The Effect of Split Sleep on Fatigue Based on the Ocular Indicator: A Train Simulator Study

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Abstract

Fatigue was identified as a contributing factor to accidents in the rail sector. Fatigue can be caused by a lack of quantity and poor quality of sleep due to split sleep. Split sleep is common in train operations because of the limited rest time. At that time, train drivers had to sleep, pray, contact family, and commute. This study aims to examine the effect of split sleep on driving fatigue. Fatigue was measured based on the blink duration and frequency through an eye tracker and subjective questionnaires, Karolinska Sleepiness Scale (KSS) and Visual Analogue Scale (VAS). Nine participants underwent two sleep conditions, namely split sleep and consolidated sleep. Split sleep divides sleep into two segments at 05.00–10.00 and 12.00–15.00. Meanwhile, consolidated sleep is carried out continuously at 05.00–13.00. Participants were asked to drive a train simulator for 2.5 hours in the laboratory after each sleep state was executed. From this study, it was concluded that there were significant differences in the conditions of split sleep and consolidated sleep. This is caused by increased fatigue based on the blink duration and frequency. However, the KSS and VAS data did not show any difference between the two sleep conditions. Therefore, split sleep can be carried out if needed by maintaining the quality and duration of sleep. Improving sleep quality and fulfilling adequate sleep duration (7–8 hours) is carried out as a mitigation strategy to reduce the effect of fatigue due to split sleep. In addition, comfortable lodging in train station can support improving the quality and fulfillment of sleep duration.

Keywords
Fatigue, train driver, split sleep, blink and simulator.

1. Introduction
1.1 Background
Fatigue has been identified as a contributing factor to accidents, injuries, and death under various conditions (Williamson et al., 2011). These conditions include the field of transportation where fatigue is an important issue for safety (Dawson et al., 2014). Gander et al. (2011) define fatigue as the inability to function in desired conditions. This is due to a lack of rest from previous work and activities. Meanwhile, Dawson et al. (2014) define fatigue as sleepiness that drives a person to sleep. Fatigue has a strong relationship with an increased risk of accidents (Williamson, et al., 2011). In fact, fatigue is recognized internationally as a fundamental safety issue in the rail sector (Dorrian et al., 2006). Train accidents caused by fatigue are included in factors related to humans which is train driver. Iridiastadi and Ikatrinasari (2012) investigated 72 factors that are closely related to train accidents in Indonesia. The results showed that the biggest cause of accidents is 'preconditions for unsafe acts'. Preconditions for unsafe acts include boredom felt by train drivers due to delayed schedule and fatigue before work. In addition, the report found the train drivers were sleepy and asleep before the accidents occurred.

In driving activities, sleep is one of the factors that is closely related to fatigue. Sleep deprivation, sleep restriction, and sleep disturbances can cause fatigue (May and Baldwin, 2009). Many studies have concluded that sleep restriction and sleep deprivation contribute to fatigue leading to incidents (Williamson et al., 2011). Kwon et al. (2019) also state that limited sleep duration and poor sleep quality can increase the risk of fatigue. Fatigue related to sleep is an issue that occurs in the railway sector in Indonesia. Train drivers do not get optimal sleep duration because they have to drive for a long time. For example, in the operation of a freight train, the travel time of a train can reach 4-5 hours under normal circumstances. In fact, the journey can take up to 8 hours due to the queues on the train tracks. On the other hand, train drivers have limited rest time due to commuting time. As a result, train drivers are forced to cut their rest (sleep) time to support other activities, such as worship, family needs, and commuting (Iridiastadi, 2021).

Split sleep (SS) is the occurrence of sleep from two to three times in a 24-hour period (Belenky et al., 2014). Meanwhile, consolidated sleep (CS) is carried out continuously in one segment within a 24-hour period. Split sleep is common in several industries, including transportation (Jackson et al., 2014). For example, the maritime workers mentioned in Short et al. (2016) have implemented shifts that provide opportunities for split sleep. On the other hand, research by Riedy et al. (2020) shows that railroad workers usually take naps as extra sleep time. In addition, the fatigue model used by Riedy et al. (2020) predicts that railroad workers, including drivers, tend to do split sleep compared to consolidated sleep. Research by Jackson et al. (2014) showed no difference in sleepiness between split sleep and consolidated sleep. However, split sleep can result in a worse mood and a less positive impact on the work environment. On the other hand, Short et al. (2016) mention that split sleep has no effect on performance, although sleep duration will be reduced compared to consolidated sleep. Zhou et al. (2015) stated that workers who underwent split sleep get sleepy easily, although their work performance remained good. However, split sleep can cause accidents related to fatigue (Williamson et al., 2011).

Fatigue due to the effect of split sleep can be assessed using a behavioral-based measures approach, such as eye blink (Sahayadhas et al., 2012). Blink which includes blink duration, blink rate, and the interval between blinks is often associated with changes in sleepiness (fatigue) (Anderson et al., 2013). Blink has been shown to predict fatigue (Cori et al, 2019). In addition, blink is commonly used to monitor fatigue in the transportation industry (Cori et al., 2019). Schleicher et al. (2008) also mentioned that the best indicator to evaluate fatigue is the blink duration and frequency. Blink duration is the total time when eye starts closing (closing), closing (closed), until eye reopening (Cori et al., 2019). Blink duration has been shown to be the most consistent parameter in subjective and objective measurements of sleep-related driving disorders (Mulhall et al., 2020). The research by Puspasari et al. (2019) also concluded that blink duration and microsleep (blink duration >500 ms) is the most sensitive parameter to detect fatigue. Meanwhile, the blink frequency is defined as the blink rate in a specific time window, usually 1 minute (Cori et al., 2019). Blink frequency changes with reduced attention and the occurrence of microsleep (Abe et al., 2011). In conditions of mild fatigue, there is an increase in the blink frequency followed by an increase in the blink duration in severe fatigue (Schleicher et al., 2008).

The blink parameter is ideal for measuring sleepiness (fatigue) because it is objective, non-intrusive, and can be recorded continuously during activity (Cori et al., 2019). Blink as an objective measure of fatigue needs to be detected through easy-to-use technology, such as eye tracking. Eye tracking technology can be used through a measuring device called an eye tracker. The eye tracker detects eye movement via infrared and the subject's gaze. Eye tracker can be used to evaluate train driver fatigue, especially in monotonous conditions (Xu et al., 2018). The research by Puspasari et al. (2019) also used an eye tracker to evaluate fatigue while driving a simulator in a laboratory. Driving simulators in laboratories are used due to time efficiency, minimal costs, and safety factors.

In addition to measuring fatigue objectively, fatigue can also be measured based on subjective assessments using the Karolinska Sleepiness Scale (KSS) and Visual Analogue Scale (VAS). The KSS questionnaire consists of nine Likert scales with a scale of 1 indicating a very alert state and a scale of 9 indicating a very sleepy state (Akerstedt et al., 2010). Meanwhile, the VAS uses an analog scale with the left end indicating not sleepy and the right end indicating sleepiness (Kaida et al., 2006).

In conclusion, split sleep is a common phenomenon that occurs in the railway sector. Train drivers are forced to split their sleep time to do other activities due to limited rest time and an uncertain work schedule. Split sleep can cause fatigue while driving and further can lead to accidents. However, research on the effect of split sleep on fatigue in Indonesia is still limited. Indonesian Railways Company Management feels the need for a study related to the effect of split sleep on driving fatigue. Therefore, this study was conducted to examine the effect of split sleep on the level of fatigue while driving a train based on the blink of eyes, KSS value, and VAS. The results of the study are expected to help Indonesian Railways Company Management to design mitigation strategies that can reduce the risk of fatigue due to split sleep.

1.2 Objectives
The purpose of this study was to examine the effect of split sleep on fatigue levels based on the blink while driving a train simulator.

2. Literature Review
Fatigue is the result of lack of sleep, circadian rhythm, workload, and sleep restriction (May and Baldwin, 2009). In addition, fatigue is the urge to rest with the aim of recovering energy (Williamson et al., 2011). Dawson et al. (2014) define fatigue as sleepiness that drives a person to sleep. Fatigue causes workers to tend to produce poor performance and unsafe actions (Williamson et al., 2011). The results of the research by Dorrian et al. (2006) observed a close relationship between fatigue and driving performance. Fatigue is one of the causes of accidents at work and has a very strong relationship with an increased risk of accidents (Williamson et al., 2011).

May and Baldwin (2009) state that there are two types of driver fatigue, sleep-related (SR) and task-related (TR). SR fatigue can be caused by circadian rhythms, sleep deprivation, and sleep restriction. TR fatigue is caused based on driving characteristics, such as duration and driving environment. According to May and Baldwin (2009), fatigue related to sleep is caused by time of day, sleep deprivation, and sleep restriction. Time of day relates to the circadian rhythm in the human body where the body has time to sleep and work. The circadian rhythm is a 24-hour pattern consisting of sleep and wake states. Circadian rhythms encourage humans to sleep at night and awake during the day (May and Baldwin, 2009). Williamson et al (2011) also stated that there is evidence that circadian rhythms increase the risk of traffic accidents and industrial injuries which are also influenced by drowsiness (fatigue). Furthermore, sleep deprivation is a state of lack of sleep, while sleep restriction is a condition that can result in increased sleepiness and decreased performance due to not getting enough sleep due to sleep restrictions. On the other hand, fatigue can be measured by the driver's sleep duration during the last 24 hours (Williamson et al., 2011). Drivers who experience accidents due to fatigue have an average sleep duration of 5.5 hours in the last 24 hours (Williamson et al., 2011).

Belenky et al. (2014) divide sleep into three conditions, i.e. consolidated sleep, split sleep, and fragmented sleep. In consolidated sleep, the sleep only occurs in one segment within 24-hour period. Meanwhile, in the split sleep condition, a person falls asleep from two to three times in a 24-hour period. In a state of fragmented sleep, a person wakes up every 2-3 minutes while asleep. Split sleep is a common occurrence in several industries, including transportation (Jackson et al., 2014). For example, the maritime workers mentioned in Short et al. (2016) have implemented work shifts that provide opportunities for split sleep. This can result in better sleep quality and performance due to a lower work-to-sleep ratio and a work schedule that starts and ends at the same time each day (Short et al., 2016).

Riedy et al. (2020) analyzed the sleep-wake behavior of railroad workers, including train drivers in Australia. The behavior or sleep conditions of train workers during rest periods are divided into split sleep and consolidated sleep. The results showed that railroad workers usually take naps as extra sleep time. Although not all railroad workers perform split sleep, the fatigue model used in the study of Riedy et al. (2020) predicts railroad workers are more likely to do split sleep. Research by Jackson et al. (2014) showed that there was no difference in sleepiness between split sleep and consolidated sleep, but it could result in a worse mood and a less positive impact on the work environment (Jackson et al., 2014). It is in contrast to the research of Short et al. (2016) which states that split sleep reduces sleep duration, but has no effect on performance. In addition, in the split sleep condition, the time required to initiate sleep is longer than in consolidated sleep (Short et al., 2016).

According to Sahayadhas et al. (2012), the detection of drowsiness (fatigue) can be measured through a behavioral-based measures approach. Behavioral-based measures detect driver behavior, such as blink. Blink and eye movements are often associated with changes in sleepiness, such as blink duration, blink rate, the interval between blinks, and pupil size (Anderson et al., 2013).). Moreover, Schleicher et al. (2008) stated that the blink duration and frequency are the best ocular indicators to evaluate fatigue. Blink duration is the most consistent parameter of subjective and objective measurement of sleep-related driving disorders (Mulhall et al., 2020). According to Akerstedt et al. (2010), blink duration is the most responsive parameter to sleepiness (fatigue) and increases during sleep deprivation conditions in field studies and driving simulators. The results of the research by Puspasari et al. (2019) also state that the blink duration parameter is one of the best parameters in fatigue detection. Besides that, blink frequency is defined as the blink rate in a specific time window, usually 1 minute (Cori et al., 2019). The results of Abe et al. (2011) show that the blink frequency changed with reduced attention and the occurrence of microsleep. A decrease in the blink frequency is followed by an increase in missed responses.

Blink can be detected using eye tracking technology. Eye tracking is used in real-time to monitor eye conditions and collect eye movement data (Xu et al., 2018). According to Xu et al. (2018), eye tracking is the main approach to collecting evidence of driver fatigue. Eye tracker can evaluate driver fatigue based on the blink indicator in a non-intrusive system (Puspasari et al., 2019; Xu et al., 2018). The research by Xu et al. (2018) involved 10 participants who were asked to drive a car simulator for 1-2 hours in monotonous conditions using an eye movement tracking device.

Furthermore, fatigue can also be detected using subjective measurements, such as Karolinska Sleepiness Scale (KSS) and Visual Analogue Scale (VAS). KSS is a subjective measure of sleepiness (fatigue) that has been validated by EEG and eye movements (Kaida et al., 2006). According to Akerstedt et al. (2010), subjectively measuring sleepiness (fatigue) is needed to monitor alertness according to the driver's perception of sleepiness (fatigue). In addition, KSS is a subjective measure of sleepiness (fatigue) which is least influenced by individual variations (Akerstedt et al., 2010). The KSS questionnaire consists of nine Likert scales with a scale of 1 indicating an extremely alert state and a scale of 9 indicating a very sleepy, great effort to keep awake, fighting sleep state (Akerstedt et al., 2010). Anderson et al. (2013) set the threshold on a scale of 6. Signs of drowsiness (fatigue) are greater when the KSS score is more than 6 and is often associated with impaired driving performance and sleep disturbances. Based on the analysis of variance conducted by Kaida et al. (2006), found a strong relationship between the results of VAS and KSS. VAS measurement uses an analog scale on a 100 mm long line, the left end of the line indicates low alertness and the right end indicates high alertness (Dorrian et al., 2006). Kaida et al. (2006) used the VAS in the context of drowsiness (fatigue) with the left end showing no drowsiness and the right end being drowsy. A VAS value greater than 40 is considered fatigued and requires rest (Watanabe et al., 2008).

3. Methodology

This study aimed to examine the effect of split sleep on fatigue based on the blink while driving a train simulator. The research was conducted using a train simulator in Laboratory. Fatigue was identified using objective and subjective measurements. The objective instrument used is an eye tracker, it can measure the blink frequency and duration. KSS and VAS were used as subjective instruments used. In addition, an additional questionnaire was also used, namely the Morningness-Eveningness Questionnare (MEQ) to determine the tendency of participants' waking time and sleepiness.

Participants in this study consisted of nine men aged 20-25 years with a minimum education of high school, no color blindness, and no history of chronic disease. Participants have a minimum height of 165 cm and ideal body mass index. The participants in this study were non train drivers, but had similar characteristics. Participants were asked to come to the laboratory for three days and were prohibited from consuming caffeine and smoking during the experiment.

Each participant got the same two treatment factors, sleep conditions and driving duration. The sleep condition treatment factor was set into two levels, i.e. split sleep and consolidated sleep shown in figure 1, while the driving duration factor had six levels based on data collection time interval, which was every 30 minutes during 2.5 hours of driving, starting from the beginning of simulation. The duration of train simulation was based on the research by Iridiastasi (2021) which shows that driving for 2 hours is enough to encourage a person's level of fatigue. Before the simulation, participants had to take a minimum 30 minutes of training and introduction to the tools used during the simulation. Next, participants were escorted to a room that had been provided to take both sleep conditions (Figure 1).

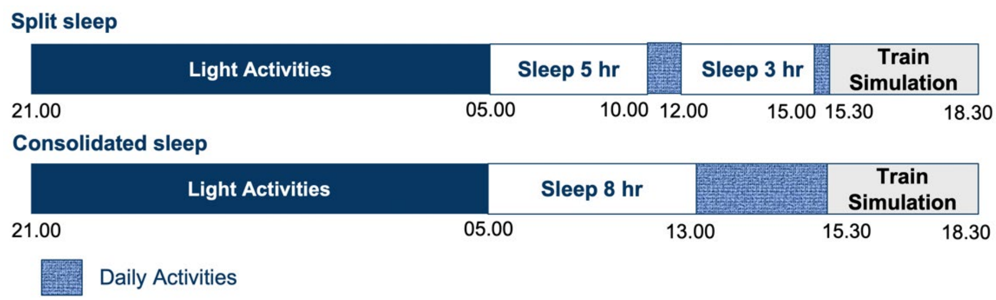


Figure 1. Sleep condition scenario

Sleep activities carried out by participants were ensured by smartwatch which detect sleep by accelerometer and gyroscope sensors (body movement sensor) and photoplethysmography (heart sensor). The definition of sleep recorded by smartwatch is a condition in which body movements slow down and decrease and heart rate decreases. In addition, this study used Software Railworks Trains Simulator with monotonous route scenario. Moreover, the condition of locomotive cabin was maintained at temperature of 27–30^{0}C, noise in 90–100 dB, and lighting in 60–80 lux. During the simulation, participants were asked to fill out the KSS and VAS every 30 minutes. Meanwhile, measurements of blink frequency and blink duration were carried out throughout the driving simulation (real-time monitoring) using GP3 Eye Tracker (GazepointTM Canada). Details of the train simulation period in this study are shown by Figure 2.

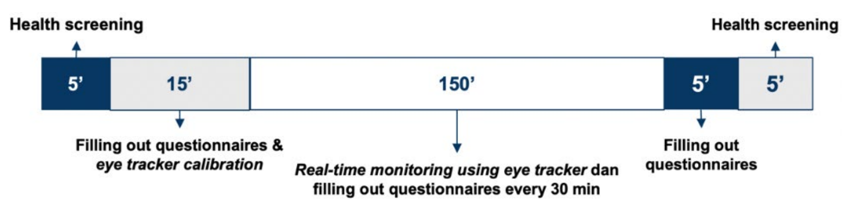


Figure 2. Details of the train simulator period

4. Data Collection

In this study, the data collected were blink duration & frequency and subjective measurements using KSS and VAS. Data on the duration and frequency of blinking were collected in *real-time* during the simulation, then segmented into 30-minute time intervals with a measurement length of two minutes (Mulhall et al., 2020). The research of Mulhall et al. (2020) also stated that there was no difference in the length of the average blink duration measurement for 2 minutes or 4 minutes, both of which gave significant results. Similarly, KSS and VAS data were collected every 30 minutes during the simulation (Schleicher et al., 2008; Anderson et al., 2013).

Blink duration and frequency data were obtained through an *eye tracker.* According to Cori et al. (2019), blink consists of three phases, namely starting to close (*closing),* closed (*closed),* and reopening (*reopening).* However, in this study, the blink data obtained only consisted of closed and open phases due to the eye tracker tools.

5. Results and Discussion

5.1 Results

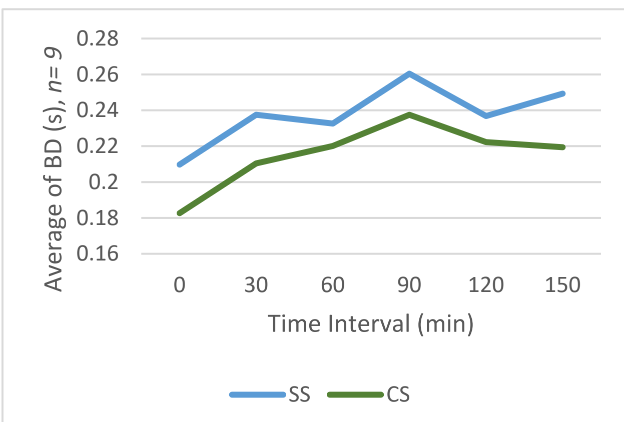
Based on MEQ questionnaire, the result did not show that there were participants who were included in the extreme so that all participants could take part in the experiment. A total of two participants were included in the moderate morning and seven participants in the intermediate category. Then, based on the results of the paired T-test, the duration of SS and CS sleep did not have a significant difference ($p = 0.308$).

Overall, the result of blink duration (BD) data in the SS condition was 0.343 ± 0.100 seconds. The result of BD data in CS condition was 0.310 ± 0.087 seconds. The initial value of the BD in the SS condition was 14.8% higher than the CS condition, while the final value of the BD in the SS condition was 13.6% higher than the CS condition. The highest average value was shown by the SS condition at 90-time intervals. Based on the results of the ANOVA test, there was a significant difference in blink din SS and CS conditions (p = 0.05). In addition, the time interval pairs 0 and 30, 0 and 90, and 0 and 150 had significant differences (p = 0.05).

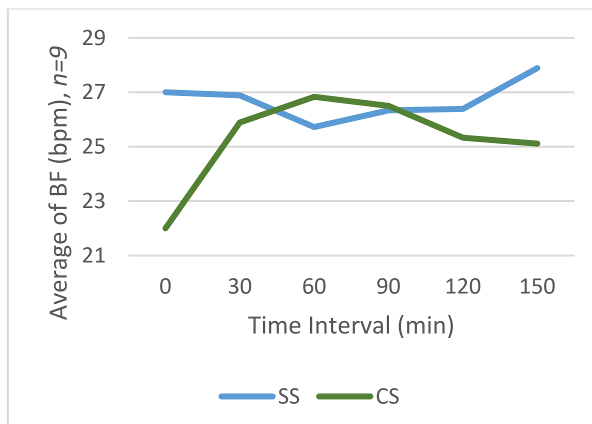
The result of eye blink frequency (BF) data in the SS condition was 26.70 ± 5.54 blinks per minute (bpm), while the result of BF data in the CS condition was 25.28 ± 5.84 bpm. The initial value of the BF in the SS condition was 22.72% higher than CS, while the final value of SS condition was 10.76% higher than CS. The highest average value is indicated by the condition of SS at 150-time interval. Based on the results of ANOVA, SS and CS had a significant difference (p = 0.05). However, the time interval on the driving duration factor had no difference (p = 0.748). Likewise, there was no interaction between sleep conditions and driving duration (p = 0.181).

The result of the KSS measurement in the SS condition was 4.7 ± 1.90, while in the CS condition was 4.8 ± 1.84. Broadly speaking, the average value of KSS in CS conditions in the initial time interval from 0 to 90 is greater than SS. However, in the last two intervals, the SS condition has a higher value. The results of the ANOVA test showed no significant differences in the SS and CS conditions (p = 0.673). However, on the driving duration factor, the time interval of 0 and 150 had a significant difference (p = 0.05).

The result of the VAS measurement in the SS condition was 48.5 ± 24.61, while the result of the VAS measurement in the CS condition was 45.2 ± 24.29. The threshold value used is 40, this value has appeared from a time interval of 30 in the CS condition and constantly above 40 in both sleep states. Based on the results of ANOVA, SS and CS did not have a significant difference (p = 0.413). However, on the driving duration factor, the time intervals 0 and 120 and the time intervals 0 and 150 had significant differences (p = 0.05) (Figure 3).



(a)



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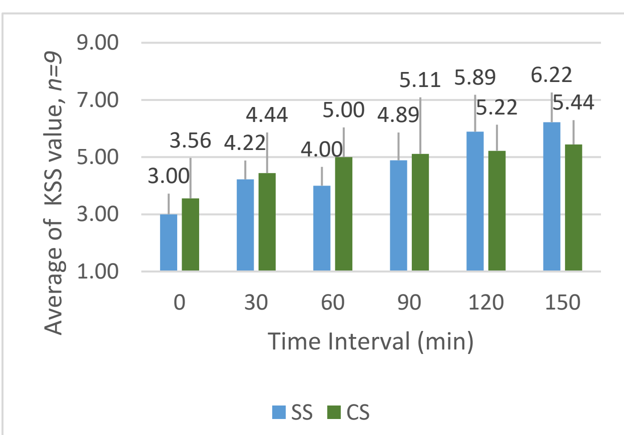
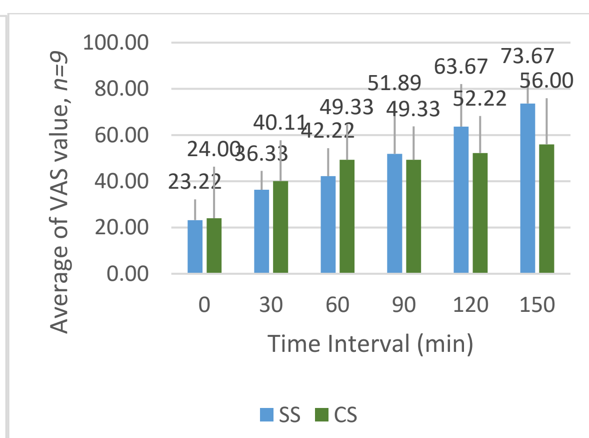


(c)



(d)

Figure 3. (a) Average of BD graph, (b) Average of BF graph, (c) Average of KSS value graph, (d) Average of VAS value graph

Based on the results of BD in this study, there is a difference between SS and CS conditions. The SS condition has a higher value than the CS condition. In addition, in the SS condition, there were three BDs which indicated microsleep, while in the CS condition there is only one microsleep. This indicates that participants got fatigue during the SS condition. Likewise, Puspasari et al. (2020) states that microsleep is an indication of a state of severe fatigue.

On the other hand, the BD parameter also showed differences in fatigue patterns which were influenced by driving duration. The lowest BD was at the beginning of the simulation, which was 0.210 seconds in the SS condition and 0.182 in the CS condition. A fairly high increase occurred in the 90th minute. The increase in BD at the beginning and end of the simulation reached 19% in the SS condition and 20% in the CS condition. However, the BD was still within the normal blink duration range for both conditions.

Similar to the BD, the BF parameter also showed a difference between SS and CS conditions. Blink increased in the SS condition at intervals of 90 and 150. The increase in the BF from the beginning to the end of the simulation also occurred in the SS condition (3%) and the CS condition (14%). This may indicate mild fatigue (Schleicher et al., 2008). However, the results show that there is no difference in fatigue patterns that are affected by driving duration. The difference in results between BD and BF on the driving duration factor may occur because BD is more sensitive in evaluating fatigue than BF (Benedetto et al., 2011).

The results of statistical tests on subjective fatigue measurement, KSS and VAS data did not show any difference in SS and CS conditions. However, there were differences in fatigue patterns based on time intervals on the driving factor. KSS value from the beginning to the end of the simulation reached 107% in the SS condition and 53% in the CS condition. Meanwhile, the increase in VAS value from the beginning to the end of the simulation reached 217% in the SS condition and 133% in the CS condition.

In this study, objective measurements of fatigue, BD and BF have a correlation with each other. Likewise, subjective measurements, KSS and VAS have a correlation with each other, such as research by Kaida et al. (2006). However, objective measurement has no correlation with subjective measurement. This seems to occur due to differences in the level of fatigue felt subjectively by participants with real conditions based on objective measurements.

5.2 Discussion

Blink has been used in several studies to objectively measure fatigue. The research of Puspasari et al. (2019) used ocular indicators, one of which was blink through an *eye tracker* to measure fatigue. The research involved a driving simulator in a laboratory that was made to resemble real conditions. The findings of Puspasari et al. (2019) showed blink duration and *microsleep* to be the best parameters in detecting fatigue. In addition, the results show that sleep duration is the most influential factor in the blink indicator.

Schleicher et al. (2008) also mention that the blink indicator is easier to measure than other ocular indicators, such as *saccadic* and pupil. Moreover, *saccadic* and pupillary indicators have rarely been studied due to difficulties in interpreting the results (Schleicher et al., 2008). It is supported by the research of Cori et al. (2019) that the blink parameter is ideal for measuring sleepiness (fatigue) because it is objective, non-intrusive, and can be recorded continuously during driving. In addition, blink has also been validated to evaluate sleepiness (fatigue) along with other measures, such as *neurobehavioral performance, electroencephalography* (EEG), and driving performance (Cori et al., 2019).

In this study, blink was used to measure fatigue in split sleep condition. Split sleep is a common phenomenon in the railway sector as the results of research of Riedy et al. (2020) state that railway workers, including machinists, tend to do split sleep. Likewise, the research by Iridiastadi (2021) states that drivers shift experience fatigue which seems to be related to shortened rest periods. The driver's rest time is limited because the driver must arrive back at the station before the next work schedule. Within the limited time for rest, the driver must sleep and do other activities such as worship, family needs, and commuting to and from the station (Iridiastadi, 2021). Thus, the machinist was forced to do *split sleep* to support all these activities.

The results of this study showed that participants' fatigue level in *split sleep* was higher than in *consolidated sleep* based on the blink parameter. This can be caused by the distance between participants' waking time to driving activities that are closer in the *split sleep* compared to *consolidated sleep.* However, participants did not feel any difference in the level of fatigue in the two conditions based on subjective measuring instruments. Apparently, *split sleep* was not a participant's complaint because of enough sleep for eight hours and the sleeping facilities provided were cool and away from crowds. Even so, the difference was still shown in the blink parameter so it was not really recommended to do *split sleep.* This is because *split sleep* can result in a worse mood and can reduce sleep duration (Jackson et al., 2014; Short et al., 2016).

If *split sleep* is something that must be maintained due to the limitations in the machinist's work schedule, *split sleep* can be done simultaneously with the implementation of the *Fatigue Risk Management System* (FRMS). FRMS is defined as the planning and control of a work environment that aims to minimize losses caused by fatigue at work (Gander et al., 2011). Broadly speaking, Gander et al. (2011) divide the FRMS approach into two, namely organizational factors in companies and regulations.

The organizational factor approach is divided into several aspects, one of which is related to sleep (Gander et al., 2011). In this case, the management of PT KAI needs to pay attention to the driver's sleep activities to reduce the effect of fatigue. One important aspect of sleep is sleep quality. Good sleep quality can restore fatigue, on the other hand, poor sleep quality can increase the risk of fatigue (Gander et al. 2011; Kwon et al., 2019). Therefore, the quality of sleep needs to be improved to reduce the risk of fatigue.

On the other hand, sleep quality is closely related to sleep duration (Kwon et al., 2019). Sleep duration also needs to be maintained to reduce the effects of fatigue due to *split sleep.* Sleep duration in the last 24 hours is one of the factors that can cause fatigue (Paterson et al. 2019). Most people need about eight hours of sleep per day to maintain optimal levels of alertness (Owens, 2007). Similarly, the research of Paterson et al. (2019) which states that a safe sleep duration for driving is 7–8 hours in a 24-hour period. To achieve sufficient sleep duration, a driver can take advantage of the break time with *split sleep* at home and at the station. Sleeping at the station is done while waiting for the work schedule to start. Therefore, the management of PT KAI needs to provide supporting sleeping facilities.

Comfortable sleeping facilities will lead to an increase in the quality and duration of sleep (Owens, 2007). Zarcone in Owens (2007) mentions several things that can improve the quality and duration of sleep, such as cool room temperature, minimal lighting, and low noise levels. The World Health Organization (2010) recommends the best noise level standard for sleep is less than 30 dB. For this reason, sleeping facilities provided by PT KAI management must be far from the railroad tracks, even better if the room is soundproof in order to reduce noise levels. In addition, sleeping facilities are equipped with *air conditioners* so that the room temperature is cool and the lighting is minimal.

Additionally, to *split sleep,* driving duration is an additional fatigue-causing factor reviewed in this study. The results show that the time interval for the driving duration of 2.5 hours resulted in changes in fatigue patterns. The fatigue pattern at the end of the driving simulation is higher than at the beginning of the simulation. In accordance with the statement of Iridiastadi (2021), the highest level of sleepiness (fatigue) occurred with the duration of driving for 2.5 hours. Under normal circumstances, freight train drivers can drive freight trains for up to 4-5 hours. In fact, driving time can increase to 6–8 hours when there is a line of freight trains on the tracks. This duration exceeds 2.5 hours which the driver can feel quite high fatigue. If the duration of the journey of freight trains or trains generally requires the driver to drive more than 2.5 hours, the FRMS approach in the form of regulation of work duration needs to be applied. For example, Law no. 22 of 2009 Article 90 mentions the working time of drivers of general motorized vehicles in which the duration of driving for 4 consecutive hours must be followed by a minimum of 30 minutes of rest. The rule for driving a maximum duration of eight hours a day is also mentioned in the law. If the driving duration regulation is applied to the railway sector, the management of PT KAI needs to train assistant machinists in driving and replace the driver while resting. Moreover, the assistant engineer must have characteristics similar to the machinist.

In addition to regulatory and organizational factors, Dawson in Riedy et al. (2020) mentions another example of FRMS, namely *real-time fatigue monitoring* (RFM). RFM can be used to directly evaluate fatigue, particularly that which is affected by *split sleep. Eye tracker* can be one of the tools used in the application of RFM. Currently, PT KAI is already using RFM technology, the driver starts to show signs of fatigue when the blink lasts more than five seconds. When the driver gets fatigue, an *alarm* in the cabin will sound so that the driver can regain consciousness and wake up. The RFM used by PT KAI is quite good, it is just that PT KAI needs to re-validate the fatigue threshold used.

5.3 Limitations

This study has limitations on the use of simulators and the fatigue factor studied. The experiments carried out in this study used a simulator and a train driver's cabin in the laboratories which was made according to real conditions. The simulator used has low fidelity so it cannot represent the conditions in the field as a whole. However, studies have proven that experiments with train simulators under monotonous conditions are more sensitive to the effects of sleep deprivation (Dunn and Williamson, 2012). This is confirmed by the research of Philip et al. (2005) who concluded that there was no significant difference in fatigue levels between the use of simulators and real driving.

In addition, only two fatigue factors were studied, sleep conditions and driving duration. Williamson et al. (2011) mentioned other factors such as time of day and time awake. On the other hand, May and Baldwin (2009) state that fatigue can be caused by work factors, such as mental stress. Time of day, time awake, and work factors were not studied in this study, so further research is needed.

6. Conclusion

This study concludes that split sleep has an effect on fatigue in train driving activities. This is indicated by the higher duration and blink parameters in split sleep than in consolidated sleep. The statistical test results also stated that the two sleep conditions differed significantly based on the blink parameters. However, the results of subjective measurements based on KSS and VAS values did not show a significant difference in the two sleep conditions. However, split sleep still has an effect to fatigue so this condition is not recommended.

If the split sleep must be maintained due to the limitations of the train driver's work schedule, the effect of split sleep on fatigue can be reduced by mitigation strategies. The mitigation strategy that can be done is improving sleep quality and fulfilling sleep duration for 7-8 hours in the 24-hour period before driving. Improving the quality and duration of sleep needs to be supported by comfortable sleeping facilities. Comfortable sleeping facilities include a cool room temperature, minimal lighting, and a noise level of less than 30 dB.

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