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Caffeine Modulation of Attention and Focus in Task Performance

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CAFFEINE MODULATION OF ATTENTION AND FOCUS IN TASK PERFORMANCE

by

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This manuscript has been read and accepted for the Graduate Faculty in Cognitive Neuroscience in satisfaction of the thesis requirement for the degree of Master of Science.

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ABSTRACT

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Caffeine has been a heavily researched drug for decades given its prevalence in global consumption, as well as its large impacts on metabolic and executive function research alike. The present study aims to combine a behavioral study (Experiment 1) with a feasibility study (Experiment 2) to test the impacts of variable caffeine consumption on task performance. For both studies, participants filled out a questionnaire regarding caffeine use. Experiment 1 examined whether caffeine modulated attention in an online behavioral task in which participants were asked to identify a target (e.g., female "ahpa"). Participants were tested twice once after consuming 12 ounces of coffee/black tea 30 minutes before the task vs. and once with no consumption of a caffeinated beverage. Results revealed no effect of caffeine on target accuracy or RTs, but participant were faster in later blocks. In addition, lower target accuracy and faster RTs were observed in blocks where targets were randomized. Experiment 2 was a case study that included the behavioral task, and the addition of a plate-based assay to test caffeine concentrations in saliva at various time points. Saliva samples indicated a slower metabolism, or longer half-life, of caffeine in an individual who consumed low/moderate quantities of caffeine daily. The future plan

is to examine performance on the behavioral task in relation to caffeine metabolism and consumption to test whether these factors modulate the effects of caffeine on behavioral attention.

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Introduction

Attention and information processing as related to various types of task performance are undoubtedly influenced by various confounding variables, specifically stimulant drugs. Common attention-deficit hyperactive disorder (ADHD) medications (ex. amphetamines, methylphenidate, atomoxetine), nicotine, and caffeine have all been heavily linked to statistically significant improvements in executive functions, including attention (Higgins et al., 2020; Lanini et al., 2015).

Executive Function

One of the most well documented interference control phenomenon is the cocktail party effect, or the "cocktail party problem" when referring to the difficulty associated with interference often found in noisy social settings such as a cocktail party (Bee & Micheyl, 2008). Speech perception in these settings can fall victim to both direct acoustic interference energetic masking as well as speech intelligibility effects via components of speech that do not overlap frequency or timing of the target (informational masking).

Speech in particular is a popular topic of study when investigating short-term memory interference as a result of information retention disruption, as it is a realistic task-irrelevant auditory stimulus—such as in the cocktail party effect. That being said, speech interference has been found to be modifiable via specific trainings of auditory selective attention. In the research by Kattner and Ellermeier (2019), participants underwent extensive dichotic-listening training intended to hone in on their selective processing when presenting a list of variable auditory stimuli. Comparing accuracy in memorizing target stimuli prior to training and after training showed that this dichotic-listening training reduced the irrelevant speech effect. Perhaps then this irrelevant speech effect (speech interference) can be affected by auditory selective attention, and thus affected by modifiers of auditory selective attention.

At the physiological level, stress hormones play a longstanding role in not only auditory selective attention, but selective attention as a whole. Under stress, humans respond in a more reactive than reflective manner, as situations perceived with urgency historically called for urgent responses for survival (Blair, 2016). The impact of stress and its subsequent developmental influence on executive functions is heavily documented across age ranges (Blair et al., 2011) and socioeconomic statuses (Evans, 2003). For example, studies on children in poverty have shown that developing in such an environment coincided with increased stress hormone levels, and likewise over-activation of stress response systems. Despite this general effect of allostatic load, it has been found that relationships providing maternal support in these stressful environments have a moderating effect on over-activation of stress response systems, and resulting moderation of executive functions involving attention and behavioral disinhibition. Interestingly, the opposite has been found to be true as well—drastic disruption of caregiving relationships in the early developmental years have been associated with under-activation of stress response systems, evidenced by children in this environment having altered diurnal variation in cortisol (Tarullo & Gunnar, 2006). Such a discrepancy only lends support to the theory that the hypothalamic-pituitary-adrenal (HPA) axis—a primary component of the stress response system, which is strongly influenced by social interaction and unpredictable situations—is paramount in eventual development of behavior regulation and executive functions (Ramos & Arnsten, 2007). The HPA axis is responsible for elevating glucocorticoid hormone levels, specifically cortisol. Therefore, individuals under high allostatic load from an early age will likewise adapt to their respective environments with either an under-activation or over-activation of stress response systems, rooted in the fact that their systemic cortisol levels are extreme. With this in mind, it is plausible to declare that stimulants of cortisol levels will ultimately impact behavior regulation, executive function,

and even auditory selective attention. Some of the most commonly used cortisol stimulant drugs include amphetamines, nicotine, and caffeine.

Caffeine

Caffeine is one of, if not the most commonly and routinely used drugs in the world today, making it an important topic of scientific research. There is a large library of literature overviewing the various effects attributed to caffeine consumption, such as its impact on physical or cognitive performance (Nehlig, 2010; Spriet, 2014). However, there exists a much smaller collection of literature focusing on individualistic caffeine metabolism in relation to performance—physical or cognitive. Of this research, the majority aim to understand the relationship between variable caffeine concentrations and their impact on physical performance in sport activities (Skinner et al., 2013). Many fewer studies have focused on the effect of caffeine on cognition. This gap in literature leaves much to be assumed concerning the effect of various caffeine concentrations and their impact on cognitive task performance, particularly in relation to individual caffeine metabolisms. In order to adequately analyze the impact of individual caffeine metabolism rates on cognitive task performance, we must first overview caffeine's mechanism of action and general metabolic processes.

Caffeine is similar enough in structure to the neuromodulator, adenosine. The individualistic metabolism of caffeine lies in the density of adenosine receptors, which are positively correlated to levels of caffeine consumption (McLellan et al. 2016). When adenosine binds to these adenosine receptors, (particularly the G-protein-coupled receptor, A_1 and A_{2a}) we begin feeling sleepier—adenosine accumulates throughout the day, which makes sense given its sleep-regulating reputation. However, when caffeine binds to adenosine receptors, its acts as an antagonist, inhibiting the typical effects of adenosine, and effectively "blocking" the fatigued

feeling that occurs from an accumulation of adenosine. This suggests that consuming high levels of caffeine will increase the presence of adenosine receptors and therefore will require more caffeine to block the presence of the adenosine receptors compared to a low caffeine consumer.

Caffeine, as well as other stimulant drugs such as amphetamines and nicotine, are metabolized by cytochrome P450 enzymes in the liver, each of which is classified by specialized subfamilies as designated in their acronyms (Miksys & Tyndale, 2002). For example, caffeine is primarily metabolized by the enzyme CYP1A2 (responsible for 77-88% of caffeine metabolite conversion), and CYP2E1 to a lesser degree. Therefore, it is the activity of these enzymes that dictate the amount of caffeine in the system that is metabolized in a given period of time. Likewise, those with a naturally-below average level, or compromised level due to conditions such as hepatic illness or pregnancy, of the CYP1A2 enzymes will experience prolonged effects of caffeine; these effects are a result of their body's subpar enzymatic activity metabolizing less caffeine compared to those with average or above average CYP1A2 enzymes (Prus, 2018; Thorn et al., 2012).

Other drugs used in conjunction with caffeine can increase enzymatic metabolic rate. Nicotine is commonly paired with caffeine consumption and modulates enzymatic metabolic rate. For this very reason, smoking increases CYP1A2 enzyme activity, subsequently increasing caffeine metabolism in the individual. With such an increase in caffeine metabolism, smokers and those that regularly consume nicotine products will experience diminished and/or shorter bouts of caffeine effects compared to those with average or below average CYP1A2 enzymes. This expedited elimination of caffeine from the system is why smokers will often drink more caffeine compared to nonsmokers and to their caffeine consumption before they began smoking; in other words, smokers must consume more to maintain comparable effects from the caffeine compared to non-smokers (Prus, 2018; Thorn et al., 2012).

With regard to individual metabolisms, or when caffeine molecules inevitably unbind from the adenosine receptors in the brain, both genetics and consumption habits play a part in determining the half-life (time required for the caffeine concentration to be halved). Typically, caffeine reaches its peak saliva-concentration roughly 45 minutes after consumption and has a half-life of three to seven hour under average metabolic conditions (Temple et al., 2017). However, this typical metabolism can be altered through chronic caffeine consumption, as this habit can eventually lead to adenosine receptor upregulation—or rather, an increase in adenosine receptor density (Daly et al., 1994; Holtzman et al., 1991). Rat studies have specifically pointed to an increase in cortical A1 adenosine receptors as a result of continuous caffeine consumption (Fredholm et al., 1982; Shi et al., 2012). It is this apparent upregulation that those who consume caffeine for long periods of time, and/or in high volumes, are expected to develop a tolerance to the effects of caffeine.

Though it is still debated whether or not caffeine significantly affects more complex ("high") cognitive functions, it is clear that caffeine affects attention and task performance, as it is widely accepted that simpler ("lower") cognitive functions, such as reaction time or attention is improved by reasonable caffeine consumption (McLellan et al. 2016; Nehlig, 2010). Despite the abundance of literature supporting this claim, much of the research is not designed around the individualistic component of variable metabolisms across participants.

This gap in this literature led to our hypotheses both involving and relating to personal caffeine metabolism and adenosine receptor density in the brain which both could contribute to the speed and the subsequently perceived impact of caffeine consumption on focus and task performance. Our study is comprised of three measures: a background questionnaire on caffeine consumption, salivary measures of caffeine concentration in relation to time, and a cognitive auditory attention task. This report focuses on a preliminary analysis of the results of the questionnaire and behavioral

auditory task (Experiment 1), and a case study of one participant who has completed all three measures (Experiment 2).

Experiment 1 included the caffeine self-report and behavioral task for a larger number of participants (15), to allow for preliminary statistical analysis. According to the U.S. Department of Agriculture, the average cup (eight ounces) of coffee contains 96mg of caffeine, or 12mg of caffeine per ounce of coffee (Agriculture Research Service, 2020). In our questionnaire we asked whether the amount of caffeine an individual consumes is related to past history of caffeine use, and their perception of how caffeine affects performance (ex. focus on a task) and reported sleep. We hypothesized that if a participant intakes 100mg-400mg of caffeine per day (approximately 8 to 33 ounces of coffee) they would self-report greater focus and/or task performance, whereas those consuming over 400mg would result in self-reporting minimal effects of caffeine, or very short-lived effects. We also hypothesized that if a participant intakes large amounts of caffeine per day (i.e. greater than 400mg) they would self-report experiencing less negative effects from caffeine, whereas consuming less daily caffeine would result in self-reporting more negative effects from caffeine (ex. compromised sleep or anxiety).

The behavioral task was designed to test auditory attention across two conditions: 1) after having consumed 12 ounces of either coffee or black tea 30 minutes prior to completing the task, 2) having not consumed any caffeinated beverage prior to completing the task that day. The behavioral task used an oddball paradigm, wherein participants were instructed to respond to an oddball (targets) auditory (speech) stimulus. However, we also asked participants to make a button press to non-targets. We hypothesized that participants would display faster reaction times on the day they consumed their caffeinated beverage prior to completing the task, and subsequently would display slower reaction times on the day they did not consume a caffeinated beverage prior

to completing the task. Likewise, we hypothesized that the day a participant consumed their coffee or black tea would result in greater accuracy (i.e., more correct responses) when compared to the day they did not consume a caffeinated beverage prior to the task. We also hypothesized that participants would perform at a faster rate (quicker reaction times) for the first four blocks (Conditions 1 and 2) than across the last four blocks (Conditions 3 and 4), as the first four blocks follow a patterned presentation of the stimuli, whereas the last four blocks follow a randomized presentation of the stimuli. This task manipulation would ideally elucidate caffeine's impact on task performance for "easy" (patterned) versus "difficult" (randomized) conditions. We also expected typical caffeine behavior to modulate the effect, but this hypothesis will be examined in a later analysis when we have more participants.

Experiment 2 was utilized as a feasibility study on a single participant involving the self-report questionnaire, the online behavioral task, and caffeine concentration testing in saliva. Saliva samples were collected and further analyzed using a basic enzyme-linked immunosorbent assay (ELISA) to determine systemic caffeine concentrations prior and subsequent to 12 ounces of black coffee. We hypothesized if the individual intakes smaller amounts of daily caffeine (i.e., less than 200 mg) they will show higher levels of salivary caffeine concentration hours after consumption, and can ultimately be labeled as a "light" caffeine drinker as a result of these two concurrent factors. Likewise, we hypothesized that if the individual intakes larger amounts of daily caffeine (i.e., greater than 400mg) they will result in lower levels of salivary caffeine concentrations hours after consumption, and can therefore be labeled as a "heavy" caffeine drinker as a result of these two concurrent factors. Three saliva samples were collected from the participant (just prior to consuming 12 ounces of black coffee, 30 minutes post consumption and two hours post

consumption, both with zero food in between) to better understand the speed of their caffeine metabolism.

Methods

PARTICIPANTS

Experiment 1 comprised of 15 volunteers (eight males, seven females), who were all English speakers with no history of intellectual or psychiatric disorders. Ages ranged from 19-years to 56-years old. Two female participants consume daily ADHD medication, and they were instructed to take their medication after completing their online behavioral task on each day, so as to lessen/remove interaction with caffeine. Participants ranged from having no (0 mg) history of daily caffeine consumption to having high (> 400 mg) daily caffeine consumption

Experiment 2 comprised of one female volunteer aged 24 years old, who is a native speaker of English and who has no history of intellectual or psychiatric disorders. The participant had a history of light to moderate daily consumption of caffeine.

MATERIALS

Qualtrics

Data from the questionnaire was collected via the City University of New York Graduate Center's Qualtrics portal, an online software for survey research. Confidentiality was maintained by connecting the participant's email addresses to their respective questionnaire results in a password-protected Microsoft Word document on the study PI's password-protected computer. Only the research team had access to this document.

PsychoPy

Data from the online behavioral task was collected using the open-source software, PsychoPy. Through PsychoPy, the behavioral task was built using Python on the Principal Investigator's local computer, then translated into Java for online implementation. This translation allowed the behavioral task to successfully upload onto PsychoPy's associated open-source library, Pavlovia, which allowed online access to the task via a specific link.

Salimetrics SalivaBio Oral Swabs and Swab Storage Tubes

Saliva was collected using Salimetrics SalivaBio Oral Swabs, or individually wrapped absorbent swabs. Once the oral swabs had been adequately saturated in saliva, the swabs are then placed in Salimetrics Swab Storage Tubes, a falcon tube with a snap cap for efficient and safe storage in the freezer.

Enzyme-linked Immunosorbent Assay (ELISA)

Saliva samples were analyzed using a competitive Enzyme-Linked Immunosorbent Assay (ELISA), specifically a Caffeine ELISA Kit from BioVision Inc. (Milpitas, CA, USA) intended to quantitatively measure caffeine in serum, urine, or saliva. Procedure began with preparation of the necessary reagents: two ul of HRP Conjugate Stock were pipetted into the Conjugate Buffer to achieve a conjugate working solution, followed by a brief vortex of the solution. The Diluted Wash Buffer was then utilized (after coming to room temperature) by diluting 10 ml Concentrated Wash Buffer with 90 ml of deionized water. Standard were created by adding 1.5 ml of Standard Buffer into the Caffeine Standard vial to create the standard, S5 (27 ng/ml). Three-fold serial dilutions following S5 were prepared to create S4 to S1 standards (see Table 1). The three saliva samples were prepared by centrifuging 0.2 ml of each sample at 10,000 g for five minutes to recover the supernatant. This supernatant was then diluted 40-fold using the Sample Diluent (i.e., 5 ul of saliva

supernatant mixed with 195 ul of Sample Diluent). 50 ul of the Standards and Samples per well were added to the microplate for the assay. Each Standard and Sample was run in triplicate (i.e. consumed three wells each). 50 ul of conjugate working solution and 50 ul of Antibody were added to all wells containing Standards or Samples. The microplate was then sealed and mixed, followed by a room temperature (25 C) incubation for 45 minutes. After incubation, 250 ul of 1X Wash Buffer were added to each well containing a Standard or Sample, followed by another room temperature incubation of 30 seconds. The 1X Wash Buffer was then completely removed (aspirated). This process was repeated three more times, for a total of four well washes. 100 u of TMB Substrate were then added to each well containing a Standard or Sample. The microplate was then inserted into a spectrophotometer to check the optical density (OD) at 650 nm for the standard containing zero caffeine (S0). Once its reading fell between 0.8 and 1.0, 50 ul of Stop Solution were added to each well containing a Standard or Sample. The microplate was then measured at an OD of 450 nm.

Table 1.

ELISA Procedure Standard Curve Concentrations

Standards	S0	S1	S2	S3	S4	S5
Concentrations (ppb)	0	0.33	1	3	9	27

Note. The six standard curve concentrations used to run the Caffeine ELISA.

PROCEDURES

Self-Reported Caffeine Use and Perceptions Background

A questionnaire covering basic demographic information, typical caffeine consumption, habitual procedures surrounding caffeine consumption, and subjective attitudes and perceptions

was administered. This questionnaire was completed in the privacy of the participant's home (online), on their own time.

The questionnaire began with a Demographics block comprised of eight questions pertaining to categorical data. These questions ranged from typical demographics, such as age and gender, to more specific questions related to caffeine consumption. These included weight (which will modulate the participant's subsequent caffeine metabolism) and possible modulating substances, such as ADHD medications or nicotine products, as these drugs can impact either task performance or caffeine metabolism, respectively.

The following five questions, constituting the Caffeine Consumption Habits block, aimed to gain insight on the participants' typical consumptions habits. For example, the participant was asked the typical quantities of caffeine they drink in a day (in ounces, specific to the kind of caffeinated drink), and what times in the day this occurs. We ended this block with two questions pertaining to the participants' sleep (i.e. what time they typically wake up, and how many hours of sleep they typically get each night), so as to gain quantifiable data concerning the effects their typical caffeine consumption has on their sleep.

The next seven questions made up the Attitudes and Perceptions block, which aimed to reveal how the participant perceived caffeine's impact on their executive functions (i.e., attention, focus, and task-performance). Such questions revolved around the participant's self-perceived positive and negative side effects, as well as their beliefs regarding how caffeine impacted their performance on specific tasks (e.g. studying, playing video games, etc.).

The final question, or the Closing block, asked the participant if they would be interested in participating in a related study involving personal caffeine measurement. The participant was able to choose either "No", which would conclude their involvement in the study, or "Yes, below

is my preferred email:", to which they would provide their email under the expectation that the research team (study PI) would contact them if they fit the inclusion criteria of the study.

Focus and Attentional Task Performance

The participant also completed an online (remote) auditory attention task via Pavlovia.org to test their ability to focus/perform a task under the influence of caffeine. The behavioral task occurred twice over the course of two days: the participant was instructed to complete the task 30 minutes after finishing 12 ounces of coffee or black tea on one day, and prior to consuming any caffeine on the other day (order of caffeine intake was counterbalanced across participants)

Note that the design of this task was selected because in a future study it will be used in a neurophysiological study that uses the mismatch negativity discriminative response to evaluate pre-attentive processing and attention allocation.

Stimuli

Meaningless Speech syllables were recorded by two female and one male speaker. Three tokens of each stimulus type (three "ehpa", and three "ahpa") were selected for each speaker for a total of 18 stimuli. The fundamental (F0) has very different frequency for the Male (mean 150 Hz). and Female Voice 1 (190 Hz) Female Voice 2 (210 Hz).

Procedure

The participant was asked to respond to a target stimulus for a specific speaker voice by pressing "1", and respond to all non-target stimuli by pressing a "0", in four practice conditions. Then, they received eight blocks where the target changed before each block. The speaker target and non-target voices alternated, with one voice and stimulus selected as the target for the first 4 blocks (see Table 1). The task difficulty was manipulated by including random selection of the stimuli for the last 4 blocks.

The behavioral task began with the presentation of target stimuli examples, followed by four practice (training) blocks comprised of three target stimuli and 13 non-target stimuli. Feedback was provided throughout the practice blocks through the display of a correct answer-counter on the screen. After a response, an interstimulus interval (ISI) of 500 ms occurred before the next stimulus.

After finishing the practice blocks, the participant was then presented with eight condition blocks comprised of 110 stimuli each: 7-11 target stimuli and 99-103 non-target stimuli (see Table 1). Each consecutive condition block after the first block presented as a target-switch in which the target stimuli changed by either the target vowel, target speaker-voice, or both. The ISI following a response was 500 ms. Feedback was not provided during any of the experimental conditions. A non-target (distracter) voice was included to increase task difficulty (ex., 4 trials of the second female voice)

Condition 1 – Block 1 served as a baseline, in that it was the first condition block and did not present as a target switch. This condition had a target stimulus of a female speaker voice saying "ehpa" (long vowel: āpa, "tape"). Condition 1 – Block 2 target switched to a target stimulus of the male speaker voice saying ("ehpa") āpa.

Condition 2 – Block 1 underwent a target switch on the vowel as well as the speaker-voice. This condition had a target stimulus of a female speaker voice saying "ahpa (short vowel ăpa as in "top"). Condition 2 – Block 2 target switched to the target stimulus of the male speaker voice saying ăpa.

Condition 3 and 4 were the same as 1 and 2, except the stimuli were selected randomly to increase task difficulty. Specifically, the male and female voice did not alternate, and the targets were not

predictable distributed, as they did not present in a patterned format as they did previously. Thus, these blocks were intended to require more focused attention.

Table 2.

Behavioral Task Condition Order

Conditions	Target Vowel	Non-Target	Target Voice	Distracter Voice
Condition 1 Block 1	/āpa/	/āpa, ăpa/	female	male, female
Condition 1 Block 2	/āpa/	/āpa, ăpa/	male	male, female
Condition 2 Block 1	/ăpa/	/āpa, ăpa/	female	male, female
Condition 2 Block 2	/ăpa/	/āpa, ăpa/	male	male, female
Condition 3 Block 1	/āpa/	/āpa, ăpa/	male	male, female
Condition 3 Block 2	/āpa/	/āpa, ăpa/	female	male, female
Condition 4 Block 1	/ăpa/	/āpa, ăpa/	male	male, female
Condition 4 Block 2	/ăpa/	/āpa, ăpa/	female	male, female

Note. The target vowel, non-target vowel, target voice, and distracter voice for the eight condition blocks of the Behavioral Task.

Caffeine Measurement

We measured caffeine levels in the individual participant's systems via saliva obtained using an oral swab. The sample was then tested for caffeine using an ELISA kit. Participants who completed the caffeine questionnaire were recruited for this portion of the study. If a participant met the inclusionary criteria (for example, age, ability to travel to the drop-off location for the samples) for this phase of the study. After a participant agreed to take part in the study, the researcher contacted them via zoom or phone to go over the consents form. After the participant verbally consented to the study, they were mailed the necessary tools (cotton oral swabs, falcon storage tubes, an ethanol wipe, and gloves) and given detailed directions on how to self-collect their saliva sample. On the day of sample collection, the participant was instructed to use the cotton swabs to collect their saliva at four different time points: prior to consuming 12 ounces of black coffee, 30 minutes post-coffee, two hours post-coffee, and four hours post-coffee (see Figure 1). The participant was also instructed to not consume any food prior or during the collection of samples. They collected these saliva samples by holding the cotton oral swab under their tongue

for two minutes at each time point, fully saturating the swab, before dropping the swab into the storage tube and wiping down the secured storage tube with an ethanol wipe. After collecting all four sample, they then delivered them to a designated meeting point (Hunter College), so as to get the sample placed into a laboratory-grade freezer within 24 hours (per the directions of the ELISA kit). The participant also gave the researcher a signed consent form during the delivery of their saliva samples (that is kept separately from the samples).

Once the participant's saliva samples were successfully in the lab, the ELISA procedure was implemented. The saliva swabs were thawed to a point at which the saliva was able to be extracted by inserting the saliva swab into a 3cc syringe and press out the saliva out into an Eppendorf vial. The syringe was then wiped down with 70% ethanol and properly disposed of in the appropriate biohazardous bin. The Eppendorf vial, gloves, and counterspace were wiped down with 70% ethanol as well. The sanitized Eppendorf vial was then labeled using a Sharpie, and place in the -20-degree Celsius freezer. Gloves and paper towels used to wipe down everything with 70% ethanol were then properly disposed of in the appropriate biohazardous bin. This procedure of extracting saliva from the oral swabs was followed for all four samples. The samples were then processed using a caffeine ELISA kit.

Analyses

The data have been analyzed using methods specific to each procedural task. The caffeine questionnaire was analyzed using the reporting function through Qualtrics. In this study, these data are presented as descriptive statistics.

The data from the behavioral task were analyzed using IGOR Pro8 (WaveMetrics, Inc.) and GraphPad Prism 9. Accuracy was computed as percentage of correct target stimuli, as well as percentage of correct non-target stimuli. False Alarms (FAs) were computed as a percentage of incorrect responses to non-target stimuli (FA=incorrect non-targets/total non-targets). For the preliminary data on the 14 participants, false alarms were very low, so the accuracy measures alone were sufficient (rather than calculate A-prime). The Median accuracy value was selected (rather than mean) as a better representation of the performance. For reaction times, the median and interquartile range were calculated for the non-target responses. These were used rather than means and SDs because they are robust against non-normal distributions and outliers. To test whether accuracy differed across condition (Caffeine, No Caffeine) or task (Pattern, Random), Kruskal-Wallis was performed. This test was selected because the accuracy measures were not normally distributed. For the reaction time data, 2-way repeated measures ANOVAs and post-hoc Tukey's Tests were performed to main effects and interactions between conditions, tasks, or blocks. An alpha less than .05 was considered significant.

For the measure of caffeine in the saliva, the data were analyzed using a spectrophotometer. This process measured amounts of light absorbed or reflected to determine levels of caffeine present in each microplate well. The spectrophotometer used BIOTEK GEN 5 microplate software from BioTek Instruments Inc. (Winooski, VT, USA). The ELISA was analyzed under an optical density (OD) of 450 nm. Samples for each category (prior to consuming the coffee, 30 minutes after finishing the coffee, and two hours after consuming the coffee) were run in triplicate the middle value was selected for further analysis (that is, the high and low values were discarded).

Results

Experiment 1

Table 1.1 and Table 1.2 display the descriptive statistics from the questionnaire data. These reveal eight high-moderate (250 mg to 400 mg) to high (> 400 mg) caffeine drinkers, and seven low (0 mg to < 100 mg) to low-moderate (100 mg to < 250 mg) drinkers.

Table 1.1

Descriptive Statistics: Experiment 2 Questionnaire Low to Low-Moderate Caffeine Drinkers

Sex	Age	Daily Consumption (mg)	Hours of Sleep
Male	28	0	9
Male	19	0	9
Female	31	48	7
Female	25	72	9
Female	44	192	5
Male	24	204	8
Female	56	240	6

Table 1.2

Descriptive Statistics: Experiment 2 Questionnaire High-Moderate to High Caffeine Drinkers

Sex	Age	Daily Consumption (mg)	Hours of Sleep
Male	56	288	6
Female	29	288	9
Male	45	318	7
Female	24	411.6	8
Female	32	424.8	8
Male	36	440.4	6
Male	32	528	7
Male	26	770.4	6

Three males and four females self-reported daily caffeine consumptions ranging from zero mg to 240 mg, categorizing them as low to low-moderate drinkers. These low to low-moderate

drinkers achieved an average of 7.6 hours of sleep per night. Five males and three females self-reported daily caffeine consumptions ranging from 288 mg to 770.4 mg, categorizing them as high-moderate to high drinkers. These high-moderate to high drinkers achieved an average of 7.1 hours of sleep per night.

Figure 1.1, Figure 1.2, and Table 1.3 all pertain to the Experiment 1 behavioral task.

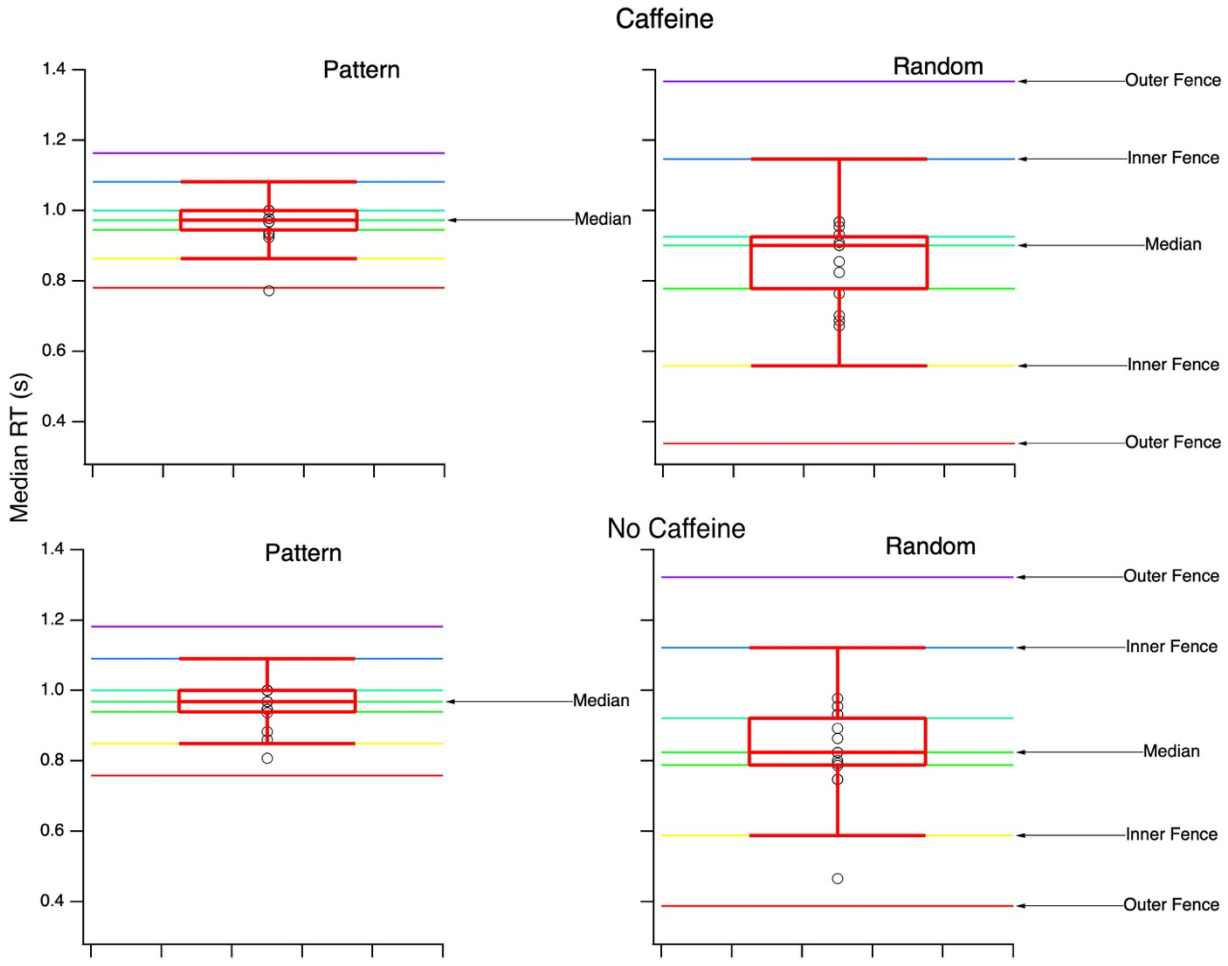

Figure 1.1 Boxplots for the target accuracy data comparing the average median scores across the first four blocks (Patterned) to those of the second four blocks (Randomized) for the caffeinated day (top two boxplots) and the non-caffeinated day (bottom two boxplots).

Does caffeine affect accuracy?

Figure 1.1 displays boxplots of median reaction time in caffeine (top) versus no caffeine (bottom) conditions. No significant difference was found between the caffeine and no-caffeine conditions for either tasks (Kruskal-Wallis, Patterned: $H = 0.02$, $p = 0.89$; Randomized: $H = 0.33$, $p = 0.57$).

The accuracy for the target data was significantly higher in the Patterned blocks when compared to the Randomized blocks for both the caffeinated and the non-caffeinated conditions (Kruskal-Wallis, $H = 11.70$, $p = 0.0006$; $H = 10.42$, $p = 0.001$, respectively). The Patterned blocks show participants performed near ceiling (near 100% accuracy), but the Randomized blocks show participants performed significantly more poorly (about half of the participants performed with less than 85% accuracy).

For the non-target accuracy, participants performed near ceiling (median accuracy scores were 100% for all eight blocks, with all participants above 95% correct) for both conditions. Thus, statistical tests were not needed to determine that there were no differences related to condition (caffeinated versus non-caffeinated) or task (Patterned versus Randomized).

Does caffeine affect reaction time?

Figure 1.2 displays boxplots of median reaction times. For the patterned condition, a 2-way repeated measures ANOVA analyzing caffeine and block as factors revealed no main effect for caffeine ($F(1, 14) = 0.523$, $p = 0.482$), but a main effect of block ($F(3, 42) = 16.90$, $p < 0.0001$). No significant interaction between block and caffeine was found ($F(3, 42)=0.071$, $p = 0.924$). A post-hoc analysis using a Tukey's Test revealed Block 1 and Block 2 were significantly slower than Block 3 and 4. Block 3 was also significantly slower than Block 4 ($p < 0.05$).

For the randomized condition, the 2-way repeated measures ANOVA analyzing caffeine and block as factors revealed no main effect for caffeine ($F(1,14) = 0.320$, $p = 0.581$), but a main effect of block ($F(3, 42) = 10.72$, $p < 0.0001$). No significant interaction between block and caffeine was found ($F(3, 42) = 0.507$, $p = 0.679$). A post-hoc analysis using a Tukey's Test also revealed Block 1 was significantly slower than Block 2 and Block 3, but Block 3 was faster than Block 4 ($p<0.05$). Table 1.3. displays the mean RT and standard deviation across blocks for the different conditions and tasks.

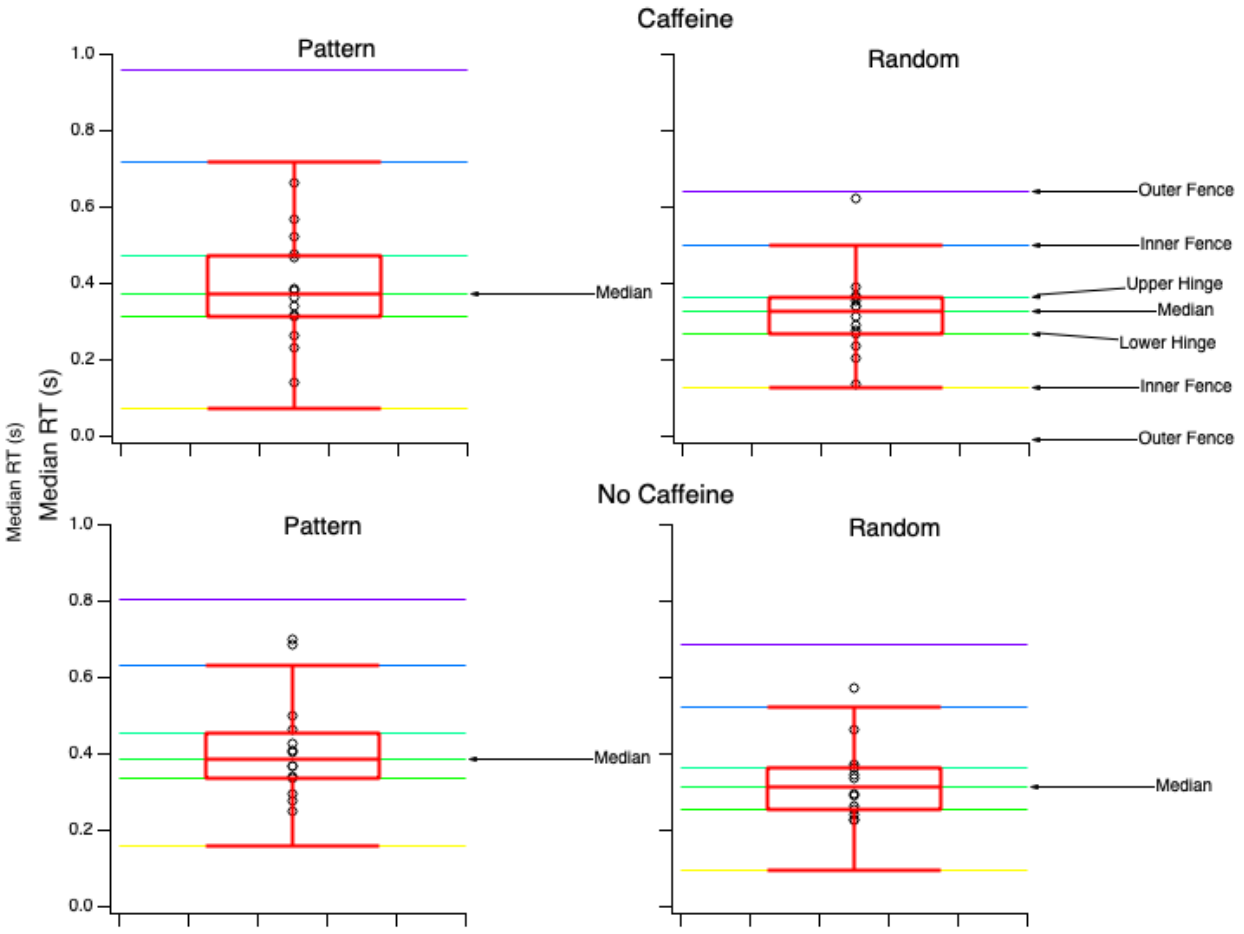

Figure 1.2 Boxplots for the median reaction time, comparing the first four blocks (Patterned) to those of the second four blocks (Randomized) for the caffeinated day (top two boxplots) and the non-caffeinated day (bottom two boxplots).

Table 1.3

Mean Reaction Times by Task and Condition

Block	First	Second	Third	Fourth
Caffeine Pattern	0.426 (.148)	0.400 (.148)	0.382 (.143)	0.328 (.142)
Caffeine Random	0.343 (.123)	0.300 (.116)	0.300 (.112)	0.328 (.110)
No Caffeine Pattern	0.460 (.171)	0.419 (.140)	0.414 (.152)	0.356 (.114)
No Caffeine Random	0.352 (.100)	0.323 (.095)	0.315 (.108)	0.331 (.099)

Note. Mean reaction times (calculated from participants' median reaction times) for each block in the Patterned and Randomized tasks for the two conditions (caffeinated and non-caffeinated).

A 2-way repeated measures ANOVA examining task and block as factors revealed a significant main effect of block ($F(3, 42) = 16.91$, $p < 0.0001$), a significant main effect of task ($F(1, 14) = 25.88$, $p = 0.0002$), and a significant interaction between block and task ($F(3, 42) = 13.78$, $p < 0.0001$). The interaction was the result of faster RTs for block 4 compared to earlier blocks for the Patterned task, but a slower RT for block 4 compared to block 3 for the Randomized task.

Experiment 2

Results from the demographics and consumption sections of the questionnaire are shown in Table 2.1. The 24-year old female participant reported weighing 135 pounds, with no history of ADHD medication or nicotine use. Her typical caffeine consumption involved 22 ounces of coffee a day, typically consumed between the hours of 8:00 A.M. and 4:00 P.M. She typically woke each day at 9:00 A.M. after having slept for eight hours. Table 2.2 shows the questionnaire results of the participant's attitudes and perceptions towards her personal caffeine use. She reported that

advantages to her caffeine use was reduced drowsiness, minimization of headaches and migraines, focus and attention improvement, and mood elevation. She reported disadvantages to her caffeine use to be the habit formation associated with caffeine consumption, restlessness, and gastrointestinal irritation.

Table 2.1

Descriptive Measurements: Demographics & Consumption

Age	24 years old
Weight	135 lbs
ADHD Medication	No
Nicotine Consumption	No
Caffeinated Beverage	Coffee
Daily Consumption	22 oz
Times of Consumption	8:00AM - 4:00PM
Typical Wake Time	9:00AM
Sleep Per Night	8 hours

Note. The participant's age, weight, prescription of ADHD medication, consumption of nicotine products, typically consumed caffeinated beverage, typical daily caffeine consumption quantity, typical time of caffeine consumption, typical wake time, and typical quantity of sleep per night in hours.

Table 2.2

Descriptive Measurements: Attitudes and Perception

Advantages	Reduced Drowsiness
	Minimizes Headaches/Migraines
	Improves Focus/Attention
	Elevates Mood
Disadvantages	Habit-Forming
	Restlessness
	Gastrointestinal Irritation
Optimal Caffeine Intake	24 oz
Worst Caffeine Intake	40 oz
Caffeine improves alertness?	Strongly agree
Caffeine improves task focus?	Strongly agree
Caffeine improves performance/reduces errors?	Strongly agree

Note. The participant's perceived advantages to caffeine, perceived disadvantages to caffeine, optimal quantity of caffeine intake, worst quantity of caffeine intake, attitude toward caffeine's ability to improve alertness, attitude toward caffeine's ability to improve task focus, and attitude toward caffeine's ability to improve performance/reduction of errors.

Table 2.3 shows results from the descriptive statistics on all eight blocks of the first day of the behavioral task data. On the first day of completion (participant consumed 12 ounces of coffee, followed by task completion 30 minutes after finishing the coffee) the participant showed average target accuracy of 1.000 (100%). In these same condition blocks, the participant's non-target accuracy was 0.991 (99.1%), with very low false alarms (errors) of 0.008 (0.8%). Reaction time for non-target stimuli averaged 0.251 s after stimulus onset, with a standard deviation of 0.064 s. Reaction time for target stimuli averaged 0.320 s after stimulus onset, with a standard deviation of

0.077 s. This participant's accuracy levels and reaction times were similar to those found in experiment 1.

Table 2.3

Quantitative Measurements: First Behavioral Task Completion Under the Influence of Caffeine

	Non-Target Accuracy	Target Accuracy	False Alarms	Average RT Non-Targets	STD RT Non-Targets	Average RT Targets	STD RT Targets
C1B1	1	1	0	0.288	0.056	0.314	0.033
C1B2	0.99	1	0.01	0.294	0.112	0.266	0.050
C2B1	1	1	0	0.293	0.059	0.257	0.061
C2B2	0.99	1	0.01	0.249	0.041	0.320	0.073
C3B1	0.98	1	0.02	0.295	0.059	0.410	0.153
C3B2	1	1	0	0.201	0.055	0.350	0.104
C4B1	0.98	1	0.02	0.211	0.058	0.337	0.079
C4B2	0.99	1	0.01	0.173	0.073	0.308	0.064
Total	0.99	1	0.01	0.250	0.064	0.320	0.077

Note. The non-target accuracy, target accuracy, false alarm frequency, average reaction times for non-targets, standard deviations for the reaction times of non-targets, average reaction times for targets, and standard deviations for reaction times of targets of the eight behavioral task condition blocks and the total values for the entire first day's task completion.

Figure 2.1 displays the participant's reaction times by trial number for Condition 1 Block 1 and Condition 2 Block 2 on the caffeine day—the first and last condition blocks in the behavioral task, to illustrate the start and finish of the patterned task. Figure 2.2 displays the participant's reaction times by trial number for Condition 3 Block 1 and Condition 4 Block 2 on the caffeine day—the first and last condition blocks that used a randomized presentation. The participant's reaction times for the last sequential block occurred at comparable rates to the first block, but with less variability. The participant's reaction times for the last randomized block was faster compared to the first block.

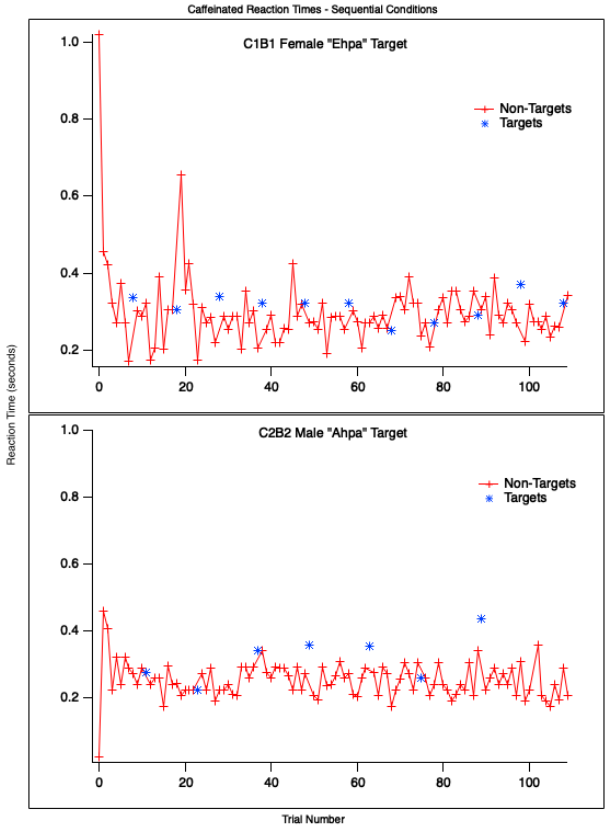

Figure 2.1. Reaction times by trial number for Condition 1 Block 1 and Condition 2 Block 2 on the caffeine day

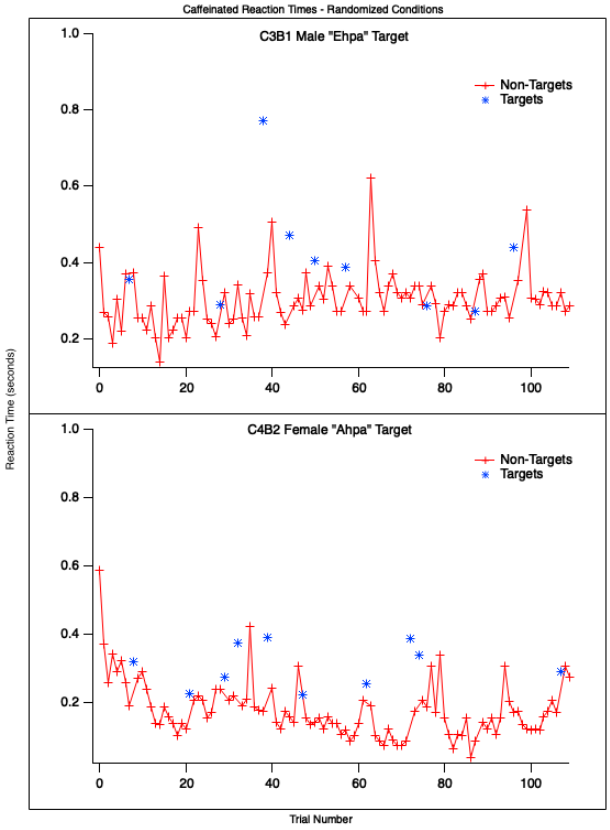

Figure 2.2 Reaction times by trial number for Condition 3 Block 1 and Condition 4 Block 2 on the caffeine day

Table 2.4 shows the descriptive statistics on all eight blocks of the no-caffeine day of the behavioral task data. The participant showed a target accuracy of 0.972 (97.2%). The participant showed non-target accuracy of 0.991 (99.1%), and very low false alarms 0.009 (0.9%). The participant showed no errors for the first three blocks. But notice for the Random blocks (C3 and C4 conditions), the participant made more errors. Reaction time for non-target stimuli averaged 0.254 s after stimulus onset, with a standard deviation of 0.068 s. Reaction time for target stimuli averaged at 0.299 s after stimulus onset, with a standard deviation of 0.060 s, which was comparable to the data in experiment 1.

Table 2.4

Quantitative Measurements: Second Behavioral Task Completion Under the Influence of Zero Caffeine

	Non-Target Accuracy	Target Accuracy	False Alarms	Average RT Non-Targets	STD RT Non-Targets	Average RT Targets	STD RT Targets
C1B1	1	1	0	0.255	0.072	0.292	0.080
C1B2	1	1	0	0.281	0.063	0.253	0.060
C2B1	1	1	0	0.272	0.068	0.247	0.030
C2B2	0.99	0.88	0.01	0.219	0.078	0.298	0.090
C3B1	1	1	0	0.258	0.076	0.316	0.073
C3B2	0.99	1	0.001	0.221	0.054	0.312	0.025
C4B1	0.97	1	0.00	0.250	0.054	0.296	0.035
C4B2	0.98	0.9	0.02	0.278	0.083	0.377	0.085
Total	0.99	0.97	0.01	0.254	0.068	0.299	0.060

Note. The non-target accuracy, target accuracy, false alarm frequency, average reaction times for non-targets, standard deviations for the reaction times of non-targets, average reaction times for targets, and standard deviations for reaction times of targets of the eight behavioral task condition blocks and the total values for the entire second day's task completion.

Figure 2.3 displays the participant's reaction times by trial number for Condition 1 Block 1 and Condition 2 Block 2 of the patterned task on the no-caffeine day, and Figure 2.4 displays these data for Condition 3 Block 1 and Condition 4 Block 2 of the randomized task on the caffeinated day. The participant's reaction times were similar to Experiment 1. In particular, the participant was slower in the 4th block of the randomized condition compared to earlier blocks, as found in Experiment 1 analysis.

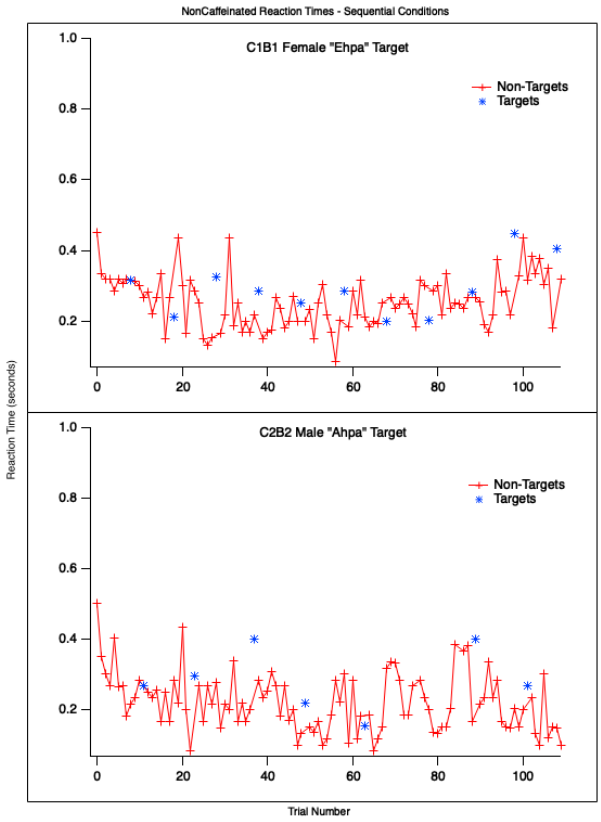

Figure 2.3 Reaction times by trial number for Condition 1 Block 1 and Condition 2 Block 2 on the no-caffeine day

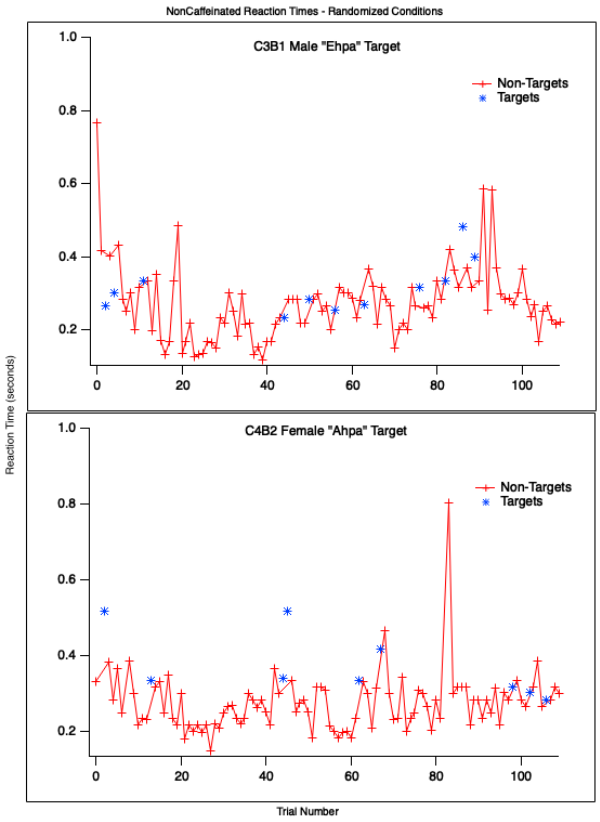

Figure 2.4 Reaction times by trial number for Condition 3 Block 1 and Condition 4 Block 2 on the no-caffeine day

Results from the Experiment 2 saliva collection procedure are show in Figure 2.5. The participant's basal caffeine concentrations averaged out to 7.959 mg/mL. Saliva samples taken at 30 minutes post-coffee consumption resulted in the highest caffeine concentrations, which averaged out to 103.312 mg/mL. Following this max caffeine concentration, the samples collected at two hours post-coffee consumption averaged out to 97.337 mg/mL.

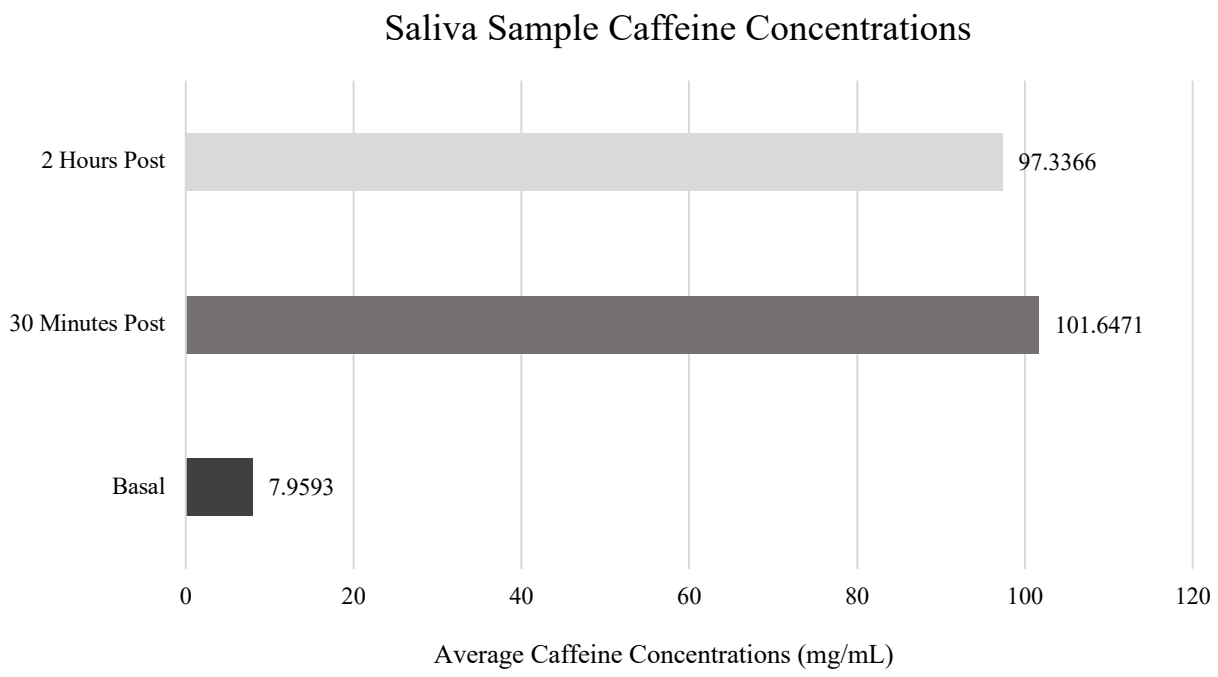

Figure 2.5 Average caffeine concentrations in mg/mL, collected at three time points (prior to consuming caffeine, 30 minutes after caffeine, and two hours after caffeine.

Discussion

Experiment 1

Experiment 1 examined whether caffeine consumed in a cup of coffee or tea affected performance on a behavioral attention task. The study showed no effect of caffeine intake on either response accuracy or reaction time in this task. The participants all performed well on the task, but they did show improvement across blocks for which the target stimulus was switched. The participants also showed lower accuracy for the randomized condition than the pattern condition (which was near ceiling performance). However, even for the randomized condition, performance was high. Previous studies have observed effects of caffeine on reaction time in attention tasks (McLellan et al. 2016; Nehlig, 2010) It is possible that we did not observe this effect because the tasks were too easy to observe differences in accuracy or reaction time related to caffeine. A future

investigation will need to examine whether caffeine modulated performance using a more difficult task (such as target and non-target female voices that are closer in pitch).

Descriptive statistics from the Experiment 1 questionnaire provided insight into the general range of caffeine consumption, nightly sleep, and various other demographic information (ex. age, sex, weight, etc.) that could impact caffeine metabolism. The addition of more participants will allow us to examine whether caffeine consumption patterns modulate performance in experiment 1. Furthermore, obtaining saliva samples to test their systemic caffeine concentrations in conjunction with their self-reported consumption data would allow us to test whether there are significant differences in behavioral or metabolism among so-called "light" versus "heavy" caffeine drinker.

The finding that target accuracy for the Patterned blocks was near ceiling (near 100%), whereas target accuracy for Randomized blocks was notably inferior (ex. half of all participants performed with a target accuracy of less than 85%) indicates that the Randomized blocks were more difficult.

The Patterned blocks resulted in slower reaction times when compared to the Randomized blocks, for both caffeinated and non-caffeinated conditions. This finding suggests that the Patterned blocks require greater vigilance (task focus), resulting in slower reactions. This could be due to the lesser level of difficulty in completing the Patterned blocks, as this creates an otherwise more monotonous situation in comparison to the Randomized blocks. The greater difficulty of the randomized blocks seemed to focus attention.

The lack of difference between the caffeine and no caffeine condition may in part be due to our small sample size. However, the pattern of findings across blocks and for the patterned and randomized conditions were quite similar. We had too few subjects to examine whether low for

high caffeine drinkers performed difference. Thus, adding more subjects to allow this factor to be added to the analysis will be important to fully evaluate our hypotheses.

Experiment 2

Results from the questionnaire fall in line with our initial hypotheses regarding caffeine consumption habits influencing personal perceptions and attitudes regarding caffeine's impact on task performance. The participant had a reported daily intake of 22 ounces of coffee, or approximately 264 mg of caffeine per day. This categorizes the participant as a low-end moderate caffeine drinker according to our previously declared standards. Likewise, this daily consumption coincides with our hypothesis that individuals who intake 100 mg to 400 mg of daily caffeine would report greater focus and/or task performance, specifically the participant in question reported strong agreement ("strongly agree") to the Perceptions and Attitudes questions of the questionnaire pertaining to alertness, focus, and task performance/reduction of errors. Further, the participant reported a fair number of disadvantages to their caffeine usage (habit formation, restlessness, and gastrointestinal irritation). This is consistent with our hypothesis that individuals who intake less than 400 mg of caffeine would report greater negative effects as a result of caffeine consumption than those who have intakes of greater than 400 mg.

The participant indicated an intake of 22 ounces of coffee a day, or approximately 264 mg of caffeine, they would be categorized as a moderate caffeine drinker. Our initial hypothesis predicted that individuals who intake smaller amounts of daily caffeine (< 200mg) would have higher salivary concentrations of caffeine hours after consumption (e.g., two hours after consumption). With this in mind, our measures indicate that the participant metabolized caffeine like a "light" caffeine drinker, despite drinking slightly more than 200 mg of caffeine per day. Their salivary caffeine concentrations only minimally decreased between 30 minutes post caffeine

consumption (an average of 103.312 mg/mL) and two hours post caffeine consumption (an average of 97.337 mg/mL), indicating that they metabolize caffeine more slowly than predicted for an individual that otherwise consumes greater than 400 mg of caffeine per day (a “high” caffeine drinker).

This case study finding indicates that the measures of caffeine in the saliva will be essential to determine who is more versus less affected by caffeine. We will also be able to determine to what extent the questions about caffeine consumption and views are correlated with caffeine metabolism.

For the behavioral task data, results are mixed in terms of agreeing with our initial hypothesis. The participant displayed similar non-target reaction times (0.251 s) on the day they consumed coffee before the task compared to the day that they had no caffeine before the task (0.254 s). The participant showed very high accuracy (near or at ceiling) for both target and non-target stimuli for both caffeine and non-caffeinated days (97 %). The absence in different in RTs may reflect that this participant behaves similar to a light coffee drinker and is less influenced by caffeine.

We had expected that this task with male and female voices would be relatively easy (and thus, accuracy might not be sensitive). A follow-up study is designed to include a more difficult task with two female voices that differ less in pitch, which is more likely to show higher errors in accuracy. However, it is important to note that the participants in experiment 1 were almost all graduate students, who are high achievers. It is possible that participants recruited from the larger population (e.g., undergraduate students) might show poorer performance. Thus, more data using the currently design need to be collected from this larger population.

Another possibility for the absence of slower reaction times on the no-caffeine day may have been related to a practice effect for participants who had no caffeine on the second day. We would expect faster reaction times on day 2 compared to day 1. In experiment 1, the day a participant consumes caffeine was counterbalanced across participants to remove this effect. However, we will need more participants to directly examine to what extent the additional experience improved performance.

In general, our findings for this case study have shown sufficient evidence for the feasibility of a larger study involving a greater range of participants (age, sex, typical caffeine consumption, etc.). When analyzing our participant as a categorical "light" caffeine drinker given their low-end moderate daily coffee consumption, their perceptions and attitudes support our hypotheses that individuals who consume light/moderate amounts of caffeine (100 mg-400 mg) will report a greater impact from caffeine—both positive and negative effects. Likewise, being analyzed as a "light" caffeine drinker further supports our hypothesis that those who consume smaller amounts of daily caffeine (< 200 mg to 300 mg, if the finding here holds up) will show a "slower" metabolism of caffeine in their saliva caffeine concentration ELISA data. This was plainly indicative in the participants average concentration levels at the three time points, as the difference between the average concentrations at 30 minutes and two hours was quite minimal, yet still a reduction as time went on.

That being said, although the behavioral task data for the participant does not unambiguously support our hypotheses, the finding is consistent with the hypothesis that low caffeine drinkers will show smaller differences in performance with and without coffee compared to high drinkers. It is also possible that a caffeine effect would be seen for heavy drinkers in a comparison of performance 30 minutes after consumption compared to hours later (when caffeine

levels drop). Thus, another future manipulation is to ask participants to undertake the task in the afternoon, 4 hours after drinking 1 cup of coffee (compared to 30 minutes after consumption).

Limitations

The results of this research must be considered in the light of several limitations. First, generalizations cannot be made from a case study of a single participant. The case study, however, did demonstrate the feasibility of conducting the larger study.

The coronavirus disease (SARS-CoV-2) pandemic (World Health Organization, 2020), or COVID-19, affected the design and timeline for completing this study. Several novel restrictions were put in place from the beginning of the pandemic in March 2020, through to the end of the year. Remote research methods were approved for students and faculty to utilize before all other methodologies; In-person research was not approved until recently (particularly research that involved biospecimens, for example, saliva). As a result, the collection of saliva samples was delayed, limiting this part of the study to a case study.

Future Directions

Going forward, our research team has several plans for expansion on this study's data and implications. Recruiting a larger sample size would be paramount in testing the hypothesis regarding heavy versus light caffeine drinkers. This sample population should include a greater range in age, sex, and caffeine consumption that would result in the ability to generalize the data results to the greater population. Qualitative data from a larger, more diverse sample from the questionnaire would lead to greater validity of the observations regarding the various impacts of caffeine. For example, surveying participants who consume larger amounts of caffeine could indicate whether our hypotheses concerning individuals who consume greater than 400 mg of

caffeine daily truly would self-report fewer general effects from caffeine (both negative and positive effects). This finding could, perhaps, be due to higher metabolism that we predict will be found in the saliva of "high" caffeine drinkers; in addition, this finding might be due to desensitization of the effects of caffeine after developing such a high tolerance.

Behavioral task difficulty could also be increased through various measures. Using a female target voice paired with a female non-target voice would make for greater difficulty than our present task of male/female target and non-target voice. Block presentation could also be altered so as to present the Randomized blocks first then the Patterned blocks for half of the participants. This would allow further analyses on any order effects.

We also plan to use electrophysiology (EEG) to test how well the participant inhibits the non-target voice (using an oddball paradigm). Here we would like to examine these neural measures, in relation to caffeine consumption and behavioral performance.

Several other executive functions can be explored in relation to caffeine. Previous literature already points to a positive impact of caffeine concerning performance in task switching paradigms. For example, ERPs collected in a task switching paradigm by Tieges et al. (2006) resulted in a larger negative deflection development within preparatory intervals for switch trials compared to that of repeat trials (no task switch, just a single task). Likewise, global processing raises many interesting questions, particularly given its role on pattern formation. Cognitive tasks such as reading comprehension rely heavily on the complex language areas of the left hemisphere, as well as the verbal and nonverbal pattern formation primarily dealt with in the right hemisphere—already known to manage global processing of scenes. Though it has been shown by previous research that small quantities of caffeine lead to improvement in global processing and text reading skills in adults (Franceschini et al., 2020; Mitchell & Redman, 1992), we could expand on these

inquiries of caffeine's impact on alternative executive functions to further question how an individual's typical daily caffeine consumption impacts global processing and task switching.

Exploring the connection between caffeine and systemic arousal would also be beneficial in determining the variability of caffeine metabolisms, and its subsequent impacts on task performance paradigms. This connection between caffeine and arousal has already been discussed in literature, particularly concerning caffeine's impact on the dopaminergic system. As far as the dopaminergic connection to caffeine's impact on task performance and other related executive functions, it has been indicated that dopaminergic transmission as a result of caffeine intake increases performance on tasks such as positive emotional word recognition and anticipatory processing (Brunye et al., 2012; Kuchinke & Lux, 2012; Tieges et al., 2006). Interestingly, the research done by Kuchinke & Lux (2012) only allowed one to deduce a "positivity advantage" in emotional word recognition as a result of caffeine intake; only positive words were shown to result in an increased performance on word recognition—negative and neutral word stimuli showed no significant improvement in word recognition when supplemented with caffeine. With this in mind, taking a more biological trajectory when measuring and analyzing systemic caffeine concentrations could render interesting findings concerning the connection between caffeine and cortisol, which both ultimately impact dopaminergic activity (Bloomfield et al., 2019; Kuchinke & Lux, 2012). Perhaps collecting samples from participants to test both caffeine concentrations as well as cortisol levels in the system in relation to various executive function performance would shed even further light on the variability of individual metabolisms and their subsequent impacts on improvement across executive functions.

Uncovering these impacts would not only aid scientific research, but also the immediate lives of individuals. The majority of laymen view common drugs such as caffeine in a black and

white ideology—it either helps or hurts. However, this could very well be a flawed view on the subject, especially when taking into account how their specific metabolism and allostatic load (both current and historical) impact their caffeine consumption.

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