of sleepiness (Kaida *et al.*, 2006). These initial data were used as a baseline (the initial conditions before driving).

For each trip, a camera was mounted on the dashboard facing the driver for the purpose of recording the participant's face during the experiment. Off-line, these recordings were analyzed in order to obtain eye-blink parameters, including frequency, duration, percentage of eye closure (PERCLOS), and microsleep. Blink duration and frequency are good indicators for measuring fatigue (Benedetto *et al.*, 2011; Schleicher *et al.*, 2008). Eye blink data (including blink frequency and duration) are related to activity, workload, and fatigue caused by work (Tsai *et al.*, 2007). Van Orden *et al.* (2001) stated that the blink frequency and duration are highly correlated with work and changes in blink behavior, which are associated with increased levels of fatigue while doing work. The blink duration was calculated when the eyelid closes until it opens back completely. The blink frequency was obtained from the number of blinks in units of time (minutes). These parameters were derived from 1-minute windows of recording, calculated every 20 minutes throughout the driving duration. Similarly, scores of KSS were also reported every 20 minutes, in addition to collecting the scores at the beginning and end of a driving session.

2.3. Data Analysis

A descriptive and an inferential data analysis were done. In this study, non-parametric statistical test was used because the amount of data processed was less than 30 and did not meet normal assumptions (Walpole *et al.*, 2012). This experiment was designed as repeated measures, with ocular indicator and subjective ratings of sleepiness as the dependent variables. The interest was to determine changes in all dependent variables as a function of driving duration. The statistical analysis was conducted using SPSS software, with a $p < 0.05$ indicating significance.

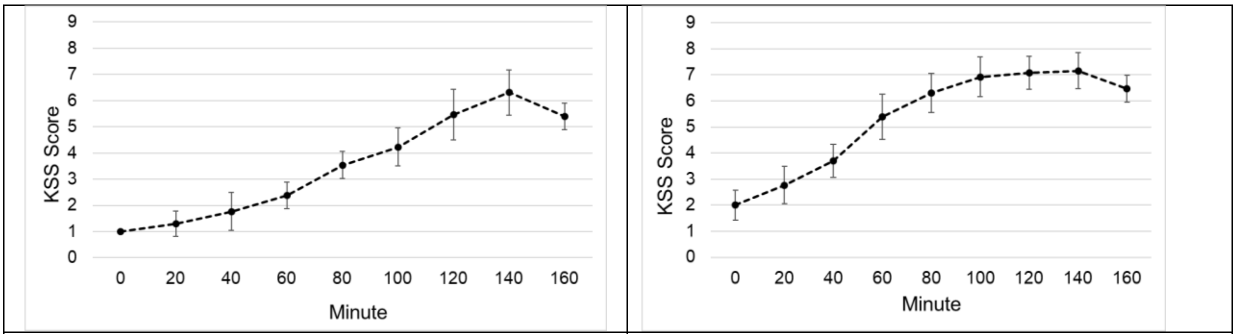
In this study, Wilcoxon Signed-Rank was used to determine the differences between conditions of the first session and the second session with 15 minutes of rest. Friedman test was used to find out the differences between data collection times for each fatigue indicator value. Finally, the Mann Whitney U test was used to identify which post-hoc traffic density conditions give a difference in the fatigue indicators. Correlations (Spearman's rho) were conducted to determine the associations among variables (Walpole *et al*., 2012).

3. Results and Discussion

3.1. Experimental Result

3.1.1. Karolinska Sleepiness Scale (KSS)

Subjective response data demonstrated a fair increase in sleepiness for the first trip ($p < 0.05$), with peak score (KSS = 6) observed toward the end of the first trip (Figure 1). There was a decrement in the KSS score at the end of the trip. A similar fatigue profile was found with respect to the second trip ($p < 0.05$). As opposed to the first trip, however, fatigue was substantially elevated. It is noteworthy that, for the first trip, a KSS of 5 was reported after approximately driving for nearly 2 hours. In contrast, the same KSS for the second trip was reported before 60 minutes of driving. The baseline values between the two conditions were significantly different ($p < 0.05$).

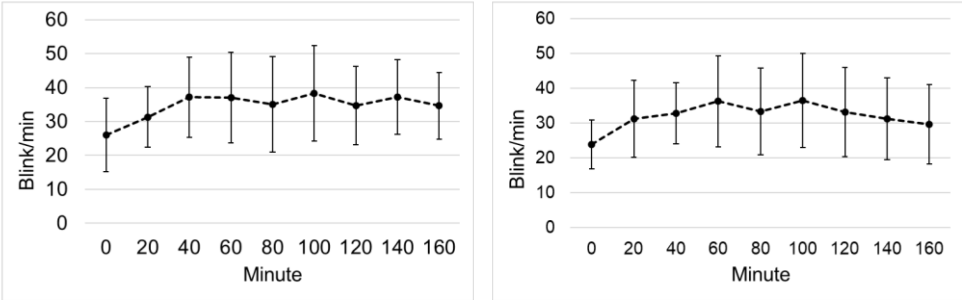


(a) (b)

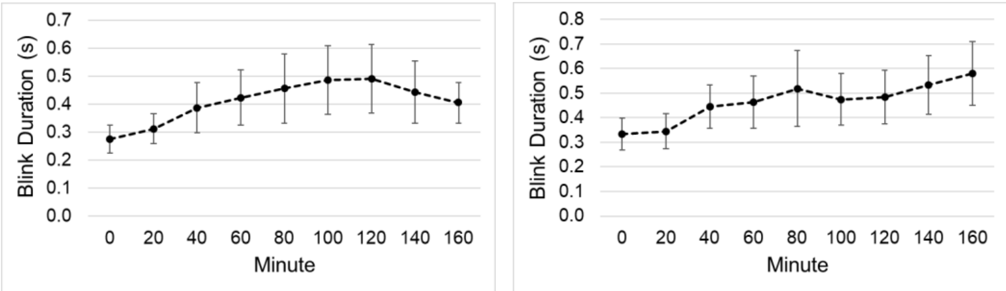
Figure 1 Changes in KSS scores throughout the first (a) and second trip (b)

3.1.2. Ocular parameters

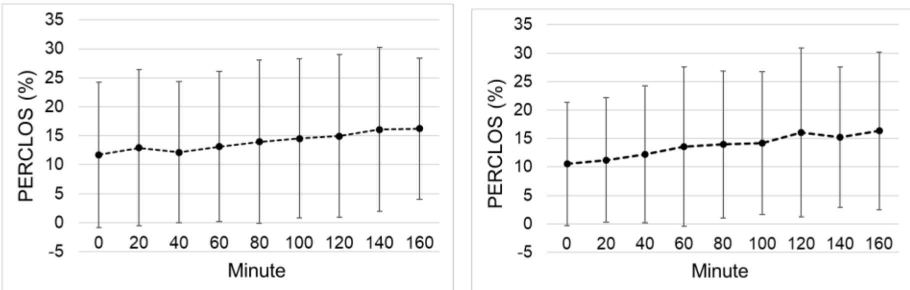
The first trip of the driving task was typically characterized by an increase in all ocular parameters ($p < 0.05$). Except for PERCLOS, all the other three parameters demonstrated peak values around 60 to 100 minutes, and subsequent significant ($p < 0.05$) reductions in eye-blink parameters toward the end of the task, resulting in somewhat inverted U-shaped curves (Figure 2). On the other hand, the second trip described in rather different patterns. The inverted U-shaped curves only applied to blink frequency and microsleep, while the blink duration and PERCLOS tended to consistently increase over time. Eye-blink duration seemed to be a parameter that could distinguish fatigue between the two trips. It is worthwhile to mention that the two trips were also discriminated by the initial (baseline) values, and when the parameter reached a certain value. Greater baseline values for the second trip were observed for the blink frequency and blink duration, whereas the opposite was true for the PERCLOS and microsleep. With respect to peak values, the blink frequency data showed maximal values at around 60- and 40-minute of driving times for the first and second trips, respectively. For this peak value, no differences were found for PERCLOS and microsleep. Note that substantial differences between the two trips were observed for blink duration, in which the end of the second trip was characterized by markedly greater duration ($p < 0.05$).



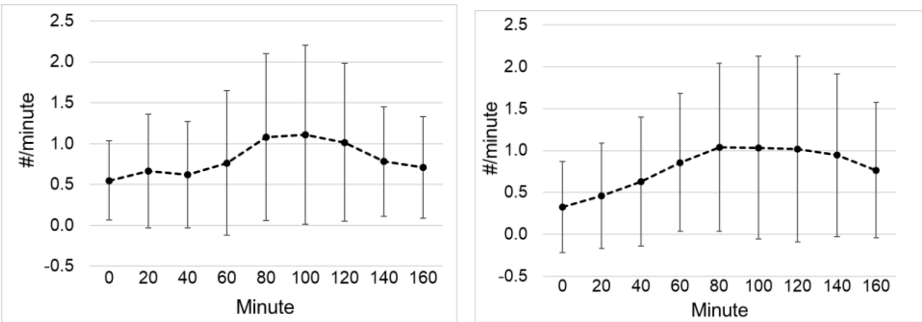
(a) Blink frequency



(b) Blink duration



(c) Percent eye closure (PERCLOS)



(d) Microsleep

Figure 2 Changes in ocular parameters as a function of driving duration. The figures on the left are for the first trip, while the ones on the right are for the second trip.

3.2. Discussion

This research was highly motivated by the fact that road crashes involving commercial drivers are fairly common in Indonesia. Current law only regulates the hours of service; but enforcement of such law is doubtful, even among public transportation companies. Though no in-depth studies addressing this concern are available, it is not uncommon for a commercial driver to work for 14-16 hours during their work shift. Informal observations among drivers operating shuttle services often demonstrate fatigue-related behavior, such as driving slowly in the right (passing) lane, speeding while at lower gears, singing incoherently, rolling down the window, rubbing the faces, or consuming candies frequently. All these symptoms clearly show behavioral responses to counter fatigue and sleepiness. Such phenomena certainly pose a safety risk, but this issue has been very rarely quantified and investigated. Several research findings pertain to fatigue and sleepiness have been reported in Indonesia (Zuraida and Abbas, 2020; Zuraida, Iridiastadi, and Sutalaksana, 2017; Puspasari *et al*., 2017, 2015; Muslim *et al*., 2015). These investigations, however, were conducted by utilizing driving simulators, with findings that could not directly be generalized within the field contexts. In contrast, this present study aimed at examining sleepiness as a result of prolonged driving duration experienced by commercial drivers.

For the driving activities investigated in this study, it was found that driving for about 2.5 hours clearly induced a moderate level of sleepiness, and an additional trip of the same duration resulted in excessive level of sleepiness. Moreover, following a driving duration of 2.5 hours with a rest period of 15 minutes was indeed not adequate. Lastly, fatigue and sleepiness were also characterized by relatively consistent changes in ocular indicators, particularly blink duration, and PERCLOS. These measures closely correlated to subjective reports of sleepiness. It should be noted that these findings were limited to only one task characteristic (task duration) and the fact that the drivers' age and gender were not examined, which could restrict generalization of the results.

3.2.1. Fatigue and time on task

Previous studies generally reported fatigue patterns that vary. It can be influenced by number of factors, including the indicators used, whether the experiment was conducted as a field study or a lab experiment, or the type of factors manipulated (e.g. sleep durations prior to the experiment). The work of Zuraida *et al*. (2019), for instance, shows the progression of sleepiness that tended to be linear. In contrast, Puspasari *et al*. (2019) found exponential patterns, particularly for drivers who did not receive enough sleep the night before. Mixed patterns of fatigue were also reported by Ingre *et al*. (2006). Participants who received an adequate amount of sleep at night were characterized by a fairly gradual increase of fatigue, whereas those who had to stay awake tended to be characterized by a sudden (exponential) increase of fatigue. This study further noted the presence of individual differences that should be taken into consideration when analyzing driving fatigue.

Patterns of fatigue have also been reported in studies examining the effects of fatigue during acute sleep deprivation (lasting 24 hours or more). Petrilli *et al*. (2005) examined subjects who undertook 24 hours of sustained wakefulness. Fatigue was evaluated by assessing changes in alertness as measured by psychomotor vigilance task (PVT) and visual analogue scale (VAS). Alertness tended to improve in the first couple of hours, but then generally (and gradually) worsened in the following hours. Substantial decrements in fatigue were found after 10 hours, and especially after 14 hours of wakefulness. Their study demonstrated that fatigue followed non-linear patterns, and inconsistent changes could be expected within the first few hours of wakefulness. In their study, Alvaro *et al*. (2016) found infrequent episodes of prolonged eyelid closure during the first 14 hours of sleep deprivation. A substantial increase of the measures was found after 17 hours of awake time. All these studies indicate that characterizing fatigue is rather difficult and strongly dependent upon the context being studied.

One of the major issues pertaining to fatigue resulted from long duration driving is how long a driver is allowed to drive continuously, before fatigue sets in and starts to impair driving performance. Furthermore, the amount of rest period following a driving task is often the subject of interest, considered as an intervention strategy to reduce the effects of fatigue. This study found that driving for about 2.5 hours resulted in moderate level of fatigue, and that a 15-minute rest period did not return fatigue measures to their baseline values. Previous studies have shown that 2 to 3 hours of driving (following a restful night sleep) generally do not yield excessive fatigue and sleepiness (Zuraida *et al.*, 2019; Puspasari *et al.*, 2018; Wang *et al.*, 2018; Di-Stasi *et al.*, 2012; Craig *et al.*, 2011). However, discrepancies do exist due to differences in experimental settings (field vs. simulator) and also due to inter-individual differences (Ingre *et al.*, 2006). The majority of investigations addressing fatigue from driving have been done by employing a simulator, which could potentially induce monotony that results in a greater feeling of fatigue. This issue, however, has not been widely and specifically addressed in previous investigations.

3.2.2. Degrees of fatigue

Findings from this and previous studies indicate that patterns of fatigue and sleepiness may not be consistent across experimental conditions. Except using subjective response such as KSS, it is probably difficult to categorize fatigue based on ocular measures. It is not clear, for example, what a 10% vs. 30% increase in blink durations really implies, or how we might draw a line between drowsy and awake/alert conditions using ocular measures. Except in a few studies (Dreißig *et al.*, 2020; Puspasari *et al.*, 2019), little has been done with respect to classifying the degrees of fatigue as a function of driving tasks.

The work of Puspasari *et al.* (2019) suggested the cut-off value of the blink duration and PERCLOS between alert vs. low-level fatigue vs. heavy fatigue conditions. However, it is also stated in the report that the practical implication of the cut-off value should be investigated further due to the small sample size of the study. An attempt to classify the driver's drowsiness state was also made by Dreißig *et al.* (2020), by developing a feature selection method based on the k-Nearest Neighbor algorithm. They utilized a large dataset of eye blink and head movements behaviours extracted from driving simulation experiments to train the machine learning model. Nonetheless, a validation of real-world data has not been conducted to confirm the model's robustness.

Schleicher *et al.* (2008) reviewed a variety of indicators and parameters that can be employed in assessing fatigue, ranging from the 'gold standard' electroencephalography (EEG) to measures of performance and subjective responses such as KSS. However, the degrees of fatigue could only be represented by a handful of measures, including self-rated responses, observer-rated facial behaviour, and microsleeps. An increase in only blink frequency could mean the presence of a low level of fatigue, while simultaneous changes in this measure and blink duration could be categorized as a severe level of fatigue. The subjective response is susceptible to biases, but it is considered as the best choice with respect to the ability in distinguishing the degrees of fatigue. Their study further noted blink duration (particularly microsleep) as a measure that correlates well with subjective responses. The work of Ingre *et al.* (2006) demonstrated similar findings, in that greater KSS scores were closely related to longer blink duration and poorer driving performance.

Using a simulator, Wang *et al.* (2018) investigated the effects of driving durations on oculomotor, driving performance, and subjective responses. Compared to baseline data, blink duration increased by about 23% after 2 hours of driving, and prolonged driving to 3 and 4 hours resulted in an increase of blink duration of nearly 115% and 190%, respectively. For each respected driving duration, their experiment showed blink frequency increases for about 3%, 16%, and 25%. Note that the peak level of subjective rating of sleepiness only reached about the mid-level of the Stanford Sleepiness Scale (SSS).

It should be noted, however, that levels of fatigue should not be evaluated solely on the basis of aggregate values, due to the presence of individual differences (Ingre *et al.*, 2006). Thus, comparisons of absolute data across different studies may not be adequate. During a 2-hour simulated driving task, data from Ingre *et al.* (2006) demonstrated that excessive

fatigue (resulting from sleep deprived condition) could result in an increase of blink duration that was twice as large as the baseline data. In a similar experiment, Puspasari *et al*. (2019) showed undue fatigue that was characterized by more than a five- to eight-fold increase in three oculomotor parameters (blink duration, PERCLOS, and microsleep).
This study clearly demonstrated that driving for about 2.5 hours only resulted in a moderate level of fatigue, but the 15 minutes of rest between driving tasks was not adequate. This result can be used by relevant stakeholders (e.g., the Ministry of Transportation or toll way operator) as a basis in determining work-rest schedules for car drivers. Relevant government regulations pertaining to this issue are available and can, thus, be modified based on the results of this (and other similar) studies.

3.2.3. Ocular indicators

This investigation demonstrated that all eyelid measurement parameters used could indeed be used for the purpose of fatigue evaluation during a prolonged driving task. Except for the final phase of the driving segments, these parameters consistently changed as a function of driving duration. Eyeblink duration and PERCLOS were found to be highly correlated with a subjective report of sleepiness (KSS), while the other two parameters (blink frequency and microsleep) were moderately correlated with KSS. Previous research generally agrees that different parameters of the eyeblink indicator could be used as an objective, non-invasive approach in the assessments of fatigue and drowsiness (Cori *et al*., 2019). Such an approach takes advantage over other subjective measures; it can be done continuously (via the use of a camera) without interfering with the driving task. The findings of this study are also in agreement with what Cori *et al*. (2019) have stated, that the use of blink duration and PERCLOS are two of the most robust parameters. At the moment, it is suggested that further investigations be carried out that study the performance of eyeblink indicators in various driving contexts found in the field. The availability of high-definition cameras and analysis software have allowed for real-time assessment of driver fatigue.

Furthermore, fatigue has often been dealt with the availability of technology that allows real-time interventions. The technology will provide a warning system (visual, auditory, or haptic) based on inputs in a form of ocular measures. A contribution of this study is that there are certain ocular parameters and criterion that can be employed with the use of technology as a means to minimize fatigue risks. It should be emphasized that blink duration was found to be a parameter with greatest association with subjective reports of sleepiness. Therefore, any fatigue detection technology that works based on blink duration profiles should have a certain degree of validity. The high correlation also means that different criteria (such as the onset of sleepiness) can be further established by following KSS classifications commonly reported in the literature.

4. Conclusions

It can be concluded here that driving for about 2.5 hours only induced a fairly moderate level of fatigue and sleepiness. However, the same amount of additional driving time was found to result in undue fatigue, despite the 15 minutes break provided following the first trip. The majority of eye-blink parameters also changed as a function of driving time, but blink duration was the only parameter that consistently increased throughout the driving task. This study suggests that shuttle companies should give more thoughtful attention to fatigue issues among their drivers and provide all the necessary precautions to mitigate fatigue risk. The findings of this study can also be used as a basis to evaluate driver rostering. It should be noted that further investigations are warranted, particularly the ones that examine the effects of rest periods between trips. Furthermore, it is certainly an interesting research issue if the onset of fatigue can be confidently determined, or if fatigue has become excessive that it interferes with driving performance. The development of drowsiness classification model is indeed an important requirement for the advancement of driver's fatigue detection technology.

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