Examining the Influence of Caffeine on Attentional Engagement in Everyday Life and During an Auditory Attention Task

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

Tyler Kruger was the sole author of Chapter 4 which was written under the supervision of Dr. Daniel Smilek and was not written for publication. This thesis consists in part of two manuscripts written for publication. Exceptions to sole authorship of material are as follows:

Material presented in Chapters 1, 2, and 5:

Dr. Daniel Smilek and Dr. Mike J. Dixon are co-authors on the publication presented in Chapter 2: The Relation Between Caffeine and Attention in Everyday Life. Most of the manuscript can be found here, however, parts of the Introduction and Discussion of the published manuscript can also be found in Chapter 1: General Introduction and Chapter 5: Concluding Remarks, respectively. This research was conducted at the University of Waterloo by Tyler Kruger under the supervision of Dr. Daniel Smilek. Dr. Daniel Smilek, Dr. Mike Dixon, and Tyler Kruger contributed to the study design. Tyler Kruger was responsible for participant recruitment, data analysis, drafting the manuscript, and submitting it for publication. Dr. Daniel Smilek and Dr. Mike Dixon also provided intellectual input on the manuscript drafts.

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Material presented in Chapters 1, 3, and 5:

Dr. Daniel Smilek, Dr. Mike J. Dixon, and Dr. Jonathan M. Oakman are co-authors on the publication presented in Chapter 3: Examining The Effects of Caffeine During an Auditory Attention Task. Most of the manuscript can be found here, however, parts of the Introduction and Discussion of the published manuscript can also be found in Chapter 1: General Introduction and Chapter 5: Concluding Remarks, respectively. This research was conducted at the University of Waterloo by Tyler Kruger under the supervision of Dr. Daniel Smilek. Dr. Daniel Smilek, Dr. Mike Dixon, and Tyler Kruger contributed to the study design. Tyler Kruger was responsible for participant recruitment, creating the attention task, data analysis, drafting the manuscript, and submitting it for publication. Dr. Jonathan Oakman also contributed to the data analysis. Dr. Daniel Smilek, Dr. Mike Dixon, and Dr. Jonathan Oakman provided intellectual input on the various manuscript drafts.

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Abstract

Caffeine is a popular psychoactive substance used by a large part of the population primarily to increase their cognitive abilities. In this dissertation I explore the links between caffeine consumption, motives to use caffeine, and attention-related experiences. After reviewing the relevant literature (Chapter 1), I report several studies (Chapter 2) exploring 1) how caffeine consumption relates to attention in everyday life using self-report measures that each target a different facet of attentional engagement, and 2) how different motivations for choosing to ingest caffeine may relate to the measures of everyday attention. Findings showed that amount of caffeine consumed in a typical day (estimated in milligrams) was not to related to attention-related experiences in everyday life. However, those who are more likely to ingest caffeine to potentially enhance their cognition, or to experience the reinforcing effects of caffeine, or to help relieve negative affect showed higher levels of inattention in everyday life. Next, I explored how caffeine (versus placebo) may influence performance and attentional engagement during a sustained auditory attention task, as well as the replicability of earlier findings regarding the effects of caffeine consumption on various attention-related experiences such as affect, arousal, boredom, sleepiness, and mental effort (Chapter 3). Participants completed two sessions of an attention task (once before consuming caffeine or placebo and once after) and intermittently responded to thought probes asking about their mind-wandering. Compared to placebo, findings showed that there was a performance and attentional benefit on the attention task following caffeine consumption. I also replicated earlier findings by showing that participants who consumed caffeine reported greater positive affect and arousal as well as less feelings of boredom, sleepiness, and mental effort compared to placebo. I also further explored the positive relation regarding the cognitive motives of caffeine consumption and the tendency to experience more inattention in everyday life. Prior to caffeine consumption, participants who had greater cognitive motives reported being less

on task; following caffeination, this correlation became non-significant. In a follow-up study (Chapter 4), I sought to replicate the main findings from the attention task and further explored the relations between cognitive motives and proportion of on task responses in a larger sample. I replicated my earlier findings by showing there was a performance and attentional benefit on the attention task following caffeine consumption. I also replicated the findings regarding affect, arousal, boredom, sleepiness, and mental effort. Importantly, however, I failed to replicate the relations between the cognitive motives and proportion of on task responses suggesting that this relation may not be as robust as originally thought. Finally, I conclude (Chapter 5) by contextualizing the main findings from the studies presented, their limitations, and suggest future directions.

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The research presented in this thesis was conducted at the University of Waterloo. I acknowledge that much of this work took place on the traditional territory of the Neutral, Anishinaabeg, and Haudenosaunee peoples. The University of Waterloo is situated on the Haldimand Tract, the land granted to the Six Nations that includes six miles on each side of the Grand River.

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Dedication

To my parents, who always reminded me to keep my goals in sight, and to my sister, brother-in-law, and nephew. I would like to thank all of you for your constant love and support, and your untiring belief in me and what I am capable of. I could not have done this without you.

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Chapter 1: General Introduction

Consider for a moment how your attention may change over the course of a day. One minute you may be experiencing moments of deep and effortless concentration in which your attention is completely focused on the task at hand—often referred to as flow (Csikszentmihalyi & Nakamura, 2010; Marty-Dugas et al., 2021; Marty-Dugas & Smilek, 2019). At other times your attention may misbehave and lapse, leading you to experience moments of absent-mindedness, attention-related errors, or mind-wandering (Cheyne et al., 2006; Seli et al., 2018; Smallwood & Schooler, 2006). Typically, these instances of inattention result in minor foibles (e.g., putting milk in the pantry and cereal in the fridge), however, these moments of inattention can sometimes result in catastrophic consequences (e.g., failing to stop at a red light; Gil-Jardiné et al., 2017). There is evidence that some people experience these sorts of attentional states more often than others, which suggests that propensities for inattention or flow can be construed as enduring traits (De Manzano et al., 2013; Mayes et al., 2014; Mosing et al., 2012).

In recent years there has been a growing interest in bolstering cognitive performance using a variety of approaches, including, for example, computer-based training (e.g., Bainbridge & Mayer, 2018; Gates et al., 2020; Simons et al., 2016; Zickefoose et al., 2013) and mindfulness-based interventions (e.g., Dunning et al., 2019; Gill et al., 2020; Whitfield et al., 2022; Yakobi et al., 2021). At first glance it seems like these methods may provide an easy and accessible way for people to improve cognition and attention. Computer-based treatments involve completing a variety of cognitive tasks with the hopes of improving overall cognition (Gates et al., 2020). The empirical evidence suggests that the brain-training interventions

improve performance on the tasks specific to that brain-training intervention, however, there is less evidence that these interventions generalize to improve everyday cognition (Bainbridge & Mayer, 2018; Gates et al., 2020; Simons et al., 2016; Zickefoose et al., 2013). There are also many types of mindfulness-based interventions, but in general, mindfulness-training refers to the practice of disengaging from distractors (e.g., mind-wandering) and directing one's attention back to the present moment (Whitfield et al., 2022). Given the nature of these interventions, researchers have investigated the potential benefits that mindfulness-based interventions may have on attention and cognition. The empirical evidence suggests small global effects of mindfulness-based interventions on cognitive functioning with small effect sizes (Whitfiled et al., 2022; Dunning et al., 2019; Gill et al., 2020; Yakobi et al., 2021). Both interventions require active training or practice to achieve noticeable improvements.

Another way to potentially improve cognitive performance is through the use of various stimulants. Stimulant medications (e.g., dextroamphetamine, methylphenidate, lisdexamfetamine, etc.) are typically prescribed to treat attention-deficit hyperactivity disorder (Boland et al., 2020; Carolan, 2021). However, non-medical prescription stimulant use has increased in popularity, especially among post-secondary students (Fairman et al., 2021; Plumber et al., 2021). The popularity of misuse is likely due to the notion that the use of these substances will enhance focus and attention (Arria & DuPont, 2010; Plumber et al., 2021).

For a large part of the population, however, caffeine seems to be the most readily available choice as a potential cognitive enhancing stimulant (Heckman et al., 2010; Weinberg & Bealer, 2004). Previous research suggests that people are motivated to use caffeine for a plethora of reasons (Ágoston et al., 2018; Batista et al., 2022; Choi, 2020; Graham, 1988; McIlvain et al.,

2011; Riera-Sampol et al., 2022; Rogers & Richardson, 1993; Soós et al., 2021; Stachyshyn et al., 2021; Turner et al., 2023). For example, people report that they choose to ingest caffeine because of the social aspects that surround caffeine consumption (e.g., grabbing a coffee with friends), because they like the taste of caffeinated beverages, or to even help manage withdrawal symptoms. (Ágoston et al., 2018; Batista et al., 2022; Choi, 2020; Graham, 1988; McIlvain et al., 2011; Riera-Sampol et al., 2022; Rogers & Richardson, 1993; Soós et al., 2021; Stachyshyn et al., 2021; Turner et al., 2023). However, the primary motivation to consume caffeinated products seems to be related to the potential to increase cognitive abilities (Ágoston et al., 2018; Batista et al., 2022; Choi, 2020; McIlvain et al., 2011). In this thesis, the primary focus will be on caffeine, and more specifically its potential influence on attentional engagement.

1.1 The Physiological Effects of Caffeine

Caffeine is a naturally occurring alkaloid and a common component of various beverages and food products (e.g., energy drinks, soft drinks, coffee, tea, chocolate, etc.; Ferré, 2016; Heckman et al., 2010; Weinberg & Bealer, 2004). Caffeine binds to adenosine receptors as a non-selective adenosine antagonist (Einöther & Giesbrecht, 2013; Ferré, 2016). Adenosine is a by-product of energy production and increases during periods of wakefulness (Basheer et al., 2004), and as extracellular adenosine concentrations increase, so does sleepiness (Basheer et al., 2004; Reichert et al., 2022). Adenosine receptors are distributed in almost all human body tissues and organs but the primary effects from caffeine result from its affinity for A1 and A2a receptors (Ballesteros-Yáñez et al., 2018). A1 receptors are mainly present in the hippocampus, cerebral cortex, cerebellum, and the numerous nuclei of the hypothalamus (Ballesteros-Yáñez et al., 2018; Einöther & Giesbrecht, 2013). Once adenosine is bound to these receptors, it inhibits the

release of various neurotransmitters (e.g., glutamate, dopamine, and acetylcholine). However, caffeine can block this inhibition resulting in an increase in neuronal activity and physiological arousal (i.e., the general wake promoting effects caffeine is known for; Ballesteros-Yáñez et al., 2018; Einöther & Giesbrecht, 2013). A2a receptors are primarily found in the striatum and are related to the analeptic properties of caffeine (i.e., once bound, caffeine can enhance psychomotor activity; Ballesteros-Yáñez et al., 2018; Einöther & Giesbrecht, 2013). Interestingly, caffeine's antagonism of adenosine receptors can be observed in doses as low as 100 mg (or approximately one cup of coffee; Cappelletti et al., 2015). Adenosine receptors also form heteromers with dopamine receptors (Volkow et al., 2015). Thus, by antagonizing adenosine receptors, caffeine can enhance dopamine signalling in the brain by increasing dopaminergic receptor availability (Volkow et al., 2015). Dopamine is associated with reward-related behaviours and motivation (Baik, 2013), however, since caffeine increases dopaminergic receptor availability instead of the amount of dopamine released (Volkow et al., 2015), it may have weaker reinforcing effects and a lower abuse potential—especially compared to other psychostimulants such as cocaine or amphetamines (Ferré, 2016). Taken together, this suggests that caffeine may have a beneficial role regarding cognition and more specifically, attention.

1.2 Caffeine Consumption and Attention

Most of the previous work has investigated the effects of caffeine during laboratory-based attention tasks. The available evidence suggests that there is a benefit following caffeine consumption on various attention tasks (Einöther & Giesbrecht, 2013). For example, studies using simple reaction time tasks—which measure how fast people respond to target stimuli and are generally thought to use bottom-up processing (Lim & Dinges, 2010)—have revealed that

caffeinated individuals have improved speed (e.g., Childs & De Wit, 2008) and sometimes also accuracy (e.g., Childs & De Wit, 2006; Fine et al., 1994; Kelemen & Creeley, 2001; Sainz et al., 2020; Smith, 2023) compared to individuals who consumed a placebo. There are also studies using choice reaction time tasks (e.g., Broadbent et al., 1986), in which people are instructed to respond to a target letter presented in the center of the screen and to ignore the distractors in the periphery. Compared to placebo, caffeine has also shown to significantly improve speed (e.g., (Attwood et al., 2007; Christopher et al., 2005; Smith et al., 2005) as well as both speed and accuracy (e.g., Smith et al., 1999) during these tasks. Finally, the effects of caffeine have also been investigated using more complex attention tasks that are generally thought to involve top-down processing (Lim & Dinges, 2010) and are usually more demanding. The general pattern observed is that consuming an acute dose of caffeine leads to improved momentary attention performance on tasks requiring higher-order processing such as executive control, task switching, response inhibition and interference (e.g., Einöther & Giesbrecht, 2013; Haskell et al., 2005; Smit & Rogers, 2000; Wilhelmus et al., 2017; Yeomans et al., 2002).

Compared to the large number of studies examining the effect of caffeine on general attention-related performance, there seems to be limited research exploring how caffeine may affect more specific aspects of attentional engagement such as mind-wandering. Mind-wandering occurs when attention is shifted away from the current task in the external environment towards unrelated self-generated internal thoughts (Bertossi et al., 2017; Kane & McVay, 2012; McVay & Kane, 2010; Smallwood & Schooler, 2006). One of the more popular methods used in studies of mind-wandering is the probe-caught method (e.g., Giambra, 1995; Smallwood & Schooler, 2006). During a task, a participant is interrupted and presented with a probe that explicitly asks

them whether they were mind-wandering or focused on the task just prior to the onset of the probe. Giambra et al. (1994) used a variant of this probe technique to assess task-unrelated images and thoughts (TUITs) after consuming caffeine or placebo. In three separate sessions, six healthy adult males completed an attention task after consuming 100 milligrams (mg) of caffeine, 300 mg of caffeine or placebo. Participants were instructed to press a button whenever a red triangle appeared (target) and to withhold their response to blue squares (non-targets). At a fixed interval, participants heard a sound and were asked to indicate if they experienced a spontaneous (i.e., unintentional) TUIT and/or deliberate (i.e., intentional) TUIT since the last time they heard the sound. Giambra et al. (1994) found that dosage level (i.e., 100 mg, 300 mg, or placebo) had no significant effect on the number of spontaneous TUITs or deliberate TUITs.

The available neuroimaging research provides some indirect evidence in support of the notion that caffeine may decrease mind-wandering during a laboratory attention task. Using functional magnetic resonance imaging (fMRI), Kahathuduwa et al. (2018) had nine healthy adult men complete a go/no-go task after consuming 160 mg of caffeine[1]. Participants viewed a blue screen and were instructed to press a button in response to white-coloured flashes (target stimuli) and to withhold their response to red-coloured flashes (distractor stimuli). They found that compared to placebo, consuming caffeine resulted in a decrease in fMRI blood oxygen level dependent responses in the right precuneus when processing target stimuli—a brain region associated with mind-wandering (Fox et al., 2015). Based on these results, Kahathuduwa et al. (2018) speculate that caffeine is associated with decreased mind-wandering when processing

[1] Participants also consumed 200 mg of L-theanine, a combination of caffeine and L-theanine, as well as placebo (distilled water) on separate days. However, we only mention caffeine.

target stimuli, however, they did not measure mind-wandering directly which prevented them from confirming their speculation. Thus, given the differences in methodology and the small sample sizes across Giambra et al. (1994; $N = 6$) and Kahathuduwa et al. (2018; $N = 9$), more research is needed to disentangle the potential effects that caffeine (versus placebo) may have on attentional engagement during a sustained attention task.

There is also little research examining how caffeine may be linked to everyday attention at the trait level. The most related available evidence comes from a recent study reported by Nguyen-Van-Tam and Smith (2022), which showed that increased caffeine use is related to increased "everyday attention performance" as measured by the Everyday Attention Questionnaire (EAQ). However, according to Nguyen-Van-Tam and Smith's (2022) description, the EAQ appears to focus primarily on distraction during multitasking and may not tap other aspects of daily attention (e.g., mind-wandering, attention lapses, flow). Other related work indexes the general category of cognitive failures, suggesting that caffeine may be associated with fewer cognitive failures in everyday life (Smith, 2005, 2009). For example, Smith (2005) showed that higher caffeine consumption was associated with fewer cognitive failures and a decreased risk of accidents at work. Similarly, Smith (2009) corroborated this finding by showing that consuming caffeine significantly reduced cognitive failures when compared to consuming no caffeine. However, it is important to note that in Smith (2005, 2009), cognitive failures were indexed by a single item asking the frequency with which participants reported having problems of memory, attention, or action. Such single-item measures are typically used when the constructs are clearly defined and unidimensional (Allen et al., 2022). Because "cognitive failures" include multiple constructs, it remains unclear which of the cognitive

constructs (i.e., attention, memory, or action) included in this single item were related to caffeine consumption.

1.3 Summary of the Present Studies

Based on these considerations, the goal of Chapter 2 was to first investigate how caffeine consumption relates to attentional engagement in everyday life. Here we collected four samples and used several measures that each target a different facet of attentional engagement. Our second goal of Chapter 2 was to explore how different motivations for choosing to ingest caffeine may relate to our measures of everyday attention. Of the many potential motivations to consume caffeine, we were primarily interested in the cognitive enhancement motivation (i.e., choosing to ingest caffeine to feel more alert, to help concentration, etc.). This primary motivation is particularly relevant considering that acute doses of caffeine can temporarily enhance momentary states of attention during laboratory tasks (e.g., Einöther & Giesbrecht, 2013) as well as the limited research exploring how self-reported caffeine consumption may positively affect everyday attention at the trait level (e.g., Nguyen-Van-Tam & Smith, 2022; Smith, 2005, 2009). To do this, we used a variety of self-report measures to broadly assess attentional traits as they manifest in everyday life. Specifically, the self-report measures targeted attention-related errors, attention lapses, mind-wandering, and deep effortless concentration (i.e., flow). We also asked participants about the amount of caffeine they consumed in a typical day as well as various motivations for choosing to consume caffeine. Contrary to what one might expect, the amount of caffeine consumed in a typical day (estimated in milligrams) was not related to attention-related experiences in everyday life. However, we found that those who are more likely to ingest caffeine to potentially enhance their cognition, or to experience the

reinforcing effects of caffeine, or to help relieve negative affect showed higher levels of inattention in everyday life.

The primary goal of Chapter 3 was to examine the effects of caffeine consumption on behavioural variability (a putative indirect measure of mind-wandering) and the amount of probe-caught mind-wandering (spontaneous or deliberate) during a sustained attention task. Participants completed two sessions of an auditory attention task. Once before consuming caffeine (or placebo) and once after consuming caffeine (or placebo). The second goal of Chapter 3 was to assess and replicate previous findings regarding the effects of caffeine consumption on various attention-related experiences such as affect, arousal, boredom, sleepiness, and mental effort. This was done by asking participants to report on their momentary experiences following each session of the attention task. Participants who received caffeine showed a performance benefit as well as reported being more on task and fewer instances of spontaneous mind-wandering (but not deliberate) compared to those in the placebo group. Participants who received caffeine also reported greater positive affect and arousal, as well as less feelings of boredom, sleepiness, and mental effort required to stay on task compared to those who received placebo. These results suggest that caffeine may benefit attentional engagement as well as performance during a sustained attention task. In Chapter 3 we also further explore the positive relation from the study in Chapter 2 regarding the cognitive motives of caffeine consumption and the tendency to experience more inattention in everyday life. To do this we examined the correlation between the proportion of on task responses from each session of the attention task and the cognitive motives for caffeine consumption. Here we found that prior to caffeine consumption, participants who had greater cognitive motives reported being less on

task. Following caffeination, this correlation became non-significant. This suggests that that those who are highly motived to consume caffeine for the cognitive benefits report being less "on task" while caffeine deprived.

Chapter 4 first focused on replicating the main findings from the attention task in a larger sample. We also sought to replicate the relations between the proportion of on task responses from each session of the attention task and the cognitive motives. To do this, we had one group of participants complete the same attention task from Chapter 3—once prior to consuming caffeine and once after. As predicted, we found that following caffeine consumption participants showed a performance benefit as well as reported being more on task and fewer instances of spontaneous mind-wandering. Contrary to our prediction, however, here we also found that participants reported less deliberate mind-wandering following caffeination. In this study we also found that, as predicted, participants reported greater positive affect and arousal, as well as less feelings of boredom, sleepiness, and mental effort required to stay on task following caffeine consumption. Importantly, we failed to replicate the relations from the study presented in Chapter 3 regarding the proportion of on task responses during the attention task and the cognitive motives. This suggests that this relation may not be as robust as originally thought.

Finally, in Chapter 5 I discuss the main findings from the studies presented in Chapters 2, 3, and 4, and how they relate to previous research. The studies included in this thesis suggest that contrary to what one might predict, caffeine consumption (in mg) was not related to trait attention in everyday life. However, we corroborated previous research that suggests there is an attentional benefit on laboratory-based attention tasks following an acute dose of caffeine. Following caffeine consumption, we showed that people had better performance and attentional

engagement during a sustained attention task. I also discuss the limitations of the studies presented in this thesis as well as some future directions in Chapter 5.

Chapter 2: The Relation Between Caffeine and Attention in Everyday Life

2.1 Introduction[2]

While several prior studies have examined the relation between caffeine use and attentional traits in everyday life (Nguyen-Van-Tam & Smith, 2022; Smith, 2005, 2009), there are multiple aspects of attention that have yet to be addressed. When refining the measurement of attention in everyday life, it is important to consider the various ways attention can function and fail in day-to-day contexts. As previously mentioned, the available evidence shows that our attention can easily lapse, leading people to experience absent-mindedness, attention-related errors, and mind-wandering while at other times people can enter flow states where their attention is completely focused on the task at hand. Previous research has demonstrated that self-reported measures of attention lapses, attention-related errors, mind-wandering, and flow in everyday life are related to corresponding attentional experiences in various laboratory attention tasks. For example, self-reported attention-related cognitive errors and lapses of attention are significantly related to errors during the Sustained Attention to Response Task (SART; Cheyne et al., 2006). During the SART, participants are instructed to press a key except for when an infrequent target appears (Robertson et al., 1997). Similarly, trait measures of mind-wandering (spontaneous or deliberate) have also been shown to correlate with state (i.e., probe-caught) measures of mind-wandering during attention tasks (Seli, Risko, & Smilek, 2016). Spontaneous mind-wandering episodes lack an obvious moment of conscious initiation, whereas deliberate episodes are associated with conscious awareness to initiate (or continue) the mind-wandering episode (Seli, Risko, Smilek, et al., 2016). Thus, these different types of mind-wandering can be

[2] Major parts of this chapter are taken directly from Kruger et al. (2024a).

construed as dissociable cognitive experiences (Seli, Risko, Smilek, et al., 2016). Trait flow has also been shown to be predictive of state flow during the SART (Marty-Dugas et al., 2021). In the study presented here, attention-related errors and attention lapses were measured using the Attention Related Cognitive Errors Scale (ARCES; Carriere et al., 2008; Cheyne et al., 2006) and the Mindful Attention Awareness Scale-Lapses Only (MAAS-LO; Carriere et al., 2008), respectively. Trait mind-wandering was measured using the Mind-Wandering-Spontaneous (MW-S) and Mind-Wandering-Deliberate (MW-D) scales (Carriere et al., 2013) and trait flow was measured using the Deep Effortless Concentration Scale—Internal (DECI) and External (DECE; Marty-Dugas & Smilek, 2019).

There is also work examining the various motivations people have for consuming caffeine (Ágoston et al., 2018; Batista et al., 2022; Choi, 2020; Graham, 1988; McIlvain et al., 2011; Riera-Sampol et al., 2022; Rogers & Richardson, 1993; Soós et al., 2021; Stachyshyn et al., 2021; Turner et al., 2023), with the goal of improving cognition emerging as one of the main motives (e.g., Ágoston et al., 2018; Batista et al., 2022; Choi, 2020; McIlvain et al., 2011; Riera-Sampol et al., 2022). However, the relations between various motives to consume caffeine and individual differences in specific attention-related cognitive functions have not been systematically addressed. One questionnaire used to index different motives for consuming caffeine is the Caffeine Motives Questionnaire (CMQ; Irons et al., 2014). The CMQ assesses four primary motives, including 1) enhancement of cognition, 2) relief of negative affect, 3) consuming caffeine because of its reinforcing effects (e.g., liking the taste or to combat headache), and 4) to control weight. While the relations between each of these motives and attention-related traits are certainly worthy of consideration, of primary interest here are the potential relations between the cognitive enhancement motive and attention-related traits. One

possibility is that people reporting poor attention in everyday life will report higher motivations to use caffeine to possibly improve their cognitive performance.

Research Questions

Chapter 2 has two aims. First, we aim to assess the relation between caffeine consumption and attentional engagement in everyday life using several measures that each target a different facet of attentional engagement. Since people also report that they are motivated to consume caffeinated products for the possibility of increasing their cognitive abilities (Ágoston et al., 2018; Batista et al., 2022; Choi, 2020; McIlvain et al., 2011), our second goal was to explore how different motivations for choosing to ingest caffeine may relate to our measures of everyday attention. To address these goals, we collected data from four samples. Sample One and Sample Two are from Kruger et al. (2024a). Sample Three is from the data presented in Chapter 3 and Sample Four is from the data presented in Chapter 4. This allowed us to complete a four-fold replication of our findings, allowing us to focus on, and ascribe theoretical weight to those relations that replicated across all four assessments (Fletcher, 2021).

2.2 Methods

Participants

The Office of Research Ethics approved all procedures. Convenience samples were recruited from the University of Waterloo's SONA system for undergraduate research experience in exchange for course credit. There were no exclusion criteria to participate in the current study.

Sample One

Participants in the first sample were recruited from September 2021 to April 2022. A total of 295 participants were recruited, however, two people were removed for not finishing the entire survey, 20 people were removed for answering randomly or in a set pattern without considering the question (see below for details), 34 people were removed for failing our caffeine-related attention check (see below), three people were removed for having unreadable data, nine people were removed for scoring greater than 2.5 standard deviations above the caffeine consumption mean, and three people were removed for not answering every item on the survey. This left 224 participants for data analysis. Two people preferred to not provide their age but for the 222 people that did, the ages ranged from 17 to 52 (M = 20.63, SD = 4.57). This first sample consisted of 30 people identifying as male, 189 people identifying as female, four people identifying as non-binary, and one person preferring not to say. The first sample was mainly comprised of white (n = 96), East Asian (n = 44), and South Asian (n = 43) peoples. See Table 2.1 below for a full summary of the demographics for the first sample.

Table 2.1

Sample One Demographics (N = 224)

Demographic Variable	*n*
Age (ranging from 17 to 52)	222
M = 20.63	
SD = 4.57	
Gender	
Female	189
Male	30
Non-binary	4
Prefer not to say	1
Race	
White	96
East Asian	44
South Asian	43
Southeast Asian	9
Black	7
Middle Eastern	6
Mixed race	6
Hispanic	4
West Indian/Caribbean	3
Indigenous	1
Prefer not to say	5

Sample Two

Participants in the second sample were recruited from May 2022 to December 2022. A total of 334 participants were recruited, however, three people were removed for not finishing the entire survey, two people were removed for attempting to answer the survey more than once (one person attempted to answer the survey three times and the other four times), 25 people were

removed for answering randomly or in a set pattern without considering the question, 50 people were removed for failing our caffeine-related attention check, one person was removed for not following the instructions, three people were removed for having unreadable data, 10 people were removed for scoring greater than 2.5 standard deviations above the caffeine consumption mean, and one person was removed for not answering every item on the survey. This left 234 participants for data analysis. Two people preferred to not provide their age, but for the 232 people that did, the ages ranged from 17 to 32 (M = 19.95, SD = 2.19). The second sample consisted of 64 people identifying as male, 160 people identifying as female, six people identifying as non-binary, and four people preferring not to say. The second sample was also predominantly comprised of white (n = 101), East Asian (n = 55), and South Asian (n = 36) peoples. See Table 2.2 below for a full summary of the demographics for the second sample.

Table 2.2

Sample Two Demographics (N = 234)

Demographic Variable	*n*
Age (ranging from 17 to 32)	232
M = 19.95	
SD = 2.19	
Gender	
Female	160
Male	64
Non-binary	6
Prefer not to say	4
Race	
White	101
East Asian	55
South Asian	36
Southeast Asian	11
Black	3
Middle Eastern	10
Mixed race	10
Hispanic	3
Prefer not to say	5

Measures

Demographics

Five demographic questions were included in the survey asking participants to indicate their age, gender, primary racial group, faculty, and year of study. Faculty and year of study were included for reasons peripheral to the current study.

Subjective Reports of Caffeine Consumption

Caffeine Consumption. The Caffeine Consumption Questionnaire (CCQ) followed a similar protocol to Landrum (1992). The CCQ gauges the amount of caffeine one consumes in a typical day in milligrams (mg). The questionnaire specifically asks the participant to consider their caffeine consumption over the last seven days and to indicate what products they consume on a typical day as well as the time of day that they normally consume it. Participants were given the following categories to choose from: coffee, tea (black or green), caffeinated soft drinks, energy drinks, caffeine pills, and dark chocolate. If participants indicated that they consumed caffeine from a particular category, they were then presented with a list of popular items from that category (i.e., items they could easily find on or around campus). However, given that this was a non-exhaustive list, if there was a product that they typically consumed but was not listed, they were instructed to specify in a textbox the size of the product and time of day they typically consumed it. The number of items were then multiplied by the amount of caffeine in each product and then summed to create an approximate amount of caffeine consumed in a typical day. The extra items listed in the textbox were also included in the calculation. Given that caffeine content can vary based on a variety of factors (e.g., type of coffee bean, roast type, grind type, water temperature, etc.), we approximated how much caffeine was in a specific item if the caffeine content could not be found. See Table A1 in Appendix A for a full summary of all listed items and their caffeine content.

Caffeine Motives Questionnaire (CMQ). The CMQ (Irons et al., 2014) assesses the motives prompting caffeine consumption. The CMQ is comprised of four factors including cognitive enhancement (CMQ-C), negative affect relief (i.e., emotional coping; CMQ-NA), reinforcing effects (i.e., non-emotional coping; CMQ-R), and weight control (CMQ-W). A five-

point scale was used to record responses to items such as “I choose to ingest caffeine to help me concentrate” (cognitive enhancement), “I choose to ingest caffeine to help deal with stress in my daily life” (negative affect relief), “I choose to ingest caffeine because I like the taste of caffeinated beverages” (reinforcing effects), and “I choose to ingest caffeine because it is a powerful diuretic” (weight control). Higher scores indicate greater motives for consuming caffeine.

Subjective Reports of Attention

Attention Related Cognitive Errors Scale (ARCES). The ARCES (Carriere et al., 2008; Cheyne et al., 2006) gauges the frequency of an individual experiencing cognitive failures in everyday life for which lapses of attention is the most probable cause. Participants answer 12-items such as “I fail to see what I am looking for even though I am looking right at it or “I have to go back to check whether I have done something or not (e.g., turning out lights, locking doors)” on a five-point scale with higher scores indicating greater cognitive failures. Previous research has shown that the ARCES is significantly related to errors of commission during the Sustained Attention to Response Task (Cheyne et al., 2006), a behavioural measure of attentional errors.

Mindful Attention Awareness Scale-Lapses Only (MAAS-LO). The MAAS-LO (Carriere et al., 2008) assesses an individual’s mindlessness and attention lapses in everyday life. It is a 12-item questionnaire derived from the 15-item MAAS by Brown and Ryan (2003). Items such as “I rush through activities without being really attentive to them” and “I find myself doing things without paying attention” are answered using a six-point scale with higher scores indicating more lapses of attention. Previous research has shown that the MAAS-LO is also significantly related to errors of commission as well as reaction time during the Sustained

Attention to Response Task (Cheyne et al., 2006), which is often taken as a behavioral index of task inattention.

Spontaneous (MW-S) and Deliberate (MW-D) Mind-Wandering. The MW-S and MW-D (Carriere et al., 2013) are self-report measures of trait mind-wandering. Items such as "I find my mind-wandering spontaneously" (MW-S) and "I allow my thoughts to wander on purpose" (MW-D) are answered using a seven-point scale with higher scores indicating greater tendency to engage in either spontaneous or deliberate mind-wandering. Previous research has demonstrated a positive association between spontaneous and deliberate mind-wandering (Carriere et al., 2013; Seli et al., 2015), however, these different types of mind-wandering can be construed as dissociable cognitive experiences (Seli, Risko, Smilek, et al., 2016). It has been shown that trait-level spontaneous mind-wandering (as indexed by the MW-S) is significantly related to state-level spontaneous (but not state-level deliberate) mind-wandering and that trait-level deliberate mind-wandering (as indexed by the MW-D) is significantly related to state-level deliberate mind-wandering (but not state-level spontaneous; Seli et al., 2016).

Deep Effortless Concentration—Internal (DECI) and External (DECE). The flow questionnaires (Marty-Dugas & Smilek, 2019) assess the frequency with which participants experience deep, effortless concentration (i.e., flow) in both internal (e.g., thinking or imagining) and external (e.g., practicing a musical instrument or playing a sport) contexts. A seven-point scale is used to record responses to items such as "I am able to completely focus on my thoughts without straining to pay attention" (DECI) and "I can easily pay attention to an external task for extended periods of time" (DECE). Higher scores indicate greater trait level flow. Previous research has demonstrated that while trait flow is not related to performance on the Sustained

Attention to Response Task, it is predictive of state flow during the task (Marty-Dugas et al., 2021).

Data Quality Items

General Caffeine Use Questions. Participants also responded to three general caffeine use questions. These questions served as a built-in attention check. A five-point scale was used to record responses the following questions: "Do you use caffeine to improve your attention and/or concentration?", "Do you use caffeine to help yourself stay awake?" and "Do you use caffeine to help you sleep?" If participants simultaneously endorsed using caffeine to help themselves stay awake as well as using caffeine to help them sleep in the general caffeine questions, we did not include them in the data analysis (i.e., they chose rarely, sometimes, often, or always for using caffeine as a stimulant and sedative).

Random Response Question. Participants were also presented with the question, "Did you respond randomly or in a set pattern (e.g., did you answer in a pattern such as AAABBBCCC without considering the question) at any point during the survey? Please answer honestly, you will not be penalized regardless of your response." If participants answered "yes" to this question, we did not include them in data analysis.

Procedure

Participants who were interested in our study were provided a link to our survey on Qualtrics. After obtaining informed consent, participants who agreed to take part in the study were presented with the measures in a random order. When a measure was presented, the order of the items within the scale were also randomized. Following the completion of the questionnaires, participants were then presented with the demographic questions and the data

quality item asking whether they responded randomly or in a set pattern without considering the question. After completing the survey, participants received 0.25 credits towards an eligible undergraduate course and were provided with a feedback letter debriefing them of the study's purpose and where to find more information related to the study.

2.3 Results

The results in this chapter are presented in three parts. First, data from Sample One and Sample Two are presented. Second, data from Sample Three is presented, and third, data from Sample Four is presented. Each sample is described in two parts. First, the psychometric properties of the measures are described. Second, the relations among the measures of attention (ARCES, MAAS-LO, MW-S, MW-D, DECI, and DECE) and caffeine use (i.e., caffeine consumption and motives for caffeine consumption) are described. A full correlation matrix for each sample that includes all the relevant study variables are presented in Table 2.6 (for Sample One and Sample Two), Table 2.10 (for Sample Three), and Table 2.14 (for Sample Four). For ease of reference, a relevant subset of the correlations reported in the full correlation matrices are show in in Table 2.5 (for Sample One and Sample Two), Table 2.9 (for Sample Three), and Table 2.13 (for Sample Four). The data were analyzed using RStudio 2023.03.1 and R 4.1.2 (R Core Team, 2021).

Psychometrics

Sample One

Descriptive statistics for the first sample are presented in Table 2.3 below. We removed nine people for scoring higher than 2.5 standard deviations above the mean for caffeine consumption. Before outlier removal, the caffeine consumption measure was leptokurtic

(original caffeine consumption kurtosis = 11.42), and some participants reported consuming an extraordinarily high amount of caffeine in a typical day. For example, one participant that was removed reported consuming 4999 mg of caffeine in a typical day or approximately 12.5 times the recommended daily amount for adults set out by Health Canada (2022). After removal, the kurtosis was within an acceptable range (kurtosis = 4.28) and the maximum amount of caffeine reported was still high but not unreasonable at 2342 mg of caffeine (e.g., see El-Nimr et al., 2019; McIlvain et al., 2011). There were only 16 participants (or 7%) that reported consuming 0 mg of caffeine per day. We also applied a square root transformation to the CMQ weight control subscale to reduce its positive skew and leptokurtic properties (original skew = 3.11 and kurtosis = 12.03). After these changes, the skew and kurtosis values for both measures were within acceptable bounds (i.e., absolute values less than 3 for skewness and absolute values less than 10 for kurtosis; Kline, 2016). Thus, after transformation, the measures had relatively normal distributions of scores. Where applicable, Cronbach's alpha was computed, and the values were acceptable (Tavakol & Dennick, 2011) for all of the measures except for the CMQ-W. Cronbach's alpha may have been low for the CMQ-W because of the restriction of range (Alkhadim, 2022). The correlations among the measures of everyday attention shown in Table 2.6 are significant but modest indicating that these measures index distinct constructs that are part of the same conceptual family.

Table 2.3

Descriptive Statistics for Sample One (N = 224)

Measure	Mean (SD)	Min	Max	Skew	Kurtosis	Cronbach's Alpha
Caffeine	429.53 (476.92)	0.00	2342.00	1.98	4.28	NA
CMQ-C	2.72 (1.12)	1.00	5.00	0.17	–0.94	.90
CMQ-NA	1.48 (0.73)	1.00	4.33	1.73	2.68	.73
CMQ-R	2.12 (0.71)	1.00	4.33	0.30	–0.51	.79
CMQ-W	1.26 (0.54)	1.00	4.67	3.11	12.03	.63
CMQ-W^{+}	1.10 (0.20)	1.00	2.16	2.45	6.79	NA
ARCES	2.91 (0.75)	1.00	5.00	0.40	0.50	.91
MAAS-LO	3.35 (0.84)	1.00	5.50	–0.01	–0.16	.87
MW-S	4.29 (1.47)	1.00	7.00	–0.27	–0.63	.91
MW-D	4.58 (1.57)	1.00	7.00	–0.30	–0.65	.92
DECI	4.26 (1.26)	1.00	7.00	0.03	–0.49	.96
DECE	4.19 (1.28)	1.00	7.00	–0.01	–0.43	.96

Note. Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire, Cognitive Motives; CMQ-NA= Caffeine Motives Questionnaire, Negative Affect Relief; CMQ-R = Caffeine Motives Questionnaire, Reinforcing Effects; CMQ-W = Caffeine Motives Questionnaire, Weight Control; ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale-Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind-Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; +Square root transformation; NA = Not Applicable

Sample Two

Descriptive statistics for the second sample can be found in Table 2.4 below. We removed 10 people for scoring higher than 2.5 standard deviations above the mean for caffeine

consumption. In the second sample some participants also reported consuming an unusually high amount of caffeine in a typical day. One participant, for example, reported consuming 3459 mg of caffeine in a typical day, which is approximately 8.7 times the recommended daily amount for adults set out by Health Canada (2022). After outlier removal, the maximum amount of daily caffeine consumption reported was 1874 mg, which is a high but still acceptable daily total (e.g., see El-Nimr et al., 2019; McIlvain et al., 2011). There were only 21 participants (or 9%) that reported consuming 0 mg of caffeine per day. The skew and kurtosis values for each measure were also within reasonable bounds. Where applicable, Cronbach's alpha was also computed, and the values were acceptable (Tavakol & Dennick, 2011) for all of the measures except for the CMQ-W. As previously mentioned, Cronbach's alpha may have been low for the CMQ-W because of the restriction of range (Alkhadim, 2022). Table 2.6 shows that, with the exception of the MW-D (which is not significantly correlated with either the MAAS-LO or the ARCES), the correlations among attention measures are significant but modest; consistent with the notion that these measures are related but distinct.

Table 2.4

Descriptive Statistics for Sample Two (N = 234)

Measure	Mean (SD)	Min	Max	Skew	Kurtosis	Cronbach's Alpha
Caffeine	401.85 (398.57)	0.00	1874.00	1.35	1.51	NA
CMQ-C	2.74 (1.05)	1.00	5.00	0.03	–0.78	.90
CMQ-NA	1.49 (0.71)	1.00	5.00	1.76	3.31	.77
CMQ-R	2.13 (0.83)	1.00	5.00	0.49	–0.33	.87
CMQ-W	1.24 (0.44)	1.00	3.00	2.13	4.19	.41
ARCES	2.96 (0.69)	1.33	5.00	0.44	0.12	.89
MAAS-LO	3.37 (0.78)	1.50	5.42	–0.26	–0.44	.86
MW-S	4.50 (1.24)	1.25	7.00	–0.03	–0.21	.86
MW-D	4.56 (1.41)	1.00	7.00	–0.27	–0.68	.90
DECI	3.90 (1.15)	1.00	7.00	0.05	–0.23	.94
DECE	4.03 (1.25)	1.00	7.00	0.06	–0.80	.96

Note. Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire, Cognitive Motives; CMQ-NA= Caffeine Motives Questionnaire, Negative Affect Relief; CMQ-R = Caffeine Motives Questionnaire, Reinforcing Effects; CMQ-W = Caffeine Motives Questionnaire, Weight Control; ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale-Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind-Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; NA = Not Applicable

Relations Between Caffeine Consumption, Attention, and Motives

The relevant correlations are shown in Table 2.5. The table includes two rows of correlations; the correlation in the top row corresponds to the first sample (S1) and the bottom row corresponds to the second sample (S2). We focus primarily on the relations that are

consistently significant across both samples. In both samples, the measure of caffeine consumption and the weight control motive for consuming caffeine (CMQ-W) were not significantly related to the attention measures (i.e., ARCES, MAAS-LO, MW-S, MW-D, DECI, or DECE). Interestingly, however, in both samples the cognitive enhancement motive for consuming caffeine (CMQ-C) was positively related to the two measures that assess inattention in everyday life (ARCES and MAAS-LO). This suggests that even though caffeine consumption is *not* related to inattention in everyday life, choosing to ingest caffeine to potentially help enhance cognition *is* associated with more inattention. In addition, an increased tendency to use caffeine to relieve negative affect (CMQ-NA) was related to increased inattention (ARCES, MAAS-LO) and spontaneous mind-wandering (MW-S) in everyday life. Finally, an increased tendency to ingest caffeine for its reinforcing effects (e.g., because they like the taste of caffeinated beverages or to help combat headaches; CMQ-R) was associated with more lapses of attention (MAAS-LO) and less internal flow (DECI) in everyday life.

For the sake of completeness, and to demonstrate that our caffeine consumption measure does correlate with other measures in a meaningful way, we examined the relations between caffeine consumption and each of the motives. These correlations are shown in Table 2.6 for first and second samples. We found that caffeine consumption was significantly related to each of the motives (i.e., cognitive, negative affect relief, reinforcing effects, and weight control) in both samples. The correlations ranged from .25 to .33 in the first sample and from .16 to .46 in the second sample suggesting that those who report consuming more caffeine also report greater motivations to consume caffeine.

Table 2.5

Zero-Order Correlations Between Caffeine Use and Attention for Samples One (N = 224) and Sample Two (N = 234)

		Caffeine	CMQ-C	CMQ-NA	CMQ-R	CMQ-W
ARCES	S1:	.075	.168*	.146*	.078	.076
	S2:	.088	.150*	.212**	.156*	.098
MAAS-LO	S1:	.074	.237***	.221***	.168*	.103
	S2:	.108	.214***	.224***	.218***	.127
MW-S	S1:	.128	.124	.176**	.076	.113
	S2:	.044	.136*	.195**	.151*	–.040
MW-D	S1:	.040	.079	.132*	.010	.037
	S2:	–.036	–.043	–.028	–.039	–.063
DECI	S1:	–.005	–.166*	–.168*	–.141*	.009
	S2:	–.109	–.039	–.080	–.140*	–.063
DECE	S1:	–.020	–.089	–.132*	–.095	.077
	S2:	–.078	–.079	–.117	–.106	–.030

Note. S1 = Sample One; S2 = Sample Two; ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale-Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind-Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire (CMQ) Cognitive Motives; CMQ-NA = Negative Affect Relief; CMQ-R = Reinforcing Effects; CMQ-W = Weight Control; *$p < .05$; **$p < .01$; ***$p < .001$

Table 2.6

Zero-order Pearson Correlations for Sample One (N = 224) and Sample Two (N = 234)

		ARCES	MAAS-LO	MW-S	MW-D	DECI	DECE	Caffeine	CMQ-C	CMQ-NA	CMQ-R
ARCES	S1:	—									
	S2:										
MAAS-LO	S1:	.646***	—								
	S2:	.617***									
MW-S	S1:	.529***	.545***	—							
	S2:	.508***	.464***								
MW-D	S1:	.260***	.245***	.517***	—						
	S2:	.050	.103	.375***							
DECI	S1:	–.396***	–.414***	–.235***	.030	—					
	S2:	–.302***	–.302***	–.175**	.198**						
DECE	S1:	–.332***	–.364***	–.361***	–.146*	.577***	—				
	S2:	–.306***	–.310***	–.208**	–.025	.398***					
Caffeine	S1:	.075	.074	.128	.040	–.005	–.020	—			
	S2:	.088	.108	.044	–.036	–.109	–.078				
CMQ-C	S1:	.168*	.237***	.124	.079	–.166*	–.089	.308***	—		
	S2:	.150*	.214***	.136*	–.043	–.039	–.079	.462***			
CMQ-NA	S1:	.146*	.221***	.176**	.132*	–.168*	–.132*	.252***	.439***	—	
	S2:	.212**	.224***	.195**	–.028	–.080	–.117	.328***	.441***		
CMQ-R	S1:	.078	.168*	.076	.009	–.141*	–.095	.334***	.481***	.595***	—
	S2:	.156*	.218***	.151*	–.039	–.140*	–.106	.394***	.509***	.571***	
CMQ-W	S1:	.076	.103	.113	.037	.009	.077	.248***	.218**	.309***	.284***
	S2:	.098	.127	–.040	–.063	–.063	–.030	.160*	.240***	.115	.207**

Note. S1 = Sample One (N = 224); S2 = Sample Two (N = 234); ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale–Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind–Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire (CMQ) Cognitive Motives; CMQ-NA = Negative Affect Relief; CMQ-R = Reinforcing Effects; CMQ-W = Weight Control *p < .05; **p < .01; ***p < .001

Replication from Data Presented in Chapter 3 and Chapter 4

Unlike the study presented in Chapter 2, there were some exclusion criteria to participate in the studies presented in Chapter 3 (i.e., Sample Three) and Chapter 4 (i.e., Sample Four). Because the primary goals of studies presented in Chapters 3 and 4 were to investigate the effects of caffeine consumption on behavioural variability and the amount of mind-wandering (both spontaneous and deliberate) during a sustained attention task, participants must have self-reported to consume caffeine at least once per week.

Sample Three

A total of 168 participants were recruited and we followed the same data strategy previously mentioned. Four people were removed for not answering every item on the survey and four people were removed for scoring greater than 2.5 standard deviations above the caffeine consumption mean. This left 160 participants for data analysis with ages ranging from 18 to 39 (M = 20.63, SD = 2.57). This sample consisted of 48 people identifying as male, 107 people identifying as female, and five people identifying as non-binary. This sample was mainly comprised of white (n = 51), East Asian (n = 39), and South Asian (n = 38). See Table 2.7 below for a full summary of the demographics.

Table 2.7

***Sample Three Demographics* (*N* = 160)**

Demographic Variable	*n*
Age (ranging from 18 to 39)	160
M = 20.63	
SD = 2.57	
Gender	
Female	107
Male	48
Non-binary	5
Race	
White	51
East Asian	39
South Asian	38
Southeast Asian	11
Other	8
Middle Eastern	5
Black	4
West Indian/Caribbean	2
Hispanic	1
Indigenous	1

Psychometrics. Descriptive statistics are presented in Table 2.8. The maximum amount of caffeine after removing the participants who scored higher than 2.5 standard deviations above the caffeine consumption mean was still high at 3126 mg. There were no participants that reported consuming 0 mg of caffeine per day (this was expected because participants had to self-report consuming caffeine at least once per week in order to be eligible to participate the study presented in Chapter 3). The skew and kurtosis values for each measure were within reasonable

bounds (i.e., absolute values less than 3 for skewness and absolute values less than 10 for kurtosis; Kline, 2016) suggesting that the measures had relatively normal distributions of scores. Where applicable, Cronbach's alpha was computed, and the values were acceptable (Tavakol & Dennick, 2011) for all of the measures except for the CMQ-W. Cronbach's alpha may have been low for the CMQ-W because of the restriction of range (Alkhadim, 2022).

Table 2.8

Descriptive Statistics for Sample Three (N = 160)

Measure	Mean (SD)	Min	Max	Skew	Kurtosis	Cronbach's Alpha
Caffeine	700.37 (652.69)	33.40	3126.00	1.74	3.12	NA
CMQ-C	3.44 (0.86)	1.00	5.00	–0.46	–0.24	.85
CMQ-NA	1.75 (0.85)	1.00	5.00	1.44	2.00	.74
CMQ-R	2.55 (0.76)	1.00	4.67	–0.05	–0.53	.81
CMQ-W	1.41 (0.53)	1.00	3.67	1.63	2.94	.43
ARCES	3.08 (0.69)	1.17	4.83	0.28	–0.05	.88
MAAS-LO	3.47 (0.78)	1.58	5.58	0.06	–0.23	.85
MW-S	4.86 (1.14)	1.50	7.00	–0.17	–0.50	.80
MW-D	5.02 (1.28)	1.25	7.00	–0.63	–0.21	.84
DECI	4.18 (1.22)	1.62	7.00	0.07	–0.65	.95
DECE	4.32 (1.29)	1.38	7.00	–0.19	–0.50	.96

Note. Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire, Cognitive Motives; CMQ-NA= Caffeine Motives Questionnaire, Negative Affect Relief; CMQ-R = Caffeine Motives Questionnaire, Reinforcing Effects; CMQ-W = Caffeine Motives Questionnaire, Weight Control; ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale-Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind-Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; NA = Not Applicable

Relations Between Caffeine Consumption, Attention, and Motives. The relevant correlations are shown in Table 2.9. A full correlation matrix that includes all the relevant study variables is presented in Table 2.13. Like the first two samples, the measure of caffeine consumption was not significantly related to the measures of inattention (ARCES, MAAS-LO),

the measures of mind-wandering (MW-S, MW-D), or our measure of internal flow (DECI). In Sample Three, the measure of external flow was negatively related to caffeine consumption suggesting that those who consume more caffeine tend to experience fewer instances of external flow.

The only correlations that fully replicated from the first two samples were the positive relations between the negative affect relief motive (CMQ-NA) and inattention in everyday life (i.e., ARCES, MAAS-LO) as well as spontaneous mind-wandering (MW-S). This suggests that an increased tendency to ingest caffeine to help relief negative affective states (e.g., depression, anxiety, or stress) is associated with more inattention and spontaneous mind-wandering. We also found that those who reported consuming caffeine for its reinforcing effects (e.g., because they like the taste of caffeinated beverages or to help combat headaches; CMQ-R) was associated with more attention-related cognitive errors in everyday life. This correlation was not consistent across the first two samples, but it was significant in Sample Two (r = .156). Finally, those who reported consuming caffeine as a means of weight control reported greater instances of experiencing deliberate mind-wandering, however, this correlation was non-significant in first two samples.

Table 2.9

Zero-Order Correlations Between Caffeine Use and Attention for Sample Three (N =160)

		Caffeine	CMQ-C	CMQ-NA	CMQ-R	CMQ-W
ARCES	S1:	.075	.168*	.146*	.078	.076
	S2:	.088	.150*	.212**	.156*	.098
	S3:	.088	.142	.263***	.220**	.051
MAAS-LO	S1:	.074	.237***	.221***	.168*	.103
	S2:	.108	.214***	.224***	.218***	.127
	S3:	.099	.150	.185*	.151	.104
MW-S	S1:	.128	.124	.176**	.076	.113
	S2:	.044	.136*	.195**	.151*	–.040
	S3:	–.023	.143	.179*	.155	.042
MW-D	S1:	.040	.079	.132*	.010	.037
	S2:	–.036	–.043	–.028	–.039	–.063
	S3:	–.037	–.024	.040	.140	.159*
DECI	S1:	–.005	–.166*	–.168*	–.141*	.009
	S2:	–.109	–.039	–.080	–.140*	–.063
	S3:	–.093	.007	–.144	–.146	–.082
DECE	S1:	–.020	–.089	–.132*	–.095	.077
	S2:	–.078	–.079	–.117	–.106	–.030
	S3:	–.163*	.042	.039	–.098	.042

Note. S1 = Sample One; S2 = Sample Two; S3 = Sample Three; ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale-Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind-Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire (CMQ) Cognitive Motives; CMQ-NA = Negative Affect Relief; CMQ-R = Reinforcing Effects; CMQ-W = Weight Control; *$p < .05$; **$p < .01$; ***$p < .001$

Table 2.10

Zero-Order Pearson Correlations for Sample Three (N = 160)

		ARCES	MAAS-LO	MW-S	MW-D	DECI	DECE	Caffeine	CMQ-C	CMQ-NA	CMQ-R
	S1:										
ARCES	S2:	—									
	S3:										
	S1:	.646***									
MAAS-LO	S2:	.617***	—								
	S3:	.623***									
	S1:	.529***	.545***								
MW-S	S2:	.508***	.464***	—							
	S3:	.499***	.506***								
	S1:	.260***	.245***	.517***							
MW-D	S2:	.050	.103	.375***	—						
	S3:	.180*	.087	.339***							
	S1:	–.396***	–.414***	–.235***	.030						
DECI	S2:	–.302***	–.302***	–.175**	.198**	—					
	S3:	–.083	–.141	–.135	.074						
	S1:	–.332***	–.364***	–.361***	–.146*	.577***					
DECE	S2:	–.306***	–.310***	–.208**	–.025	.398***	—				
	S3:	–.272	–.229**	–.280***	–.153	.303***					
	S1:	.075	.074	.128	.040	–.005	–.020				
Caffeine	S2:	.088	.108	.044	–.036	–.109	–.078	—			
	S3:	.088	.099	–.023	–.037	–.093	–.163*				
	S1:	.168*	.237***	.124	.079	–.166*	–.089	.308***			
CMQ-C	S2:	.150*	.214***	.136*	–.043	–.039	–.079	.462***	—		
	S3:	.142	.150	.143	–.024	–.007	.042	.195*			
	S1:	.146*	.221***	.176**	.132*	–.168*	–.132*	.252***	.439***		
CMQ-NA	S2:	.212**	.224***	.195**	–.028	–.080	–.117	.328***	.441***	—	
	S3:	.263***	.185*	.179*	.040	–.144	.039	.149	.294***		
	S1:	.078	.168*	.076	.009	–.141*	–.095	.334***	.481***	.595***	
CMQ-R	S2:	.156*	.218***	.151*	–.039	–.140*	–.106	.394***	.509***	.571***	—
	S3:	.220**	.151	.155	.140	–.146	–.098	.303***	.180*	.496***	
	S1:	.076	.103	.113	.037	.009	.077	.248***	.218**	.309***	.284***
CMQ-W	S2:	.098	.127	–.040	–.063	–.063	–.030	.160*	.240***	.115	.207**
	S3:	.051	.104	.042	.159*	–.082	.042	.149	.226**	.324***	.273***

Note. S1 = Sample One (*N* = 224); S2 = Sample Two (*N* = 234); S3 = Sample Three (*N* = 160); ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale–Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind–Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire (CMQ) Cognitive Motives; CMQ-NA = Negative Affect Relief; CMQ-R = Reinforcing Effects; CMQ-W = Weight Control; *p < .05; **p < .01; ***p < .001

Sample Four

A total of 188 participants were recruited and we followed the same data strategy previously mentioned. Two people were removed for not answering every item on the survey and after removing these people three additional people were removed for scoring 2.5 standard deviations above the caffeine consumption mean. This left 182 people for data analysis with ages ranging from 17 to 42 (M = 19.73, SD = 3.06). This sample consisted of 22 people identifying as male, 152 people identifying as female, and 7 people identifying as non-binary, and 1 person preferring not to say. This sample was mainly comprised of white (n = 74), South Asian (n = 37), and East Asian (n = 27). See Table 2.11 below for a full summary of the demographics.

Table 2.11

***Sample Four Demographics* (*N* = 182)**

Demographic Variable	*n*
Age (ranging from 17 to 42)	182
M = 19.73	
SD = 3.06	
Gender	
Female	152
Male	22
Non-binary	7
Prefer not to say	1
Race	
White	74
East Asian	27
South Asian	37
Southeast Asian	10
Other	8
Middle Eastern	5
Black	11
West Indian/Caribbean	2
Hispanic	7
Indigenous	1

Psychometrics. Descriptive statistics are presented in Table 2.12. The maximum amount of caffeine after removing the participants who scored higher than 2.5 standard deviations above the caffeine consumption mean was high at 2489 mg. There was one participant that reported consuming 0 mg of caffeine per day. This was unexpected because participants had to self-report consuming caffeine at least once per week to be eligible to participate in the study presented in

Chapter 3. Upon further investigation, this participant reported consuming caffeinated soft drinks but only reported consuming ginger ale, which to our knowledge does not contain any caffeine.

The skew and kurtosis values for each measure was within reasonable bounds (i.e., absolute values less than 3 for skewness and absolute values less than 10 for kurtosis; Kline, 2016) suggesting that the measures had a relatively normal distribution of scores. Where applicable, Cronbach's alpha was computed, and the values were acceptable (Tavakol & Dennick, 2011) for all of the measures except for the CMQ-W. Cronbach's alpha may have been low for the CMQ-W because of the restriction of range (Alkhadim, 2022).

Table 2.12

Descriptive Statistics for Sample Four (N = 182)

Measure	Mean (SD)	Min	Max	Skew	Kurtosis	Cronbach's Alpha
Caffeine	707.32 (611.66)	0.00	2489.00	1.18	0.53	NA
CMQ-C	3.40 (0.96)	1.00	5.00	–0.58	–0.22	.86
CMQ-NA	1.77 (0.83)	1.00	4.00	0.94	–0.18	.74
CMQ-R	2.55 (0.76)	1.00	4.44	0.15	–0.55	.81
CMQ-W	1.38 (0.51)	1.00	4.00	1.82	4.46	.32
ARCES	3.10 (0.69)	1.42	4.75	0.22	–0.23	.89
MAAS-LO	3.58 (0.79)	1.42	5.58	–0.08	–0.08	.86
MW-S	5.07 (1.13)	1.00	7.00	–0.45	0.02	.82
MW-D	5.21 (1.26)	1.75	7.00	–0.43	–0.37	.85
DECI	4.17 (1.31)	1.00	7.00	0.04	–0.59	.95
DECE	4.09 (1.29)	1.38	7.00	–0.05	–0.77	.96

Note. Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire, Cognitive Motives; CMQ-NA= Caffeine Motives Questionnaire, Negative Affect Relief; CMQ-R = Caffeine Motives Questionnaire, Reinforcing Effects; CMQ-W = Caffeine Motives Questionnaire, Weight Control; ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale-Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind-Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; +Square root transformation; NA = Not Applicable

Relations Between Caffeine Consumption, Attention, and Motives. The relevant correlations are shown in Table 2.13. A full correlation matrix that includes all the relevant study variables is presented in Table 2.14. Like the first two samples, the measure of caffeine consumption was not significantly related to the measure of cognitive errors (ARCES), the

measures of mind-wandering (MW-S, MW-D), or our measures of flow (DECI, DECE). In Sample Four however, the measure of attention lapses (MAAS-LO) was positively related to caffeine consumption suggesting that those who consume more caffeine also report more attention lapses.

We also replicated most of the relations from the first two samples. Those who report consuming caffeine for the potential cognitive benefits (CMQ-C) report more inattention (ARCES, MAAS-LO) in Sample Four. Those who report consuming caffeine to help relief negative affect (CMQ-NA) also report more instances of inattention (ARCES, MAAS-LO) as well as more spontaneous mind-wandering (MW-S) in everyday life. Finally, those who report consuming caffeine for its reinforcing effects (CMQ-R) also report more lapses of attention in everyday life (MAAS-LO); we did not replicate the negative relation between the reinforcing effects motive (CMQ-R) and internal flow (DECI) in Sample Four.

In Sample Four, we also found that consuming caffeine to help relieve negative affect (CMQ-NA) was associated with less flow (both internal, DECI, and external, DECE). The correlation with both internal and external flow was not consistent across the first two samples but was significant in Sample One (internal flow $r = –.168$, external flow $r = –.132$). Those who report consuming caffeine for its reinforcing effects (CMQ-R) also report more cognitive errors (ARCES) and spontaneous mind-wandering (MW-S) in everyday life. These correlations were also not consistent across the first two samples, but it was significant in Sample Two (ARCES $r = .156$, MW-S $r = .151$). Finally, those who reported consuming caffeine as a means of weight control (CMQ-W) reported greater inattention (ARCES, MAAS-LO) in everyday life, however, these correlations were non-significant in the first two samples.

Table 2.13

Zero-Order Correlations Between Caffeine Use and Attention for Sample Four (N = 182)

		Caffeine	CMQ-C	CMQ-NA	CMQ-R	CMQ-W
ARCES	S1:	.075	.168*	.146*	.078	.076
	S2:	.088	.150*	.212**	.156*	.098
	S3:	.088	.142	.263***	.220**	.051
	S4:	.067	.164*	.351***	.241**	.255***
MAAS-LO	S1:	.074	.237***	.221***	.168*	.103
	S2:	.108	.214***	.224***	.218***	.127
	S3:	.099	.150	.185*	.151	.104
	S4:	.163*	.147*	.354***	.289***	.180*
MW-S	S1:	.128	.124	.176**	.076	.113
	S2:	.044	.136*	.195**	.151*	–.040
	S3:	–.023	.143	.179*	.155	.042
	S4:	.106	.144	.202***	.216**	.021
MW-D	S1:	.040	.079	.132*	.010	.037
	S2:	–.036	–.043	–.028	–.039	–.063
	S3:	–.037	–.024	.040	.140	.159*
	S4:	–.049	.075	.045	.031	.058
DECI	S1:	–.005	–.166*	–.168*	–.141*	.009
	S2:	–.109	–.039	–.080	–.140*	–.063
	S3:	–.093	.007	–.144	–.146	–.082
	S4:	–.074	–.167*	–.158*	–.041	–.023
DECE	S1:	–.020	–.089	–.132*	–.095	.077
	S2:	–.078	–.079	–.117	–.106	–.030
	S3:	–.163*	.042	.039	–.098	.042
	S4:	–.090	–.046	–.187*	–.088	.008

Note. S1 = Sample One; S2 = Sample Two; S3 = Sample Three; S4 = Sample Four; ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale-Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind-Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire (CMQ) Cognitive Motives; CMQ-NA = Negative Affect Relief; CMQ-R = Reinforcing Effects; CMQ-W = Weight Control; *$p < .05$; **$p < .01$; ***$p < .001$

Table 2.14

Zero-order Pearson Correlations for Sample Four (N = 182)

		ARCES	MAAS-LO	MW-S	MW-D	DECI	DECE	Caffeine	CMQ-C	CMQ-NA	CMQ-R
ARCES	S1:										
	S2:	—									
	S3:										
	S4:										
MAAS-LO	S1:	.646***									
	S2:	.617***									
	S3:	.623***	—								
	S4:	.605***									
MW-S	S1:	.529***	.545***								
	S2:	.508***	.464***								
	S3:	.499***	.506***	—							
	S4:	.543***	.499***								
MW-D	S1:	.260***	.245***	.517***							
	S2:	.050	.103	.375***							
	S3:	.180*	.087	.339***	—						
	S4:	.216***	.240**	.414***							
DECI	S1:	–.396***	–.414***	–.235***	.030						
	S2:	–.302***	–.302***	–.175**	.198**						
	S3:	–.083	–.141	–.135	.074	—					
	S4:	–.314***	–.279***	–.218**	.056						
DECE	S1:	–.332***	–.364***	–.361***	–.146*	.577***					
	S2:	–.306***	–.310***	–.208**	–.025	.398***					
	S3:	–.272	–.229**	–.280***	–.153	.303***	—				
	S4:	–.289***	–.193***	–.268***	.009	.371***					
Caffeine	S1:	.075	.074	.128	.040	–.005	–.020				
	S2:	.088	.108	.044	–.036	–.109	–.078				
	S3:	.088	.099	–.023	–.037	–.093	–.163*	—			
	S4:	.067	.163*	.106	–.049	–.074	–.090				
CMQ-C	S1:	.168*	.237***	.124	.079	–.166*	–.089	.308***			
	S2:	.150*	.214***	.136*	–.043	–.039	–.079	.462***			
	S3:	.142	.150	.143	–.024	–.007	.042	.195*	—		
	S4:	.164*	.147*	.144	.075	–.167*	–.046	.274***			
CMQ-NA	S1:	.146*	.221***	.176**	.132*	–.168*	–.132*	.252***	.439***		
	S2:	.212**	.224***	.195**	–.028	–.080	–.117	.328***	.441***		
	S3:	.263***	.185*	.179*	.040	–.144	.039	.149	.294***	—	
	S4:	.351***	.354***	.202**	.045	–.158*	–.187*	.373***	.453***		
CMQ-R	S1:	.078	.168*	.076	.009	–.141*	–.095	.334***	.481***	.595***	
	S2:	.156*	.218***	.151*	–.039	–.140*	–.106	.394***	.509***	.571***	
	S3:	.220**	.151	.155	.140	–.146	–.098	.303***	.180*	.496***	—
	S4:	.241**	.289***	.216**	.031	–.041	–.088	.387***	.304***	.633***	
CMQ-W	S1:	.076	.103	.113	.037	.009	.077	.248***	.218**	.309***	.284***
	S2:	.098	.127	–.040	–.063	–.063	–.030	.160*	.240***	.115	.207**
	S3:	.051	.104	.042	.159*	–.082	.042	.149	.226**	.324***	.273***
	S4:	.255***	.180*	.021	.058	–.023	.008	.141	.344***	.385***	.327***

Note. S1 = Sample One (*N* = 224); S2 = Sample Two (*N* = 234); S3 = Sample Three (*N* = 160); S4 = Sample Four (*N* = 182); ARCES = Attention Related Cognitive Errors Scale; MAAS-LO = Mindful Attention Awareness Scale–Lapses Only; MW-D = Mind-Wandering Deliberate; MW-S = Mind–Wandering Spontaneous; DECI = Deep Effortless Concentration–Internal; DECE = Deep Effortless Concentration–External; Caffeine = Caffeine Consumption Questionnaire; CMQ-C = Caffeine Motives Questionnaire (CMQ) Cognitive Motives; CMQ-NA = Negative Affect Relief; CMQ-R = Reinforcing Effects; CMQ-W = Weight Control *p < .05; **p < .01; ***p < .001

2.4 Discussion

Chapter 2 assessed the relations between caffeine consumption and attentional engagement in everyday life. We used several measures that each target a different facet of attentional engagement (e.g., attention lapses, mind-wandering, and flow). We also explored how different motivations for choosing to ingest caffeine related to our measures of everyday attention. Contrary to what one might predict, here we found that the amount of caffeine one consumes in a typical day (in mg) was not significantly related to our measures of inattention (i.e., attention-related cognitive errors and lapses of attention), mind-wandering (both spontaneous and deliberate), or flow (both internal and external) in everyday life. This is interesting when compared to the numerous studies showing an attentional benefit on laboratory attention tasks following an acute dose of caffeine (e.g., see Einöther & Giesbrecht, 2013; Irwin et al., 2020) as well as the limited studies showing that caffeine consumption is associated with fewer cognitive failures (e.g., Nguyen-Van-Tam & Smith, 2022; Smith, 2005, 2009). The second goal for the present study was to examine how various motivations for choosing to consume caffeine using the Caffeine Motives Questionnaire (Irons et al., 2014) may relate to our measures of everyday attention. In this regard, we found that those who scored higher in cognitive motivations, or the reinforcing effects motivations, or negative affect relief motivations reported greater cognitive errors, attention-lapses, and spontaneous mind-wandering, as well as less internal and external flow in everyday life.

One possible explanation for the discrepancy between our findings and previous reports regarding the relation between caffeine consumption and attention may be related to differences in how attention was assessed across studies. For example, caffeine use may be

differentially related to momentary states of attention (as assessed in laboratory studies) and more enduring traits of attentional engagement in everyday life (as indexed by our subjective report questionnaires). Indeed, in its function as a central nervous stimulant that binds to adenosine receptors as an adenosine antagonist (Einöther & Giesbrecht, 2013), caffeine's effects may be time limited. This would mean that caffeine could have momentary effects shortly after ingestion (indexed during a laboratory task) without also having enduring effects capable of boosting attention continuously in day-to-day life (indexed by our subjective report questionnaires). Furthermore, the studies that included a measure related to trait attention (Nguyen-Van-Tam & Smith, 2022; Smith 2005; 2009) may have measured a different aspect of attention (e.g., primarily distraction, Nguyen-Van-Tam & Smith, 2022), or a broader construct (e.g., cognitive failures, Smith, 2005; 2009) than we have. It is plausible that caffeine consumption is only related to specific aspects of attention, memory, or action in everyday life.

Another possible explanation for the discrepancy between our findings and previous reports linking caffeine consumption to attentional/cognitive traits may have to do with disparities in the demographics of the samples tested in the relevant studies. Compared to the Smith (2005) and Smith (2009), in which the average age was 41.00 and 49.60, respectively, our samples were younger, with average ages of 20.63, 19.95, 20.63, and 19.73 in Samples One, Two, Three, and Four, respectively. Thus, it may be plausible that caffeine consumption is related to fewer cognitive failures in an older population but not a younger one. Nguyen-Van-Tam and Smith (2022) also showed a significant relation between the amount of caffeine consumed in a day (in mg) and better attentional performance. However, when looking at different age groups, Nguyen-Van-Tam and Smith (2022) found that this relation

was significant for people 55 years of age (or older) but not for people 18 to 34 or 35 to 54 years of age. More research is still needed to corroborate this possibility.

When considering the reasons people report consuming caffeine, we found people who reported consuming caffeine for the potential cognitive enhancements, to help deal with negative affect, or because of the reinforcing effects (e.g., to combat headaches, liking the taste, etc.) also reported greater cognitive errors, attention-lapses, and spontaneous mind-wandering, as well as less internal flow in everyday life. This could mean that those who have attentional difficulties may consume caffeine in an attempt to ameliorate these problems, with these attempts being unsuccessful. It is also possible that any attentional benefit of caffeine use that is originally sought after diminishes from chronic caffeine consumption, leading people to use more caffeine to combat withdrawal symptoms. Caffeine tolerance and experiencing caffeine withdrawal symptoms (e.g., headaches, low mood, etc.) can occur quickly and with as little as 100 mg of caffeine per day (Griffiths et al., 1990). Thus, it is possible that while the Caffeine Motives Questionnaire (Irons et al., 2014) used in this study assesses various reasons for choosing to ingest caffeine (e.g., to enhance cognition, because of the reinforcing effects, negative affect relief, and to help weight control) it may also be indexing a related motivation—namely withdrawal relief. This possibility is something that future work should also address.

Chapter 3: Examining The Effects of Caffeine During an Auditory Attention Task

3.1 Introduction[3]

In Chapter 2, we examined the relation between caffeine consumption and attentional engagement in everyday life using several measures that each target a different facet of attentional engagement. We also explored how different motivations for choosing to ingest caffeine related to our measures of everyday attention. Chapter 3 examines the effects of caffeine consumption (versus placebo) on behavioural variability and the amount of mind-wandering (both spontaneous and deliberate) during a sustained attention task. One sustained attention task that can provide a behavioural index of inattention while also providing an opportunity to measure mind-wandering using intermittent thought probes is the Metronome Response Task (MRT; Seli et al., 2013). During the MRT, participants are instructed to press a button synchronously with a continuous metronome tone. Throughout the task, thought probes appear to assess whether the participant is on task or mind-wandering. Mind-wandering during the MRT can also be assessed indirectly via response time variability. Previous research suggests that response time variability during the MRT is significantly greater during mind-wandering episodes compared to periods of on task performance (Seli et al., 2013, 2014).

In this study, caffeine deprived participants were randomly assigned to either chew caffeinated chewing gum (the caffeine condition) or regular non-caffeinated chewing gum (the placebo condition) and completed two sessions of the MRT. Throughout the MRT,

[3] Major parts of this chapter are taken from Kruger et al. (2024b).

participants were asked to indicate whether they were on task, spontaneously mind-wandering, or deliberately mind-wandering just prior to the interruption. Participants completed the MRT twice, once before chewing caffeinated gum (or placebo) and once after chewing the caffeinated gum (or placebo). Between each session, the participants chewed their assigned gum for 20-minutes. Thus, by the time participants completed the second session of the MRT (MRT-2), enough caffeine would have been metabolized to theoretically effect their MRT-2 performance from the beginning to the end of the session.

The secondary aim of Chapter 3 was to assess and replicate previous findings investigating the effects of caffeine consumption on various attention-related experiences such as affect, arousal, boredom, sleepiness, and mental effort. This was done by asking participants to report on their momentary experiences following each session of the MRT. Previous research suggests that compared to placebo, consuming caffeine is related to positive mood (e.g., Childs & De Wit, 2006; Ruxton, 2008; Smith et al., 2005), increased arousal (Smith et al., 2006), as well as reduced feelings of boredom (e.g., Loke, 1988; Smit & Rogers, 2002), (e.g., Roehrs & Roth, 2008; Snel & Lorist, 2011), and perceived exertion (e.g., Azevedo et al., 2016; Martin et al., 2018).

Hypotheses

If caffeine consumption improves attention performance, we would expect that response variability ought to be lower in the caffeine condition than the placebo condition after participants chewed their assigned gum (i.e., during the second session of the MRT or MRT-2). We also expected that after chewing their assigned gum (i.e., during MRT-2), participants in the caffeine condition would report being more on task and have fewer episodes of spontaneous and deliberate mind-wandering than those in the placebo condition.

Based on previous research, we also predicted that compared to placebo, participants who received caffeine would report more positive affect, greater arousal, less boredom, less sleepiness, and less mental effort required to stay on task during MRT-2.

Finally, we also further explore the interesting relation from the study presented in Chapter 2 that showed a positive correlation between the cognitive motives for consuming caffeine and more inattention in everyday life. We chose to explore this relation because the cognitive motives index various motivations related to attentional experiences (e.g., choosing to ingest caffeine to feel more alert, to help focus attention, etc.) more so than the other motives. To do this we examined the correlations between the proportion of on task responses from each session of the MRT and the cognitive motives for consuming caffeine. If caffeine serves to improve attention as previous in-lab research suggests (e.g., Einöther & Giesbrecht, 2013), we would expect to see a significant negative correlation between the cognitive motives for caffeine consumption and the proportion of on task responses during MRT-1 (i.e., the session in which people are un-caffeinated). Following caffeination in MRT-2 we would expect this correlation to disappear (i.e., become non-significant) for the caffeinated group.

3.2 Methods

Participants

The Office of Research Ethics approved all procedures. A convenience sample was recruited from the University of Waterloo's system for undergraduate research experience in exchange for course credit. To be eligible to participate, participants must have self-reported to consume caffeine at least once per week. A total of 168 participants were recruited, however, 41 people were removed for various reasons. Specifically, 6 people were removed

for indicating that they consumed caffeine before participating, 20 people were removed for not following instructions resulting in unusable data, 14 people were removed because they did not respond to 10% or more of the trials of the attention task (i.e., 90 trials or greater), and one person was removed for not answering all of the subjective measures following the attention task. This left 127 participants for data analysis with ages ranging from 18 to 39 (M = 20.43, SD = 2.50). The sample consisted of 38 people identifying as male, 84 people identifying as female, and 5 people identifying as non-binary. The sample was predominantly comprised of white (n = 41), East Asian (n = 32), and South Asian (n = 30) peoples; see Table 3.1 below for a full summary of the demographics. After the exclusions there were 68 people in the placebo condition and 61 people in the caffeine condition.

Table 3.1

***Demographics* (*N* = 127)**

Demographic Variable	*n*
Age (ranging from 18 to 39)	
M = 20.43	
SD = 2.50	
Gender	
Female	84
Male	38
Non-binary	5
Race	
White	41
East Asian	32
South Asian	30
Southeast Asian	7
Black	3
Middle Eastern	3
Mixed race	5
Hispanic	1
West Indian/Caribbean	1
Indigenous	1
Other not listed	3

Materials

Gum was chosen as the method of caffeine administration because chewing leads to bioavailability that is similar to capsules but at a faster rate (Kamimori et al., 2002). Depending on the product availability at the time of recruitment, each participant in the caffeine condition received two pieces of peppermint or spearmint flavoured Military Energy

Gum (https://militaryenergygum.com/). Each piece contained 100 mg of caffeine (total = 200 mg). Each participant in the placebo condition received two pieces of Pür peppermint gum (https://thepurcompany.com/). Each piece contained 0 mg of caffeine. We chose this brand of gum because it is less popular than other brands on the market.

Attention Task and Related Measures

Metronome Response Tasks (MRT)

Each trial of the MRT began with 700 milliseconds (ms) of silence followed by the presentation of a tone (lasting 100 ms) and a further 500 ms of silence (total trial duration = 1300 ms). Participants wore headphones while completing the task. Participants were told to press the space bar in sync with the presented tones and that these rhythmically presented tones would be presented equally spaced apart from one another for the entire task. Participants first completed 18 practice trials to familiarize themselves with the task and then completed 10 blocks of 90 trials (900 trials total for each session).

The primary measure of sustained attention in the MRT is the overall rhythmic response time (RRT) variability. We calculated the RRTs as the difference between the onset of each metronome tone and the associated button press (see Seli et al., 2013). MRT RRT variances were then computed using a moving window[4] of the current and preceding four trials across all trials throughout the task (excluding the first five trials of the task and the five trials immediately following a thought probe). These variance scores were normalized using a natural logarithm transformation and for each participant, we computed the average of the transformed variance scores across the entire moving window. Higher scores indicate

[4] We used a moving window because it retained the temporal component of the variance across the task. Computing the overall variance of the RRTs would not retain this temporal component.

that participants were more variable in timing the spacebar presses to coincide with the metronome tones.

Mind-Wandering Probes

Mind-wandering was assessed using 10 thought probes (one in each block) that were pseudo-randomly presented between trials 40 and 89 (inclusive) of the 90 trial blocks of the MRT. When a thought probe was presented, the task was temporarily stopped, and the participant was shown the following question: “During the task, just before this screen appeared were your thoughts on task, spontaneously mind-wandering, or deliberately mind-wandering?” These three options were defined to participants in the instructions they received before beginning the MRT. Specifically, the instructions stated:

> "On task" means that your thoughts were focused on things such as timing your presses to coincide with the tone. "Spontaneously mind-wandering" means that despite your intention to stay "on task" you find your thoughts have uncontrollably shifted away from the task to other things. "Deliberately mind-wandering" means that you have intentionally decided to think about things other than the task at hand.

After providing a response to a thought probe, participants were instructed to press the space bar to resume the MRT. The primary measures of interest were the proportion of on-task, spontaneously mind-wandering, and deliberately mind-wandering responses as a function of the total number of thought probes in each MRT session.

Baseline and Post-MRT Questions

At the beginning of each session of the MRT and following each session of the MRT, participants were asked to indicate their level of affect, arousal, boredom, and sleepiness.

Participants were also asked to indicate the amount of mental effort that was required to stay on task following each session of the MRT. The Self-Assessment Manikins (SAMs; Bradley & Lang, 1994) were used to measure affect and arousal on a scale from 1 to 9 in which higher scores indicate more positive affect and more arousal. Boredom was gauged by asking participants to indicate their current level of boredom on a scale from 1 (not bored at all) to 7 (extremely bored). The Karolinska Sleepiness Scale (KSS; Miley et al., 2016) was used to measure sleepiness in which higher scores indicate greater sleepiness, and mental effort was measured by asking the participant how much mental effort was required to stay on task on a scale from 1 (absolutely no effort) to 10 (extreme effort). See Appendix B for the exact wording of the baseline and post-MRT questions.

Apparatus

The MRT and associated measures (i.e., the thought probes and post-MRT questions) were presented on a Macintosh iMac programmed using PsychoPy version 2021.2.3 (Peirce et al., 2019). Participants also answered the various survey questionnaires from Chapter 2 on the iMac via Qualtrics.

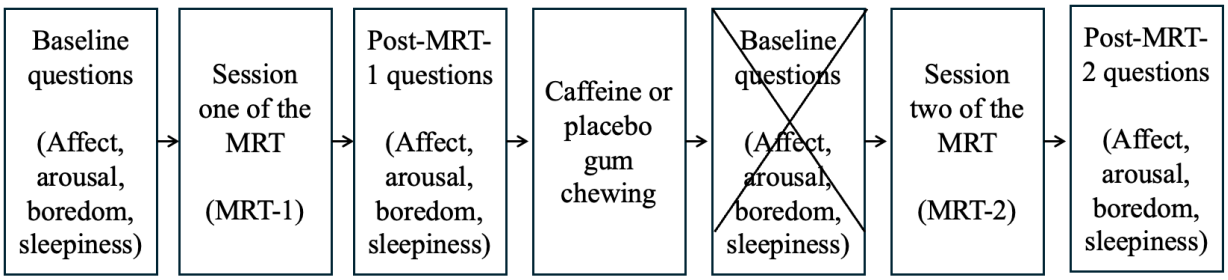
Procedure

See Figure 3.1 for a summary of the procedure. Participants who self-reported consuming caffeine at least once per week were eligible to sign up for the study. Interested participants signed up through the University of Waterloo's system for undergraduate research experience. After obtaining informed consent, participants who agreed to take part in the study first completed baseline questions regarding affect, arousal, boredom, and sleepiness. These baseline questions were collected before each session of the MRT. However, the second session baseline questions were not analyzed . The participants then

listened to the instructions of the MRT and completed 18 practice trials. If they did not have any questions for the researcher, participants then completed the experimental trials of the MRT. Immediately following the MRT, participants answered the affect, arousal, boredom, sleepiness, and mental effort questions and then were given an envelope containing the chewing gum (caffeinated or placebo). They were instructed to chew it for 20-minutes and while chewing, participants answered the various survey questionnaires. After 20-minutes of chewing, participants disposed of the chewing gum and completed a second session of the MRT which followed the same procedure as above. Finally, participants were then asked to guess which condition they were in and indicated whether they had consumed caffeine before participating. The entire study took approximately 90-minutes and participants received 0.25 credits for every 15-minutes of participation up to a maximum of 1.5 credits towards an eligible undergraduate course and were provided with a feedback letter debriefing them of the study's purpose and where to find more information related to the study.

Figure 3.1

Experimental Procedure From Chapter 3



Note. The baseline questions prior to completing MRT-2 were not analyzed.

3.3 Results

The results of Chapter 3 are described in three sections. We first analyze the overall MRT RRT variance and thought probe responses. Second, we analyze the questions

following each MRT (i.e., affect, arousal, boredom, sleepiness, and mental effort). For each analysis, a 2 (condition) by 2 (session) mixed analysis of variance (ANOVA) was conducted. Three separate ANOVAs were conducted for each of the thought probe responses; we opted to assess these separately because the responses were dependent (e.g., if they had 8 on task responses and 2 spontaneously mind-wandering responses for the 10 thought probes, deliberate mind-wandering responses would have had to be zero). It was predicted that there would be a significant interaction in each model such that differences between conditions would be larger in the second session (after caffeine or placebo ingestion) than in the first session. However, given that our predictions primarily involved effects following the consumption of the gum, we opted to conduct simple effect analyses even in the absence of a significant higher order interaction because of their theoretical importance (Howell, 2012). Thus, all simple effect analyses were evaluated using two-tailed, non-direction *t*-tests. The data was analyzed using RStudio 2023.03.1 and R 4.1.2 (R Core Team, 2021). Finally, we further explore the positive relation between the cognitive motives for consuming caffeine and failures of attention in everyday life.

Overall MRT RRT Variance and Thought Probe Responses

Figure 3.2 shows the overall MRT RRT variability and the proportions of on task, spontaneous mind-wandering, and deliberate mind-wandering responses during each session of the MRT. There was a significant condition by session interaction for overall RRT variability, $F(1, 125) = 8.32$, $p = .005$ and a significant condition by session interaction for the proportion of on task responses, $F(1, 125) = 8.52$, $p = .004$. This interaction was not significant for the proportion of spontaneous mind-wandering responses, $F(1, 125) = 2.30$, p

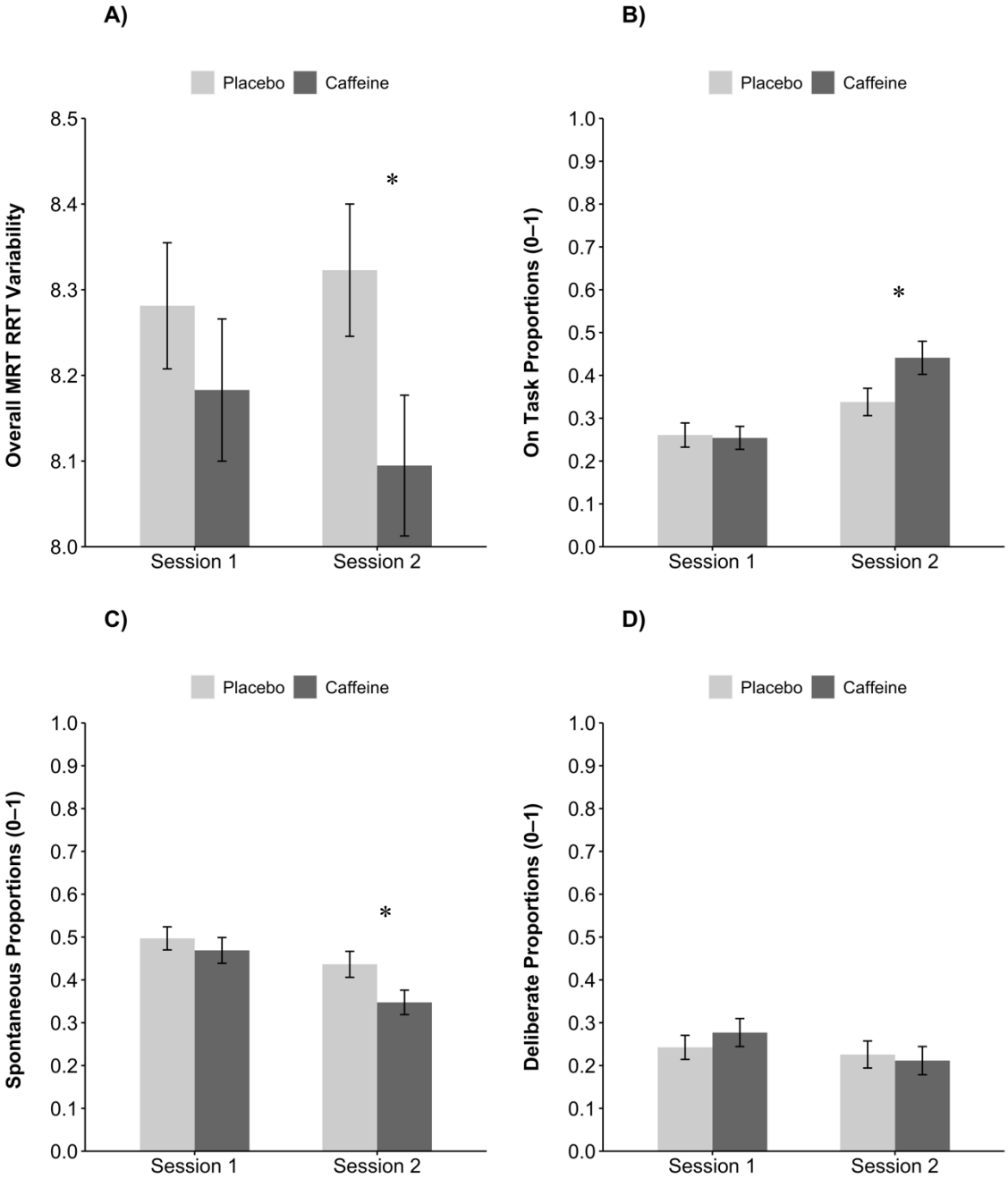
= .13, nor was this interaction significant for deliberate mind-wandering responses, $F(1, 125) = 1.36$, $p = .25$.

To ensure that the random assignment of participants did not result in any significant differences before the experimental manipulation between the two conditions, we examined the simple effects for the first session of the MRT. Simple effect analyses revealed no significant differences between the two groups for overall MRT RRT variability, $t(125) = -0.89$, $p = .38$, the proportion of on task responses during the MRT, $t(125) = -0.17$, $p = .87$, the proportion of spontaneous mind-wandering responses, $t(125) = -0.70$, $p = .49$, nor for the proportion of deliberate mind-wandering responses, $t(125) = 0.81$, $p = .42$.

After the experimental manipulation (i.e., during MRT-2), simple effect analyses revealed that participants in the caffeine condition had significantly less overall RRT variability (Figure 3.1A), $t(125) = -2.02$, $p = .045$, as well as significantly more on task responses (Figure 3.1B), $t(125) = 2.07$, $p = .041$, and significantly fewer spontaneous mind-wandering responses (Figure 3.1C), $t(125) = -2.12$, $p = .036$, than the participants in placebo condition. There were no significant differences between the caffeine and placebo conditions in deliberate mind-wandering (Figure 3.1D) during the second session of the MRT, $t(125) = -0.31$, $p = .75$.

Figure 3.2

Overall Variability and Thought Probe Proportions for Each Session of the MRT for the Study Presented in Chapter 3



Note. A) The overall MRT RRT variability transformed using a natural logarithm. B) The proportion of on task responses. C) The proportion of spontaneous mind-wandering responses. D) The proportion of deliberate mind-wandering responses. For each panel, the error bars are ±1 standard error of the mean. * $p < .05$; ** $p < .01$; *** $p < .001$

Baseline Questions

Recall that participants were asked about their current levels of affect, arousal, effort, boredom, and sleepiness before starting the MRT sessions (baseline) and again after each of the MRT sessions. We also analyzed the baseline questions prior to the first session of the MRT (MRT-1) to ensure that the random assignment of participants did not result in any significant differences between the two conditions. Four participants did not answer the baseline questions for the first session; one participant in the placebo condition did not answer the baseline boredom question, one participant in the placebo condition and one participant in the caffeine condition did not answer the baseline arousal question, and one participant in the placebo condition did not answer the baseline arousal or baseline sleepiness question. Thus, these participants were removed from their respective baseline analyses but were kept for the remaining post-MRT analyses since that is the primary analysis of interest. For the baseline measures assessed prior to MRT-1, we did not find any significant differences in affect, $t(125) = –0.72$, $p = .47$, arousal, $t(122) = –0.04$, $p = .97$, boredom, $t(124) = –1.49$, $p = .14$, or sleepiness, $t(124) = 0.19$, $p = .85$, between the placebo and caffeine conditions (indicating that our random assignment of participants into the caffeine and placebo groups did not lead to spurious differences between groups *prior* to caffeine or placebo ingestion).

Post-MRT Questions

Figure 3.3 shows the scores for affect, arousal, boredom, sleepiness, and mental effort following each session of the MRT. There was a significant condition by session interaction for affect, $F(1, 125) = 15.37$, $p < .001$, arousal, $F(1, 125) = 6.98$, $p = .009$, boredom, $F(1,$

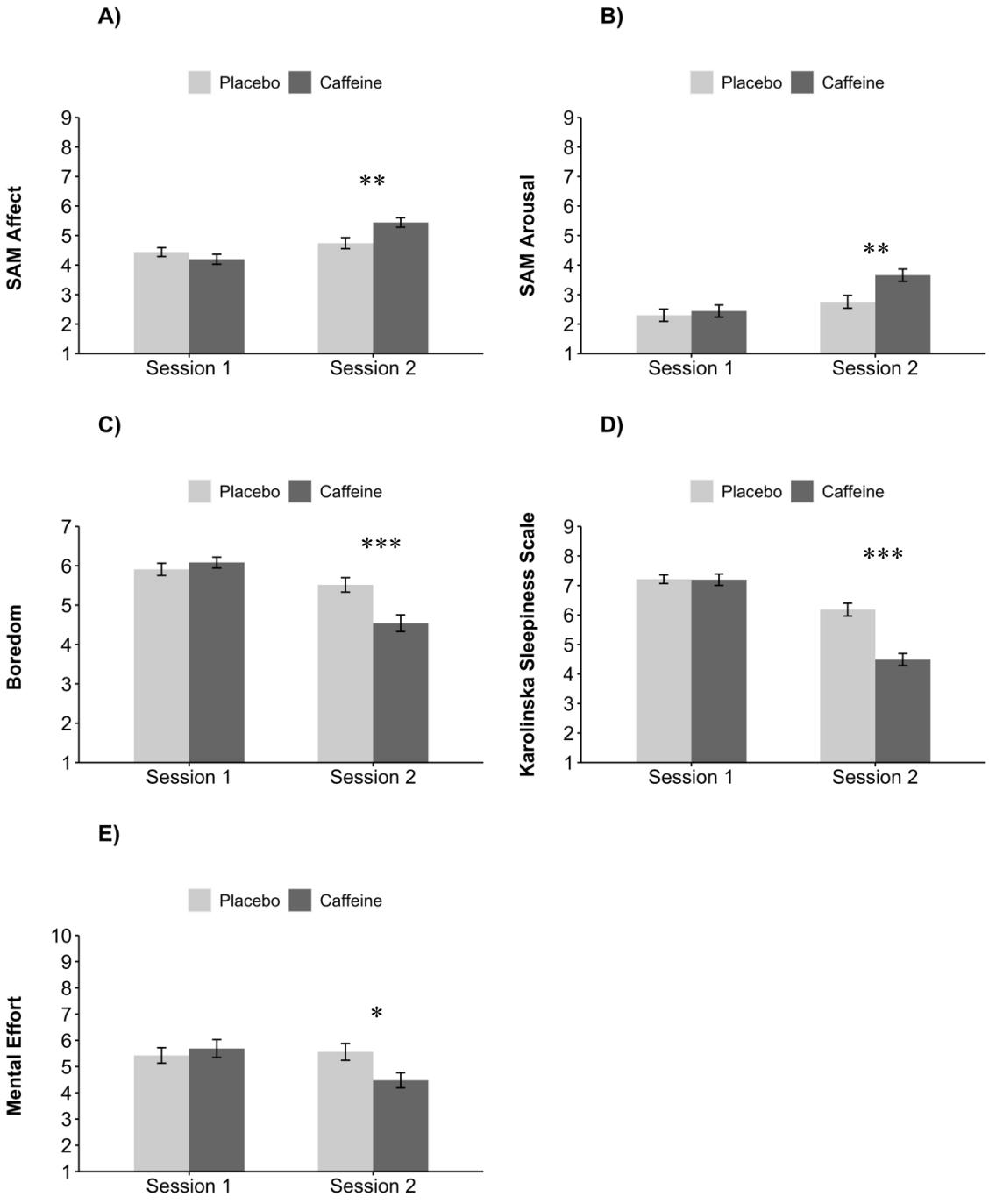
125) = 16.05, $p < .001$, sleepiness, $F(1, 125) = 26.93$, $p < .001$, and mental effort, $F(1, 125) = 13.62$, $p < .001$.

To further ensure that the random assignment of participants did not result in any significant differences for MRT-1, we conducted simple effect analyses comparing the caffeine and placebo groups prior to chewing the caffeinated or placebo gum. As expected, these revealed no significant differences between the caffeine and placebo conditions for affect, $t(125) = –1.08$, $p = .28$, arousal, $t(125) = 0.48$, $p = .63$, boredom, $t(125) = 0.82$, $p = .41$, sleepiness, $t(125) = –0.06$, $p = .95$, or mental effort, $t(125) = 0.59$, $p = .56$.

After the experimental manipulation (i.e., MRT-2), simple effect analyses revealed that, participants in the caffeine condition had significantly greater positive affect (Figure 3.3A), $t(125) = 2.84$, $p = .005$, arousal (Figure 3.3B), $t(125) = 2.97$, $p = .004$, as well as significantly less boredom (Figure 3.3C), $t(125) = –3.48$, $p < .001$, sleepiness (Figure 3.3D), $t(125) = –5.68$, $p < .001$, and mental effort (Figure 3.3E), $t(125) = –2.50$, $p = .014$. Collectively, these results suggest that participants reported an increase in mood and arousal as well as reduced feelings of boredom, sleepiness, and mental effort required to stay on task following caffeine consumption compared to participants who did not consume caffeine.

Figure 3.3

Post-MRT Questions Following Each Session of the MRT for the Study Presented in Chapter 3



Note. A) Average affect following the MRT. B) Average arousal following the MRT. C) Average boredom following the MRT. D) Average sleepiness following the MRT. E) Average mental effort required to stay on task following the MRT. For each panel, the error bars are ±1 standard error of the mean. * $p < .05$; ** $p < .01$; *** $p < .001$

Exploratory Hypothesis: Cognitive Motives and Inattention

Recall that in Chapter 2 we found an interesting positive relation between the cognitive motives for consuming caffeine and failures of attention in everyday life. Here we further explore this relation by examining the correlations between the proportion of "on task" responses from each session of the MRT and the cognitive motives for consuming caffeine. We expected to see a significant negative correlation between cognitive motives for ingesting caffeine and the proportion of on task responses during MRT-1 where people are un-caffeinated, however, following caffeine consumption we would expect this correlation to disappear (i.e., become non-significant). Thus, we restricted our analyses to only those participants in the caffeine condition since we were interested in the effects before caffeine consumption (i.e., MRT-1) and following caffeine consumption (i.e., MRT-2).

For MRT-1, we found a significant medium negative correlation between the cognitive motives factor of the Caffeine Motives Questionnaire and the proportion of "on task" responses, $r(59) = -.32$, $p = .011$. This suggests that those who are highly motived to consume caffeine for the cognitive benefits report being less "on task" while caffeine deprived. As predicted, after administering the caffeine, we found that the correlation between the cognitive motives of the Caffeine Motives Questionnaire and the proportion of "on task" responses during MRT-2 became non-significant, $r(59) = -.14$, $p = .29$. While it is tempting to attribute this difference in significance to caffeine, Steiger's Z (which assesses whether the magnitudes of the two dependent correlations are significantly different from one another; Steiger, 1980) indicated that the pre-caffeine correlation ($r = -.32$) and the post-caffeine correlation ($r = -.14$) were only marginally different, $Z = -1.63$, $p = .10$. Chapter 4 re-evaluates these correlations using a larger sample size in order to determine whether the

change from significant correlation in an un-caffeinated state, to a non-significant correlation once caffeinated, is a veridical, replicable finding.

3.4 Discussion

Chapter 3 explored how caffeine consumption (versus placebo) in a caffeine deprived sample influences attentional engagement as indexed by self-reported mind-wandering and performance on an attention task (the MRT) as well as other attention-related variables. The results revealed that, as predicted, participants who consumed caffeine reported being more on task and had fewer instances of spontaneous mind-wandering during the second session of the MRT. However, contrary to our predictions, we did not find any significant differences in deliberate mind-wandering during the second session of the MRT. These findings corroborate the neuroimaging results from Kahathuduwa et al., (2018) but not the probe caught mind-wandering results from Giambra et al., (1994). It is possible that the differences in outcomes between our study and the study reported by Giambra et al., (1994) are due to differences in statistical power as Giambra et al., (1994) had a small sample size of six. In terms of performance, our results showed that those who consumed caffeine were able to keep more in sync with the metronome tone during the second session of the MRT compared to participants who did not consume caffeine. This finding is consistent with previous research showing that caffeine consumption has psychomotor benefits (Einöther & Giesbrecht, 2013; Irwin et al., 2020). It also corroborates the self-report findings of the current study given that those who are better able to keep in sync with the metronome tone reported being more "on task." Finally, we showed that participants who consumed caffeine also reported greater positive affect and arousal as well as less boredom, sleepiness, and mental effort required to stay on task than those who did not consume caffeine. These

findings are also corroborate previous research showing that following caffeine consumption, participants report greater positive mood (e.g., Childs & De Wit, 2006; Ruxton, 2008; Smith et al., 2005), increased arousal (Smith et al., 2006), as well as less boredom (e.g., Loke, 1988; Smit & Rogers, 2002), sleepiness (e.g., Roehrs & Roth, 2008; Snel & Lorist, 2011), and perceived exertion (e.g., Azevedo et al., 2016; Martin et al., 2018).

One potential explanation for the attentional benefits of caffeine consumption found in our study might be related to the executive-control failure account of mind-wandering. This account suggests that mind-wandering occurs when the executive-control system fails to supress interfering thoughts (Kane & McVay, 2012). If we consider the pharmacodynamics of caffeine and its relation to executive-control, we might be able to explain the differences in the proportion of on task and spontaneous mind-wandering reported between the participants who did and did not consume caffeine. Adenosine receptors are distributed in almost all human body tissues and organs (Ballesteros-Yáñez et al., 2018). A1 receptors, however, mediate the neuroexcitatory effects of caffeine and are highly concentrated in the frontal cortex—a brain region associated with executive control (Bauer et al., 2003; Friedman & Robbins, 2022). Thus, it is plausible that the excitability of the frontal cortex following caffeine consumption resulted in fewer failures of executive-control (i.e., fewer episodes of spontaneous mind-wandering and more instances of being on task) compared to those who did not consume caffeine.

Another potential explanation for the various benefits of caffeine consumption found in this study is related to the withdrawal reversal hypothesis of caffeine consumption. Caffeine is a central nervous system stimulant; thus, acute caffeine consumption can result in increased alertness and positive mood as well as reduce feelings of fatigue (Smith, 2002).

Consuming smaller doses of caffeine (e.g., 17 mg) can also elicit feelings of relaxation in the consumer whereas consuming higher doses of caffeine (e.g., 1.5 mg/kg of body weight) can induce feelings of physical arousal (Herz, 1999; Smith et al., 2006). However, chronic caffeine consumption can result in increased tolerance leading to withdrawal symptoms upon cessation (Rogers, 2007; Ruxton, 2008). Withdrawal symptoms include headaches, fatigue, low mood and low energy as well as difficulty concentrating (Griffiths et al., 1990; Juliano & Griffiths, 2004; Schuh & Griffiths, 1997). These symptoms may be present for individuals who regularly consume as little as 100 mg/day and do not receive their regular dose of caffeine (Griffiths et al., 1990). Since the participants in the current study were all withdrawn from caffeine prior to participating—a common study design in this literature—it is plausible that caffeine withdrawal worsened cognitive function, and that subsequent caffeine consumption in our study restored cognitive function to baseline. However, we note that prior studies have shown that participants who have consumed caffeine earlier in the day still show a performance benefit after consuming an additional dose compared to those did not consume an additional dose (e.g., Einöther & Giesbrecht, 2013; Ruxton, 2008; Smith et al., 2005). Thus, it is not entirely clear whether our results are driven by caffeine withdrawal, and whether similar results would emerge if an additional dose of caffeine was administered to individuals who already consumed caffeine earlier in the day.

Finally, we also further explored the positive relation between the cognitive motives for consuming caffeine (e.g., choosing to ingest caffeine to feel more alert or to help concentration) and more inattention in everyday life reported in Chapter 2. Here we found that those who are highly motivated to consume caffeine for the cognitive benefits report being less “on task” during the MRT while caffeine deprived. Following caffeine

consumption, this relation became non-significant. On the surface it may seem like participants may be self-medicating with caffeine to help ameliorate the attention problems they experience. This may help explain why we did not observe any relations between caffeine consumption and trait attention in everyday life reported in Chapter 2, but we did observe less state inattention following caffeine consumption. However, before speculating any further we must investigate the robustness of this finding by replicating it in a larger sample size.

Chapter 4: Further Examining How Motivations for Caffeine Consumption Relate to Attentional Engagement During an Auditory Attention Task

4.1 Introduction

The findings from Chapter 3 showed that those who were highly motivated to use caffeine to enhance cognition reported being less on task in a non-caffeinated state, $r(59) = -.32$, $p = .011$. After consuming caffeine, we found that this correlation became non-significant, $r(59) = -.14$, $p = .29$. As a next step, we sought to replicate this relation as well as the main findings regarding the attention task (i.e., the MRT; Seli et al., 2013) from Chapter 3 using a larger sample size. During the MRT, participants are instructed to press a button synchronously with a continuous metronome tone. Throughout the task, thought probes appear to assess whether the participant is on task or mind-wandering. Mind-wandering during the MRT can also be assessed indirectly via response time variability. Previous research suggests that response time variability during the MRT is significantly greater during mind-wandering episodes compared to periods of on task performance (Seli et al., 2013, 2014).

Hypotheses

We predicted that participants would report being more on task and less spontaneous mind-wandering during the MRT following caffeine consumption. Based on the results from Chapter 3, we also predicted that there would be no differences in deliberate mind-wandering during the MRT in an un-caffeinated versus caffeinated state. Finally, we predicted that

participants would report greater positive affect, more arousal, less boredom, less sleepiness, and less mental effort required to stay on task following caffeine consumption.

4.2 Methods

Participants

A total of 188 participants signed up for our study, however 47 people were removed for various reasons. Specifically, 7 people were removed for indicating that they consumed caffeine before participating, 8 people were removed for not following instructions resulting in unusable data, 21 people were removed because they did not respond to 10% or more of the trials of the attention task (i.e., 90 trials or greater), 6 people were removed for not answering all of the subjective measures following the task, 4 people were removed because they did not answer all of the thought probe responses, and 1 person was removed because they withdrew from the study. This left 141 participants left for data analysis with ages ranging from 17 to 42 (M = 19.68, SD = 3.12). The sample consisted of 16 people identifying as male, 118 people identifying as female, 6 people identifying as non-binary, and 1 person preferring not to say. The sample was predominantly white (n = 66), South Asian (n = 25), and East Asian (n = 17); see Table 4.1 below for a full summary of the demographics.

Table 4.1

***Demographics* (*N* = 141)**

Demographic Variable	*n*
Age (ranging from 17 to 42)	141
M = 19.68	
SD = 3.12	
Gender	
Female	118
Male	16
Non-binary	6
Prefer not to say	1
Race	
White	66
South Asian	25
East Asian	17
Southeast Asian	6
Black	7
Middle Eastern	4
Hispanic	7
West Indian/Caribbean	1
Indigenous	2
Other not listed	6

Materials

The materials were identical to those used in the study presented in Chapter 3 except there was no regular (placebo) gum. Everyone received 200 mg of peppermint or spearmint caffeinated Military Energy Gum. The flavour was dependent on product availability at the time of recruitment

Attention Task and Related Measures

Metronome Response Task (MRT)

The MRT was identical to the one used in Chapter 3.

Mind-Wandering Probes

The mind-wandering probes were identical to the one used in Chapter 3.

Post-MRT Questions

The post-MRT questions (i.e., affect, arousal, boredom, sleepiness, and mental effort) were identical to those used in Chapter 3. However, unlike Chapter 3, there were no baseline questions.

Apparatus

The equipment used was identical to those presented in Chapter 3.

Procedure

The procedure was identical to Chapter 3 except there was only one group of participants (in which everyone received 200 mg of caffeine) and there were no baseline questions prior to completing MRT-1.

4.3 Results

The results of Chapter 4 are described in three sections. We first sought to replicate the findings concerning the overall MRT RRT variance and thought probe responses from Chapter 3. Second, we sought to replicate the caffeine's effects on the responses to the affect, arousal, boredom, sleepiness, and mental effort questions following the MRT-1 (i.e., un-caffeinated) and MRT-2 (i.e., caffeinated). For the analysis regarding the proportion of

deliberate mind-wandering in MRT-1 versus MRT-2, a two-tailed dependent samples *t*-test was conducted since based on our findings in Chapter 3, we predicted no significant differences in deliberate mind-wandering. For all other MRT-1 versus MRT-2 comparisons, we used one-tailed dependent samples *t*-tests given that we were replicating the findings of those exposed to caffeine in Chapter 3. Three separate *t*-tests were also conducted for each of the thought probe responses; they are assessed separately because the responses are dependent on one another. Based on the results from Chapter 3, it was predicted that participants would report being more on task and report fewer instances of spontaneous mind-wandering in the second (caffeinated) MRT-2 session. We also predicted that there would be no significant difference in deliberate mind-wandering for MRT-1 and MRT-2. We predicted that participants would also report more positive affect, greater arousal as well as less boredom, sleepiness, and mental effort required to stay on task during the caffeinated MRT-2 session. Third, we also predicted that there would be a significant negative correlation between the cognitive motives for caffeine consumption and the proportion of on task responses during MRT-1 since participants were un-caffeinated, and that this correlation would become non-significant during MRT-2 following caffeine consumption.

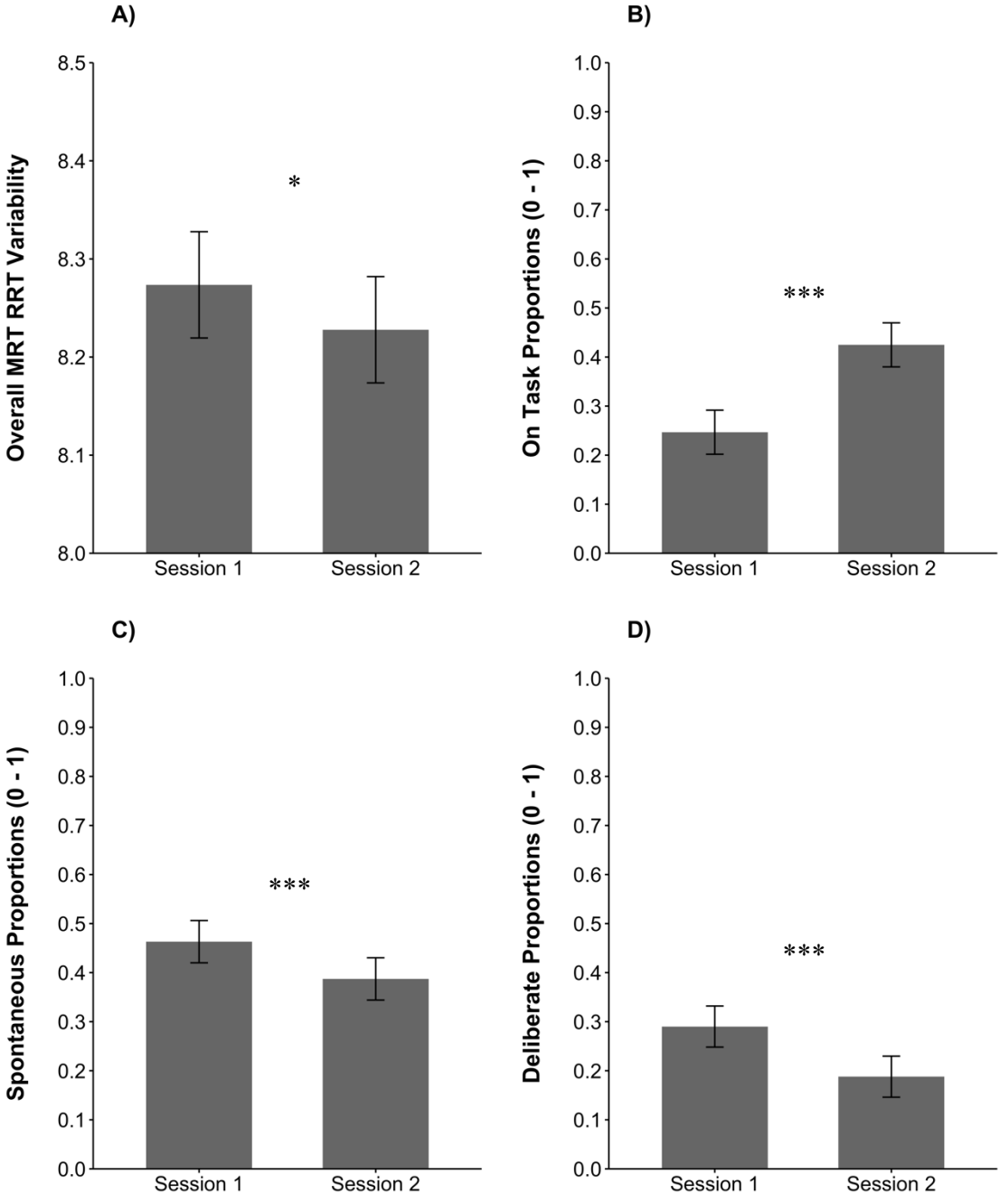
Chapter 3 Replication: Overall MRT RRT Variance and Thought Probe Responses

Figure 4.1 shows the overall MRT RRT variability and the proportions of on task, spontaneous mind-wandering, and deliberate mind-wandering responses during each session of the MRT. Looking first at performance in MRT-1 (un-caffeinated) versus MRT-2 (caffeinated), there was a significant decrease in overall RRT variability, $t(140) = 1.67$, $p = .049$ (Figure 4.1A), and a significant increase in the proportion of on task responses, $t(140) = –7.83$, $p < .001$ (Figure 4.1B). There were also significant decreases in spontaneous mind-

wandering, $t(140) = 3.48$, $p < .001$, but (unlike the study in Chapter 3) also deliberate mind-wandering, $t(140) = 4.82$, $p < .001$ (Figure 4.1C and Figure 4.1D, respectively).

Figure 4.1

Overall Variability and Thought Probe Proportions for Each Session of the MRT for the Study Presented in Chapter 4



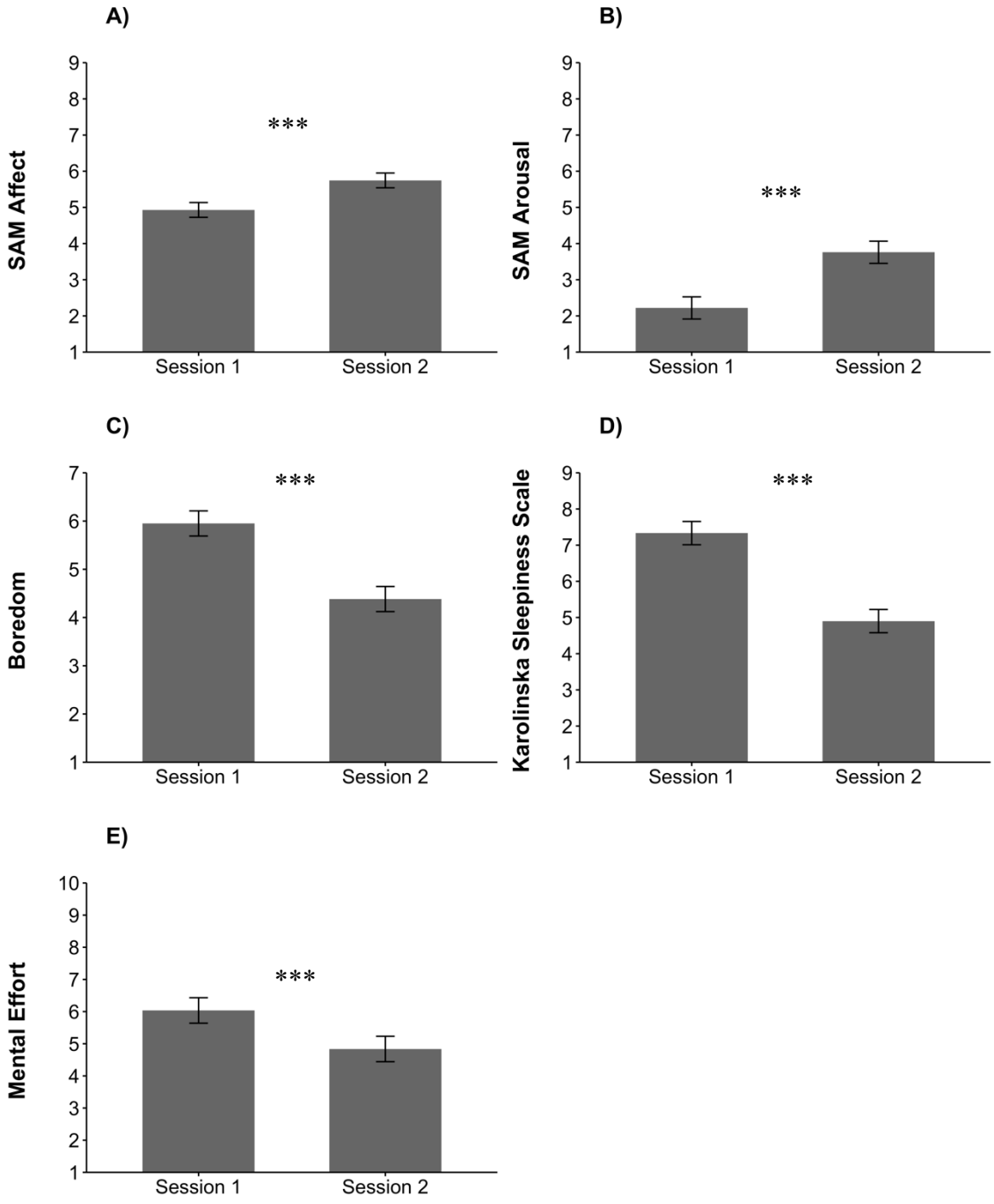
Note. A) The overall MRT RRT variability transformed using a natural logarithm. B) The proportion of on task responses. C) The proportion of spontaneous mind-wandering responses. D) The proportion of deliberate mind-wandering responses. For each panel, the error bars are Loftus & Masson (1994) 95% CIs. * $p < .05$; ** $p < .01$; *** $p < .001$

Chapter 3 Replication: Post-MRT Questions

Figure 4.2 shows the scores for affect, arousal, boredom, sleepiness, and mental effort following each session of the MRT. When contrasting the ratings following MRT-1 (un-caffeinated) compared to MRT-2 (caffeinated), positive affect significantly increased, $t(140) = –7.88$, $p < .001$, (Figure 4.2A), as did arousal, $t(140) = –9.92$, $p < .001$ (Figure 4.2B). Participants also reported being less bored following caffeine consumption in MRT-2 $t(140) = 11.90$, $p < .001$ (Figure 4.2C). They were also less sleepy, $t(140) = 14.95$, $p < .001$, (Figure 4.2D), and required less mental effort to stay on task during MRT-2 in their caffeinated state, $t(140) = 5.99$, $p < .001$(Figure 4.2E).

Figure 4.2

Post-MRT Questions Following Each Session of the MRT for the Study Presented in Chapter 4



Note. A) Average affect following the MRT. B) Average arousal following the MRT. C) Average boredom following the MRT. D) Average sleepiness following the MRT. E) Average mental effort required to stay on task following the MRT. For each panel, the error bars are Loftus & Masson (1994) 95% CIs. * $p < .05$; ** $p < .01$; *** $p < .001$

Further Exploring the Relation Between Cognitive Motives and Inattention

Recall that Chapter 3 showed that those who were highly motivated to use caffeine to enhance cognition reported being less on task in a non-caffeinated state, $r(59) = –.32$, $p = .011$. After consuming caffeine, we found that this correlation became non-significant, $r(59) = –.14$, $p = .29$. However, since we could only analyze the participants in the caffeine condition for the study presented in Chapter 3, we sought to replicate this intriguing finding in the current experiment.

Contrary to our prediction, when the participants were caffeine deprived in the current study, we found that the relation between the cognitive motives of caffeine consumption and the proportion of "on task" responses was non-significant, $r(139) = –.02$, $p = .79$. After consuming caffeine, we found that this correlation remained non-significant, $r(139) = .12$, $p = .16$. Thus, as promising as the results were in Chapter 3 regarding the cognitive motives for caffeine consumption and the proportion of "on task" responses during each session of the MRT, the results from the current experiment did not replicate.

4.4 Discussion

In a larger sample, the study presented here further explored how caffeine consumption in a caffeine deprived sample influenced attention engagement as indexed by self-reported mind-wandering and performance on the MRT as well as other attention-related variables. The results revealed that, as predicted, when participants were caffeinated in MRT-2, they reported being more on task, and reported fewer instances of spontaneous mind-wandering. However, contrary to our predictions, we also found that participants reported fewer instances of deliberate mind-wandering following caffeination in MRT-2 compared to their un-caffeinated state during MRT-1. In terms of performance, we also showed that as

predicted, participants were able to keep more in sync with the metronome tone during MRT-2 following caffeination. This finding also corroborates the self-report findings of the current study given that those who are better able to keep in sync with the metronome tone should also report being more "on task." Finally, we also showed that, as predicted, participants reported greater positive affect and arousal as well as less boredom, sleepiness, and mental effort required to stay on task following caffeine consumption.

One potential explanation for the attentional benefits of caffeine consumption found in Chapter 4 may also be related to the aforementioned executive-control failure account of mind-wandering. Recall that adenosine receptors are highly concentrated in a brain region associated with executive control (i.e., the frontal cortex; Bauer et al., 2003; Friedman & Robbins, 2022). Thus, the excitability of the frontal cortex following caffeination may have resulted in fewer failures of executive control (i.e., less instances of mind-wandering and more instances of being on task). The executive-control failure account of mind-wandering may also help explain why we observed differences in deliberate mind-wandering (apart from the fact that we had a larger sample size). In both Chapter 3 and Chapter 4, we did not collect data regarding how people decided to engage in deliberate mind-wandering. Deliberate mind-wandering may occur because of a conscious decision to initiate or continue a mind-wandering episode (Seli, Risko, Smilek, et al., 2016). In other words, mind-wandering may start out as spontaneous, but once the mind-wandering episode is detected, the participant may deliberately decide to continue to mind-wander. Thus, if people consciously decided to engage in deliberate mind-wandering from the start we may not observe an influence of caffeine on deliberate mind-wandering (which may be why we did not observe any differences between the participants in the caffeine and placebo groups in the

study from Chapter 3). However, if consuming caffeine results in fewer failures of executive control, participants may not have had the opportunity to continue to deliberately mind-wander. This may result in fewer instances of deliberate mind-wandering reports if participants never had the chance to start out spontaneously mind-wandering in the first place. To examine this possibility, future research will need to assess *how* participants decided to engage in deliberate mind-wandering.

Finally, we also further explored the relations between the cognitive motivations for caffeine consumption and the proportion of on task responses during each session of the MRT. Recall that we found that those who are highly motivated to consume caffeine for the cognitive benefits reported being less "on task" while caffeine deprived. However, following caffeine consumption, this relation became non-significant. Contrary to our prediction, when the participants were caffeine deprived in the current study, we found that the relation between the cognitive motives of caffeine consumption and the proportion of "on task" responses was non-significant, and that this relation remained non-significant after consuming caffeine. Thus, given that this finding did not replicate in a larger sample size, the original finding described in Chapter 3 is unreliable and may be due to a Type I error.

Chapter 5: Concluding Remarks

In a series of studies, I have investigated the link between caffeine consumption and the potential influence it has on attention. The first study explored how caffeine consumption and different motivations for caffeine consumption relate to everyday experiences of attention (e.g., attention-related cognitive errors, attention lapses, mind-wandering, and flow). Contrary to prior research (e.g., Nguyen-Van-Tam & Smith, 2022; Smith, 2005, 2009), we found that the amount of caffeine one self-reports consuming in a typical day (estimated in mg) was not related to the measures of attentional engagement in everyday life. Our study also showed that those who scored higher in the cognitive motivations (e.g., choosing to consume caffeine to feel more alert), the reinforcing effects motivations (e.g., choosing to consume caffeine to combat a headache), or the negative affect relief motivations (e.g., choosing to consume caffeine to help deal with stress) reported greater attention-related cognitive errors, attention-lapses, and spontaneous mind-wandering, as well as less internal and external flow in everyday life. The second study of this thesis explored how caffeine consumption (versus placebo) affected attentional engagement during a sustained attention task (i.e., the MRT). This study also explored how caffeine consumption (versus placebo) affected different attention-related constructs (e.g., affect, arousal, boredom, sleepiness, and effort). Compared to placebo, participants reported more instances of being on task as well as less episodes of spontaneous mind-wandering after consuming caffeine. Compared to placebo, participants also reported greater positive affect and arousal, as well as less feelings of boredom, sleepiness, and mental effort required to stay on task compared to those who consumed caffeine. Finally, in the third study of this thesis, we replicated these findings from the second study in a much larger sample size. The results from both of these studies are in

line with prior research suggesting that consuming an acute dose of caffeine benefits attention during laboratory-based attention tasks (e.g., Attwood et al., 2007; Childs & de Wit, 2006, 2008; Christopher et al., 2005; Fine et al., 1994; Kelemen & Creeley, 2001; Sainz et al., 2020; Smith, 1999, 2005, 2023). Thus, overall, caffeine seems to influence performance and inattention during a task; however, at the trait level, caffeine is not associated with attentional experiences in everyday life.

While the present studies yielded several interesting findings it is important to consider some of the limitations. When using surveys to investigate the effects that caffeine may have on attention it is difficult to 1) accurately gauge caffeine consumption and 2) disentangle the effects that caffeine has on attention from the possible effects of other potentially psychoactive compounds (e.g., polyphenols). The amount of caffeine found in various plants (e.g., coffee or tea) can vary depending on the coffee bean type, brew method, grind type, tea oxidation, and the steep temperature and steep length (Olechno et al., 2021). We tried to address these issues by providing participants the opportunity to include the exact caffeinated product they consumed rather than estimate using a predetermined amount of caffeine. We may be underestimating one's intake of caffeine, for example, if we used the average amount of 135 mg of caffeine in 237mL of brewed coffee reported by Health Canada (2022) instead of the amount reported by a specific company (e.g., according to their website, Starbuck's True North Blend™ contains approximately 180 mg of caffeine per 236 mL serving). Further, polyphenols found in natural foods (e.g., chlorogenic acid, catechins, and anthocyanins; Magrone et al., 2017; Wang & Ho, 2009) may have other psychoactive effects and may also be related to overall health (e.g., Shang et al., 2021; Tajik et al., 2017; Tan et al., 2021). Since the non-caffeine components of foods may have knock-on effects on

attention, it is critical that future research consider how different components of foods may impact attention-related experiences.

It is also important to consider some of the limitations of examining the effects that caffeine may have on attention in the laboratory. Given the aforementioned limitations, we chose to administer caffeine via chewing gum instead of through beverages that naturally contain caffeine (i.e., coffee or tea) in the studies reported in Chapter 3 and Chapter 4. Even though the main psychoactive ingredient in the caffeinated chewing gum was caffeine, it is still not a perfect method of delivery. Participants may not be used to consuming caffeine in this way and may have been able to tell which gum they received. In the study reported in Chapter 3, participants were blinded to which condition they were in, however, since the caffeine in chewing gum reaches the bloodstream at a faster rate than when it is consumed via capsules or beverages (Kamimori et al., 2002) the psychoactive effects may have been more salient. Thus, if participants "thought" they felt the effects of caffeine it may have biased their responses during the study. This is especially true given that we recruited people who self-reported consuming caffeine at least once per week—this also means that our results from the studies presented in Chapter 3 and Chapter 4 may not generalize to non-consumers of caffeine. Therefore, future research should consider alternative methods to administer caffeine and recruit participants who either do not consume caffeine and/or consume caffeine infrequently.

Finally, it is important to consider some of the limitations regarding the samples we recruited in studies presented in this thesis. Since we recruited convenience samples from the University of Waterloo (which are mostly younger and female), our results may not generalize to other demographics. This is especially true given that there are individual

differences in the pharmacokinetics of caffeine which were not accounted for. For example, individual differences in genetics can affect caffeine metabolism as those with autosomal recessive genes metabolize caffeine more slowly than those with autosomal dominant genes (Smith et al., 2006). Caffeine metabolism is also increased in those who use nicotine and decreased during the luteal phase of the menstrual cycle in women (Smith et al., 2006). Certain medications (e.g., oral contraceptives and selective serotonin reuptake inhibitors) can also affect caffeine metabolism (Smith et al., 2006). Thus, future research should consider how these individual differences may affect how caffeine is related to attention.

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Appendix A

Caffeine Content

Category	Item		Average Caffeine Amount (mg)
Coffee	Starbucks	Short (236 mL)	163
		Tall (354 mL)	238
		Grande (473 mL)	299
		Venti (591 mL)	388
	McDonald's Hot	Small (285 mL)	87
		Medium (420 mL)	129
		Large (540 mL)	165
		Extra Large (650 mL)	199
	McDonald's Iced	Small (380 mL)	104
		Medium (485 mL)	149
		Large (590 mL)	181
	Tim Horton's Hot	Small (296 mL)	140
		Medium (414 mL)	205
		Large (591 mL)	270
		Extra Large (710 mL)	330
	Tim Horton's Iced	Small (380 mL)	60
		Medium (515 mL)	130
		Large (648 mL)	160
	Tim Horton's Iced Capp	Small (380 mL)	90
		Medium (515 mL)	120
		Large (648 mL)	150
	William's Café Hot	Small (355 mL)	202
		Medium (473 mL)	269
		Large (710 mL)	337
	William's Café Iced	Small (473 mL)	267
		Large (710 mL)	404
	University of Waterloo Campus	Small (355 mL)	202
		Medium (473 mL)	269
		Large (591 mL)	337
	Home	Regular brew (236 mL)	135
		Decaf brew (236 mL)	3
		Instant (236 mL)	91
		Espresso (30 mL)	40

Category	Item		Average Caffeine Amount (mg)
Black Tea	Starbucks	Short (236 mL)	50
		Tall (354 mL)	50
		Grande (473 mL)	100
		Venti (591 mL)	100
	McDonald's	Small (285 mL)	50
		Medium (420 mL)	50
		Large (540 mL)	50
		Extra Large (650 mL)	100
	Tim Horton's	Small (296 mL)	50
		Medium (414 mL)	50
		Large (591 mL)	100
		Extra Large (710 mL)	100
	William's Café	Small (355 mL)	50
		Medium (473 mL)	50
		Large (710 mL)	50
	University of Waterloo Campus	Small (355 mL)	50
		Medium (473 mL)	50
		Large (591 mL)	50
	Home	Regular tea (236 mL)	50
		Decaf tea (236 mL)	0

Category	Item		Average Caffeine Amount (mg)
Green Tea	Starbucks	Short (236 mL)	30
		Tall (354 mL)	30
		Grande (473 mL)	60
		Venti (591 mL)	60
	McDonald's	Small (285 mL)	30
		Medium (420 mL)	30
		Large (540 mL)	30
		Extra Large (650 mL)	60
	Tim Horton's	Small (296 mL)	30
		Medium (414 mL)	30
		Large (591 mL)	60
		Extra Large (710 mL)	60
	William's Café	Small (355 mL)	30
		Medium (473 mL)	30
		Large (710 mL)	30
	University of Waterloo Campus (Various Shops)	Small (355 mL)	30
		Medium (473 mL)	30
		Large (591 mL)	60
	Home	Regular tea (236 mL)	30
		Decaf tea (236 mL)	0

Category	Item		Caffeine Amount (mg)
Soft Drinks	Can (355 mL)	Pepsi	38
		Diet Pepsi	35
		Pepsi Zero	38
		Mountain Dew	54
		Brisk	11
		Diet Brisk	11
		Dr. Pepper	41
		Diet Dr. Pepper	41
		Coca-Cola	34
		Diet Coca-Cola	46
		Coca-Cola Zero	34
		Barq's Rootbeer	22
	Bottle (500 – 591 mL)	Pepsi	63
		Diet Pepsi	59
		Pepsi Zero	63
		Mountain Dew	91
		Brisk	18
		Diet Brisk	18
		Dr. Pepper	68
		Diet Dr. Pepper	68
		Coca-Cola	48
		Diet Coca-Cola	64
		Coca-Cola Zero	48
		Barq's Rootbeer	31

Category	Item		Caffeine Amount (mg)
Energy Drinks	Smaller Cans (250 – 355 mL)	Coca-Cola Energy	114
		Coca-Cola Energy Zero	114
		Red Bull	80
	Larger Cans (360 – 500 mL)	Red Bull	160
		Amp Energy	142
		Bang	300
		Beaver Buzz	180
		C4	200
		Full Throttle	160
		Monster	166
		Mountain Dew Kick Starter	68
		NOS	160
		Rockstar	160

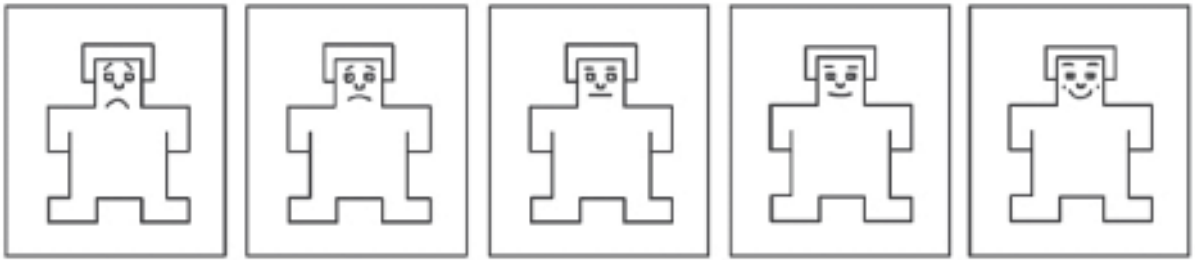
Category	Item		Caffeine Amount (mg)
Supplements	Caffeine Pills	Smaller dose	100
		Larger dose	200
Chocolate	Dark Chocolate (30 g)	Cocoa	20

Appendix B

Baseline and Post-MRT Questions

Affect (Bradley & Lang, 1994)

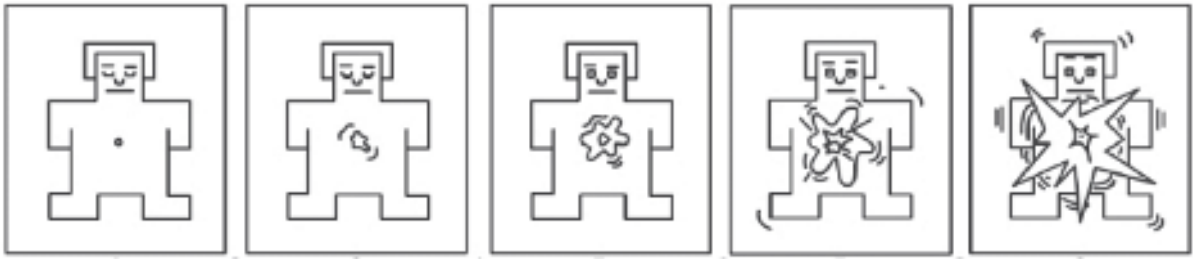
Please indicate your current mood/affect on the scale from 1 to 9 using the mouse. Higher scores indicate greater mood/affect.



1 2 3 4 5 6 7 8 9

Arousal (Bradley & Lang, 1994)

Please indicate your current level of arousal on the scale from 1 to 9 using the mouse. Higher scores indicate greater excitement/arousal.



1 2 3 4 5 6 7 8 9

Boredom

How bored do you feel right now? Please indicate your current level of boredom on the scale from 1 to 7 using the mouse.

1	2	3	4	5	6	7
Not bored at all						Extremely bored

Karolinska Sleepiness Scale (Miley et al., 2016)

How sleepy do you feel right now? Please indicate your current level of sleepiness by choosing the appropriate description using the mouse.

1 – Extremely alert

2 – Very alert

3 – Alert

4 – Rather alert

5 – Neither alert nor sleepy

6 – Some signs of sleepiness

7 – Sleepy, but no effort to keep awake

8 – Sleepy, some effort to keep awake

9 – Very sleepy, great effort to keep awake, fighting sleep

Mental Effort

How much mental effort was required to stay on task? Please respond using the mouse.

1	2	3	4	5	6	7	8	9	10
Absolutely no effort									Extreme effort