Conference Paper

Visual Attention, Driving Behavior and Driving Performance among Young Drivers in Sleep-deprived Condition

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Abstract

Traffic accident is one of the main causes of death among young drivers, both in developed and developing country. Sleep deprivation is agreed to be one of the major contributing factors. In this study, we investigate the effect of sleep deprivation on visual attention during driving and how it contributes to driving behaviors and performance. Twelve male students (mean age = 21.6 years, SD = 0.6 years) who already had valid driving license participated in this study. They were required to drive on a driving simulator in two conditions: normal sleep and sleep-deprived condition. In normal sleep condition, participants were allowed to have a normal sleep for at least 8 h prior to having driving simulation session, whereas in sleep-deprived condition, participants performed simulated driving session after 24 h of continuous sleep deprivation. We found that visual attention, represented by fixation duration and number of fixation on Direct Sight, decreased during driving simulation in sleep deprivation condition. In addition, we observed performance deterioration in sleep deprivation condition.

Keywords: sleep deprivation, visual attention, driving behavior, driving performance

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1. Introduction

Traffic accident is one of the main cause of death of young people in the world [1]. Soehodho [2] further reported that young drivers of 20 to 30 years old have higher rate of traffic fatalities, especially in Indonesia. Driver sleepiness contributes to a considerable proportion of traffic accidents. Numerous studies have investigated the effects of sleep deprivation (SD) on various aspects of performance, including driving. There have been a number of studies reported that driving in SD condition results to an increase of traffic accident rate [3–7] and it is associated with impaired alertness and cognitive performance [8, 9]. Several cognitive function decrements such as decreased of alertness level [10] and failure of vigilant attention [11, 12] have been associated with traffic accidents during SD condition.

It has suggested that driving performance depends on visual attention during driving [13]; accurate visual scanning of the driving environment is of importance in determining driving performance. Loss in visual attention including a failure in detecting relevant driving events is reported as one of the main factors of traffic accidents [14]. Decrement in these cognitive functions in SD condition is believed to alter driving performance [15–18]. There have been a number of studies investigating how SD negatively affects driving performance [15–18] and how lack of visual attention results in traffic accidents [13, 14]. However, to the authors' knowledge, there are relatively few studies examining the relationships among SD, visual attention and driving performance.

In this study, we investigated the visual attention, driving behavior and driving performance of young drivers in SD condition. We conducted a driving simulator study instead of on-road study considering the safety and ethical issues. An on-road study investigating the effect of SD may yield some safety and ethical issues. It would also be difficult to control the experimental study. Therefore, driving simulator is an option to conduct an experimental study on the effect of SD during driving as it has been suggested that driving simulator can generate driving conditions that is nearly similar to on-road study [17, 19]. An eye tracking device was used to measure participant fixations and to determine how drivers' attention was allocated. We hypothesized that the impairments of driving behavior and driving performance in SD condition is mediated, at least in part, by reduction of visual attention during driving.

2. Methods

2.1. Participants

We recruited twelve healthy undergraduate and postgraduate students aged between 20 and 24 years (mean age = 21.6 years, SD = 0.6 years), to participate in this study. They had their valid driving license for a minimum of two years (mean = 3.9 years, SD = 0.9 years). They were non-shift workers, free from sleep disorders in the last three months and had no medication. Prior to participating in this study, the experiment procedures were explained to the participants and the consent was obtained prior to the participation of the protocol. Experiment protocols used in this study conformed the guidelines contained within the Declaration of Helsinki and has received approval from local ethic committee.

2.2. Apparatus and materials

Driving simulation software used in this study was City Car Driving version 1.5 (Multi Soft Corp., Russia) run on a personal computer with AMD FX^{TM} –4100 Quad-core 3.6 GHz processor, 4 GB RAM, AMD NVidia GForece graphic cards with 1 GB memory and windows 7 Professional 64-bit operating system. The dynamic environment was presented on a 32" LCD monitor (Toshiba TV Screen, resolution 1366 x 768 pixels). Logitech driving force with manual transmission (Logitech G27) was used to simulate the steering wheel, clutch, and pedal. Similar routes, including urban, suburban, and highway driving, were chosen and used for all experiment sessions.

GP3 Gazepoint eye tracker (Gazepoint, Research Inc., Canada) was installed about 10 cm in front of the monitor and was placed 70 cm in front of participant's eyes. During the process of driving simulation and eye movement recording, each participant was asked not to move their heads during the process of driving to avoid error in gaze estimation.

2.3. Experiment procedures

Two days prior to the main experiments, participants had a familiarization session on driving simulator with urban scenario. The familiarization session took approximately 15 min or until the participants were able to drive using driving simulator with less errors. In the day prior to the experiment, they were instructed to sleep regularly the night before the experiment days. Participants were required to sleep for at least 8:00 h before the test days, going to bed no later than midnight and getting up no later than 09:00 hours. No nap was allowed on the day prior to the driving test. Participants were also asked to abstain from caffeinated beverages consumption before the test.

On the experiment day, participants arrived at the laboratory around 9:00 p.m. For normal sleep (NS) condition, participants were then asked to have normal sleep in a sleeping chamber for approximately 8:00 h before attending the driving simulation session. For the sleep-deprived (SD) condition, they were asked to keep awake at night

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before attending the experiment session from their arrival to the laboratory until the driving simulation session in the morning.

In the driving simulation session, participants were asked to drive a 10-min predetermined route with 60 km/h of maximum speed and were instructed to obey the traffic law throughout the driving simulation session for each driving condition. The starting point and the final points were similar for all the two experiment conditions. The routes incorporated a 2-lane urban road with 50 percent traffic density that include traffic lights, intersection, left and right turn, etc. Participants might encounter different driving situations throughout the routes due to the dynamic nature of driving simulation; some participants might have a green light while other might encounter a red light and must stop at the same intersection.

2.4. Measurements

The measurements included subjective sleepiness, visual attention, driving performance and driving behavior. A 9-points of Karolinska Sleepiness Scale (KSS) [20] was used to measure subjective sleepiness prior to starting the driving simulation session. The KSS scales were translated in Indonesian [21] to avoid bias during assessment.

Visual attention was measured in term of participants' eye movements during driving. Eye movements were recorded by using eye tracking sensor (Gazepoint, Research Inc., Canada) with 60Hz sampling rate and 0.5° to 1.0° spatial accuracy. Prior to starting the driving simulation session, participants were seated in front of the eye tracking sensor to permit data collection. Once they aligned with the monitor screen, the calibration process started. This calibration entails a visual target that moves around the screen. The target consists of a calibration grid with 9 positions. The target consists of calibration bullet points that appeared one after the other in the same order for all participants, starting from the top left corner. Participants were required to follow this target with their gaze for a period of time. Participants' gazes were recorded throughout the driving simulation session and analyzed using Gazepoint Analysis Software v2.12.1.

Driving behavior was scored with a four-categorical scale, as suggested in Di Stasi et al. [22]: 1 = safe behavior (no accidents, avoided (no accidents, avoided hazards without hard braking or coming too near, followed the speed limits), 2 = precaution behavior (did not follow the speed limit, applied the brakes hard, came near other vehicles), 3 = hazardous behavior (hard breaking near other vehicles) and 4 = accident [22]. Driving performance measure in this study was measured from the simulator's

Figure 1: Area of Interest (AOIs) analyzed to investigate visual attention of participants during driving simulation.

automatic log that were automatically logged and summarized in the driving simulator. The logged data include the average driving speed and number of driving errors due to traffic rules violation (TR).

2.5. Data analysis

Data are presented in mean ± standard deviation. Two eye movement measures are reported, number of fixations and mean average of fixation duration (in %). To examine when key proportions of the visual display were fixated, an area of interest (AOI) analysis was perform. The driving scene was divided into five AOIs as shown in the Fig 1: (1) Direct sight; (2) Right mirror; (3) Upper mirror; (4) Lower speedometer; and (5) Upper speedometer. The main focus of statistical analysis was Direct sight AOI that signifies the dominant viewing area of the driver, that is, showing the main road area, cars, and pedestrians as suggested by Mackenzie and Harris [23]. Prior to performing statistical analysis, data were tested for normal distribution using the Kolmogorov–Smirnov test. A paired *t*-test was performed to investigate mean difference between two conditions for normally distributed data. A Wilcoxon signed-rank test was performed for categorical data obtained from manual observation (risky driving behavior) or when the assumption of normal distribution data was violated. Significant level was established at $P < 0.05$. All statistical analysis was performed using R Statistical Software (version 2.14.0; R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Subjective sleepiness

Paired *t*-test on subjective sleepiness showed statistically difference between SD condition and NS condition ($P < 0.01$). SD condition resulted in significantly higher subjective sleepiness score (KSS score = 7.25±0.1) than in NS condition (KSS score = 2.41±0.07).

3.2. Visual attention

Table 1 depicts the number of fixations and mean average of fixation duration (in %) in SD and NS conditions. Based on the AOI analysis, we found that almost all participants directed their gaze to Direct Sight AOI in both conditions. Statistical analysis revealed significant differences between SD and NS in the number of eye fixation ($P = 0.003$) and mean average of eye fixation duration ($P = 0.04$) for Direct Sight AOI. These show that participants paid more attention on Direct Sight AOI during driving simulation in NS condition than in SD condition. There were no significant differences between NS and SD condition for the other AOIs, except for the mean average fixation duration for Upper Mirror AOI ($P = 0.04$).

Table 1: Average eye fixation duration (%) and eye fixation number (#) for all AOIs.

	Fixation Duration (%)		Fixation Number (#)	
AOI	**Normal Sleep (NS)**	**Sleep Deprivation (SD)**	**Normal Sleep (NS)**	**Sleep Deprivation (SD)**
Direct Sight	44.5 ± 3.5	37.2 ± 2.1*	964 ± 79	754 ± 43**
Right Mirror	0.5 ± 0.1	0.48 ± 0.11	17 ± 4	14 ± 3
Upper Mirror	0.9 ± 0.23	0.5 ± 0.1*	54 ± 11	31 ± 7
Lower Speedometer	2.1 ± 0.8	1.4 ± 0.5	50 ± 17	37 ± 10
Upper Mirror	1.2 ± 0.4	1.1 ± 0.3	42 ± 17	26 ± 6

Note: * *shows significant difference between NS and SD at $P < 0.05$*; ** shows significant difference between NS and SD at $P < 0.01$.

3.3. Driving performance

The mean and standard deviation of driving performance and driving behavior are shown in Table 2. It reveals that, on average, participants drove their vehicle during driving simulation faster in SD condition than in NS condition (P = 0.003). Consistently, participants also produced more driving errors in SD condition than NS condition (P = 0.004). Statistical analysis on risky driving behavior score showed significant difference between the two conditions. Risky driving behavior score was significantly higher in SD condition, as compared to the NS condition ($P < 0.001$).

Table 2: Driving performance measures.

	Normal Sleep (NS)	Sleep deprivation (SD)
Driving Speed (km/h)	39.04 ± 3.9 km/h	45.7 ± 5.6 km/h**
Driving Errors (#)	6.3 ± 1.0	18.3 ± 3.3**
Driving Behavior	1.8 ± 0.2	3.8 ± 0.3**

3.4. Correlation analysis

Correlation analysis showed that subjective sleepiness (KSS score) negatively correlated with mean average fixation duration (r = −0.32; P = 0.07), and number of fixation (r = −0.38; P = 0.04) on Direct Sight AOI. In contrary, KSS score showed positive correlation driving behavior (r = 0.78; $P < 0.01$). In addition, there were also moderate correlations between average eye fixation duration and driving behavior score (r = −0.33; P = 0.06) and between eye fixation number and driving behavior score (r = −0.41; P = 0.03), indicating that driving behavior score increased when eye fixation on Direct Sight AOI decreased.

4. Discussion

A number of studies have reported that sleep deprivation is associated with increased accident risk and driving impairment. In this study, we investigated the effect of sleep deprivation on visual attention and driving performance and behavior of young drivers. Driving performance was significantly impaired during driving after one night of sleep deprivation. We found that the number of driving errors and driving behavior significantly increased during driving simulation in the morning with sleep-deprived condition.

We used eye tracking device to evaluate visual attention during driving simulation in sleep-deprived condition. Eye movements (eye fixation number and duration) on certain area of interest (Direct Sight, Mirror, etc.) were used as the behavioral aspect of visual attention. It has been noted that sleep deprivation results in decreased oculomotor function [24] which impairs visual search performance [25]. In this study, we found evidences of impairment of visual attention in sleep-deprived condition. Total time spent on fixations has shown noticeable difference between sleep-deprived and fresh states. The average eye fixation duration on Direct Sight AOI has noticeably dropped in sleep-deprived condition. These results are in agreement with Wibirama et al. [28] findings reporting a reduction on average viewing time for Direct Sight AOI during driving simulation in the morning with sleep deprivation condition. These findings indicated that participants in this study might not be able to pay enough attention to the driving environment in sleep-deprived condition and they might not develop complete and accurate knowledge of driving states.

Many studies reported how lack of visual attention results in traffic accidents [13, 14]. Correlation analysis showed that average eye fixation duration and eye fixation number negatively correlated to driving behavior score. These findings suggest that impairments of driving behavior and driving performance of young drivers in sleep deprivation condition is mediated, at least in part, by reduction of visual attention during driving.

5. Conclusion

We were able to confirm our hypothesis in this study. This study revealed negative effects of sleep deprivation on visual attention and driving performance. Driving in the morning with sleep-deprived condition leads to a poor driving performance. Impairment of driving performance in sleep-deprived condition is mediated by reduction of visual attention during driving.

Conflict of Interest

The Authors declare that they have no competing interest.

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