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Does Caffeine Improve Task Performance on Sustained Attention and Response Inhibition?

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Abstract

Caffeine is the most widely used psychoactive stimulant in the world (Alsabri, Mari, Younes, Elsadawi, & Oroszi, 2018). Concurrently, desktop-based assessments of psychological constructs have become increasingly relevant as the rise of remote and computer-based work has occurred. In this context, we investigated whether caffeine intake affects performance on measures of sustained attention (SA) and response inhibition (RI). Using the Inquisit Lab software, we conducted a between-subjects, randomised controlled trial (RCT) comparing performance on the AX Continuous Performance Task (AX-CPT) and the Stop Signal Task (SST) in participants who consumed either decaffeinated or caffeinated Nespresso Arpeggio coffee. We committed our statistical analysis of the task responses using Python's SciPy statistics library. Our study found that caffeine intake markedly improved performance on measures of SA and RI.

The experimental group responded faster and more accurately to the task probes in the AX-CPT ($p = .04$), indicating enhanced SA. By calculating the integration point of Stop Signal Reaction Time (SSRT), the study demonstrated that when doing the SST, participants in the experiment condition required less time to inhibit prepotent responses (μ SSRT = 182.68 ms, σ = 48.61ms) than those in the placebo condition (μ SSRT = 217.38 ms, σ = 75.40ms). The statistical significance of the differences in performance, $t(25) = 1.32$, $p = .099$, indicates that the time required to inhibit prepotent responses was reduced for those who had consumed caffeine.

Key words

Attention, caffeine, cognitive psychometry, Continuous Performance Task (AX-CPT), executive function, reaction, response inhibition, Stop Signal Task (SST).

Terminology

AX-Continuous Performance Task (AX-CPT)

Latency (Reaction Time):
The interval, measured in milliseconds (ms), between the onset of the probe stimulus (e.g., the letter "X") and the participant's keypress response. Task software automatically recorded both stimulus presentation and response timing.

Accuracy:
The proportion of correct responses across target (AX) and non-target (AY, BX, BY) trials, with errors reflecting lapses, incorrect keypresses, or no response before the cut-off time (500 ms) (Cohen et al., 1999; Braver, 2012).

Stop Signal Task (SST)

Stop Signal Delay (SSD):
SSD was defined as the duration (ms) between the onset of the go stimulus and the presentation of the Stop Signal. An adaptive staircase procedure increased SSD following successful response inhibition and decreased it following failed response inhibition, thereby adjusting difficulty for each participant.

Stop Signal Reaction Time (SSRT):
SSRT was operationalised as an estimate of the time required to inhibit a prepotent response. SSRT was calculated using the integration method (Logan & Cowan, 1984), in which the finishing time of the stop process is inferred from the distribution of go reaction times.

Caffeine Intake

Experimental Group:
Participants ingested one cup of Nespresso coffee containing approximately 85 mg of caffeine, prepared with 30 ml of milk. Consumption occurred 45 minutes before task administration to align with the peak plasma caffeine concentration (Nehlig, 2010).

Control Group:
Participants ingested one cup of decaffeinated coffee prepared with 30 ml of milk under the same conditions as the experimental group.

Neuro-Cognitive Assessments

Sustained Attention:
Defined as the ability to maintain stable performance over time. Operationally, this was assessed through accuracy scores and intra-individual variability in reaction times across AX-CPT trials.

Response Inhibition:
Defined as the ability to suppress a dominant or automatic response. Operationally, this was measured through SSRT estimates derived from the SST.

Dual Mechanisms of Control (DMC)

Proactive Control:
A sustained, goal-directed form of cognitive control, reflected in anticipatory adjustments. This was indicated by slower but more accurate responses on AY trials in the AX-CPT.

Reactive Control:
A transient, contextual form of cognitive control, reflected in corrective adjustments triggered by infrequent or unexpected events. Operationally, this was indicated by increased response latencies and reduced error rates on BX trials in the AX-CPT (see Braver, 2012)

Population and Sampling

To enable the generalisation of findings, this South African study was conducted in the Southern Suburbs of Cape Town and included participants aged 18–35 years (μ age = 23 years). Screening ensured that all participants were computer-literate, had previous experience working remotely, and were medically suitable for caffeine consumption (i.e., not pregnant and without sleep sensitivity or digestive issues).

A combination of non-probability sampling techniques was used to recruit participants for this experiment. First, convenience sampling was applied to gather participants based on their availability and willingness to participate. Next, a snowball sampling technique was employed, whereby initial participants were asked to invite additional participants. Such an approach is considered appropriate when resources, time, and workforce are limited (Blanche, Durrheim & Painter, 2006; Etikan, Musa & Alkassim, 2016).

The final sample consisted of 27 participants (15 females, 12 males). They were allocated to either the experimental condition (n = 15), where participants had a regular cup of coffee before completing the assessments, or the control condition (n = 12), where participants had decaffeinated coffee before performing the same evaluations. Of the total sample, 21 were students, while the remainder consisted of those who were either employed (n = 5) or self-employed (n = 1).

Methods

Recruitment

Participants were recruited to investigate the effects of caffeine on cognitive performance —specifically, sustained attention and response inhibition. Recruitment took place through word of mouth, messaging services, and by inviting existing participants to refer others. All participants were instructed to abstain from consuming coffee on the day of testing. On arrival, each participant signed a written consent form outlining the study's aims, procedures, and any potential risks associated with caffeine intake.

Screening occurred in two stages. First, prospective participants received an electronic consent form via email describing the study and its requirements. Those who returned the signed form were randomly allocated to either the experimental group (caffeine) or the placebo group (decaffeinated). The second stage of screening took place in person on the day of testing to ensure participants were fit to partake.

Instrumentation

To carry out this task, we needed to use Milliseconds *Inquisit Lab Software* and a Nespresso Machine with 40 Nespresso Pods (20 caffeinated and 20 decaffeinated). We had to obtain an empty classroom (at the Independent Institution of Education, Varsity College, Cape Town). We also ensured that participants were wearing wired headphones throughout the task.

Procedure

Testing was conducted in an empty classroom. Each participant was seated alone at a desk equipped with a laptop and wired headphones throughout the tasks. Participants assigned to the experimental group consumed a cup of Nespresso coffee prepared with milk. They then waited 45 minutes to allow for optimal caffeine absorption (Nehlig, 2010; Alsabri et al., 2018). During this interval, the researcher provided a brief explanation of the tasks at hand and their relevance to understanding the effects of caffeine. After the waiting period, participants were escorted to the testing area and instructed to keep the assessment headphones on for the duration of the study. Before testing began, the researcher verbally reiterated key elements of the consent form to confirm understanding and emphasised that all data would remain confidential and be used solely for the research purposes of the study.

Participants then completed four assessments: a Simple Reaction Time Task (SRTT), the AX-Continuous Performance Task (AX-CPT), the Stop Signal Task (SST), and a brief survey of their habitual caffeine consumption. Each task included on-screen instructions, which were reinforced with verbal explanations to ensure comprehension before the task began. Following the completion of the tasks, participants took part in a brief debriefing and were asked to share their impressions of the study. Finally, responses were exported as .csv files using Inquisit software and prepared for subsequent statistical analysis.

Statistical Analysis

Analysis was performed using Python's SciPy Library, which contains the statistical algorithms used to suggest comparable significance in task performance between the experimental and control conditions.

Simple Reaction Time Task (SRTT) Analysis

Comparison of the simple reaction time based on study conditions

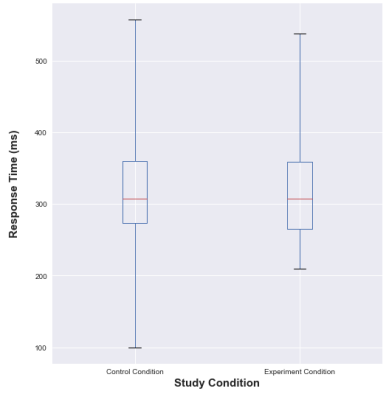

Figure 1

Simple Reaction Time (SRT) refers to the amount of time (in ms) it took participants to respond (by pressing the spacebar) after the latent stimulus (a black 'X') turned into the probe stimulus (a red dot).

Descriptive statistics of the SRTs calculated in three categories, namely:

1. The sample population (All of the participants)
2. The experiment Sample (Participants who had caffeinated coffee)
3. Control Sample (Participants who had decaffeinated coffee)

The t-test is used to measure the difference between two means (in this case, mean response times) to see if we can infer that sample performance differed based on caffeine consumption (Kim, 2015). An independent samples t-test was used to compare and analyse the average response latency of the control and the experimental conditions to understand whether caffeine had a significant impact on the SRTs of the participants. This task was designed to assess basic response times for comparison with performance on subsequent, more complex tasks.

AX-Continuous Performance Task (AX-CPT) Analysis

For the AX-CPT, descriptive statistics were calculated for the latency of responses and the percentage of correct responses. To further analyse the AX-CPT scores (Gonther, 2018), we compared the mean reaction times and the percentage of correct responses between the study samples (Chow et al., 2014). We used an independent samples t-test to suggest that significant differences in the psychometric measures were based on caffeine consumption.

Stop Signal Task (SST) Analysis

The SST analysis compares the performance of the sample groups, with a focus on mean reaction times. The analysis also comprises a comparison of the SSRT estimation ($\mu_{ssrt\_integration}$). The SSRT is an estimation of the covert Stop Signal reaction time (ms) and can be used as an estimation of latent response inhibition. To calculate the SSRT, we used various metrics to find the probability of responding to a Stop Signal.

- The correct go trials (i.e., with valid response times) are used to ascertain the internal latency of a complete "go" process.
- The probability that a participant responds to the stop signal, p(response| signal)

- The average Stop Signal Delay (SSD) across the trials for that subject.
- The integration point. Found by using the percentage likelihood of responding to a stop signal as a quartile on the go-process distribution.
- This is because the fraction of stop failures equals the fraction of go-processes that finish before the stop process. The corresponding value on the go-process distribution returns an estimate of when the stop process typically finishes.

The slower the SSRT, the more difficult it is to stop the prepotent go-process, and the faster the SSRT, the easier it is to interrupt the go-process (Verbruggen et al., 2019). This score is computed within the Inquisit software and provides an operational score for the Stop Signal Task.

Results

Caffeine influenced performance on both the AX-CPT and the Stop Signal Task (SST). For the AX-CPT, participants who consumed caffeine responded significantly faster than controls, $t(25) = 1.81$, $p = .041$. For the SST, the caffeine group responded faster, with a marginal effect that approached conventional significance, $t(25) = 1.322$, $p = .099 < .10$.

Review of the Simple Reaction Time Task (SRTT)

Unlike the other tasks, mean response scores on the Simple Reaction Time Task (SRTT) did not differ significantly between groups, although the caffeine group was slightly faster on average. The sample population's average reaction time was $\mu_{reaction} = 321$ms, $\sigma = 66.97$ms. Those who consumed caffeine ($N = 15$) had a mean reaction time of $\mu = 319.46$ ms ($\sigma = 94.47$), whereas those who did not ($N = 12$) averaged $\mu = 324.09$ ms ($\sigma = 133.61$). A two-sample t-test comparing the experimental condition to the control condition tells us that the slight difference isn't statistically significant, $t(25) = 0.724$, $p = .234$. Nevertheless, the SRTT provided a basic measure of simple reaction time to stimulus changes.

Review of the AX-Continuous Performance Task (AX-CPT)

In the AX Continuous Performance Task (AX-CPT), participants who consumed a caffeinated Nespresso Arpeggio coffee responded significantly faster than those who drank the decaffeinated version. The experiment group showed a mean response latency of $\mu = 427.94$ ms ($\sigma = 94.47$ ms), compared with the mean response latency of $\mu = 505.73$ ms ($\sigma = 133.61$ ms) in the control group. An independent-samples t-test, $t(25) = 1.81$, $p = .041$, confirmed that caffeine consumption facilitated faster responses. Across all participants, the overall mean latency was $\mu = 466.83$ ms ($\sigma = 114.04$ ms).

Performance also varied markedly by trial type. Across all trial codes, the mean latency was $\mu = 450.19$ ms ($\sigma = 147.80$ ms), yet the AY trials were notably slower, averaging $\mu =$

549.51 ms (σ = 151.97 ms). A one-sample t-test indicated these AY latencies were significantly slower than the overall mean, $t(25) = 8.16$, $p < .001$. Accuracy was likewise lowest on AY trials (μ ≈ 79 % correct), suggesting that the initial "A" cue misled many participants. Consistent with the Dual Mechanisms of Control framework (Braver, 2012), this pattern reflects greater reliance on proactive control: when the cue was "B," participants could prepare the correct response in advance, yielding faster latencies (μ ≈ 424.50 ms, σ = 178.76 ms) and higher accuracy (μ ≈ 90 %) on BX trials.

A 2 × 4 mixed ANOVA with factors Group (experimental, control) and Trial Type (AX, AY, BX, BY) revealed a significant main effect of Trial Type, $F(3, 112) = 41.62$, $p < .001$, $\eta^2 = .53$, with slower responses on AY trials compared to AX, BX, and BY. There was also a significant Group × Trial Type interaction, $F(3, 112) = 4.87$, $p = .003$, $\eta^2 = .12$, indicating that the experimental group was faster on BX and BY trials compared to the placebo group. Independent *t*-tests confirmed this pattern: BX trials, $t(25) = 2.56$, $p = .017$, Cohen's $d = 0.78$.

Accuracy analyses revealed higher error rates on AY and BX trials compared to AX and BY trials, consistent with increased demands on proactive control. However, the experimental group exhibited significantly fewer false alarms on BX trials, suggesting more effective inhibition of contextually inappropriate responses.

Figure 1

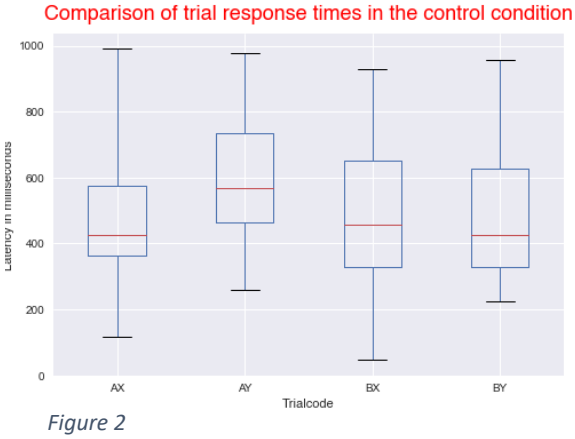

Figure 2

	trialcode	AX	AY	BX	BY
latency	min	90.00	213.0	11.0	31.00
	q25	323.75	432.0	281.5	278.75
	median	368.00	498.0	330.0	383.50
	q75	447.00	581.0	451.5	504.75
	max	752.00	752.0	714.0	751.00

Figure 3

	trialcode	AX	AY	BX	BY
latency	min	118.00	259.0	47.0	224.00
	q25	362.75	463.0	330.0	327.75
	median	425.00	569.0	456.0	425.00
	q75	573.50	735.0	651.0	625.50
	max	990.00	979.0	930.0	958.00

Figure 4

Figures 1–4 show descriptive distributions of reaction times (RTs) for the AX-CPT task across experimental and control groups. Descriptive tables report medians, interquartile ranges, and extremes for each trial type. In addition, mean RTs and standard deviations were calculated.

Review of the Stop Signal Task (SST)

The SST analysis used the SSRT integration score ($\mu_{ssrt\_intergration}$ = 200.03 ms, σ = 43.201 ms) to measure performance. This score revealed that individuals in the control condition ($\mu_{ssrt\_integration}$ = 217.38 ms, σ = 75.40 ms) had a more difficult time inhibiting prepotent responses compared to those in the experimental condition ($\mu_{ssrt\_integration}$ = 182.68 ms, σ = 48.61 ms). We demonstrate that caffeine intake improved the time required to stop an initiated go-process ($t(25) = 1.32$, $p = .099$). The probability that the sample group would respond to the stimulus even when there was a Stop Signal ($\mu_{probabilityOfResponse}$ = 50.86 ms, σ = 15.11 ms) was higher than that of the experiment group ($\mu_{probabilityOfResponse}$ = 46.80 ms, σ =15.42 ms). However, this result was not statistically significant, $t(25) = 0.695$, $p = 0.247$.

Proactive control recruits predictive contextual cues to prepare behavioural responses in advance. Participants using this method of control demonstrate more anticipatory and sustained activity in the lateral prefrontal cortex (reflecting active maintenance of contextual information) (Gonthier et al., 2016). Much like in other studies focused on the AX-CPT paradigm, participants used proactive control which allowed them to prepare target responses when the cue was not an 'A' and this translated into better response latency ($\mu_{latency}$ = 424.502, σ = 178.755741) and performance ($p = .9$) on BX trials because the response was already prepared when the 'B' cue showed (and worst performance ($p = .79$) and latency ($\mu_{latency}$ = 549.51 ms, σ = 151.97 ms on AY trials because participants were incorrectly prepared a target response due to the 'A' cue).

Findings

Discussion

Summary of Key Findings

The present study tests the hypothesis that caffeine influences performance in measures of SA and RI. In this study, caffeine improved performance on the AX-CPT (our measure of SA) by increasing the likelihood that a participant would respond correctly to a trial and also decreasing the average response latency of participants in the experiment condition, demonstrating that our operational definition of SA was improved by the participants having caffeine in their coffee.

The SSRT integration score measured performance in the SST (our measure of RI), and we found that caffeine significantly improved response latency to the task stimuli.

Although the reaction times for the Simple Reaction Time Task were higher in the experiment condition, the differences were not of a significant degree, and this study shows that caffeine did not have a substantial impact on performance in the SRTT.

Together, these outcomes support the view that acute caffeine administration enhances both SA and inhibitory control, consistent with prior psychopharmacological and cognitive-control findings (Kahathuduwa et al., 2017; Lorist & Tops, 2003).

Limitations

Several limitations to this study must be acknowledged. The first limitation is that although both the AX-CPT and SST are well-validated neurocognitive paradigms for assessing attention and inhibition (Logan & Cowan, 1984), the present study relied exclusively on behavioural metrics. Without neuroimaging or electrophysiological data (e.g., EEG or fMRI), inferences regarding neural activation patterns remain indirect. Consequently, while caffeine's behavioural effects are evident, their precise neural correlates—particularly within the anterior cingulate, dorsolateral prefrontal cortex, and basal ganglia—cannot be confirmed.

Second, individual variability in caffeine metabolism (CYP1A2 genotype, habitual intake, sleep quality, and baseline arousal) may have influenced outcomes (Rogers et al., 2010). Future designs should control for or stratify participants by these factors. Third, the sample size and the absence of physiological monitoring (e.g., heart rate, cortisol, or electrodermal indices) limit the interpretability of the results across populations and contexts. Furthermore, the laboratory-based digital interface may not fully capture the ecological complexity of real-world cognitive performance.

Future Directions

Future research should incorporate neurophysiological measurements (EEG, fMRI, or fNIRS) to identify the neural circuits modulated by caffeine during attention and inhibition. Combining behavioural paradigms with imaging would clarify whether improvements stem primarily from enhanced cortical efficiency, increased neural synchronisation, or modulation of arousal.

Longitudinal or cross-over designs could evaluate tolerance effects and withdrawal interactions to determine the stability of caffeine's cognitive benefits over time. Genetic profiling (e.g., CYP1A2 and ADORA2A polymorphisms) could further elucidate why some individuals experience greater benefits or adverse side effects. Finally, extending this research to clinical or aging populations could reveal whether caffeine ameliorates deficits in executive control associated with neurocognitive decline or psychiatric conditions.

Conclusion

In summary, the study provides convergent behavioural evidence that caffeine enhances sustained attention and response inhibition when administered before task engagement. These findings reinforce caffeine's role as a mild cognitive enhancer and lend empirical support to neurocognitive models linking adenosine antagonism to improved executive functioning. Although neural-level confirmation remains to be established, the present results offer a valuable behavioural foundation for future neuropsychological investigations into the mechanisms of cognitive control.

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