The Effects of Sleep Quality on Vigilance and Driving Performance in a Train Simulator

D Siswanto\textsuperscript{1,2}, H Iridiastadi\textsuperscript{1,3} and K Muslim\textsuperscript{1,4}

\textsuperscript{1}Institut Teknologi Bandung, Jl. Tamansari 64, Bandung, Indonesia
\textsuperscript{2}hainiel@gmail.com, \textsuperscript{3}hiridias@vt.edu, \textsuperscript{4}kmuslim@ti.itb.ac.id

Abstract. Train driving activity requires high vigilance to prevent human errors that can lead to accidents. One factor mentioned to reduce vigilance is poor sleep quality. But so far, not many studies have proven the effect of sleep quality on vigilance. Previous researches did not clearly conclude this effect. In addition to being vigilant, sleep quality is also thought to effect driving performance because of the close relationship between vigilance and driving performance. Based on those backgrounds, this study aimed to prove the effects of sleep quality on vigilance and driving performance through experiments in a train simulator under monotonous condition, which in some studies is also proved to reduce vigilance. This study involved eight male subjects who experienced two good and poor sleep quality treatments. Through vigilance measurements with Psychomotor Vigilance Task (PVT) and electroencephalograph (EEG) using Multivariate Analysis of Variance (MANOVA) with significant value 0.05, it showed that there were effects of sleep quality on mean reaction times, minor lapses, mean relative band powers for theta, and speeding simultaneously (p-value = 0.015). The results of paired sample t-tests also showed the effects of monotonous driving conditions that affect mean reaction times (p-value = 0.01 on good sleep quality; p-value = 0.000 on poor sleep quality) and minor lapse (p-value = 0.000 on good sleep quality, p-value = 0.045 on poor sleep quality) at the beginning and the end of the experiment. From this study, it can be concluded that the quality of sleep affects vigilance and driving performance, so that poor sleep quality decreases vigilance.

Keywords: vigilance, sleep quality, monotonous, Psychomotor Vigilance Task, electroencephalograph

1. INTRODUCTION

Vigilance becomes an important factor in train driving that tends to be a repetitive task, tedious task with high risk but low level of control [1, 2]. It is described as a cognitive process related to a person’s ability to maintain sustained attention for capturing signals over a prolonged period [3]. Vigilance is a combination of alertness and attention [4]. Vigilance decrement causes a slowdown in cognitive function and increases reaction time which can cause human errors while working [5]. Because train driving is considered to be a high-risk job [2], errors made while driving can lead to accidents. Train accidents have a more serious impact and incur very high costs even though their frequency is lower than road traffic accidents [6, 7]. Investigations on 23 train accidents in Australia found that 65% of accidents were caused by a slip in attention [8].

Driving is basically a vigilance task that requires psychomotor reactions and is very sensitive to fatigue, so vigilance decrement is often used as an indicator to detect fatigue [9]. Vigilance decrement is also expressed as a result of the influence of sleepiness [10]. Because driving is a picture of changes
in vigilance, individuals who perform poorly on the vigilance test will also perform poorly when driving, especially in monotonous conditions [4]. Decreased alertness due to fatigue illustrates the reduced ability of individuals to drive because they are no longer able to maintain the sustained attention needed when driving [11, 12]. Low cognitive workload when driving a train and repetitive tasks lead to work monotony that can trigger a decrease in train driving awareness [13].

Sleep-related factors are often called as causes of fatigue which will reduce vigilance and work performance [14]. Prolonged wakefulness or sleep deprivation causes slowing of responses (errors of omission) and errors of response when there is no stimulus (errors of commission) [15]. Decreasing number of lapses (reaction time greater than 500 milliseconds) is also stated to be sensitive to the effect of sleep deprivation in healthy subjects [5]. Sleep deprivation is also stated to worsen cognitive performance such as vigilance, working memory, long-term memory and decision making [16]. In individuals who experience chronic sleep deprivation (sleep duration of 3 hours per night for 7 consecutive nights) there is also a decrease in mean reaction times and increased lapses [17].

Aside from sleep deprivation, poor sleep quality also affects performance when driving a train [18]. Sleep disorders or poor sleep quality is reported to be a cause of vigilance (sustained attention) decrement in 1266 train drivers in Belgium [2]. Investigations conducted on 30 train drivers at PT. Indonesian Railroad (KAI) DAOP II Bandung also showed 73.33% of drivers experienced poor sleep quality which made them sleepy while on duty [19]. A study on hospital nurses reported problems of reduced attention and increased errors when sleep quality deteriorated [20]. Poor sleep quality has also been associated with an increase in human errors committed by train drivers through a study of 4634 train drivers in South Korea [21]. Accumulation of exposure to the work environment with high demand but low levels of control (high strain) was associated with poor sleep quality and increased fatigue [1]. The characteristics of these high strains were found in train driving that has high responsibility and demands to be vigilant even in monotonous conditions or low level of control [2, 13]. So far, not many studies have shown an association between vigilance and sleep quality. Researches that have been done related to the association between vigilance and sleep quality have not given any conclusive results. One study proved that poor sleep quality decreases vigilance [22] while another study stated that vigilance alteration was not sensitive to sleep quality [23]. However, the results of the study [2] hinted at the importance of conducting studies on the effect of sleep quality on vigilance because it was reported to be the cause of decreased vigilance for most train drivers.

Poor driving performance due to fatigue closely related to accident risk [14]. This decrease in performance is associated with a decrease in vigilance as a sign of increased fatigue [27]. A decline in performance can also be seen from the failure or slowdown in responding to stimulus [28]. Furthermore, drivers who subjectively assess their quality of sleep as poorly, have a higher risk of an accident while driving [14].

The purpose of this study was to investigate the effects of sleep quality on vigilance and performance while driving a train simulator. The use of simulators is based on safety, cost, and convenience reasons [24, 25] and the ability to measure performance accurately [26]. From the results of this study, it was expected that the effects of sleep quality on vigilance and the relationship between vigilance alteration and train driving performance can be concluded.

2. METHODS
This study involved 8 subjects (male, 21-25 years), each undergoing two experimental treatments, namely good and poor sleep quality. The indicator used to assess sleep quality was the value of sleep efficiency. Sleep efficiency values greater than 85% (SE ≥ 85%) were categorized as good sleep quality, while sleep efficiency values less than 85% (SE < 85%) were categorized as poor sleep quality [29]. Sleep efficiency was calculated as a comparison between total sleep time (TST) and the duration of the sleep episode (DSE) [30]. TST shows the length of time someone slept, while DSE shows the duration from the attempt to sleep (sleep onset latency) to the last wake without trying to fall asleep again (final awakening). In this study, DSE lasted 8 hours and TST measurements were performed with Fitbit Charge 2.
Psychomotor Vigilance Task (PVT) was used to measure alertness in this study. Vigilance test was performed with PC-PVT 2.0 with 5 minutes' duration [31]. PC-PVT was a development of PVT-192 which has become the gold standard. The advantages of PC-PVT were that it is easy to use, testing and analysis integrated in one system so that it minimizes the possibility of loss of data due to the process of transferring data from the device to the computer, the test results can be directly seen after testing, and simple data storage [31]. Parameters of PVT used as indicators of vigilance were mean reaction times and minor lapses (number of responses with reaction time greater than 500 milliseconds). PVT was carried out at the beginning and the end of the experiment with a train simulator. While driving a train simulator, vigilance is measured by electroencephalograph (EEG). The use of EEG to measure vigilance by reason of changes in brain waves can be an indicator of changes in vigilance [32]. The measured brain waves were theta (4-7 Hz) which is a sensitive measure to represent vigilance alteration because when power theta rises, vigilance decreases [33]. The EEG used in this study was Muse EEG 2, produced by InteraXon Inc., Toronto, Canada, and sold commercially (https://choosemuse.com).

The train simulator that was used was RailDriver Desktop Train Cab Controller (model RD-91-MDT-R) which was designed by PI Engineering USA with dimensions of 34 cm x 18 cm x 10 cm and weighs 2.5 kg. Each subject runs the train simulator for 120 minutes in a monotonous condition where the train did not stop from the first station to the end. Driving performance measured by the amount of speeding generated from the Train Simulator 2017. Speeding is the condition when the train’s speed exceeds the allowable limit.

3. RESULTS AND DISCUSSIONS

Each subject experienced treatments of good and poor sleep quality. Good sleep quality is sleep continuity or uninterrupted sleep [34]. From this definition, for poor sleep quality, subjects were disturbed by waking up the subject every 2 hours. Sleep efficiency was calculated as a comparison between total sleep time (TST) and duration of the sleep episode (DSE) [30]. Sleep efficiency greater than 85% (SE ≥ 85%) categorized as good sleep quality and sleep efficiency less than 85% (SE < 85%) categorized as poor sleep quality [29]. The results of sleep efficiency for all subjects showed an average sleep efficiency of 91.82 ± 3.32% for good sleep quality and 74.74 ± 3.68% for poor sleep quality.

Vigilance measurement of each subject was carried out with PC-PVT 2.0 with a duration of 5 minutes at the beginning and at the end of the experiment. The 5-minute duration was chosen because it was not too short and has been validated to replace the PVT test duration for 10 minutes which is considered to be too long [35]. The results of the vigilance measurement with PC-PVT 2.0 can be seen in Table 1. Table 1 shows that mean reaction times and minor lapses were worse in poor sleep quality. Measurements at the end of the experiment (finish) also show a decrease in alertness that can be seen from the increase in mean reaction times and minor lapses. This indicates the hypothesis that there was a monotonous effect on alertness.

Table 1. Vigilance measurement results with PC-PVT 2.0

| Sleep Quality | Period | Reaction Times (min) | Minor lapses |
|---------------|--------|----------------------|---------------|
|               |        | Mean | SD    | Mean | SD   |
| Good          | Start  | 296.83 | 35.24 | 2.00 | 0.76 |
|               | Finish | 355.25 | 27.20 | 3.88 | 1.13 |
| Poor          | Start  | 366.73 | 74.26 | 2.88 | 1.73 |
|               | Finish | 389.27 | 57.09 | 5.75 | 1.83 |

Vigilance measurements were also carried out by the Muse EEG while subjects run the simulator. The Muse EEG produces absolute band powers data for theta (θ) which is then converted to relative band powers for theta [36]. Measurement of vigilance with the Muse EEG only done in the frontal lobe because vigilance was associated with the work of the frontal lobe [33]. Driving performance in a train simulator was measured by the amount of speeding, which is the violation of the speed limit. In the
condition of good sleep quality, the average number of speeding was 12.75 ± 3.41. In poor sleep quality, the average number of speeding has almost doubled (23.88 ± 3.83). This indicates the effects of sleep quality on driving performance.

The effects of sleep quality on vigilance and driving performance were tested by Multivariate Analysis of Variance (MANOVA). The dependent variables involved were mean reaction times and minor lapses of the PC-PVT, mean relative band powers for theta, and the average number of speeding on the train simulator. The MANOVA test results can be seen in Table 2. The method used for the MANOVA test was Wilk’s Lambda with a significance level (α) of 0.05. Testing was done with SPSS software. Based on the MANOVA test results, it was concluded that sleep quality simultaneously affected mean reaction times, minor lapses, the average of relative band powers for theta, and the average amount of speeding. The results of the EEG measurements while driving (Fig. 1) also showed the relative band powers for theta that were higher in poor sleep quality than in good sleep quality. This result was consistent with previous research which stated that when vigilance decreases, theta power increases [33].

While running the train simulator, subjects got monotonous driving conditions. To analyze the effects of monotonous driving conditions on vigilance, a paired sample t-test was performed on the results of the PC-PVT 2.0 test for the beginning and end of the experiment. Paired sample t-test results for mean reaction times and minor lapses with a significance level (α) of 0.05 can be seen in Table 3 through 6.

Paired sample t-test results showed that there were differences for mean reaction times and minor lapses at the beginning and the end of the driving experiment with the train simulator under monotonous conditions in all conditions of sleep quality. This showed the effects of monotonous conditions that cause vigilance decrement while driving. As can be seen from Table 1, there was vigilance decrement as indicated by increasing mean reaction times and minor lapses both in conditions of good and bad sleep quality.

### Table 2. MANOVA test result

| Multivariate<sup>a,b</sup> | Within Subjects Effect | Value | F    | Hypothesis df | Error df | Sig. |
|---------------------------|------------------------|-------|------|---------------|----------|------|
| Sleep Quality             | Wilk’s Lambda          | 0.028 | 21.088<sup>c</sup> | 5.000 | 3.000 | 0.015 |

a. Design: Intercept  
  Within Subjects Design: Sleep Quality  
b. Tests are based on average variables.  
c. Exact statistic

![Figure 1. Relative band powers for theta while driving the train simulator](image-url)
Table 3. Paired sample t-test for mean reaction times on good sleep quality

| Paired Samples Test (Mean reaction times) | Paired Differences | 95% Confidence Interval of the Difference |
|------------------------------------------|--------------------|------------------------------------------|
| Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Start-Finish (Good) | -33.157 | 26.927 | 9.520 | -55.668 | -10.646 | -3.483 | 7 | 0.010 |

Table 4. Paired sample t-test for mean reaction times on poor sleep quality

| Paired Samples Test (Mean reaction times) | Paired Differences | 95% Confidence Interval of the Difference |
|------------------------------------------|--------------------|------------------------------------------|
| Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Start-Finish (Poor) | -58.417 | 20.127 | 7.116 | -75.244 | -41.590 | -8.209 | 7 | 0.000 |

Table 5. Paired sample t-test for minor lapses on good sleep quality

| Paired Samples Test (Minor lapses) | Paired Differences | 95% Confidence Interval of the Difference |
|------------------------------------|--------------------|------------------------------------------|
| Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Start-Finish (Good) | -3.375 | 1.408 | 0.498 | -4.552 | -2.198 | -6.780 | 7 | 0.000 |

Table 6. Paired sample t-test for minor lapses on poor sleep quality

| Paired Samples Test (Minor lapses) | Paired Differences | 95% Confidence Interval of the Difference |
|------------------------------------|--------------------|------------------------------------------|
| Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Start-Finish (Poor) | -4.250 | 5.203 | 1.840 | -8.600 | 0.099 | -2.310 | 7 | 0.045 |

4. CONCLUSIONS
The results of the study concluded the effects of sleep quality on vigilance, as measured by PC-PVT 2.0 (mean reaction times and minor lapses) and EEG (relative band powers theta). Poor sleep quality worsens the vigilance needed when driving a train. Sleep quality also affects the driving performance (speeding) in the simulator. Monotonous driving condition also proved its effects shown by decreasing vigilance while driving. This is evidenced by a significant increase in mean reaction times and minor lapses from the beginning to the end of driving.
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