COGNITIVE EFFECTS OF COFFEE CONSUMPTION IN INDIVIDUALS WITH LOW VERSUS HIGH SLEEP QUALITY

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by

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CHAPTER I.

ABSTRACT

The present study examined the effects of sleep quality and acute coffee consumption on sustained attention. Seventy-five college students participated in the 2x2 mixed design experiment, with beverage type (8 ounces water vs. coffee) as the within subjects factor, and sleep quality (high vs. low sleep quality, assessed by the Pittsburgh Sleep Quality Index) as the between subjects factor. Participants completed a continuous performance test to assess sustained attention and vigilance performance on two separate days after consuming coffee or water, in a counterbalanced design. Statistical analysis revealed no main effect of sleep quality on sustained attention. In contrast, there was a main effect of beverage condition on sustained attention, with fewer errors of commission following coffee consumption compared to water. There was no interaction between sleep quality and beverage condition on sustained attention. Although results failed to demonstrate an interaction between sleep and caffeine, findings support prior work demonstrating that caffeine is a central nervous system stimulant that has a positive effect on sustained attention. Furthermore, the positive effects of coffee on sustained attention appear to occur regardless of an individual's quality of sleep.

Keywords: sleep quality, caffeine, coffee, sustained attention.
CHAPTER II.
INTRODUCTION

*Health Significance of Sleep*

Sleep is important for many aspects of human functioning. Extensive research literature documents the restorative powers of sleep, as well as its psychological importance (Hardin, 2009; Kamdar, Needham, & Collop, 2012). Proper sleep (i.e. approximately 8 hours in a 24 hour cycle) is correlated with better school performance (Kelly, Kelly, & Clanton, 2001), normative emotional functioning (Vandekerckhove & Cluydts, 2010), advantageous health conditions (Wong et al. 2013), and is indirectly linked (through more positive mood states) to improved self-esteem (Wong et al. 2013). Notably, better sleep is also linked to an increased ability to pay attention (Doran, Van Dongen, & Dinges, 2001).

Given the many important functions of sleep, it is not surprising that sleep deprivation accidents cost over 43 billion dollars annually (Hossain & Shapiro, 2002). Other expenses, such as work productivity or psychological losses, are harder to quantify, costing more than just capital. For example, students and adolescents who do not obtain the proper amount of sleep are vulnerable to problems including poor academic performance (Aronen, Paavonen, Fjallberg, Soininen, & Torronen, 2000; Dahl & Lewin, 2002; Kahn et al., 1989), emotional and behavioral problems (Chervin, Dillon, Archibold & Ruzika, 2003; Gregory & O’Connor, 2002), as well as daytime sleepiness.
(Levy, Gray-Donald, Leech, Zvagulis, & Pless, 1986). In addition to shortened sleep, irregular sleep patterns may also be detrimental, as correlational research shows that students who have slept longer and later on weekends compared to during the school week, demonstrate psychomotor slowing and concentration issues (Taub & Berger, 1974). These results align with findings from similar studies (Breslau, Roth, Rosenthal, & Andreski, 1997; Taub & Berger, 1974; Van Dongen, Maislin, Mullington, & Dinges, 2003), indicating that excessive sleep, shortage of sleep, and disruption of regular circadian rhythms all have detrimental effects on sleep quality.

**Measurement of Sleep Adequacy**

Adequacy of sleep is commonly assessed using measures of “sleep quality,” which combine several aspects of sleep, including duration, latency (or the amount of time it takes one to fall asleep), and subjective experience, such as depth and restfulness of sleep (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). These items are then quantified to produce a global score, which is used to determine the effectiveness of one’s sleep. Subjects who report poor subjective sleep quality (such as depth of sleep) show poorer restorative sleep, measured by short wave sleep cycles (Keklund, & Åkersted, 1997). Similarly, poor sleep duration, another aspect of sleep quality, is correlated with several health factors, including obesity and mortality (Kripke, Garfinkel, Wingard, Klauber, & Marler, 2002; Taheri, Lin, Austin, Young, & Mignot, 2004).

While objective and subjective sleep measurements are both valid indicators of healthy and abnormal sleep, objective measures such as documentation of circadian
rhythms often need to be assessed over a longer period of time in order for differences to appear (Lockley, Skene, & Arendt, 1999). Other objective methods commonly employed in sleep assessment are unable to distinguish between nighttime restlessness and nighttime waking (e.g., actigraphy; Lockley, Skene, & Arendt, 1999), making it difficult to assess global sleep quality, or are cost-prohibitive (e.g., polysomnography). However, subjective methods can assess sleep over a much longer time period, in an inexpensive and retrospective manner. While subjective measures such as questionnaires may be subject to self-report bias, participants are generally accurate in comparison to objective measures of sleep (Lockley, Skene, & Arendt, 1999).

Sleep and Attention

In addition to the increased risk for poor restorative sleep and disturbed sleep, reduced sleep quality has a detrimental cognitive impact. The negative effects on cognition and academic performance can be observed after just one night of inadequate sleep (Bishop, Roehrs, Rosenthal, & Roth, 1997; Carskadon & Dement, 1979; Drake et. al, 2001; Wright, Badia, Myers, & Plenzler, 1997). Low sleep quality is correlated with detrimental effects on attention, whereas high sleep quality has been shown to have facilitating cognitive effects (Kjellberg, 1977; Martella, Marotta, Fuentes, & Casagrande, 2013). These findings strengthen the link between sleep quality and academic performance, suggesting that attention is highly susceptible to poor sleep, as well as other aspects of sleep quality such as sleep latency (Drake et. al, 2001).
Sleep deficits can occur over short periods of time or long periods of time, and both produce detrimental effects on attention, demonstrated by Van Dongen and colleagues in their 2003 study. Using a between subjects design, participants were placed in a total sleep reduction condition (88 hours without sleep) or in one of three chronic sleep restriction conditions of 4, 6, or 8 hours (over 14 days). To assess cognitive functioning, participants were given a psychomotor vigilance task every 2 hours. The psychomotor vigilance task is a widely used measure of sustained attention, and has been shown to be especially perceptive to the effects of sleep deprivation (Lim, & Dinges, 2008). Subjects who were chronically sleep deprived displayed negative dose-related effects, which appeared with increasing intensity as sleep was reduced, and was linked to poorer performance on the vigilance task (Van Dongen et al., 2003). Similar effects occurred after 88 hours of total sleep elimination, and in both conditions these effects occurred at all points throughout the day. The authors also examined attentional "lapses" in which the subject failed to respond in a timely manner (i.e. 500 ms), interrupting sustained attention. Williams, Lubin, & Goodnow, (1959) showed that such lapses are caused by “microsleeps” and slow eyelid closures (as cited by Lim & Dinges, 2008), in which the subject briefly falls into stage I or stage II of sleep (Lim & Dinges, 2008). Van Dongen and colleagues (2003) found that after 14 days of sleep restricted to 4 hours per night, participants experienced the same number of lapses as those who had had no sleep for 2 nights. While the negative effects on sustained attention, such as lapses, occurred most frequently after total sleep reduction, they occurred just as frequently in chronic sleep restriction after some time. Based on this study's findings, the authors concluded
that chronic sleep restriction can elicit similar attentional impairments to those seen following 2 days of total sleep elimination (Van Dongen et. al, 2003).

Adequate and consistent sleep helps to restore the body physically and mentally (Wong et al. 2013), and students who obtain proper and consistent sleep perform better academically, and are subjectively happier as well (Kelly, Kelly, & Clanton, 2001; Vandekerckhove & Cluydts, 2010). Research also clearly suggests that low sleep quality is detrimental to attention (Vriend et. al., 2012), and these effects grow with each consecutive day of sleep deprivation and low sleep quality (Van Dongen et. al, 2003). However, poor sleep is very common as 35% of adults report obtain less than 7 hours of sleep per night (CDC, 2009). Given the prevalence of poor sleep, and the physical, emotional, and cognitive effects of reduced sleep, many individuals with low sleep quality may compensate these effects with the use of a stimulant, such as caffeine.

The Physiology of Caffeine

Caffeine, a drug that affects the central nervous system, is directly linked to acceleration of the cardiovascular system (Pelligrino, Xu, Vetri, 2010; Smit & Rogers, 2000; Yoto, Motoki, Murao, Yokogoshi, 2012) and, by proxy, subjective feelings of alertness. This effect is due in part to caffeine’s effect on adenosine receptors, which affect blood flow and oxygen consumption (Haskó & Pacher, 2008). Another important role that adenosine receptors play is in the regulation of the neurotransmitters dopamine and glutamate (Fuxe, Ferré, Genedani, Franco, & Agnati, 2007; Schiffmann, Fisone, Moresco, Cunha, & Ferré, 2007). Through the antagonistic and agonistic effects of these
neurotransmitters, caffeine affects motor performance and increases wakefulness (Heatherley, Hayward, Seers, & Rogers, 2005; James, 2004; Rogers et al., 2010; Rogers et al., 2012; Warren et al., 2010).

Caffeine is consumed extensively throughout the world in many different forms, including beverages such as coffee, tea, soda, and energy drinks, as well as chocolate and other foods (Fredholm, Bättig, Holmén, Nehlig & Zvartau, 1999). In the United States and Canada, the average person consumes from 210 to 238 milligrams of caffeine daily, and 143 to 180 milligrams comes from coffee alone (Fredholm et al., 1999). These results suggest that the average person is a chronic caffeine user and may experience tolerance effects (Rogers et al., 2012). Such findings demonstrate the need to distinguish between acute and chronic caffeine use, as it is difficult to quantify the alerting and invigorating effects of caffeine under conditions of withdrawal.

**Effects of Caffeine on the Body and Brain**

An extensive set of literature describes the effects of caffeine on the human body, from mood states, to motor movements, to cognitive functioning. These effects are produced by a wide variety of caffeine doses (Smith, 2002), which yield varied results on the body and brain. Even when using similar caffeine doses, no standard results have been formed, due in part to variation in participants or methods (Lieberman, Wurtman, Emde, Roberts, & Coviella, 1987). While some research examining cognitive effects of caffeine has prescreened participants for caffeine use, few studies attempt to exclude participants who regularly use caffeine. It is therefore difficult to discern what
phenomena are actually being studied: the effect of caffeine ingestion on cognitive performance or the suppression of cognitive performance by caffeine withdrawal. A myriad of factors (e.g., dose, frequency, and tolerance) affect an individual’s cognitive response to caffeine (Nehlig, 1999).

Past research examining both habitual and non to low users of caffeine has yielded a new model, the withdrawal reversal hypothesis (Rogers, Martin, Smith, Heatherley, & Smit, 2003). This hypothesis states that caffeine consumption has no net benefit on objective and subjective measures of cognition in habitual users, and conversely that caffeine withdrawal leads to lowered objective cognitive performance and subjective experience of cognitive ability (Rogers et al., 2005). These effects are postulated to occur because habitual caffeine users are in a constant cycle of withdrawal and consumption, and consuming caffeine only serves to alleviate withdrawal symptoms (Rogers et al., 2003). Non-users of caffeine, however, will experience positive effects of caffeine consumption, as they are not under the effect of withdrawal symptoms. This theory suggests that effects of caffeine are best studied under acute intake conditions, differentiating between habitual versus infrequent or non-caffeine users.

To examine the withdrawal alleviation model in the context of attentional performance, Haskell and colleagues (2005) compared 24 young adult habitual consumers of caffeine (more than 50 mgs of caffeine daily) and non-consumers (less than 50 mgs of caffeine daily). Participants were asked to refrain from caffeine consumption 24 hours prior to their appointments and each appointment was 48 hours apart to provide a washout period for the caffeine consumption. All participants receive 0 mgs, 75 mgs, or
150 mgs of caffeine during three separate sessions, counterbalanced using a Latin Squares design, and were put through various cognitive tests during each session. Cognitive tests included simple reaction time, vigilance reaction time, working memory, and rapid visual information processing task and were completed 30 minutes after caffeine ingestion. No baseline differences were observed between non-users and users. After caffeine ingestion, simple and vigilance reaction time, performance on the working memory task, and the rapid visual information task all improved in users and non-users. This provides evidence against the withdrawal alleviation hypothesis, that caffeine does have cognitive benefits in not only non-users, but caffeine-withdrawn users as well.

To demonstrate the severity of withdrawal symptoms, Rogers and colleagues (2005) conditioned a group of habitual caffeine users on caffeine or a placebo for three weeks. In a counter balanced design, half of each group was given caffeine or a placebo prior to testing. Those who had been conditioned on caffeine and received a placebo, experienced typical withdrawal symptoms (i.e. headache, reduced alertness, perception of tasks as harder etc.), and performed significantly slower on the simple reaction time task as well as the other cognitive tests. Participants who had not consumed caffeine for three weeks not only outperformed their withdrawn counterparts, but also experienced more positive mood states and perceived the tasks as easier. In addition, the immediate effects of caffeine failed to boost performance of the participants who had been conditioned on caffeine for three weeks and were free from overnight withdrawal effects. These results demonstrate the detrimental effects of caffeine withdrawal, and in contrast to the work of Haskell and colleagues (2005), support the claim that caffeine does not improve cognitive
performance in typical users of caffeine, except to alleviate withdrawal. Given the
different findings from these studies, questions remain regarding caffeine and cognitive
performance in the context of the caffeine alleviation hypothesis.

While a great deal of work has examined the immediate effects of caffeine on
people who typically use caffeine, there is less work addressing the effects of caffeine on
non-users. However, the available research suggests that caffeine likely benefits cognitive
performance when administered to non-users. For example, Childs and de Wit (2006)
conducted a study to examine the effects of caffeine consumption in non-caffeine users.
They found that after several different doses of caffeine, non-users (defined as using less
than 300 mgs per day) showed an increase in subjective feelings of cognitive arousal as
well as a boost in attention performance (Childs & de Wit, 2006). This work underlies the
importance of differentiating between regular users of caffeine and non-users when
conducting research on caffeine's immediate effects. Although it remains uncertain if
regular users truly benefit from caffeine or instead simply experience alleviation of
withdrawal symptoms, it is clear that it is of great methodological importance to consider
a subject's routine caffeine use in this type of work.

Sleep Quality, Caffeine, and Attention

Few studies have examined the relationship between sleep quality, caffeine, and
attention performance. Those that do reveal methodological limitations, most notably
failure to control for prior caffeine use or experimental manipulation of participant sleep
that prevents understanding of the natural effects of low sleep quality. For example,
Lieberman and colleagues (2002) looked at the effects of caffeine on sleep-deprived Navy SEALs. At the beginning of the week, participants were sleep deprived for 72 hours with only a 90-minute nap during the 72 hours. After having abstained from caffeine for three days (in effort to mitigate effects of caffeine withdrawal), the participants were given caffeine in one of three doses. Participants took a visual vigilance test and visual reaction time test at a pre-caffeine baseline, as well as one hour and eight hours after consuming caffeine. The sleep deprivation condition was effective in diminishing cognitive performance. Moreover, after consuming caffeine, performance significantly increased in the vigilance and reaction time task as well as more complex tests of memory and cognition (Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002). These results show that caffeine can indeed improve cognition in situations for which cognition has been degraded by sleep loss. However, one limitation of this study is the unnatural manipulation of sleep (i.e., nearly total sleep deprivation for 72 hours does not reflect ecologically valid sleep quality reduction; Taub & Berger, 1974). The researchers also did not collect information regarding subjects’ prior caffeine use, which could have significantly impacted results. Furthermore, the effectiveness of the 3-day caffeine “wash-out” period is not fully clear, as caffeine withdrawal averages between two and three days, but may occur for up to six days in some individuals (Van Dusseldorp & Katan, 1990). In addition, the study was conducted under very stressful Navy SEAL training conditions, which could have confounded results.

Lorist, Snel, Kok, and Mulder (1994) examined the interaction between caffeine consumption, sleep deprivation, and attention in a more naturalistic way. In their study,
all subjects were regular users of caffeine, and were asked to abstain from caffeine consumption 12 hours prior to their session. Subjects in the sleep-deprived condition arrived at 10:30 p.m. and were kept awake until 3 a.m., at which time they were given 200 mgs of caffeine. In contrast, subjects in the well-rested condition arrived at 8:30 a.m. the next day, at which time they were given 200 mgs of caffeine. Ninety minutes following the initial caffeine dose, subjects were given a second dose of caffeine (50 mgs) and cognitive testing began. Both groups were given a memory load task (i.e. a task design to test working memory and the amount of information that can be processed and made sense of), with a high and low condition. Participants in the well-rested condition performed significantly better on both the high and low memory load than the sleep deprived participants. This study provides a more natural look into sleep disturbance and its interaction with cognitive performance, as participants in the optimal condition obtained a normal night’s sleep whereas the experimental group was sleep deprived and tested during their normal sleep period. The results strengthen the idea that caffeine improves performance regardless of the state the subject is in (Doran et al., 2001; Patat et al., 2000). Unfortunately, as several studies have shown, the 12 hour washout period would not be enough time for full caffeine withdrawal to take place, and some participants may have been experiencing caffeine withdrawal when they underwent testing. As such, this study does not clearly address the acute cognitive effects of caffeine consumption, or shed light on its effects on cognition in the context of natural observation of sleep quality.
Current Study

The present study examines the effects of sleep quality and coffee ingestion on cognition, specifically attention. Other studies that have examined these variables have looked at only experimental sleep deprivation, in which patients were purposefully sleep deprived. To measure sleep in a more naturalistic manner, we assess individuals current sleep habits, rather than examining experimental sleep deprivation. In an effort to avoid confounding effects of chronic caffeine use (i.e., tolerance and withdrawal), we examined only low to non-users of caffeine. Further, to enhance the ecological validity of our work, 100 mg of caffeine was administered via 8 ounces of black coffee.

Our study aimed to determine if attention performance differs in individuals with high versus low sleep quality; we expected participants with higher sleep quality to demonstrate better attention performance than those with lower sleep quality. We also sought to determine the effects of coffee intake on attention performance; we expected that attention performance would be better following 100 mg caffeine (coffee) relative to a water control condition. A final exploratory aim was to determine if there was an interaction effect on cognitive performance between beverage conditions and sleep quality; no specific hypothesis was made in this regard, as there is insufficient prior work on which to base a hypothesis. The results of this study will help to better understand the effects of low sleep quality on sustained attention and vigilance, will help determine if use of coffee can improve attention performance, and will examine if the potentially negative effects of low sleep quality on attention can be ameliorated through drinking coffee.
CHAPTER III.

METHODS

Participants

The study utilized a 2x2 mixed factorial design (within factor: 8 ounces coffee versus water; between factor: low versus high sleep quality). A total of 75 college students (Average age = 21.19, 57.3% female) were recruited by ads placed on the Kent State University campus. Participants were screened by telephone to exclude those with self-reported history of or current: diabetes, lactose intolerance, neurological disorder and/or injury, head injury (i.e., loss of consciousness exceeding 10 minutes), psychiatric disorder, drug and/or alcohol dependence, learning disorder, or impaired sensory function, that would preclude cognitive testing. Participants were also screened for prior caffeine use, and excluded if they consumed more than 100 mgs of caffeine on a daily basis.

Measures

The Pittsburg Sleep Quality Index (PSQI) (Buysse et al., 1989) is a self-report questionnaire designed to assess sleep quality. Based upon clinical data, a global score above 5 indicates poor sleep (Buysse et al., 1989). The PSQI has been demonstrated a valid and reliable measure in healthy and abnormal populations (Buysse et al., 1989). Our study used a modified 9 question computer-based version of this index, which excluded questions that were answered by a roommate. This version produces a global score on a
scale of 0-21 points. The established cut-off for "poor sleep" (i.e., a score above 5) was used to create "low" and "high" sleep quality groups.

The Food Frequency Questionnaire (FFQ) (Block, Woods, Potosky, & Clifford, 1990) was used to assess participants’ diets over the last year. This 110 question survey takes approximately 35 minutes to complete, and asks participants to identify how frequently they eat certain food groups and take vitamin supplements. Dietary information for this questionnaire was obtained from the National Health and Nutrition Examination Survey 1999-2002 dietary recall data and from the USDA Food and Nutrient Database for Dietary Studies, version 1.0 (Block, 2005). We used this measure to examine participants' self-reported caffeine intake. Given prior research demonstrating withdrawal effects may occur in individuals consuming as little as 100 mgs of daily caffeine (Evans and Griffiths, 1999), we chose to exclude those who consumed 100 mgs or more per day.

The Standard Continuous Performance Test (SCPT) from the Automated Neuropsychological Assessment Battery (ANAM) was used to assess vigilance and sustained attention. The ANAM is a computerized battery with a number of neuropsychological tests to assess mental abilities. All tests in the ANAM battery utilize alternate forms to minimize practice effects (Short, Cernich, Wilken, & Kane, 2007), and also begin with practice sessions, which further reduce practice effects (Beglinger et. al., 2005). The Standard Continuous Performance Task requires that participants attend to a computer screen, which displays upper case letters (A-Z). Participants are asked to only respond when the target letter (“B”) is presented. The full task (with practice tests) takes
6-7 minutes to complete. The ANAM battery has been shown to have a high validity in a large group of populations, including healthy and abnormal patients (Brunner et. al., 2007; Short et al., 2007). The dependent variables used in the current study included reaction time, commission errors, and omission errors, as all three are susceptible to both sleep deprivation (Lim, & Dinges, 2008) and the effects of caffeine (Haskell et al., 2005; Rogers et al., 2003; Smit & Rogers 2000).

Procedure

The Kent State Internal Review Board (IRB) approved all procedures and participants provided signed informed consent before participation. Participants in the current study were all enrolled in a larger study examining the effects of glucose on several cognitive measures. Participants were asked to get a good night’s sleep and to abstain from exercise and alcohol use 24 hours prior to their sessions. Participants came into the lab on two separate occasions, having also abstained from food and liquid (excluding water) for eight hours prior to their session. At the beginning of the first session, participants drank 8 ounces of either coffee (100 mgs caffeine) or water, which was counterbalanced to prevent order effects. All participants were asked to drink the beverage within 10 minutes. Participants then completed self-report measures. The SCPT was administered 30 minutes after the participant completely finished drinking the designated beverage, as it takes 30-45 minutes for caffeine to reach peak blood levels (Juliano & Griffiths, 2004). Any self-report measures or items not completed prior to the
SCPT testing were completed after its conclusion. Procedures at the second session were the same as the first, using the beverage not consumed during the initial session.

Analysis Plan

To examine for possible main effects of sleep quality on the 3 attention variables, an analysis of variance was conducted. Omission errors, commission errors, and reaction time from the SCPT were the dependent variables, while the independent variable was sleep quality (high versus low). To examine for possible main effects of beverage condition on the attention variables, a repeated measures t-test was conducted for the water and coffee conditions. The dependent variables were again omission errors, commission errors, and reaction time, while the independent variable was beverage type (water and coffee conditions). To examine for a possible interaction of beverage type and sleep quality on the attention variables, a 2x2 mixed multivariate analysis of variance was conducted. Omission errors, commission errors, and reaction time from the SCPT were the dependent variables. The independent variables were: 1) high sleep quality versus low sleep quality (between factor) and 2) caffeine versus water (within/repeated factor). Significant findings at the omnibus level were clarified with univariate analysis of variance with correction for multiple comparisons.
CHAPTER IV.

RESULTS

Descriptive Statistics

In the current study, 57.3% of participants were female, with an average age of 21.19. Racial make-up was 64.1% Caucasian, 1.3% Hispanic/Latino, 2.6% Asian American, 24.4% African American, and 3.8% other. Sixty-four percent of the participants demonstrated low sleep quality (i.e. global scores of 5 and above). It should be noted that our low sleep quality group was significantly larger than our high sleep quality group ($X^2 (1, N = 74) = 5.88, p = 0.02$).

Aim I: Testing Main Effects of Sleep Quality on Sustained Attention

To determine the effect of sleep quality on attention, a one-way analysis of variance was conducted. Participants with high sleep quality and low sleep quality did not significantly differ on performance for SCPT reaction time ($F(1,73) = 2.537, p = .116$), SCPT omission errors ($F(1,73) = .403, p = .527$), or SCPT commission errors ($F(1,73) = 1.108, p = .296$). These results indicate there is no difference between individuals demonstrating high versus low sleep quality on attention performance. Results do not support our hypothesis that those with high sleep quality would outperform those with low sleep quality on these measures.

Aim II: Testing Main Effects of Beverage Condition on Sustained Attention

A series of repeated measures t-tests were used to compare attention performance between the two beverage conditions (see Table 1). When comparing the two conditions
SCPT reaction time ($t(74)=1.420, p = .160$), and SCPT omission errors ($t(74)=1.068, p = .289$) the two groups did not significantly differ. However, a repeated measures t-test comparing the coffee condition and the water condition on SCPT commission errors did reveal significant results ($t(74)=2.338, p = .022$), with fewer commission errors made following coffee compared to water. These results partially supported our hypothesis that attention performance on the SCPT would improve after drinking coffee compared to water.

*Secondary Aim: Testing for Interaction Effects of Sleep Quality and Beverage Condition on Sustained Attention*

To examine the interaction between sleep quality and beverage condition on the three attention variables, a 2x2 mixed multivariate analysis of variance was conducted. Comparison of high versus low sleep quality groups revealed no differences between beverage conditions on any of the three variables. Specifically, when SCPT omission errors were examined, no significant results were found between the water condition and the coffee condition $F(1,73)=0.23, p = 0.63$. When SCPT commission errors were examined, no significant results were found between the water condition and the coffee condition $F(1,73)=3.06, p = 0.08$. Finally, when SCPT reaction time was examined, no significant results were found between the water condition and the coffee condition $F(1,73)=0.99, p = 0.32$. 
CHAPTER V.
DISCUSSION

Caffeine is a widely used CNS stimulant that is used to combat the effects of fatigue and sleep deprivation (Heatherley et al. 2005; James, 2004; Rogers et al. 2010; Rogers et al., 2012; Warren et al., 2010), but the interactive effects of caffeine and sleep quality have previously been infrequently examined. The present study investigated the effects of drinking coffee in individuals who do not regularly use caffeine, examining for differences in sustained attention between individuals with high sleep quality versus those with low sleep quality. No main effect of sleep quality was found, as individuals with low sleep quality did not differ significantly from those with high sleep quality on any of the measures of sustained attention. In contrast, a main effect was found for coffee, such that drinking coffee yielded fewer commission errors compared to water on the sustained attention test, though other variables were not significantly different. Finally, no significant interaction of sleep quality and beverage type was found.

To test our first hypothesis that individuals with high sleep quality would demonstrate better performance than those with low sleep quality, we compared sustained attention performance in participants who reported low sleep quality to those who reported high sleep quality. We found no significant differences in reaction time, omission errors, or commission errors on the SCPT. These results are not congruent with other studies that have examined the effect on sustained attention after sleep deficits (Doran et al., 2001). This could be due to a variety of factors. For instance, our low sleep
quality group was significantly larger than the high sleep quality group. With a greater number of individuals with high sleep quality, we may have had greater power to detect a difference. It is also possible that our method of identifying sleep quality was not optimal. To determine sleep quality in participants, the PSQI was used, as it has been demonstrated a reliable and valid measure of sleep quality (Buysse et al., 1989). We chose to measure sleep quality in this way, as it allowed for assessment of sleep quality in a natural environment, rather than inducing sleep deprivation as previous studies have done. However, even though this measure has been demonstrated a good method for approximating sleep quality, it is possible that participants are not fully aware of their sleep problems, or are otherwise inaccurate in reporting sleep difficulties (Furnham, & Henderson, 1983). Future research studies may alleviate such issues by using sleep journals or collecting more objective sleep data, possibly by making use of actigraphs (Ancoli-Israel et. al., 2003).

Our second hypothesis, that coffee consumption would improve sustained attention performance, was partially supported when comparing SCPT performance in coffee and water conditions. Coffee appeared to decrease the number of commission errors that participants made, without increasing reaction time or decreasing omission errors. This means that during the coffee condition, participants were able to more effectively inhibit false positive responses errors than during the water condition. These results are highly consistent with other studies of caffeine and sustained attention (Childs & de Wit, 2006; Haskell et al., 2005), and our results provide further evidence that inhibitory control in non-users of caffeine may be more effective after drinking coffee.
However, not all sustained attention variables improved following coffee compared to water, specifically reaction time and omission errors. Although the reason for inconsistency across variables is not entirely clear, it is important to note that while these variables are all part of one larger subtest of sustained attention, they reflect very different aspects of sustained attention. While making fewer commission errors demonstrates better control of impulsivity, the combination of reaction time and omission errors remaining similar suggests that information processing ability and speed did not change. Given that these variables represent different cognitive functions, it is not completely unexpected that they would react differently in response to coffee. In addition, it is possible that a different amount of caffeine would yield different effects. The current study utilized an ecologically valid dose of caffeine (i.e., 8 ounces of coffee; 100 mgs caffeine), but it is possible that a larger amount of caffeine would induce cognitive improvement across SCPT variables.

Finally, in examining for possible interaction of sleep quality and beverage type on sustained attention, we found no significant effects. This lack of interaction means that sleep quality did not affect attention performance differently in the coffee and water conditions. Some of the same methodological limitations noted above could account for the lack of interaction, specifically, it is possible that a larger sample is needed to detect effects, or that a single cup of coffee is simply not adequate to counteract the effects of low sleep quality (Gottselig et. al., 2006). Future directions should include larger sample sizes as well as administration of caffeine or coffee at varying doses to examine if increasing the amount of caffeine is better at mitigating the effects of low sleep quality.
would also be interesting to compare individuals with high sleep quality, low sleep quality, and experimentally induced sleep-deprivation in performance on measures of sustained attention. Perhaps caffeine is only effective after sleep deprivation, as opposed to “normal” low sleep quality, which an individual may adjusted to over time, if sleep quality is chronically low. Aeschbach and colleagues (2001) demonstrated that individuals with habitual short sleep (i.e. 6 hours or less) experience higher sleep pressure (the processes which allow an individual to fall asleep) than habitual long sleepers (i.e. 7 hours or more). This means that an individual who is experiencing sleep deprivation would be more likely to fall asleep during testing than their well-rested counterparts, which could contribute to "microsleep" attention lapses, as observed in prior work by Williams, Lubin, & Goodnow (1959), (as cited by Lim & Dinges, 2008). Thus, individuals with just poor sleep quality (rather than true sleep deprivation) may not show the same intensity of effects on attention as those who have been sleep deprived.

As previously alluded to, one limitation of the current study was the significant difference in sample size between our low sleep quality group and our high sleep quality group. Because our high sleep group quality was significantly smaller than our low sleep quality group, this could have hidden effects between the two groups on our measure of sustained attention. Another limitation was that a single dose of coffee was used, and the participants could not be blinded to this condition. Although the goal of our study was to examine an ecologically valid caffeine dose and delivery (i.e., a cup of coffee), to more purely examine the effects of caffeine on sustained attention, it would have been beneficial to compare several different doses of caffeine to a placebo condition, to
determine to if more or less caffeine would exaggerate effects on sustained attention, and to do so in a blinded manner, so that participants would not know if they were consuming a beverage with or without caffeine.

The results of the present study provide more detail about the effects of caffeine and sleep on attention, and are the first to examine the attention effects of drinking coffee in individuals with high and low sleep quality. Studying the effects of coffee in a sample of caffeine non-users is a relatively new idea in the field, as was the examination of participants by chronic natural sleep patterns, rather than experimentally induced sleep deprivation. The results of the study suggest that coffee does improve aspects of attention in non-users of caffeine, however sleep quality did not further explain this relationship. Our results suggest that a cup of coffee yields partial improvement in sustained attention in a sample of healthy college students, regardless of their sleep quality.
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<table>
<thead>
<tr>
<th></th>
<th><strong>High Sleep Quality</strong></th>
<th><strong>Low Sleep Quality</strong></th>
<th><strong>Total</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(N = 27)</td>
<td>(N = 48)</td>
<td>(N = 75)</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPT Reaction Time</td>
<td>459.52 (54.41)</td>
<td>478.56 (46.90)</td>
<td>471.71 (50.22)</td>
</tr>
<tr>
<td>CPT Omission Errors</td>
<td>0.26 (0.59)</td>
<td>0.35 (0.64)</td>
<td>0.32 (0.62)</td>
</tr>
<tr>
<td>CPT Commission Errors</td>
<td>0.44 (0.75)</td>
<td>0.29 (0.50)</td>
<td>0.35 (0.60)</td>
</tr>
<tr>
<td><strong>Coffee</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPT Reaction Time</td>
<td>444.48 (48.86)</td>
<td>474.88 (58.00)</td>
<td>463.93 (56.49)</td>
</tr>
<tr>
<td>CPT Omission Errors</td>
<td>0.22 (0.51)</td>
<td>0.23 (0.47)</td>
<td>0.23 (0.48)</td>
</tr>
<tr>
<td>CPT Commission Errors</td>
<td>0.07 (0.27)</td>
<td>0.21 (0.50)</td>
<td>0.16 (0.44)</td>
</tr>
</tbody>
</table>

*Note: p < 0.05*