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Effects of caffeine intake and performance pressure on working memory

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Abstract: Performance pressure and caffeine consumption, a common combination in daily life, have both been shown to affect cognitive performance. However, previous research has not fully elucidated the extent to which the effects of caffeine and performance pressure impact cognitive function, especially working memory. This study aims to examine the possibility that caffeine can enhance working memory performance under pressure. A total of 61 participants aged 18 to 32 participated, divided into four groups. Experiment-based data collection was conducted with a single-blind design. Working memory was measured by Modular Arithmetic Tasks with the OpenSesame program. All participants were asked to perform arithmetic tasks and arousal levels were measured using the Galvanic Skin Response (GSR). The findings revealed no evidence of an interaction effect of caffeine intake and performance pressure on working memory ($F= .632$, $p= .431$, $\eta_p^2 = .012$). Given the prevalence of caffeine intake prior to facing high-pressure situations, the consumption of a cup of coffee does not improve cognitive performance as many would expect. However, caffeine intake had a stabilizing effect on the skin conductance response values during performance under pressure. Clinical psychologists can use a daily dose of caffeine as an alternative intervention or preventative measure to help patients reduce performance pressure-related anxiety.

Keywords: caffeine; Galvanic Skin Response; Modular Arithmetic Tasks; OpenSesame; performance pressure; working memory

Abstrak: Tekanan kinerja dan konsumsi kafein merupakan kombinasi umum dalam kehidupan sehari-hari, keduanya terbukti memengaruhi kinerja kognitif. Namun, penelitian sebelumnya belum sepenuhnya menjelaskan sejauh mana efek kafein dan tekanan kinerja berdampak pada fungsi kognitif, terutama *working memory*. Penelitian ini bertujuan untuk menguji efek kafein terhadap *working memory* di bawah kondisi tekanan kinerja. Sebanyak 61 peserta berusia 18 hingga 32 tahun berpartisipasi pada penelitian ini, dibagi secara acak menjadi empat kelompok. Pengumpulan data berbasis eksperimen dilakukan dengan desain *single-blind*. Alat ukur yang digunakan adalah *Modular Arithmetic Tasks* dengan program *OpenSesame* untuk mengukur *working memory* serta *Galvanic Skin Response* (GSR) untuk mengukur tingkat gairah. Hasil menunjukkan bahwa tidak ada bukti efek interaksi konsumsi kafein dan tekanan kinerja pada *working memory* ($F= 0{,}632$, $p= 0{,}431$, $\eta_p^2 = 0{,}012$). Mengingat prevalensi asupan kafein sebelum menghadapi situasi tekanan tinggi, konsumsi secangkir kopi tidak meningkatkan kinerja kognitif seperti yang diharapkan banyak orang. Namun, konsumsi kafein memiliki efek stabilisasi pada nilai respon konduktansi kulit selama kinerja di bawah tekanan. Psikolog klinis dapat menggunakan kafein dengan dosis harian sebagai intervensi alternatif atau tindakan pencegahan untuk membantu pasien mengurangi kecemasan yang berkaitan dengan tekanan kinerja.

Kata Kunci: kafein; *Galvanic Skin Response*; *Modular Arithmetic Tasks*; *OpenSesame*; tekanan kinerja; *working memory*

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Introduction

As humans, we perform activities involving cognitive processes. When performing cognitive tasks, we require and must be able to process various sources of information. The resource used for these mental activities is working memory, which comprises a limited amount of information stored in our brains that is applied to complete cognitive tasks (Cowan, 2014). Baddeley (2007) defined working memory as a system with limited storage and processing capabilities. This limitation is primarily applied to cognitive control, which requires abstract reasoning, flexibility, and hierarchical rules to select behavior (Westbrook & Braver, 2016). Consequently, optimizing the allocation of working memory is critical to maximizing behavior and producing good performance.

Ericsson and Delaney (1999) suggested that working memory is crucial in human cognition. Every human activity involves working memory ability, including the reasoning process, language understanding, planning, and spatial processing, all of which relate to the prefrontal cortex (PFC) (Cools & D'Esposito, 2011; Miller & Cohen, 2001). In educational settings, working memory has been positively related to fluid intelligence, mathematical problem solving, and general academic achievement (Alloway & Alloway, 2010; Uittenhove & Lemaire, 2013; Unsworth & Engle, 2005). As a result, the positive working memory link should be relatively robust for higher-order cognitive activities, as such tasks are mental operations that require rule and goal maintenance to be completed successfully (Smeding et al., 2015).

Numerous internal and external factors influence working memory optimization, mainly when complex cognitive processing is performed. Individual factors such as age, personality, and medical or mental conditions are examples of internal factors (Blasiman & Was, 2018). Meanwhile, external factors such as hostile environments, stressful situations, and substances frequently impact working memory performance. Performance pressure and the consumption of certain substances, such as caffeine, are external factors that affect working memory in daily life.

In everyday life, stressful situations such as workload, peer pressure, job selection, and evaluation have a significant impact on individuals' psychological health. In educational settings, numerous tests, evaluations, and due dates can generate anxiety, thus exerting pressure on students to perform well. Excessive anxiety can lead to stress that impairs working memory performance (Vogel & Schwabe, 2016). It has been hypothesized that stress-induced changes in working memory contribute to decreased performance. Stress, on the other hand, has been found to have both enhancing and inhibiting effects on working memory, depending on the specific memory process or stage affected by the stress and the activity profile of critical physiological stress response systems (DeCaro et al., 2011; Smeding et al., 2015; Yu, 2015).

Working memory is considered important in the human cognition-related ability to conduct a variety of everyday tasks such as driving, writing, reading, and various others (Baddeley, 2007, 2012). Our current focus is on the latter—mental arithmetic. Working memory capacity has been significantly connected to arithmetic problem-solving competence and, in particular, the speed of both fact retrieval and execution of the carry operation (Beilock, 2008; Jansen et al., 2013; Mattarella-Micke et al., 2011).

Numerous studies have demonstrated that when feeling under high pressure to achieve well, individuals frequently show less than optimal performance, commonly known as the phenomenon of choking under pressure (Beilock et al., 2004; DeCaro et al., 2011). Choking under pressure occurs in both real-world and laboratory settings, such as when solving math problems, in exams, in competitive situations, and when high incentives are given (Beckmann et al., 2013; DeCaro et al., 2010; Mattarella-Micke et al., 2011; Wan & Huon, 2005). In an experimental setting, performance pressure is commonly manipulated by stress-induced situations (monetary reward, evaluation, monitoring, and peer pressure) (Beilock et al., 2004; Boere et al., 2016; Smeding et al., 2015). These manipulations can trigger stress for individuals and lead to choking under pressure.

Distraction theory can mainly be used to explain decreased performance on cognitive tasks caused by performance pressure. According to distraction theory, stress creates a distracting environment (such as feelings of worry and thinking about the consequences of one's performance) that diverts individual attention away from task completion and performance (Ashcraft & Kirk, 2001; Wine, 1971). As a result, the accessible working memory to complete the main task will be reduced, resulting in poor performance (Beilock, 2008; Yu, 2015). This occurs due to a diversion of the available working memory for completing the primary task to irrelevant matters such as worries, causing performance to deteriorate and become sub-optimal (Beilock, 2008; Yu, 2015).

Decreased cognitive performance due to performance pressure can also be explained by a biopsychological mechanism, specifically the role of dopamine (DA), a neurotransmitter, which is crucial in complex cognitive functions, including working memory. In brain mechanisms, the relationship between cognitive performance and DA release conforms to the inverted U-shape law (Cools & D'Esposito, 2011). While increased DA may initially result in improved PFC control and performance, when DA levels in the PFC rise above optimal levels, PFC control declines, resulting in poor performance on PFC-dependent tasks such as working memory (Cools & D'Esposito, 2011).

In a clinical psychology setting, caffeine has been related to a range of psychiatric and substance use disorders in the general population. In some instances, caffeine has been observed to have beneficial effects, with low dosages demonstrated to alleviate anxiety and enhance mood (Haskell et al., 2005; Lieberman et al., 2002; Smith et al., 1999). Caffeine consumption has also been associated with a lower risk of depression compared to abstinence (Smith, 2009).

Aside from the clinical effects, people in society believe that coffee can provide a temporary boost to cognitive performance. Caffeine is the most consumed psychostimulant globally, and it can improve cognitive performance. Caffeine is a central nervous system stimulant with positive effects such as increased alertness, the provision of a temporary boost of energy, and elevated mood (Peeling & Dawson, 2007; Smith, 2002). Some people consume caffeine-containing beverages, especially coffee, when they feel a strong need to perform at their best in a critical situation. According to Cappelletti et al. (2015), caffeine consumption is increasing worldwide, with a motivation set primarily to improve concentration and memory, and increase physical performance.

At the neurochemical level, caffeine influences performance via its effect on the endogenous neuromodulator adenosine. Specifically, it can readily cross the blood-brain barrier and inhibits the A1 and A2A adenosine receptors (Addicott et al., 2009; Pelligrino et al., 2010). Caffeine binds to the A1 and A2A receptors by this mechanism, rendering adenosine binding impossible. A1 adenosine receptors are found in nearly every brain area and are known to prevent transmitter release in all neuron types (Lorist & Tops, 2003). Thus, caffeine inhibits the function of adenosine, increasing other neurotransmitters, including DA.

Early elimination of one's initial anxiety response appears to be crucial, before anxiety can diminish actual performance. As such, prevalent caffeine consumption in stressful situations is a common practice in the context of everyday life (such as deadlines, final exams, professors giving lectures, and doctors performing high-risk surgery). Surprisingly, the combination of performance pressure and caffeine intake may significantly affect how well people work since caffeine, like performance pressure, is known to increase DA levels. Importantly, the relationship between DA release and PFC control takes the form of an inverted U (Arnsten, 2009). In other words, when DA levels in the PFC exceed optimal levels, PFC control decreases, resulting in impaired performance on tasks that rely on the PFC, including working memory. Thus, when individuals perform in stressful situations, both caffeine intake and performance can affect working memory. Caffeine has also been found to enhance the performance-degrading effect of pressure at exceptionally high doses of 200 mg (Boere et al., 2016).

In biological mechanisms, both performance pressure and caffeine impact multiple neurotransmitter systems related to cognitive functioning (Brunyé et al., 2010; Carli & Invernizzi, 2014). In moderate doses, caffeine, like performance pressure, can improve performance; however, in high doses, such as more than 200 mg, it can impair performance (Lorist & Tops, 2003). At the psychological level, it is believed that caffeine-induced increases in performance are mediated by a general increase in attention and processing speed, as well as a reduction in fatigue (Glade, 2010; Lorist & Tops, 2003). The decrease in task performance is caused by caffeine at higher doses (such as more than 200 mg) due to increased DA. As a result, it influences cognitive performance by modulating the degree to which the PFC controls activity (Arnsten, 2009; Lorist & Tops, 2003; Smith, 2002).

In the present study, the participants were asked to solve a series of mathematical arithmetic tasks. Mental arithmetic tasks illustrate the organization of working memory because they require intensive processing in real time (Beilock et al., 2004). Due to the complexity of challenging mathematical operations, such as carrying during addition and borrowing during subtraction, working memory is deemed to be of particular importance (Beilock et al., 2004). Meanwhile, performance pressure can lead to thoughts and anxieties that interfere with the executive core (Beilock et al., 2004).

In mental arithmetic problems dependent on working memory, individuals have been found to respond differently depending on whether the initial subtraction step involved large numbers (greater than 10) and borrowing from the ten's column (for example, 46-28). Larger numbers and borrow operations demand longer sequences of steps and the storage of a greater number of intermediate memory products, thereby increasing working memory requirements (Imbo et al., 2007). When performance pressure affects working memory, performance on problems demanding high working memory should be more likely to deteriorate than on those demanding low working memory (Beilock, 2008; Smeding et al., 2015).

In this study, the mental arithmetic tasks were demonstrated, with each segment consisting of low-demand problems requiring a single-digit subtraction without borrowing, intermediate problems requiring a double-digit subtraction without borrowing, and high-demand problems requiring a double-digit subtraction with borrowing. Complex problems involving large numbers and borrow operations place a greater demand on working memory capacity than problems involving small numbers and no borrow operation (Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001). If stress affects working memory, then performance should be more likely to decline on problems requiring more working memory than on problems requiring less working memory.

The mental arithmetic tasks were presented in three blocks. The initial block served as a pre-test performance measurement. The second section was designed to stabilize performance. The objective of the third phase was to measure the effects of the pressure manipulation. Based on Beilock et al. (2004), during the third session, half of the participants were subjected to performance pressure versus no performance pressure. The pressure scenario was founded on common sources of pressure across skill domains, including financial incentives, peer pressure, and social evaluation (Beilock et al., 2004; Boere et al., 2016). Although the precise manner in which these various sources of pressure exert their influence is an empirical question, the objective of this study was to document the actual phenomenon of choking under pressure. We thus created a pressure scenario that incorporated as many elements of high-pressure performance as feasible.

According to the preceding description, performance pressure and caffeine can interact. The combination of performance pressure and caffeine intake can significantly affect a person's performance. A stimulation is essentially psychological and is associated with either external or internal stimuli that cause stress or, more broadly, arousal (Christopoulos et al., 2019). Thus, to observe the effect of our manipulation on the participants' arousal, we used the skin conductance response (SCR). SCR is a biomarker of arousal with a well-known psychophysiological functioning; it is a well-established, robust, and inexpensive method that provides an objective transient indication of autonomic nervous system arousal that tracks changes in the visceral status of the body due to increased sympathetic activity (Christopoulos et al., 2019; Lempert & Phelps, 2014). As a result of elevated sympathetic activity, SCR amplitude is correlated to arousal level and can be evoked by external stimuli with either a positive or negative emotional valence (Bradley et al., 2001; Reimann & Bechara, 2010). SCR has been linked to various essential components of human behavior, such as anxiety, emotional responses, and decision-making. However, SCR amplitude is sensitive to stimulus intensity. Thus, SCR usage must be rigorously monitored to ensure the data obtained contains no excessive noise or artifacts causing signal fluctuation (Braithwaite et al., 2013; Dawson et al., 2000). Artifacts can also be generated by a subject's abrupt movements and tugging on the electrode wires (Braithwaite et al., 2013).

A change in skin conductance is generally known as the Galvanic Skin Response (GSR). As a result of elevated sympathetic activity, GSR signal amplitude is linked to arousal level and can be elicited by positive or negative emotional stimuli (Bradley et al., 2001; Reimann & Bechara, 2010). Prior studies have confirmed that caffeine increases SCR, heart rate, respiratory activity, blood pressure, and subjective alertness (Batista et al., 2022; Flaten et al., 2003; Lyvers et al., 2004). We measured SCR and blood pressure to explore how caffeine and performance pressure affect working memory. Taking a measure of SCR enabled us to explore whether or not performance pressure induced higher arousal rates. During the experimental session, GSR measurement was taken to determine how our manipulations affected SCR. In addition, the participants' blood pressure was measured as this had previously been found to correlate with caffeine consumption.

The combination of caffeine consumption and performance stress is common; however, the extent of its effect on working memory is unknown. The idea is that clinical psychologists can use caffeine as an alternative to behavioral intervention to alleviate performance-related anxiety in patients. Furthermore, individuals can self-medicate with caffeine because it is a legal, evidence-based substance. To the best of our knowledge, only one study by Boere et al. (2016) has examined the effects of caffeine and performance stress on cognitive performance and found that while caffeine and performance pressure affect cognitive performance, there was no hint of an interaction effect. Furthermore, caffeine was found to enhance the performance-degrading impact of pressure at exceptionally high doses of 200 mg (Boere et al., 2016). However, while their study used large amounts of caffeine, it did not control the participants to avoid caffeine consumption 24 hours before the experiment, which may have affected the result (Boere et al., 2016). Therefore, this study provides novelty by examining the effects of low doses of caffeine (equivalent to a cup of coffee) and performance pressure on working memory. Through the interaction effect of caffeine consumption and performance pressure on working memory, the study was designed to test the idea that low doses of caffeine can improve working memory under performance conditions. The proposed hypothesis is that caffeine and performance pressure interact with working memory and that groups that consume caffeine while under high-performance pressure have better working memory.

Methods

Participants and Design

An experimental method with a between-subject design was used in this study. The study used purposive sampling with clear criteria and rationale for inclusion. To obtain a relatively homogeneous sample and reduce other potentially confounding factors associated with cognitive abilities, we recruited participants aged between 18 and 32 years. This age range was chosen because, according to Hale et al. (2011), the basic multi-components of working memory tend to persist in adulthood. Furthermore, to avoid gender differences, only male participants were included. Previous works have shown that hormone and menstrual cycles play a role in working memory, especially in females (Duff & Hampson, 2000; Hampson & Morley, 2013; Lejbak et al., 2011). To avoid familiarity with the task, participants recruited from Universitas Gadjah Mada, Yogyakarta, Indonesia, were not mathematics majors (Beilock et al., 2004). The participants comprised 61 people (100% male; mean age = 23.3 years, age range = 18–32 years), who were randomly assigned to four groups: those who consumed caffeine with high performance pressure (n = 15), those who consumed caffeine with low-performance pressure (n = 15), those who consumed decaffeinated coffee with high performance pressure (n = 15), and those who consumed decaffeinated coffee with low performance pressure (n = 16). According to Cohen et al. (2007), experimental methodologies require at least 15 participants. These references are accessible to researchers with tiny sample sizes. However, our design has several observations per participant per condition. Zwaan et al. (2018) demonstrated that several cognitive psychology effects have effect sizes of $d_z > 0.5$ when considering multiple observations per condition. It is thus reasonable to expect that averaging multiple observations per condition per participant will increase the power of an experiment (Brysbaert, 2019).

Summarily, the participants were randomly assigned to one condition of the 2 (type of pressure: low vs. high) x 2 (type of coffee: caffeinated vs. decaffeinated: single-blind) between-subjects design (see Table 1). Each potential participant had to abstain from caffeine-containing food and beverages (such as coffee, soft drinks, tea, green tea, and chocolate) and herbal supplements for 24 hours before the start of the experiment. Each participant provided informed consent following a procedure approved by the Ethics Commission of Gadjah Mada University Faculty of Psychology under 176/UN1/FPSi.1.3/SD/PT.01.01/2020.

For medical reasons, the consent form contained the inclusion criteria of no history of gastric acid, high blood pressure, visual disturbances, and vertigo. Participants who did not meet these inclusion criteria were welcome to withdraw. The data of seven participants were excluded from the analysis because their accuracy score was below 55% (according to Beilock et al., 2004; Boere et al., 2016), resulting in a final sample of 54 participants.

In this study, the participants completed a modular arithmetic task under performance pressure. Performance pressure was manipulated through arithmetic problems that required working memory performance (low, medium, and high demand) and three pressure conditions simultaneously (such as monetary incentives, pressure from groups, and social evaluation). This scenario was created to investigate how performance constraints can interfere with, and even deplete, working memory capacity for modular arithmetic tasks. Pressure situations can cause participants to feel pressured and reduce accuracy. Arithmetic problems requiring significant working memory are difficult to solve because performance pressure can lead to distracting thoughts and careless calculation errors, resulting in sub-optimal performance in situations where performance is under pressure (creating choking under pressure). In addition, the completion of the modular arithmetic task demanded a mental calculation process that required working memory performance. Understanding how performance pressure impairs working memory performance, even through relatively simple calculations, can thus explain how performance degradation can occur (choking under pressure).

Measurement

Modular Arithmetic Tasks

Based on Beilock et al. (2004), the modular arithmetic task comprised three sessions of 24 simple arithmetic problems, such as $36 \equiv 22 \pmod 2$, which were used to assess working memory demand. In this task, the participants were asked to validate arithmetic questions in the form of arithmetic statements on a computer screen, determining whether the statements were true or false. The arithmetic problems were solved by deducting the second number from the first ($36 - 22 = 14$) and dividing the result by the third or modular number ($14/2 = 7$). If the result of this division was a whole number, such as 7 in this case, then the statement was true; otherwise, it was false.

Table 1

List of Participants

Type of Coffee	Type of Pressure	
	Low Pressure	High Pressure
Caffeinated coffee	15 participants	15 participants
Decaffeinated coffee	16 participants	15 participants

Note. The participants were divided into four groups based on the type of pressure and coffee.

The arithmetic problems were manipulated into low, medium, or high working memory demand. The problems were performed by manipulating whether the solution to the problem required a single-digit subtraction operation without borrowing for low-demand tasks, e.g., 6 ≡ 2 [mod 3]; a two-digit subtraction operation without borrowing for intermediate-demand tasks, e.g., 46 ≡ 15 [mod 7], or a two-digit loan subtraction operation for high-demand tasks, e.g., 55 ≡ 28 [mod 9]. Each session consisted of 8 low-demand, 8 medium-demand, and 8 high-demand questions (Beilock et al., 2004). The questions in each block were presented in random order (see Table 2). Every true statement had a false pair in the same session (created by changing only the "mod" or modular number).

Procedure

The participants took their blood pressure in a separate room before the experiment began. The first GSR measurement was taken for five minutes as a baseline measurement. Furthermore, caffeine manipulation was administered to the participants based on their group (see Figure 1).

Caffeine Manipulation. Caffeine consumption in this study was at a low dose of 50 mg, equivalent to the caffeine content of food and beverages (equal to one 2 mg coffee sachet). Caffeine was given to two groups (high-performance pressure and low-performance pressure) in the form of coffee drinks containing 50 mg of caffeine. This manipulation design enabled us to investigate the effect of caffeine independent of pressure (by looking at the pressure-free blocks 1 and 2 as a function of caffeine intake). Crucially, it also enabled us to determine whether caffeine increased the effect of performance pressure. We estimated an increase in performance from blocks 1 to 3 in persons who had consumed caffeine (vs. the decaffeinated condition).

The coffee was a robusta variety dissolved in 150 ml of 80°C water. Meanwhile, the decaffeinated conditions were divided into high-performance and low-performance groups, and the participants consumed decaffeinated coffee from the same brand. The participants were instructed to finish their coffee drink within 5 to 8 minutes. They were then asked to wait 30 minutes for the caffeine to fully react in their bodies (Boere et al., 2016; Lorist & Tops, 2003). The experimenter measured the participants' blood pressure again precisely 30 minutes after they had finished their coffee drinks.

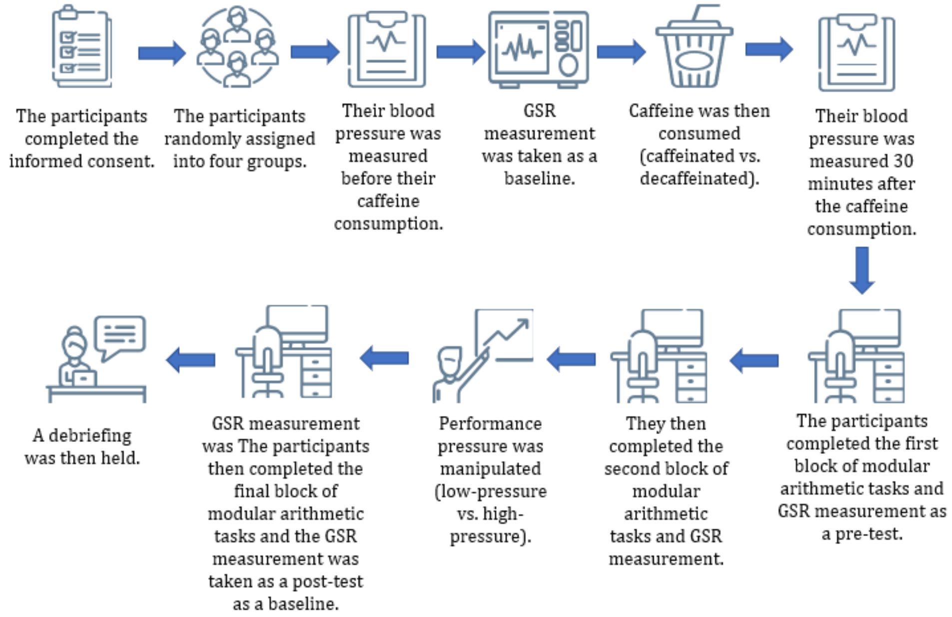
Table 2

The Mental Arithmetic Problems

Modular arithmetic tasks based on the type of working memory demand	Measures		
	Block 1	Block 2	Block 3
Low-demand (single-digit subtraction operations)	8 problems	8 problems	8 problems
Intermediate (a two-digit subtraction operation without borrowing)	8 problems	8 problems	8 problems
High demand (a two-digit loan subtraction operation)	8 problems	8 problems	8 problems
∑ arithmetic problems in each block	24 problems	24 problems	24 problems

Figure 1

Experiment Procedure



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Following the coffee intake, the participants commenced the modular arithmetic tasks. According to the research of Bailock et al. (2004) and Boere et al. (2016), modular arithmetic assignments should be divided into three sessions. The participants were asked to complete the task in two sessions with no time constraints and instructed to maximize speed and accuracy during these first two sessions. GSR measurements were also taken while the participants worked on the arithmetic tasks.

After completing two sessions of arithmetic assignments, the participants were asked to summon an experimenter, who provided instructions and manipulated performance pressure based on the group conditions previously obtained. Participants in high-pressure conditions were exposed to three concurrent, pressure-inducting manipulations, according to Beilock et al. (2004).

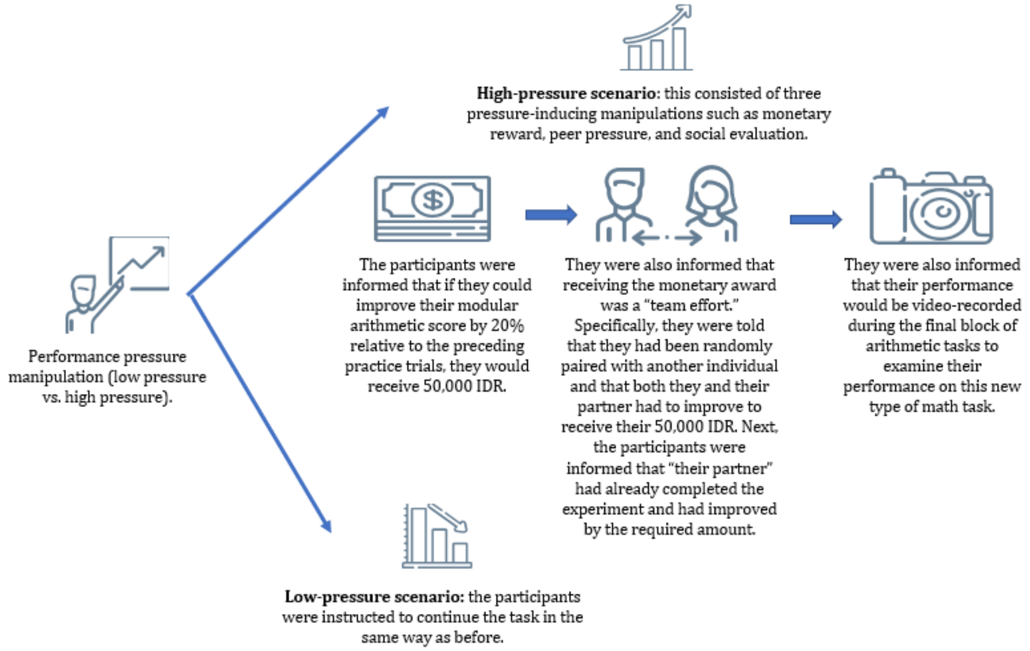
Performance Pressure Manipulation

In the third session, the experimenter induced pressure reflecting real-life situations. The pressure scenario consisted of three sources of pressure: monetary reward, peer pressure, and social evaluation (see Figure. 2). In experimental settings, this manipulation of performance pressure is commonly used to produce the choking under pressure phenomenon (Beilock, 2008; Beilock et al., 2004; Boere et al., 2016; Smeding et al., 2015).

First, the participants were informed that the amount of money they could earn was contingent on their next performance. Moreover, they were explicitly told that their performance in the previous session score had been calculated to receive the prize money (50,000 IDR), so their performance in the third session had to improve by 20% relative to their previous score. They were

Figure 2

The Scenario of Performance Pressure Manipulation



High-pressure scenario: this consisted of three pressure-inducing manipulations such as monetary reward, peer pressure, and social evaluation.

Performance pressure manipulation (low pressure vs. high pressure).

The participants were informed that if they could improve their modular arithmetic score by 20% relative to the preceding practice trials, they would receive 50,000 IDR.

They were also informed that receiving the monetary award was a "team effort." Specifically, they were told that they had been randomly paired with another individual and that both they and their partner had to improve to receive their 50,000 IDR. Next, the participants were informed that "their partner" had already completed the experiment and had improved by the required amount.

They were also informed that their performance would be video-recorded during the final block of arithmetic tasks to examine their performance on this new type of math task.

Low-pressure scenario: the participants were instructed to continue the task in the same way as before.

also told that if their performance did not improve, they would only receive 20,000 IDR. Second, in the peer pressure scenario, participants were informed that they had been paired with other participants who had previously participated in the experiment as "a team." As team partners, the participants were informed that they and their partner must improve their performance to receive the total prize money. However, they were also told that their partner had already successfully improved their performance. In applying this scenario, the participants were led to believe that their reward and that of their partners depended on their performance in the last session. Lastly, for the social evaluation scenario, the experimenter activated a video camera mounted on a tripod and informed the participants that the experiment would be recorded to observe how serious they were about completing the task in the third session. In this way, the participants in the high-pressure situations were subjected to a variety of performance pressures simultaneously.

Performance pressure manipulation (low pressure vs. high pressure). High-pressure scenario: this consisted of three pressure-inducing manipulations such as monetary reward, peer pressure, and social evaluation. The participants were informed that if they could improve their modular arithmetic score by 20% relative to the preceding practice trials, they would receive 50,000 IDR. They were also informed that receiving the monetary award was a "team effort." Specifically, they were told that they had been randomly paired with another individual and that both they and their partner had to improve to receive their 50,000 IDR. Next, the participants were informed that "their partner" had already completed the experiment and had improved by the required amount. They were also informed that their performance would be video-recorded during the final block of arithmetic tasks to examine their performance on this new type of math task. Low-pressure scenario: the participants were instructed to continue the task in the same way as before. They completed the tasks in the last 24 modular arithmetic trials after being subjected to performance pressure manipulation (see Figure 2 for details). Finally, after the third-session assignments had been completed, the experimenter gave and explained the debriefing procedure, and each participant received a reward based on their performance.

Manipulation Check

Blood Pressure

Acute caffeine consumption has been linked to several acute cardiovascular effects, including increased blood pressure (Riksen et al., 2009). As a result, the treatment check was performed by measuring blood pressure to determine the success or failure of the treatment in the form of caffeine consumption for caffeinated and decaffeinated beverages.

Galvanic Skin Response

In this study, the GSR was measured using a Bluetooth-connected Shimmer3 GSR+ plate to obtain objective data regarding the level of arousal in each participant. The Shimmer3 GSR+ plate was placed on the distal phalages of the middle and index fingers of the participants's non-dominant hand. Lang (1995) claimed that the GSR has a linear relationship with arousal and reflects emotional and cognitive activity (Boucsein, 2012). GSR measurements were taken twice: once before coffee consumption (baseline) and once while working on the modular arithmetic tasks.

Results

Before testing the research hypothesis, the researcher ensured there were no outliers from the data by analyzing the accuracy and response time (RT). The RT for each arithmetic question and the average RT for each session was calculated for each participant. An average RT for each session that deviated by more or less than three standard deviations (3SD) was considered an outlier and was removed from the entire data (Beilock et al., 2004). Next, the accuracy score and RT for each arithmetic problem with the correct answer were analyzed. Then, a two-way ANOVA test was performed on the accuracy of working memory performance to assess the interaction effect of caffeine and performance pressure.

Interaction Effect of Caffeine and Performance Pressure

Testing of the main hypothesis, namely the interaction effect of caffeine and performance pressure, was conducted by analyzing data on changes in accuracy scores in the pre-test and post-test sessions. The analysis used a 2 (type of performance pressure: low vs. high) x 2 (type of coffee: caffeinated vs. decaffeinated) ANOVA. Two-way ANOVA analysis showed no interaction effect between the type of coffee and the type of performance pressure (F= .632, p= .431, η_p^2 = .012). We also looked at the main effect of each independent variable on working memory, specifically caffeine and performance pressure. Furthermore, the analysis found no main effect of performance pressure on working memory (F = .945, p = .336, η_p^2 = .019), indicating that performance pressure did not impair working memory. However, neither was there a main effect of the type of coffee (F = 1.004, p = .321, η_p^2 = .020), indicating that caffeine did not improve working memory. As a result, there is no direct evidence to support the hypothesis that caffeine improves working memory performance in high-pressure situations. The line pattern of changes in accuracy can be used to interpret the pattern of these results) (Figure 3).

Performance Pressure Effects

To explore whether performance pressure impaired working memory performance, the average accuracy score was analyzed in a 2 (type of performance pressure: low vs. high, between subjects) x 2 (session: pre-test vs. post-test, within-subject) ANOVA. The analysis revealed no difference in working memory between the high and low performance pressure types (F = .020, p = .889, η_p^2 = .00). Moreover, there was no difference in working memory before and after working pressure application (F = .084, p = .773, η_p^2 = .02). The analysis also revealed no interaction between the session (pre-test and post-test) and the type of performance pressure (high-low) (F= 1.131p= .292, η_p^2 = .021), indicating that the difference in the pre-test to

Figure 3

Changes in Accuracy based on Performance Pressure and Type of Coffe

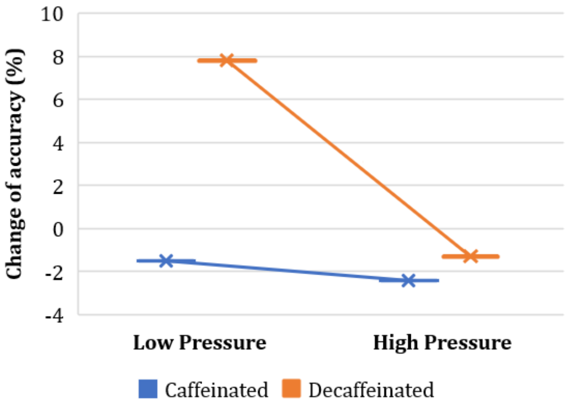
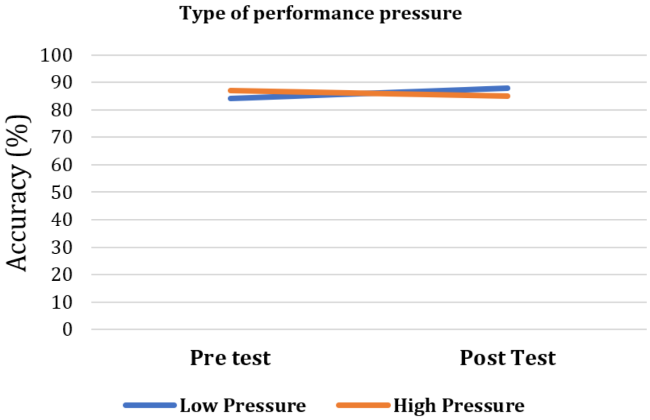


Figure 4

Working Memory Performance based on Performance Pressure Type



post-test scores between the two groups were not statistically significant. In other words, no evidence was found that performance pressure affects working memory. Figure 4 depicts this pattern of results.

Moreover, to further investigate the effects of performance pressure on working memory performance, the researchers used a 2 (performance pressure: high vs. low, between subjects) x 2 (session: pre-test vs. post-test, within-subject) x 2 (task demand: low vs. high, within-subject) ANOVA. This analysis revealed that task demand had no main effect (F = .122, p = .728, η_p^2 = .001).

Furthermore, there was no interaction between session (*pre-test vs. post-test*) and task demand type (*high demand vs. low demand*) based on performance pressure (F= .034, p= .855, η_p^2 = .00), indicating that the difference in the pre-test and post-test scores for the two types of task demand (high and low) was not statistically significant. This pattern of results can be interpreted using the average pattern of working memory performance (Figure 5).

Effects of Caffeine

The average working memory accuracy score before and after the given performance pressure manipulation was calculated to examine the effect of caffeine consumption on working memory. A 2 (task demand types: low vs. high, within-subject) x 2 (coffee types: caffeinated vs. decaffeinated, between subjects) ANOVA was used for the analysis. The results of the analysis showed no interaction effect of task demand (low vs. high demand) and coffee (caffeinated vs. decaffeinated) (F = .147, p = .703, η_p^2 = .003). The absence of this interaction indicated that the change in accuracy from low- to high-demand tasks was not significantly different between the two groups of coffee types (caffeinated vs. decaffeinated). As a result, there was no evidence that caffeine manipulation directly affects working memory. However, the analysis found that the type of task load (task demand) significantly impacted working memory (F = 48.906, p = .000, η_p^2 = .485). Both groups (caffeine and decaffeinated) experienced decreased accuracy as they progressed from the low- to high-demand tasks. In other words, accuracy decreased when the task was high-demand or required a lot of working memory. Figure 6 depicts the pattern of analysis results.

Manipulation Check

Blood Pressure

Checking of the caffeine consumption manipulation was conducted on blood pressure, namely each systolic and diastolic score with a 2 (coffee types: caffeinated vs. decaffeinated, between subjects) x 2 (session: pre-test vs. post-test, within subjects) ANOVA. This analysis revealed no significant differences in pre-test vs. post-test scores between the two groups (F = .006, p = .939, η_p^2= .000). However, there was a significant difference in the systolic reading between the pre-test (Mean = 116.25, SD = 11.27) and post-test (Mean = 108.11, SD = 16.11) with (F = 12.259, p = .001, η_p^2 = .194). According to these findings, the systolic scores of both groups decreased between the pre-test and the post-test. This pattern of results is shown in Figure 7.

Furthermore, analysis of the diastolic scores revealed an interaction effect between the type of coffee (caffeinated vs. decaffeinated) and the session (pre-test and post-test) (F = 21.575, p = .000, η_p^2 = .285). Pre-test session; caffeine (Mean = 76.46, SD = 9.16); decaffeinated (Mean = 78.86, SD = 7.78). Post-test session; caffeine (Mean = 78.57, SD = 7.02); decaffeinated (Mean = 71.5, SD = 5.54). These results show that the change in diastolic scores between the pre-test and the post-test was significantly different in the two groups. The pattern of analysis results is shown in Figure 8.

Figure 8 shows that the type of coffee influences the effect on the diastolic score. The diastolic score in the caffeine group decreased between the pre-test and the post-test, whereas in the decaffeinated group, it remained stable.

Arousal

The manipulation of performance pressure on the GSR value was checked, namely each GSR value with a 2 (type of performance pressure: low pressure vs. high pressure, between subjects) x 3 (session: baseline vs. pre-test vs. post-test, within-subjects) ANOVA test. The analysis results revealed no main effect of the type of performance pressure at the group level (F = .260, p = .613, η_p^2 = .005).

Figure 5

Working Memory Performance based on the Type of Task Demand

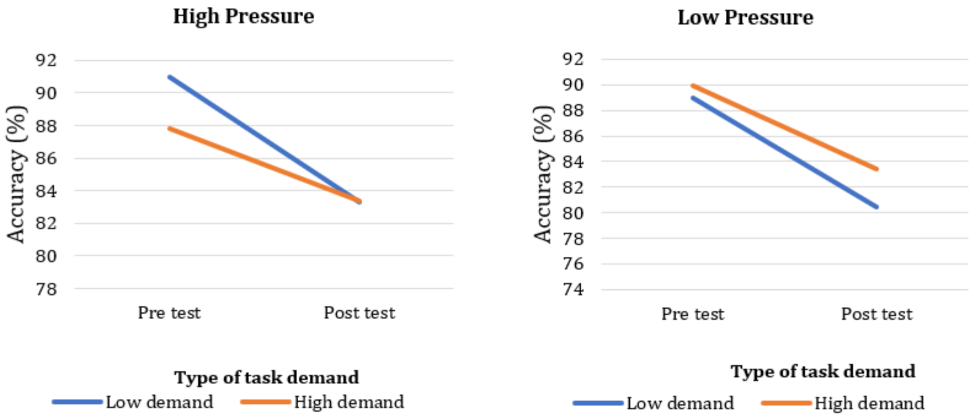


Figure 6

Working Memory Performance based on Caffeine Consumption

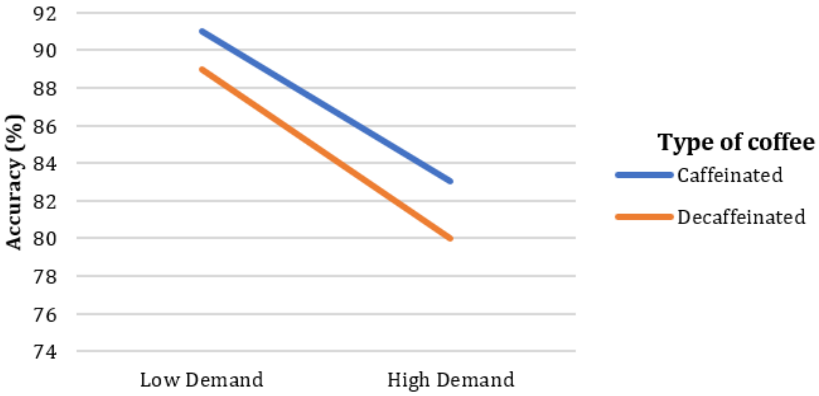


Figure 7

Systolic Changes based on Type of Coffee

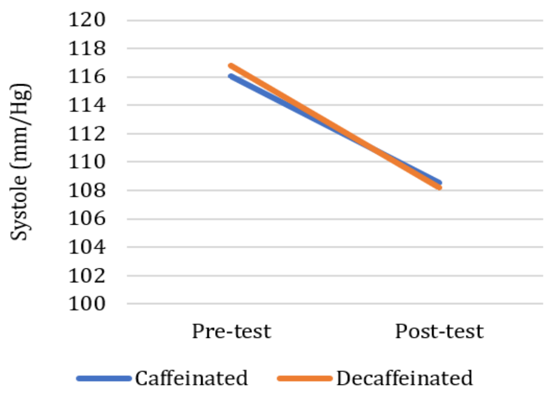


Figure 8

Diastolic Changes based on Type of Coffee

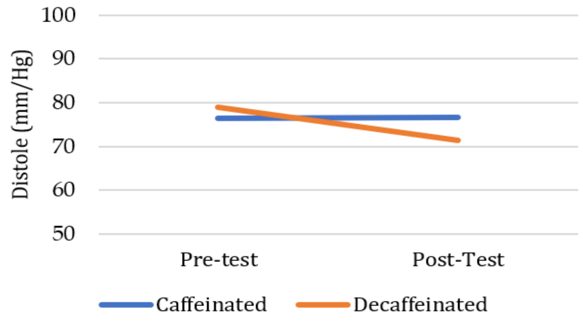


Figure 9

Changes in the GSR Values based on the Given Performance Pressure

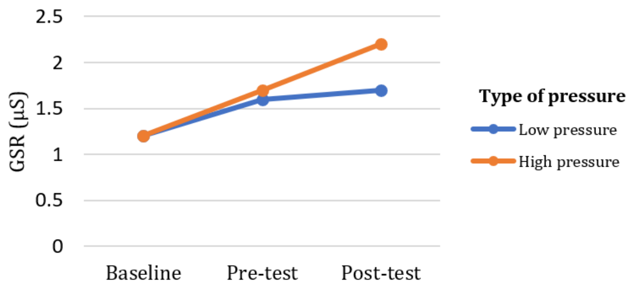
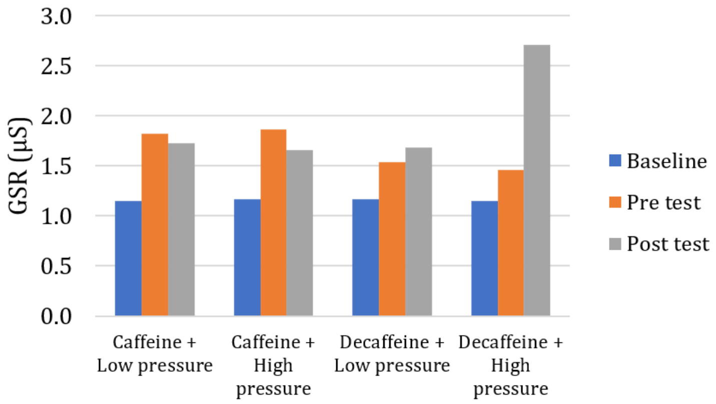


Figure 10

The Average of GSR Values between Four Groups



Furthermore, there was an interaction effect between the three sessions (baseline vs. pre-test vs. post-test) and performance pressure type (low vs. high) (F = 5.432, p = .001, η_p^2 = .176), indicating that arousal was affected by the level of performance pressure applied. However, at the within-subject level, the results of this analysis showed that the session had a main effect (F = 16.546, p = .000, η_p^2 = .245). Figure 9 depicts this pattern of results.

Moreover, the GSR value in each group was subjected to a 3 (baseline, pre-test, and post-test) x 4 (group: caffeine with low pressure, caffeine with high pressure, decaffeinated with low pressure, and decaffeinated with high pressure) ANOVA. The analysis showed an interaction effect between the session and the group (F = 57.074, p = .000, η_p^2 = .774), suggesting a difference in the four groups' GSR or arousal values. Furthermore, analysis of the GSR value based on the session showed a main effect from the session (baseline vs. pre-test vs. post-test) (F = 302.021, p = .000, η_p^2 = 858), indicating that the GSR value in the four groups increased from the baseline to the pre-test and post-test sessions, as shown in Figure 10.

In conclusion, caffeine and performance pressure were found to have no interaction effect, indicating that caffeine did not improve working memory performance in high-pressure situations. There was no evidence that our pressure manipulation directly impacted working memory performance based on accuracy. A manipulation check of the GSR measurement results confirmed that the level of performance pressure did not affect the participants' arousal. Similar to performance pressure, our caffeine manipulation had no direct effect on working memory, as indicated by a decrease in the systolic scores for both groups from the pre-test to the post-test. However, both groups (caffeine and decaffeinated) experienced a fall in accuracy when faced with multiple requests for high-demand working memory.

Discussion

Caffeine is a psychostimulant commonly used to improve cognitive, affective, and physical performance (Glade, 2010; Peeling & Dawson, 2007; Ullrich et al., 2015). Caffeine use before performance frequently leads to higher performance and better subjective experiences compared to placebo settings. On other cognitive functions, a moderate to high level of caffeine intake, with 100–200 mg doses, has been found to increase working memory (Klaassen et al., 2013; Lin et al., 2023; Nehlig, 2010). In contrast to caffeine, performance pressure impairs an individual's performance. People under performance pressure are prone to distraction and bad subjective sentiments, resulting in sub-optimal performance. This study examines the effect of caffeine intake and performance pressure on working memory by examining the interaction effect between caffeine and performance pressure

Interaction Effect of Caffeine and Performance Pressure

We tested the combined effects of performance pressure and caffeine to investigate whether caffeine improves working memory performance in pressure situations. The analysis showed no evidence of an interaction effect between caffeine and performance. These results could be related to the fact that the two manipulations, namely coffee ingestion and performance pressure, did not significantly affect working memory. The results of this study align with the research of Boere et al. (2016), who found a null result, namely the absence of an effect of caffeine at the group level. According to the Bayes factor analysis by Boere et al. (2016), caffeine only affected the performance of those participants who had a history of using coffee, namely four hours before the trial experiment. In their study, the researchers did not control participants to avoid caffeine-containing beverages prior to beginning the experiment. The peak of caffeine in blood plasma levels occurs within 30–60 minutes of consumption. As a result of the effect of caffeine, those participants who had consumed coffee four hours before the experiment began (vs. the participants who had not) performed worse, regardless of the experimental condition. Caffeine was observed to reduce the performance of individuals with a history of coffee intake compared to those with no consumption, for both low working memory performance (low demand) and high working memory performance (high demand) (Boere et al., 2016).

Aside from performance pressure, the existence of a null result was also validated by assessing the effect of caffeine ingestion on working memory, which revealed no significant influence of the type of coffee. Working memory deteriorated between the low-demand and high-demand tasks in both the caffeinated and decaffeinated groups. In other words, when the task required a large amount of working memory, both groups experienced reduced working memory.

Reduced blood flow to the brain may also occur in stressful settings since energy will be expended on overcoming anxiety and performance pressures as opposed to cognitive work (Costa et al., 2019). There was no difference in systolic blood pressure between the caffeinated and decaffeinated groups. However, caffeine manipulation decreased diastolic blood pressure in the decaffeinated group from the pre-test to the post-test. In contrast, diastolic blood pressure remained steady in the caffeinated group, indicating that caffeine helped in maintaining consistent diastolic blood pressure despite performance pressure. Mental stress was associated with increases in diastolic blood pressure (El Sayed et al., 2016). Moreover, the current study, caffeine had a stabilizing effect on SCR values during performance stress. Several studies have found a relationship between the SCR signal and emotional arousal, with SCR values rising as emotional arousal rises (Boucsein, 2012; Critchley, 2002). As previous studies have shown, caffeine can have positive effects such as reducing anxiety, elevating mood, and promoting calmness

(Lieberman et al., 2002; Richards & Smith, 2015; Schneider et al., 2006).

The difference in the results between this study and prior studies could be attributed to the amount of caffeine used, as 50 mg did not affect working memory. Caffeine dosage is known to impact blood pressure changes significantly and should thus be evaluated (Mort & Kruse, 2008). Previous research by Jee et al. (1999) found that blood pressure increased gradually with each cup of coffee (0.8 mm Hg systolic and 0.5 mm Hg diastolic per cup). Several studies have found that moderate doses of caffeine, such as 200 mg, 250 mg, and 300 mg, can increase cognitive performance, such as working memory and attention (Adan et al., 2008; Addicott et al., 2009; Lieberman et al. 2002; Reidel et al., 1995). The amount of caffeine consumed at these levels exceeds that of a single serving of drink or food in general (Smith et al., 1999). In this study, we used a caffeine dose (50 mg) equivalent to the caffeine content in a cup of coffee; thus, it is comparable with the level of caffeine consumed before people face stressful situations. In low doses of up to 100 mg, caffeine can boost cognitive capacities (Lieberman et al., 2002). Moreover, in this study, caffeine was given as a coffee drink. In most prior studies on the effects of caffeine on improving cognitive performance, caffeine was administered in capsule form in high doses (Lorist & Tops, 2003; Peeling & Dawson, 2007).

In addition, it is critical to consider the timing of blood pressure monitoring with respect to caffeine intake. The amount of caffeine in blood plasma levels reaches a peak 30–60 minutes after ingestion (Lorist & Tops, 2003). According to previous research, blood pressure rises 30 minutes after coffee use, peaks between one and two hours after consumption, and the effects can still be noticed up to four hours later (Boere et al., 2016; Cappelletti et al., 2015). The initial tasks may have been performed too quickly after caffeine was consumed, resulting in it not being fully disclosed for the necessary neurochemical processes.

There are numerous possible reasons for the contrast in the results of the performance pressure manipulation between this study and prior studies. In this study, working memory appeared stable under performance pressure conditions. Several variables contribute to the lack of a performance pressure effect on working memory. We assume that other factors, such as the internal characteristics of individuals, can alter performance under pressure, thereby explaining the absence of variations in working memory. For example, individuals who manage stress well or have agility exhibit great strategies in particular environmental contexts (McCann & Selsky, 2012). In line with drive theory, a person's performance is determined by their drive or level of arousal (Böheim et al., 2019). In this study, one of the inducers of performance pressure was a monetary prize of 50,000 IDR for those individuals who improved their performance by 20% over their previous session test. Empirical research indicates that higher incentives boost effort, resulting in higher production (Dechenaux et al., 2015). Therefore, in this high-pressure situation, an individual may have viewed the performance pressure as a driving force to maintain or increase their performance rather than as a pressure that worsened it. This is consistent with the findings of Uziel's (2007) experimental meta-analysis study, which indicated that the effect of pressure on performance is generally beneficial if the agent is extroverted and has high self-esteem.

The manipulation of performance pressure in this study included three components (monetary rewards, group member pressure, and social evaluation via video recordings). These three components combined several pressure sources to create a performance pressure effect. This method, however, did not mitigate the impacts of the three pressure sources; for instance, the effect of monetary rewards vs. video recording at the individual level. Future study is expected to be able to test each source of performance pressure since it is probable that the psychological consequences of the three pressure sources vary for each individual (DeCaro et al., 2011). In addition, the functional implications of the effects of caffeine create different behavioral outcomes, which depend on the paradigm of the task given and the level of arousal in the individual (Lorist & Tops, 2003).

The presence of a null result in the study findings can be explained further by the molecular processes underlying caffeine and performance pressure. DA release has been linked to poor cognitive performance under performance pressure (Aarts et al., 2014; Bijleveld & Veling, 2014). Caffeine, especially at high doses, is known to enhance DA levels; hence, it is plausible that caffeine consumption may impair performance when under performance pressure (Smith, 2013). The findings of this study are contrary to the notion that performance pressure and caffeine influence cognitive performance via broad physiologic pathways. By way of explanation, the results of this study could be attributed to performance pressure and coffee controlling working memory performance via several biological pathways. This finding is consistent with prior research by Boere et al. (2016), who found that different biological pathways drive the behavioral impacts of performance pressure and caffeine. However, due to the complex underlying brain processing, it is still likely that both biological mechanisms of performance pressure and caffeine involve the DA system (Boere et al., 2016).

Pressure-induced performance likely impaired working memory performance in this study by raising DA levels above their optimal levels. When combined with low levels of caffeine, caffeine is predicted to improve performance when under performance pressure. However, no further performance benefits were observed due to caffeine ingestion. The presence of a null result in the study could be attributed to the fact that the period between caffeine ingestion and arithmetic task execution was 30 minutes. However, the peak of caffeine in blood plasma is known to occur 30–60 minutes after ingestion (Lorist & Tops, 2003). It may thus be possible that the task in the experiment was undertaken too soon. As such, the neurochemical processes after coffee consumption had not been fully activated.

This study has certain experimental method limitations that may result in null results. These limitations are attributable to three factors that are difficult to control. First, the caffeine levels employed in this study were minimal (50 mg, or the equivalent of a 2-gram coffee sachet); as such, it did not affect higher-order cognitive functions such as working memory. We used a 50 mg dose of caffeine to simulate a real-life situation. However, another study demonstrating that caffeine affected cognitive function used high doses of coffee as pills. Second, the working memory task was given too quickly, precisely 30 minutes after caffeine ingestion. As such, the chemical processes attributable to caffeine consumption may not have been fully activated. However, if the participants had performed the task one to two hours after the peak caffeine reaction time, they may have experienced boredom, affecting their psychology and, thus, their cognitive performance. Finally, the characteristics of the participants were not ideal in that they may not have been in a comparable physical condition; for example, some may have experienced fatigue or a lack of sleep. This would appear complicated to control, considering that the participants had different activity levels and were not monitored within 24 hours in the laboratory before the experiment began. According to Lieberman et al. (2002), caffeine can benefit cognitive functions such as memory under stress and lack of sleep at optimal doses of 200 mg.

Future research in this area must identify the effect of “typical caffeine” in a pressure situation with various participants for generalizing purposes, considering its proximity to everyday existence. Moreover, attention must be paid to the form of caffeine ingested (e.g., coffee drinking or pill), as this may have a distinct effect. In conclusion, this study has demonstrated that drinking a cup of coffee containing a low dose of caffeine under pressure situations does not affect working memory performance. Thus, despite having a similar biological mechanism, these findings indicate no interaction effect for caffeine in low doses and performance pressure on working memory. The findings also lead us to comprehend that the combination of caffeine intake (especially at low doses equivalent to a cup of coffee) and performance stress has no negative or positive effects on working memory. In addition, our findings suggest that students, employees, athletes, and others should be aware of the potential cognitive and behavioral incidental exposure to caffeine-containing beverages such as coffee, cola, chocolate, and tea. Exposure to these substances may increase daily caffeine consumption, provoking unanticipated caffeine-effect-type responses that individuals may wish to mitigate, particularly before high-stakes situations. Lastly, this study has practical applications in everyday life. High-pressure situations (such as workload, deadlines, peer pressure, and competition) can be a clinical issue for an individual’s psychology, causing stress and a decrease in performance. It appears to be crucial to eliminate one’s initial anxiety response early on, before anxiety has a chance to diminish actual performance. Daily caffeine intake can be a positive habit, producing positive effects such as reducing anxiety, elevating mood and well-being, and promoting calmness (Lieberman et al., 2002; Richards & Smith, 2015; Schneider et al., 2006). Given the prevalence of caffeine consumption prior to performing tasks under pressure, while drinking a cup of coffee does not improve performance as many would expect, it can be useful for coping with stress. Caffeine is a legal substance; furthermore, clinical psychologists can suggest caffeine-containing beverages as an alternative intervention and prevention to reduce anxiety under performance pressure.

Conclusion

We investigated the effect of caffeine and performance pressure on working memory. This study found no evidence that caffeine and performance pressure interact. The absence of such an interaction suggests that the decline in accuracy from low demand to high-demand tasks on the arithmetic problems was not significantly different between the two groups of coffee types (caffeinated vs. decaffeinated). Thus, we found no evidence that caffeine ingestion directly affects working memory. Furthermore, performance pressure (high vs. low) produced no difference in working memory either before or after the induction of performance pressure. However, diastolic blood pressure remained steady in the caffeine group, indicating the role of caffeine in maintaining its consistency. Thus, caffeine likely reduces anxiety and increases calmness, without affecting working memory directly. Thus, in the context of clinical psychology treatment, caffeine intake would be useful under performance pressure. Furthermore, this study highlighted a main effect of the type of task load (task demand), namely a decrease in accuracy from low-demand to high-demand task types in both groups (caffeine and decaffeinated). Accuracy decreases when the task is a high-demand problem or requires high working memory. For optimal cognitive performance, a daily intake of caffeine can serve as an alternative to stress management.[]

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Author Contribution Statement

Laila Indra Lestari: Conceptualization; Data Curation; Formal Analysis; Investigation; Methodology; Project Administration; Resources; Validation; Visualization; Writing Original Draft; Writing, Review & Editing**. Sri Kusrohmaniah:** Conceptualization; Data Curation; Formal Analysis; Funding Acquisition; Methodology; Project Administration; Resources; Validation; Writing, Review & Editing.

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