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The Effect of Caffeine on Drivers' Alertness and Situation

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Abstract

Traffic accidents are one of the leading causes of death in Indonesia, with human factors being the major contributor. One contributing factor is drowsiness, which can reduce drivers' alertness and situational awareness. Caffeine consumption is widely recognized as an effective method to enhance alertness and reduce drowsiness. This study aims to analyze the effect of caffeine consumption in a cup of coffee on drivers' alertness and SA through a driving simulation. This study involved 16 male students, with an average driving experience of 3.81 years. Alertness was measured using the Karolinska Sleepiness Scale and electroencephalography. SA was measured using the Quantitative Analysis of Situation Awareness method, which includes Actual Situation Awareness, bias, and Perceived Situation Awareness. The results indicate that caffeine consumption enhances objective alertness. Caffeine also enhances drivers' detection performance, as evidenced by increased detection sensitivity. Drivers who consumed caffeine had a higher hit rate and a lower false alarm rate, indicating improved accuracy in distinguishing relevant information while driving. Caffeine also influenced drivers' bias strategy, making participants more permissive in decision-making and decreasing bias value. However, no significant differences were found in PSA and subjective alertness.

Keywords: Alertness; Caffeine; Electroencephalography; Situation Awarenesse

1. Introduction

Traffic accidents are one of the leading causes of death in many countries, including Indonesia [1]. According to data from the Research and Development Agency of the Ministry of Transportation [2], traffic accidents in Indonesia are the third leading cause of death after HIV/AIDS and tuberculosis. Data from the Indonesian National Police (2011) shows that in 2010, an average of 84 people died each day due to traffic accidents, equivalent to 3–4 fatalities per hour. The trend of fatalities from traffic accidents has shown a significant increase since 2020, rising from 23,529 deaths in 2020 to 28,131 in 2022 [3]

Cars are the second most vulnerable mode of transportation involved in accidents after motorcycles, with 72% of victims suffering minor injuries, 14% experiencing serious injuries, and 14% resulting in fatalities [2]. This indicates that although cars are considered safer than motorcycles, they still carry a high risk of accidents.

According to the Ministry of Communication and Digital [5], the majority of these accidents are caused by human factors (61%), followed by vehicle-related factors (9%) and infrastructure or environmental factors (30%). Human factors include driving skills, personality, driver attitude, and drowsiness. Among these factors, drowsiness is a leading cause of accidents and near-miss incidents [6]. Drowsiness is known to increase the risk of accidents up to twofold by reducing alertness [7,8,9]. Alertness is the ability to remain focused and awake, which is influenced by sleep duration, the body's biological clock, and other factors [10]. As many as 39% of accidents are caused by inattentive, fatigued, or drowsy drivers, indicating decreased alertness [2]

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Under drowsy conditions, a driver's situation awareness (SA) performance declines due to impaired visual attention, perception, and working memory [11]. According to Endsley, as cited in Wijayanto et al. [11], SA is an individual's ability to identify, understand, and project elements of the driving environment. A decline in SA can lead drivers to fail to perceive critical driving information, increasing the risk of accidents [12].

One way to identify alertness is to measure drowsiness using subjective methods, such as the Karolinska Sleepiness Scale (KSS) questionnaire, and objective methods, such as electroencephalography (EEG) to measure brainwave activity [13]

One effective method for combating drowsiness is caffeine consumption, a known stimulant that can reduce drowsiness and enhance alertness [14]. Caffeine works by inhibiting sleep-inducing substances and stimulating the sympathetic nervous system to increase alertness [6]. Horne and Reyner [15] found that caffeine consumption can reduce drowsiness in sleep-deprived drivers, as indicated by fewer road violations and decreased subjective and objective drowsiness, as measured by EEG. Mahachandra et al. (2017) also found that coffee consumption effectively reduces drowsiness in sleep-deprived drivers.

Most studies on the effects of caffeine on driving have used relatively high doses, ranging from 100 to 300 mg [7,15,16]. Research findings suggest that higher doses improve driving performance and reduce drowsiness. However, in everyday life, drivers typically consume only one cup of coffee, which contains about 80 mg of caffeine, before driving [17].

2. Material and methods

This study was conducted at the Work System Engineering and Ergonomics (RSKE) Laboratory of the Industrial Engineering Department, Diponegoro University. The research utilized a driving simulator and an electroencephalography (EEG) device. The driving simulator served as a test tool to replicate real-world driving conditions, while the EEG device objectively measured alertness by analyzing theta, alpha, and beta brainwaves. Additionally, the study employed the Karolinska Sleepiness Scale (KSS) questionnaire to subjectively assess alertness (drowsiness) and the QUASA probes to evaluate situation awareness.

2.1. Participants

A total of 16 participants were selected based on significance power calculations using G*Power software. The experimental procedure followed a counterbalanced design, with participants randomly assigned to two groups. The first group of eight participants received the caffeine treatment first, while the second group received the non-caffeine condition first.

This study employed purposive sampling, focusing on young drivers aged 20–25 years. Young drivers (≤25 years old) tend to have lower tolerance to drowsiness [18,19]. They are also more likely to drive while drowsy and lack experience in handling decreased alertness [19]. Research by Ryan [20] indicated that male and female drivers exhibit different traffic accident rates, with male drivers being more involved in traffic accidents [2]. Thus, this study focused exclusively on male drivers to minimize variability among participants [6]. The participants were also required to have at least two years of driving experience, as situation awareness improves with driving experience [19].

2.2. Variables

This study included independent and dependent variables. The independent variable was caffeine consumption (X), while the dependent variables were alertness (Y1), assessed through objective EEG measurements and subjective KSS questionnaire responses, and situation awareness (Y2), measured using QUASA probes.

2.3. Alertness

In the context of driving, alertness refers to an individual's ability to remain conscious, awake, and responsive to driving conditions. In this study, alertness was measured through drowsiness, assessed subjectively using the Karolinska Sleepiness Scale (KSS) and objectively using electroencephalography (EEG). KSS consists of a 9-point scale ranging from 1 (fully alert) to 9 (extremely drowsy), with scores above 5 indicating drowsiness. The drowsiness gradient was determined by comparing KSS scores before and after the treatment.

The EEG device used was the Emotiv EPOC+ with 14 electrodes. The study focused on theta (4–7 Hz), alpha (8–13 Hz), and beta (13–30 Hz) waves from electrodes located at F3 and F4 in the frontal lobe. Burgess and Simons [21] suggested that the frontal lobe is the most effective region for detecting alertness-related brain activity, making these locations ideal for measuring drowsiness [13].

EEG signals were recorded at a sampling frequency of 128 Hz [15] and required signal filtering to remove noise that could affect the analysis. A band-pass filter was applied, allowing frequencies between 1 and 50 Hz to pass. The data were then transformed using the Fast Fourier Transform (FFT) to the frequency domain [22]. Power Spectral Density (PSD) analysis was conducted to evaluate the power of theta, alpha, and beta waves. The data from these three brainwaves were converted into drowsiness ratio values [23]. The drowsiness gradient was then calculated per minute.

2.4. Situation Awareness (SA)

According to Endsley (1995), SA refers to an individual's ability to perceive and comprehend environmental elements and anticipate future conditions [11]. SA consists of three levels: perception (Level 1 SA), comprehension (Level 2 SA), and projection (Level 3 SA). For example, a driver must first perceive their current speed (Level 1 SA), determine whether they are exceeding the speed limit (Level 2 SA), and anticipate the necessary adjustments to maintain a safe speed (Level 3 SA).

SA was measured based on actual situation awareness (ASA), bias, and perceived situation awareness (PSA) [24]. This study used the Quantitative Analysis of Situation Awareness (QUASA) method, which involves true/false probes and simultaneous self-ratings. The true/false probes provided information about driving situations, either as actual signals or as noise, followed by true or false answer options. Simultaneous self-ratings allowed participants to assess their confidence in their answers on a scale from 1 (very uncertain) to 5 (very certain) [25]. The collected responses from the true/false probes and self-ratings were used to determine ASA, bias, and PSA scores.

2.5. Data Collection Procedure

This study involved 16 participants who met the inclusion criteria. Participants were randomly assigned to two counterbalanced groups: one received the caffeine treatment first, while the other received the non-caffeine treatment first. The caffeine used in this study was derived from Nescafé Gold Blend instant coffee, which contains approximately 89.4 mg of caffeine per 3 grams of coffee, while the non-caffeine treatment used Nescafé Gold Blend Decaf, which contains about 2.4 mg of caffeine per 3 grams of coffee [17]. Although decaf coffee still contains some caffeine, the amount is very small and is considered representative of the non-caffeine condition in this study.

Data collection was conducted from noon to the afternoon, during the circadian low alertness period [26], specifically between 12:00 PM and 5:00 PM. Upon arrival at the laboratory, participants were fitted with EEG devices while resting and seated in the driving seat to stabilize their initial condition before data collection. Next, a baseline recording was performed with eyes closed and open for 30 seconds.

Participants then completed the Karolinska Sleepiness Scale (KSS) questionnaire before receiving treatment (pre-treatment). Following this, they underwent a 10-minute driving practice session on the driving simulator before beginning the main simulation, which lasted 1 hour.

During the simulation, alertness was objectively measured via EEG, while situation awareness (SA) was assessed using the QUASA method with the freeze-probing technique. The simulation was paused periodically to present true/false probes regarding road and traffic conditions [11]. The QUASA probes consisted of 42 statements covering traffic signs, surrounding vehicles, environmental conditions, and vehicle status.

After the simulation session ended, the EEG device was removed, and participants completed the KSS questionnaire again (post-treatment). Subsequently, participants were given a 10-minute rest period in the laboratory to monitor potential caffeine-related side effects. They were also advised to avoid caffeine for at least 10 hours after the study to prevent caffeine accumulation.

3. Results and discussion

The participants in this study consisted of 16 healthy male university students, with a mean (SD) age of 21.2 (0.4) years. All participants had held a Class A driving license (SIM A) for an average (SD) of 3.69 (1.3) years and had an average (SD) driving experience of 3.81 (1.5) years. Additionally, participants were accustomed to driving an average (SD) of 2.3 (2.2) days per week and an average (SD) of 1.89 (1.4) hours per trip. All participants regularly consumed caffeinated coffee, with an average (SD) of 2.06 (0.3) cups per day.

3.1. Effect of Caffeine on Situation Awareness

3.1.1. Actual Situation Awareness (ASA)

ASA measures the extent to which an individual accurately understands an ongoing situation relative to reality [24]. In the QUASA method, the d-value represents the ASA, calculated as the difference between the Z-scores of the hit rate and the false alarm rate from true/false probes [25]. The hit rate represents the proportion of successful detections of actual information (signal) during the driving simulation. In contrast, the false alarm rate indicates the proportion of incorrect identifications of non-existent information (noise) [25]. The obtained ASA data is shown in Figure 1.

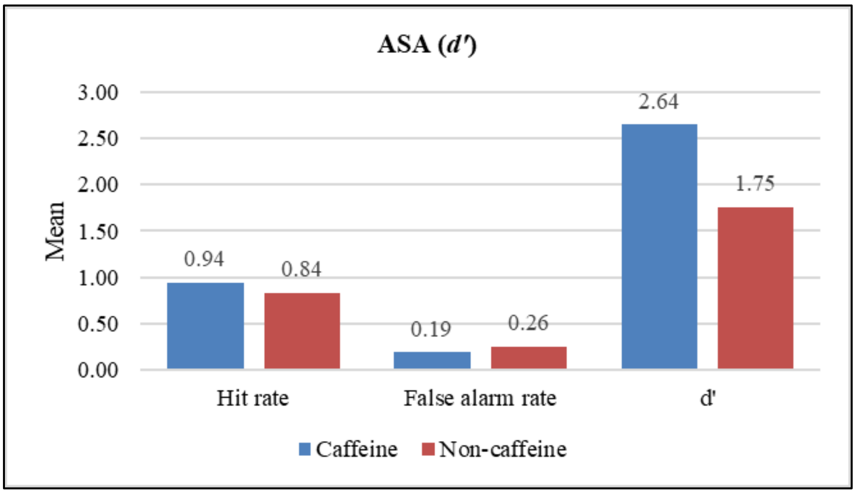

Figure 1 Mean ASA (d’) Values

The results of this study indicate that caffeine consumption improves detection performance (d’) during the driving simulation. The mean hit rate in the caffeine condition was higher than in the non-caffeine condition (0.94 > 0.84), indicating that caffeine enhances the accuracy of signal detection. Additionally, the mean false alarm rate in the caffeine condition was lower than in the non-caffeine condition (0.19 < 0.26), suggesting that participants were less likely to misidentify non-existent signals (noise). The differences in hit rate and false alarm rate between the two conditions demonstrate that caffeine consumption enhances detection performance, as reflected in increased sensitivity to distinguish signals from noise during the driving simulation. This sensitivity is referred to as detection sensitivity (d’).

The d' value reflects the extent to which participants can differentiate actual signals from noise. The d' value ranges from $-\infty$ to $+\infty$ [24], with higher values indicating better ASA during the driving simulation. In this study, all participants obtained positive d ' values, meaning they could distinguish signals from noise in both experimental conditions. However, the mean d' value in the caffeine condition was higher than in the non-caffeine condition (2.64 > 1.75).

The difference in mean d' values suggests that caffeine consumption increases detection sensitivity, allowing participants to differentiate relevant information while driving more accurately. In other words, caffeine enhances alertness, which positively affects information detection performance. This finding is supported by a paired t-test, which showed a significant difference in ASA between the two conditions ($p = 0.001 < 0.05$).

Previous studies have shown that caffeine reduces drowsiness and enhances alertness [17]. Additionally, Wijayanto et al. [11] found that individuals with higher alertness tend to have better ASA. Increased alertness enables drivers to maintain attention for longer periods [11].

ASA is influenced by information-processing capacity, including visual attention and perception [11]. According to Chaparro et al., as cited in Wijayanto [11], drivers with poor visual attention tend to fail to absorb information about their surroundings fully. A decline in visual attention leads to incomplete or inaccurate situational understanding, negatively impacting ASA.

In the non-caffeine condition, drowsiness may reduce drivers' attention capacity, leading to omissions in the early stages of SA—specifically, perceiving the surrounding environment (Level 1). This condition affects situational understanding (Level 2) and the driver’s ability to position themselves within the situation (Level 3). Consequently, participants struggled to respond to critical driving elements. Since road conditions can change rapidly, drivers must remain focused, be aware of their surroundings, and anticipate potential events.

According to Kaber in Wijayanto et al. [11], another factor influencing ASA is working memory. Working memory plays a crucial role in understanding driving elements, perceiving, and retaining information about the driving environment [11]. Difficulties in maintaining SA may arise due to high memory storage and processing demands. Drowsiness impairs temporal memory and information retrieval, ultimately leading to a decline in drivers' situation awareness, particularly in the non-caffeine condition [16].

3.1.2. Bias

Bias measures the extent to which individuals accept or reject information, which can be influenced by factors such as experience or personal opinions (Edgar et al., 2017). Bias is categorized into two strategies: conservative (participants are more cautious in providing answers) and liberal (participants tend to give more positive responses, even at the risk of being incorrect) (McGuinness, 2004). The comparison of participants' bias strategies is shown in Figure 2.

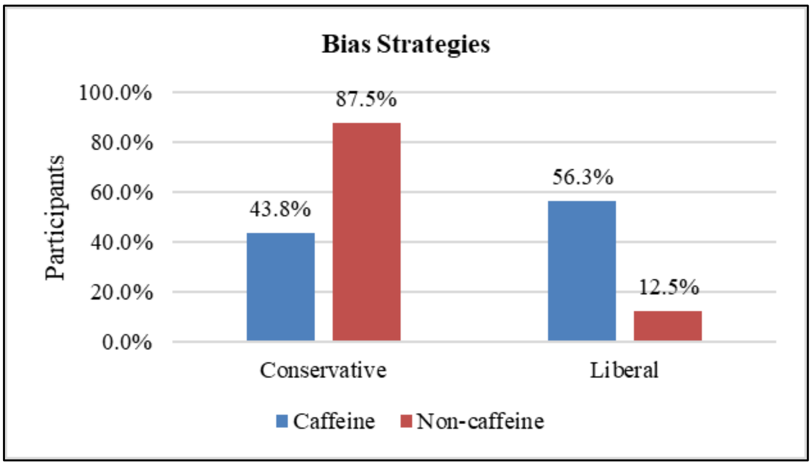

Figure 2 Bias Strategies

The study results indicate that caffeine consumption makes participants more permissive in decision-making, as evidenced by reduced bias values. The mean bias value in the caffeine condition was lower than in the non-caffeine condition (0.44 < 1.41). A lower bias value in the caffeine condition suggests a tendency for participants to accept information as correct (liberal), even when it is actually incorrect. Conversely, a higher bias value in the non-caffeine condition led participants to be more restrictive in their decision-making. They tended to reject information as incorrect (conservative), even if it was actually correct. This excessive caution could hinder quick, accurate decision-making while driving, leading to failures to notice other vehicles or to disregard traffic signs.

The differing bias strategies between the two conditions indicate that caffeine consumption influences participants' decision-making in distinguishing between signals and noise during the driving simulation. This finding is reinforced by the Wilcoxon test, which showed a significant difference in bias between the two conditions ($p = 0.003 < 0.05$).

Research suggests that caffeine affects how individuals process and recall information, making them more open-minded or leaning toward a liberal bias [27]. Additionally, caffeine enhances one's ability to process persuasive messages more deeply, increasing the likelihood of agreeing with viewpoints different from their initial beliefs. Studies have shown that after consuming caffeine, individuals are more likely to change their opinions when presented with information contradicting their prior beliefs [28,29].

3.1.3. Perceived Situation Awareness (PSA)

Perceived situation awareness (PSA) is a measure of a person's confidence in their understanding of a situation, based on subjective judgment [30]. In the QUASA method, PSA values are obtained through the confidence levels provided by participants in simultaneous self-ratings. Unlike ASA, which assesses participants' understanding, PSA only reflects their confidence in recognizing, understanding, and predicting a situation, without considering whether their answers are correct.

The study results indicate that caffeine consumption does not have a significant effect on participants' perception of situation awareness during the driving simulation. In this study, no significant differences in PSA were found between the two treatment conditions. In other words, participants' confidence in their situational understanding remained relatively the same under both caffeine and non-caffeine conditions. This finding is supported by the paired t-test, which showed no significant difference ($p = 0.864 > 0.05$).

Although caffeine can enhance ASA by reducing drowsiness and improving information detection processes (between signal and noise), this effect does not directly impact PSA because PSA is related to subjective perception or self-confidence in drivers [30]. Caffeine may make drivers more objectively alert (thus increasing ASA), but it does not directly alter how participants assess their confidence in understanding a situation. Factors such as personality, experience, and self-confidence are likely more dominant in shaping this subjective perception, suggesting that increased alertness from caffeine does not necessarily lead to an increase in subjective confidence (PSA)

According to Endsley [31], caffeine's effects do not directly enhance overall situation awareness, as SA requires deeper cognitive engagement. Additionally, the SA process is influenced by driver conditions and experience, which are not directly improved by caffeine. Therefore, caffeine consumption alone is insufficient to influence drivers' subjective perception or confidence in their situational understanding.

3.1.4. Situation Awareness Calibration

SA calibration aims to identify biases in participants' self-assessment, determining whether they tend to experience overconfidence (positive bias) or underconfidence (negative bias). Overconfidence reflects excessive self-assurance in one's SA, while underconfidence indicates low self-confidence. In this study, SA calibration was used only as additional information; thus, a paired t-test was not conducted, as the analysis focused on the main variables under investigation. The participants' SA calibration is illustrated in Figure 3.

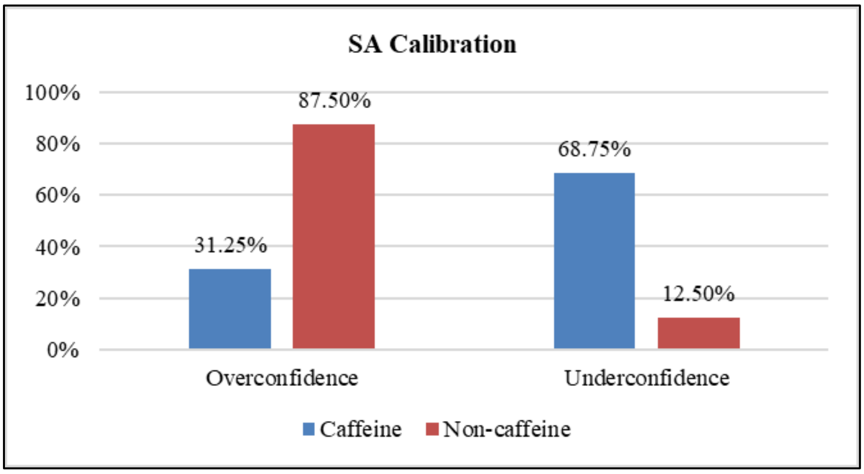

Figure 3 SA Calibration

SA calibration is calculated by comparing perceived accuracy and actual accuracy [25]. Actual accuracy measures participants' correctness in recognizing situations based on the percentage of correct responses to true/false probes in QUASA. The higher this value, the better participants differentiate between actual situations (signal) and non-existent ones (noise). Meanwhile, perceived accuracy represents participants' subjective confidence in the correctness of their answers, measured through simultaneous self-ratings in QUASA. If perceived accuracy exceeds actual accuracy, participants experience overconfidence; conversely, if perceived accuracy falls short of actual accuracy, they experience underconfidence [25].

The perceived accuracy obtained in the non-caffeine condition was higher than the actual accuracy. This indicates that drivers operating under drowsy conditions (without caffeine) tend to be overconfident. Participants in the non-caffeine condition believed they were driving correctly, even though their driving behavior was inadequate and potentially dangerous to themselves and other road users. On the other hand, in the caffeine condition, perceived accuracy was lower than actual accuracy, indicating underconfidence. Participants felt insufficiently confident, even though their driving behavior and performance had actually improved.

3.2. Effect of Caffeine on Alertness

Alertness in driving refers to the driver's ability to remain aware, awake, and responsive to surrounding conditions. This study measured alertness in two ways: subjectively using the Karolinska Sleepiness Scale (KSS) questionnaire and objectively using electroencephalography (EEG). The KSS is a 9-point scale ranging from 1 (fully alert) to 9 (very drowsy). Participants completed the KSS twice: before (pre-treatment) and after 60 minutes of treatment (post-treatment). A KSS score above 5 indicates drowsiness.

The results showed that caffeine consumption had no significant effect on subjectively measured alertness. Based on the paired t-test on KSS score gradients, there was no difference between the caffeine and non-caffeine conditions ($p = 0.324 > 0.05$). Caffeine had no significant effect on subjectively measured alertness, as caffeine-induced changes in brain metabolites were negatively correlated with subjective drowsiness perception. Thus, these neurotransmitter changes did not directly reduce participants' perceived drowsiness [32].

Additionally, a study by Bartrim et al. [33] found that caffeine's ability to reduce perceived drowsiness remains limited, even after sleep deprivation, indicating that psychological factors play a crucial role in how individuals perceive alertness. Although no significant difference was found between the two treatment conditions, the average pre-treatment KSS score in the caffeine condition was higher than in the non-caffeine condition. After treatment, the average KSS score in the caffeine condition decreased, whereas the non-caffeine condition remained stable. This suggests that caffeine can lower subjective drowsiness, but the difference between conditions was not statistically significant.

Meanwhile, objective alertness was assessed using an electroencephalogram (EEG) device that recorded participants' brainwave activity for 60 minutes. The brain wave data used in this study were taken from the frontal lobe, the brain region responsible for decision-making, concentration, alertness regulation, and movement control (both voluntary and reflexive). EEG electrodes were placed at points F3 and F4 to record frontal lobe activity. This selection was based on Burgess and Simons [21], who stated that the frontal lobe is the most effective area for detecting alertness relevant to drowsiness assessment [13].

The analyzed brain waves included theta, alpha, and beta waves, which were used to calculate the EEG drowsiness ratio. The power values of these waves were converted into EEG drowsiness ratio gradients to assess drowsiness progression per minute under both treatment conditions. The results showed that caffeine consumption significantly influenced objectively measured alertness. The paired t-test on the EEG drowsiness ratio gradient indicated a significant difference between the caffeine and non-caffeine conditions ($p = 0.002 < 0.05$).

This occurred because caffeine inhibits adenosine, a compound that induces drowsiness, and stimulates neurotransmitter production, thereby activating the sympathetic nervous system and increasing alertness [6,7]. Figure 4 illustrates the changes in objectively measured drowsiness for one participant (e.g., participant 8), showing that drowsiness increased more rapidly in the non-caffeine condition compared to the caffeine condition.

At the start of the experiment, drowsiness in the non-caffeine condition declined significantly between minutes 10 and 20, then fluctuated, gradually increasing until the end of the session. In contrast, in the caffeine condition, significant drowsiness reduction occurred between minutes 30 and 40, after which drowsiness stabilized. After minute 40, the caffeine condition exhibited a more stable trend with smaller fluctuations, whereas the non-caffeine condition experienced a sharp increase in drowsiness after minute 45. This indicates that caffeine had started to take effect.

This effect aligns with studies showing that caffeine reaches peak plasma concentration within 15–120 minutes after consumption, with an average of about 30 minutes [34].

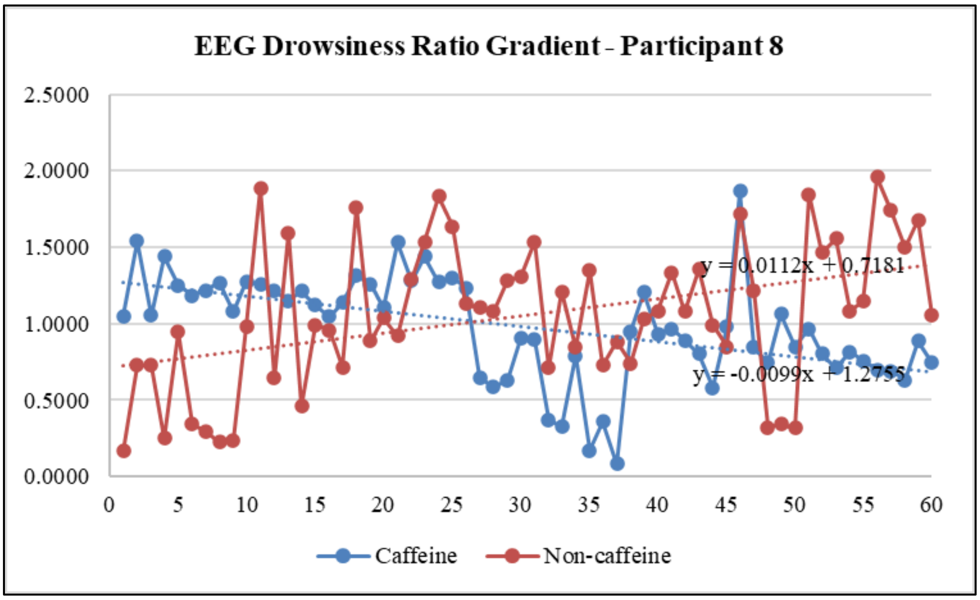

Figure 4 EEG Drowsiness Ratio Gradient of Participant 8

These findings are consistent with the study by Mahachandra et al. [13], which found that caffeine consumption significantly affected alertness as measured objectively. However, there was a difference in subjective measurement results. Mahachandra et al. [13] found that caffeine also had a significant effect on alertness in subjective measurements, whereas the present study did not yield similar results. Caffeine can enhance performance and objectively measured alertness, but does not necessarily make individuals feel more alert.

This discrepancy may be attributed to circadian rhythms, individual differences in drowsiness perception, and the nature of drowsiness itself. Circadian rhythms influence perceived drowsiness, which typically peaks when body temperature is at its lowest, around early morning (2:00–6:00 AM) and in the afternoon (2:00–4:00 PM) [15]. However, objectively measured drowsiness does not always align with circadian rhythms [36]. This means that someone may feel very drowsy at certain times but still perform adequately and remain alert, or vice versa.

Moreover, individuals perceive drowsiness differently. Those with naturally shorter sleep patterns often do not report high drowsiness, even when objective measurements indicate significant drowsiness [37]. This suggests that not all individuals experience increased perceived alertness after consuming caffeine, even if their performance improves [38].

Caffeine can enhance alertness and performance but does not always reduce subjective perceptions of drowsiness-related fatigue [38]. The placebo effect of caffeine consumption may also influence this discrepancy. The placebo effect occurs when individuals feel better after receiving a fake treatment, simply because they believe it is effective [39].

In this study, a placebo effect may have occurred if participants expected caffeine to make them more alert, leading them to report lower post-treatment KSS scores. These expectations could influence their perception of drowsiness, resulting in no significant difference between the caffeine and non-caffeine conditions. Previous studies have shown that expectations of caffeine consumption can enhance perceived alertness, even when caffeine levels in the body are insufficient to produce significant effects [40].

4. Conclusion

Caffeine consumption in a cup of coffee (89.4 mg) can enhance drivers' alertness, as measured objectively. However, subjective alertness analysis indicates that caffeine treatment does not have a significant effect. Nevertheless, when comparing pre- and post-treatment conditions, caffeine consumption tends to reduce the average drowsiness score measured using the KSS. In contrast, in the no-caffeine condition, the average drowsiness score remains relatively stable before and after treatment.

Regarding SA performance, caffeine has been shown to significantly affect ASA and bias, enabling drivers to distinguish relevant information while driving more accurately. However, caffeine does not significantly affect PSA.

To improve and maintain driver alertness and situation awareness (SA) and reduce drowsiness-related risks and accidents, it is recommended to consume caffeine at an optimal dose (<200 mg). High doses of caffeine (>200 mg) may shorten sleep duration, increase daytime drowsiness, and lead to sleep disturbances and aggressive driving behavior [7]. Additionally, getting sufficient sleep of at least 7 hours per night, along with short naps before driving and caffeine consumption, can enhance alertness and reduce the risk of drowsiness-related accidents [15]. Drivers are also advised to take breaks during long trips. According to Law No. 22 of 2009 on Road Traffic and Transportation, public motor vehicle drivers are required to take a minimum 30-minute rest after driving for four consecutive hours [41].

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Statement of ethical approval

This study was conducted in accordance with applicable ethical standards for research involving human participants. All participants were informed about the purpose, procedures, potential risks, and benefits of the study before participation. Participation was voluntary, and informed consent was obtained from all participants prior to data collection. Participants were also assured of the confidentiality of their personal information and could withdraw from the study at any time without penalty.

Statement of informed consent

Informed consent was obtained from all participants prior to their involvement in the study. Participants were provided with clear information regarding the study objectives, experimental procedures, potential risks and benefits, data confidentiality, and their right to withdraw from the study at any time without consequences. Only participants who voluntarily agreed to participate were included in the research.

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