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THE EFFICACY OF ONE-TIME AND INTERMITTENT INTAKE OF COFFEE AS A COUNTERMEASURE TO SLEEPINESS ON PARTIALLY SLEEP-DEPRIVED DRIVERS

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ABSTRACT

Research has been done the effect of coffee on sleepiness. Several studies claim that caffeine is proven to overcome sleepiness. However, little is known about the effect of various methods and amounts of coffee intake on a sleep-deprived person. This study compares the effectiveness of one-time and intermittent intake of coffee to overcome driver sleepiness due to partial sleep deprivation. This study used a within-subject experimental design in a driving simulator. There were eight participants, all of whom met certain criteria. The participants' degree of sleepiness was measured objectively and subjectively. Objectively, the degree of sleepiness was measured based on alpha, beta, and theta brainwaves using an electroencephalograph (EEG); subjectively, this study used the Karolinska Sleepiness Scale (KSS). The participants experienced partial sleep deprivation the night before each experiment. The results of this study support previous studies' findings that coffee can reduce sleepiness. This study also found differences in the effectiveness of one-time vs. intermittent intake of coffee (sig. value for EEG = 0.025; sig. value for KSS = 0.001). For partially sleep-deprived drivers, one-time coffee intake was found to be more effective in counteracting both objective and subjective sleepiness than intermittent coffee intake.

Keywords: Coffee; Countermeasure; Driver; Intake; Sleepiness

1. INTRODUCTION

Traffic accidents are the third most common cause of death in Indonesia (BIN, 2011). The majority of traffic accidents in Indonesia are caused by human factors. One of the human factors that causes accidents is driver sleepiness (Korlantas, 2012). Sleepiness increases the risk of traffic accidents (Cummings et al., 2001). Increased levels of fatigue and sleepiness have been proven to increase driver reaction time and decrease cognitive ability, including reducing the driver's ability to recognize danger signs or to take corrective action (Dinges et al., 1997).

Many studies have found that the caffeine in coffee is an effective countermeasure against sleepiness. The significant difference in several studies on caffeine is that they used different methods to provide coffee to the participants. Several studies provided caffeine in the form of a coffee drink (Horne & Reyner, 1999), while others provided caffeine in the form of a slow-release tablet (De Valck & Cluydts, 2001) or a low-dose capsule that participants took frequently (Wyatt, 2004). One study found that the effects of a slow-release caffeine tablet can be used as a valuable countermeasure to driver sleepiness due to partial sleep deprivation

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(De Valck & Cluydts, 2001). However, that study did not directly compare slow-release caffeine tablets with other forms of caffeine intake.

In Indonesia, however, caffeine is usually taken in the form of coffee. Professional drivers, who drive for long hours or in conditions conducive to sleepiness (such as driving during regular sleep times), commonly drink one or two cups of coffee before driving or during their rest period. This condition was observed in the previous study by Mahachandra et al. (2009). Nevertheless, a slow-released method of caffeine or coffee intake was never sighted in the real working situation. In order to get the slow effect of caffeine intake, however, workers usually drink their coffee on several intakes, called intermittent method. Yet, the effect of this method, compared to the regular intake (one-take), is still unknown.

On the other hand, circadian factors and sleep duration are equally important in determining a driver's degree of sleepiness (Horne & Reyner, 1995). One study compared driver sleepiness under three conditions: long-term sleep deprivation (> 45 hours), short-term sleep deprivation (≤45 hours), and partial sleep deprivation (<5 hours) (Pilcher & Huffcutt, 1996). This study found that partial sleep deprivation had a stronger negative effect on cognitive abilities than long-term or short-term sleep deprivation. Cognitive function is essential to driving, and accidents due to driver sleepiness usually occur because of decreased cognitive function (McKernon, 2009).

This study seeks to complement previous research on sleepiness and coffee. This study compares the effectiveness of regular caffeine and slow-release caffeine intake on driver sleepiness. Regular caffeine intake was provided in the form of one-time coffee intake, while slow-release caffeine intake was in the form of intermittent coffee intake. These methods appropriately reflect professional drivers' actual experiences, especially in Indonesia.

2. METHODS

This study used a within-subjects design experiment to address the research question. The experiments were conducted in a car-driving simulator to approximate a realistic driving situation.

2.1. Participants

Eight ITB students were recruited as participants. They were healthy men aged 20-25 years old. All of them normally consume moderate amounts of caffeine, and all participants were non-smokers who do not drink alcohol or use drugs. They had all had a driving license for at least one year and normally drive one hour per day. To ensure that no participant had a sleep disorder, they were asked to fill out the SLEEP-50 questionnaire.

2.2. Instruments

Bagasse paper sheets were coated with different concentrations of gelatin solution (0.5, 1, 1.5,
The instruments used in this study were coffee, a car-driving simulator, an Electroencephalograph (EEG), and the Karolinska Sleepiness Scale (KSS).

2.2.1. Coffee

Two boxes of Nescafe instant coffee, with a total volume of 350 ml and containing 130 mg of caffeine, was used in this study. The caffeine doses were chosen because the average effective dose of caffeine for an adult is between 100-200 mg for one intake (Karch, 2000).

2.2.2. Driving simulator

Many studies on driver sleepiness have been carried out in a driving simulator because it offers an easily controlled environment. The use of a simulator also avoided the risk of accidents on a real highway. This study used a driving simulator in the Institut Teknologi Bandung. The driving simulator was installed inside a real car. Logitech G-27 was used to simulate the steering wheel, clutch, and pedals and was installed on the dashboard. The software *City Car Driving* was used to simulate a real driving situation and was projected onto a screen in front of the car. Similar routes, including urban, suburban, and highway driving, were chosen and used for all experiments.

2.2.3. Electroencephalograph (EEG)

An EEG was used to observe and record the participants' objective sleepiness as represented by brainwave activity. The EPOC Emotiv EEG was used in this study because it is wireless. This EEG has 14 channels and uses gold electrodes and a 128 Hz sampling rate for data recording.

Figure 1 EEG used in this study

2.2.4. Karolinska Sleepiness Scale (KSS)

The KSS was chosen to measure subjective sleepiness because of its validity in identifying sleepiness compared to objective measurements such as an EEG (Kaida et al., 2006). The KSS divides the levels of subjective sleepiness into nine degrees, including very alert, very sleepy, have to fight sleepiness, and difficulty staying awake. The KSS used in this study was translated into Bahasa Indonesia (Mahachandra et al., 2009), as shown in Table 1.

2.3. Data Collection Procedure

Two types of data were collected in this study: (a) brainwave data (using an EEG) to determine objective sleepiness; and (b) subjective sleepiness scale data (using the KSS).

2.3.1. Time of data collection

The data was collected in the morning, between 6:00 and 9:00 a.m., in order to get the maximum effect of the previous night's sleep deprivation.

Table 1 Karolinska Sleepiness Scale (Indonesian version)

Scale	Description
1	*sangat awas dan terjaga* (very alert)
2	
3	*awas dan terjaga* (alert, normal level)
4	
5	*tidak awas dan terjaga tapi juga tidak mengantuk* (neither alert nor sleepy)
6	
7	*mengantuk tapi tidak susah untuk terjaga* (sleepy, but no effort to keep awake)
8	
9	*sangat mengantuk, susah melawan kantuk, dan susah untuk tetap terjaga* (very sleepy, great effort to keep awake, fighting sleep)

2.3.2. Pre-experiment procedure

On the night before each experiment, the participants were instructed to reduce their usual sleep duration by half to achieve a condition of partial sleep deprivation. Before the data was collected, the participants were asked to fill out an informed consent form and a questionnaire about their physical condition. The participants also practiced using the simulator for about fifteen minutes each.

2.3.3. Data collection process

A within-subjects design was used in this study. Each participant was given two treatments, which were arranged using a counterbalance method. For each experiment, the participant drove the simulator for 45 minutes on the chosen route, starting soon after the practice session. The driving duration was chosen based on previous studies on the time needed for the absorption of caffeine, which ranges from 15–45 minutes (Karch, 2000). Each participant received two treatments: (a) one-time intake of coffee: 350 ml were drunk during the first minute of driving; and (b) intermittent intake of coffee: 175 ml were drunk during the first minute, and the rest was drunk during the twenty-seventh minute of driving. This timing was chosen because the body begins to absorb caffeine during the fifteenth minute after drinking it, so in the twenty-seventh minute, the effects of the first intake of caffeine would be seen.

2.3.4. EEG data collection

The center of consciousness and alertness in the human brain is most easily detected in frontal lobe (Burgess & Simons, 2005), so the data recording focused on that area (F3 and F4), as shown in Figure 2. Each of the electrodes was referenced and grounded to the ear lobes (A1 and A2). The EEG recorded the raw data regarding voltage differences between the frontal lobe and the reference area in theta waves (4–8 Hz), alpha waves (8–13 Hz), and beta waves (13–30 Hz). These frequencies were chosen determine the drivers' degree of sleepiness; an active condition is indicated by a high number of beta wave, and drowsiness is indicated by alpha and theta waves.

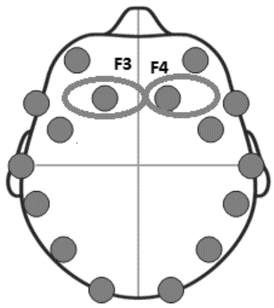

Figure 2 The chosen areas (F3 and F4)

2.3.5. KSS data collection

KSS data were recorded every nine minutes by directly asking the participants to rate their level of sleepiness.

2.4. Data Processing Procedure

2.4.1. EEG data processing

The brainwave data was processed on a MatLab to obtain the power spectral density values for the theta, alpha, and beta waves. Data was processed consecutively to exclude artifacts and noise, to normalize the data, to transform the data from time-based to frequency-based using the Fast Fourier Transform algorithm, and to calculate the Power Spectral Density (PSD) of each frequency. In this study, levels of objective sleepiness were indicated with the ratio $(\alpha+\theta)/\beta$. The PSD of alpha and theta waves increases as sleepiness increases (Akerstedt & Gillberg, 1990), while a high density of beta waves indicates an awake and alert state (Davidson, 2000). The slope value was also calculated for each experiment. SPSS software was then used to check the normality and homogeneity of the data. If the set of data was normal and homogeneous, then a paired t-test would be performed; otherwise, a Wilcoxon test was performed. A comparison was made to determine the effect of the two treatments on the slope.

2.4.2. KSS data processing

First, the slope of the KSS data was calculated. Then, the normality and homogeneity of the data were tested using SPSS software. A paired t-test or a Wilcoxon test was then conducted to determine the effect of the two treatments on the slope alteration.

3. RESULTS AND DISCUSSION

3.1. Data Collection

Figure 3 shows the EEG data collected from one participant. All of the participants had similar EEG results. For each treatment, the linear regression was collected and the slope value was calculated to express the alteration in the participant's level of sleepiness. Figure 4 shows the data and slope for KSS. Visually, the one-time coffee intake appears to have a lower slope value for both the EEG and the KSS, indicating a lower degree of sleepiness.

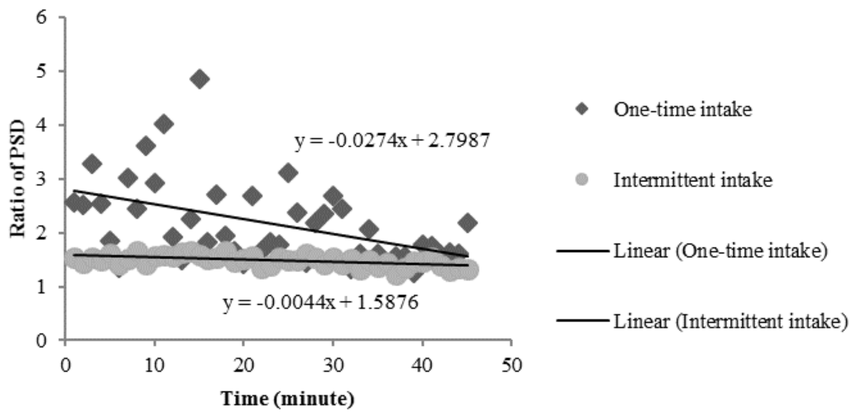

Figure 3 Example of EEG data (participant #2)

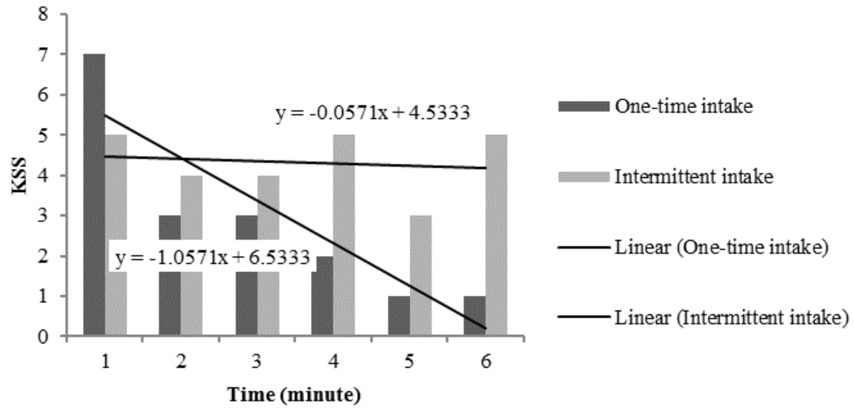

Figure 4 Example of KSS data (participant #2)

Figure 5 and Figure 6 illustrate the participants' overall sleepiness, based on objective and subjective measurements, respectively. As stated before, objective sleepiness was measured by calculating the slope value of the ratio $(\alpha+\theta)/\beta$, indicating the power spectral density of brainwaves, while subjective sleepiness was measured by the slope value of the KSS over the course of the experiment.

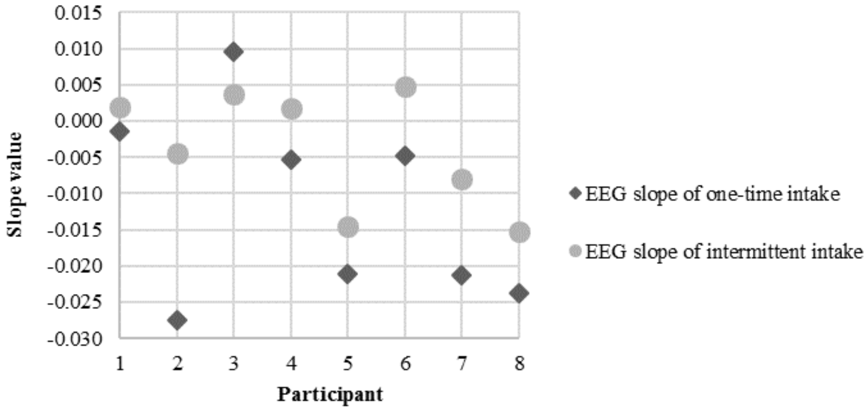

Figure 5 EEG slope of all participants

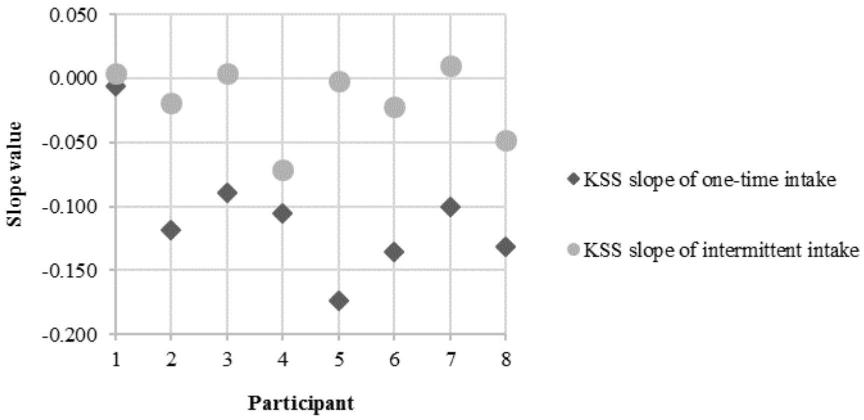

Figure 6 KSS slope of all participants

3.2. Effect of Coffee on Sleepiness Level

Objective sleepiness, which is expressed by the EEG slope, has a mean value of -0.0119 (st.dev.= 0.0132) for one-time coffee intake and -0.0037 (st.dev. = 0.0081) for intermittent intake of coffee. Both values are negative, which indicates that the level of sleepiness decreased over the course of the experiment. This implies that, objectively, the caffeine in coffee effectively reduces the level of sleepiness. This result supports the findings of previous studies that coffee reduces driver sleepiness (Cummings et al., 2001; De Valck & Cluydts, 2001; Horne & Reyner, 1999; Mets et al., 2012; Philip et al., 2006).

Subjective sleepiness is indicated by the KSS slope value. The average values of the slopes are -0.1064 (st.dev. = 0.0478) for a one-time intake and -0.0182 (st.dev. = 0.0279) for intermittent intake of coffee. Both of these values are also negative, again indicating that the level of sleepiness decreased over the course of the experiment. This implies that, subjectively, the caffeine in coffee effectively reduces driver sleepiness.

3.3. Effect of Treatments on Objective Sleepiness

The paired samples t-test on the $(\alpha+\theta)/\beta$ ratio found a significant value of 0.025 ($t = -2.837$; $df = 7$). Since this is less than α (0.05), H_0 is rejected. Therefore, we can conclude that the treatments (one-time and intermittent) had a significant effect on brainwaves. Moreover, the slope value for one-time coffee intake (-0.0119) was more negative than the slope value for intermittent coffee intake (-0.0037). This indicates that one-time coffee intake is a more effective countermeasure for sleepiness due to partial sleep deprivation than intermittent coffee intake.

3.4. Effect of Treatments on Subjective Sleepiness

A comparison of the KSS slope value for both treatments using a paired samples t-test found a significant value of 0.001 ($t = -5.135$; $df = 7$), which is less than the value of α (0.05). Therefore, H_0 is rejected, which means that there are highly significant differences in the effect of one-time coffee intake and intermittent intake on the level of subjective sleepiness. One-time coffee intake is a better countermeasure against sleepiness than intermittent coffee intake. This is indicated by the slope value for one-time intake (-0.1064), which is more negative than the slope value for intermittent intake (-0.0182).

3.5. Additional Issues in the Study

3.5.1. Phenomenon of increased sleepiness

As stated earlier, the linear regressions of both the EEG and KSS data reflect the alterations in the participants' level of sleepiness. Several previous studies have shown that coffee or caffeine effectively mitigate sleepiness, especially when sleepiness is measured subjectively (Cummings et al., 2001; De Valck & Cluydts, 2001; Horne & Reyner, 1999). Therefore, this study hypothesized that the slope value after coffee intake over time would be negative, indicating a lower level of sleepiness over time. This would indicate the effectiveness of coffee intake in reducing driver sleepiness. However, as shown in Table 2, some participants experienced an increase in their level of sleepiness over time, denoted by a positive symbol. Although this phenomenon occurred inall experiment sessions (both treatments), the amount is not significant.

Table 2 Slope alteration over time

Participant	EEG Slope		KSS Slope	
	One-take	Intermittent Intake	One-take	Intermittent Intake
1	-	+	-	+
2	-	-	-	-
3	+	+	-	+
4	-	+	-	-
5	-	-	-	-
6	-	+	-	-
7	-	-	-	+
8	-	-	-	-

Moreover, this phenomenon could be caused by several things. It is known that the circadian cycle regulates human sleep and wakening. Masking is an important concept to understand when discussing circadian rhythms. Masking refers to the effects of non-circadian factors on the circadian rhythm (Van Dongen & Dinges, 2001). Masking factors include experimental design, interference from irrelevant stimuli (cigarettes, alcohol), boredom and perception factors, stress, food intake, posture, ambient temperature, background noise, lighting conditions, and drug intake (Van Dongen & Dinges, 2001). In addition to these factors, physical and mental activity may also be a masking factor (Van Dongen & Dinges, 2001). In this study, experiments were conducted in the morning, while the participants' sleep on the previous night was restricted to only 3–5 hours. The time for the controlled experiment was chosen to reduce the influence of the participants' physical and mental activity, because most of them do not usually undertake a lot of physical and mental activity in the morning. However, not all of the masking factors could be controlled. Masking factors such as boredom, perception, and stress tend to be difficult to control. Boredom could have resulted from the potentially monotonous driving conditions of the simulator. These masking factors could be the reason for increases in objective sleepiness over the course of the experiment.

As with the measures of objective sleepiness, some KSS slope data value in this study indicated that the participants felt sleepier after drinking coffee. This phenomenon is shown as a positive symbol on Table 2. This phenomenon could also be due to masking factors (Van Dongen & Dinges, 2001). One masking factor, perception, has a considerable influence on this phenomenon because the KSS is subjective, so the results of the questionnaire depend on how one defines the perceived level of sleepiness.

3.5.2. Patterns in subjective measurement of alterations in sleepiness

Moreover, the alterations in KSS values for some participants followed similar specific patterns. Participants would feel their sleepiness level began to decrease immediately after drinking coffee, but it tended to increase in the final minutes of the experiment, as shown in Figure 7. This alteration pattern is illustrated by the line above the bar. It could be caused by perception, because the participants believed that coffee could reduce their level of sleepiness. Therefore, subjective sleepiness tended to decrease after coffee intake. However, after several minutes of driving, they began to feel bored because of the monotony of the driving simulator. This boredom caused the participants to feel (subjectively) even sleepier than before.

3.5.3. Caffeine dose and format

This study examined the effect of 350 ml of coffee with a caffeine content of 130 mg. The amount of coffee and the caffeine dose were determined in accordance with the average effective dose of caffeine for a normal adult, which is 100–200 mg per intake (Karch, 2000). Therefore, a dose of 130 mg of caffeine per intake is safe and was not expected to harm any of the participants. However, caffeine given in a liquid form can intensify its function as a diuretic. This could cause the participants to need to urinate during the data collection process. This occurred with some of the participants. In these cases, the data collection process was repeated on another day. In previous studies on coffee and caffeine, caffeine was usually administered in a capsule or tablet form (De Valck & Cluydts, 2001; Wright et al., 1997), or in a smaller amount of coffee (no more than one cup or 125 ml) (Mets et al., 2012; Philip et al., 2006). Further studies might choose one of these alternatives to avoid the diuretic effect of caffeine.

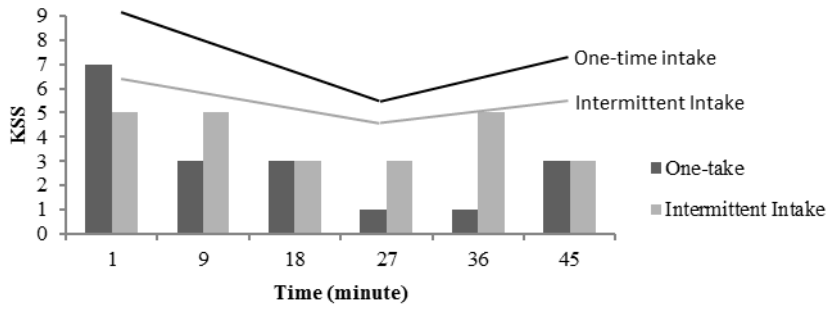

Figure 7 Example of KSS data (participant #3)

3.5.4. Objective sleepiness indicator

As is well known, objective sleepiness can be measured through many changes in the human body, such as brainwaves, variations in heart rate (Mahachandra et al., 2012), and blinking (Mahachandra et al., 2011). In this study, changes in brainwaves were selected as one of the dependent variables because of this measure's high validity compared to others. A wireless EEG was used in this study to measure brainwaves. It has been proven that alpha and theta brainwave activity increases as sleepiness increases (Akerstedt & Gillberg, 1990), while the prevalence of beta waves indicates an awake and alert state (Davidson, 2000).

3.5.5. *Subjective sleepiness indicator*

The other dependent variable in this study, besides brainwave activity, was subjective sleepiness as measured by the KSS. Subjective drowsiness can be measured by several methods, including the visual analogue scale (VAS) (Beaumont, 2001; Wyatt, 2004), the Samn-Perelli seven-point fatigue scale (SPS) (Brown et al., 2014), and the Karolinska Sleepiness Scale (KSS) (Mahachandra et al., 2009; Mets et al., 2012; Wyatt, 2004). The VAS lets participants indicate their level of sleepiness on a ten-centimeter long continuum, with the caption "not tired" on one end and "tired" on the other end. This method is very simple but difficult to interpret because no number value for subjective sleepiness is defined along the line (Millar, 2012). The SPS is a subjective fatigue scale that maps seven points from "fully alert, not tired" to "very tired, unable to work effectively" (Millar, 2012). The KSS describes nine points on its sleepiness scale; one indicates "alert and mindful" and nine indicates "very sleepy, it is a great effort to remain alert and aware" (Akerstedt & Gillberg, 1990). The KSS was selected for this study based on Kaida et al.'s (2006) findings that the KSS has a high correlation with EEG measures of sleepiness, indicating high validity for this scale.

3.5.6. *Control variables*

The control variables in the study included the amount of coffee and caffeine, age and gender, participants' coffee intake habits, sleep time and duration, ability to drive, the physical environment of the car simulator, cigarette use, alcohol consumption, drug use, and diseases associated with sleep disorders. Most of the variables could be easily controlled by creating similar situations for each experiment with all participants, or by carefully selecting the participants. However, some other variables were harder to control, such as sleep time and duration on the previous day to ensure a condition of partial sleep deprivation.

The night before the experiment, the subjects were supposed to sleep three to five hours. To control their subjects' duration and quality of sleep, De Valck & Cluydts (2001) required the subjects to sleep in the sleep laboratory the night before the experiment. In this study, due to limited facilities, sleep time and duration were controlled in three stages: (a) A few days before the experiments were conducted, the subjects were instructed to sleep for only three to five hours the night before the experiment; (b) A researcher confirmed each participant's sleep time and duration by double-checking with someone in the participant's residence; and (c) On the day of the experiment, each participant was asked to respond to a questionnaire on sleep time and duration. Although this did not establish as much control as that exercised by De Valck & Cluydts (2001), it could be ascertained whether the participants were experiencing partial sleep deprivation.

4. CONCLUSION

This study aimed to compare the effects of one-time coffee intake with intermittent coffee intake on the sleepiness of drivers experiencing partial sleep deprivation. Coffee intake, either at once or intermittent, is proved to be highly effective in reducing driver sleepiness. This was demonstrated by a decrease in sleepiness, or by the negative value of the EEG and KSS slopes. It was also found that a one-time coffee intake reduces sleepiness more effectively than intermittent intake. This was concluded from the significant differences between the EEG and KSS slopes for one-time coffee intake vs. intermittent intake (sig. value for EEG = 0.025; sig. value for KSS = 0.001).

The main purpose of this study is to help the Indonesian government and the private transportation sector to reduce the number of accidents in Indonesia related to driver sleepiness. Based on the study's results, it is expected that the government and private sector will recommend or require coffee intake to counteract driver sleepiness. Drivers are advised to consume coffee (one-time intake) containing 100–200 mg of caffeine immediately before driving.

5. ACKNOWLEDGEMENT

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