THE ACUTE EFFECTS OF CAFFEINE ON PSYCHOMOTOR SPEED, REACTION TIME, MEMORY, AND EXECUTIVE FUNCTIONING

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This project is dedicated to my father, Michael West.

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ABSTRACT

THE ACUTE EFFECTS OF CAFFEINE ON PSYCHOMOTOR SPEED, REACTION TIME, MEMORY, AND EXECUTIVE FUNCTIONING

by Adrienne L. West

Caffeine is the most widely consumed drug in the world, as it is present in regularly consumed beverages and foods such as coffee, tea, and cocoa. Past research has suggested that caffeine may improve general levels of performance in some cognitive domains, although there have been few well controlled studies that have examined performance across an array of performance measures. Most research regarding the impact of caffeine on cognitive functioning has been limited to performance on specific aspects of attention, vigilance, and motor skills, whereas little is known about the impact on memory and executive functioning. The current study will investigate the effects of caffeine ingestion on a battery of cognitive tasks, including memory and executive functioning measures. Fifty five (N = 55) participated in the present study, which utilized a double-blind treatment administration procedure. Using a repeated-measures within-group design, participants completed a neurocognitive battery on three separate occasions to determine whether there were differences on psychomotor, memory, and executive functioning following varying doses of caffeine (100 mg or 300 mg) or placebo (0 mg). Subjective effects of the dose were assessed with self-report questionnaires. It was hypothesized that participants would demonstrate improved performance on the battery following caffeine doses relative to placebo. Varying caffeine doses did not result robust differences across testing sessions, and there were not consistent differences in reaction time, memory, or psychomotor speed. However, significant differences were observed for visual memory and risk-taking tasks. These results disconfirm previous research suggesting a more robust impact of caffeine on

cognitive functioning, and lend support to the notion that caffeine intake will not alter performance on cognitive measures in an assessment situation. Furthermore, these findings demonstrate the necessity for well-controlled measures in future studies to clarify the absolute effects of caffeine on cognitive functioning.

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CHAPTER I

INTRODUCTION

Psychopharmacological Response to Caffeine

Caffeine is a naturally occurring plant alkaloid in a family of xanthines which is present in coffee, tea, and cocoa (Nehlig, 2007). It is the most widely consumed drug in the world and the principle pharmacological source of arousal, alertness, and wakefulness for millions of people (Smith, Osborne, Mann, Jones, & White, 2004). The popularity of this substance has prompted research in regarding its impact on daily functioning, which has generally demonstrated improvements in attention, vigilance, and motor skills following caffeine administrations. However, the mixed research in this area has been hard to reconcile, as there have been few well controlled studies that have examined performance across an array of performance measures.

Pharmacokinetics of Caffeine

Caffeine is rapidly absorbed from the digestive tract, reaching peak absorption though the gastrointestinal tract between 40 and 70 minutes after ingestion (Mumford et al., 1995). The duration of effects can vary, as caffeine typically has a half-life of three to seven hours, although this can vary in women using oral contraceptives or who are in late-stage pregnancy (Nehlig, 2007).

The mechanism in the brain by which caffeine works is not yet fully understood, although advancing research tools have permitted investigators to further study the chemical and its effects (Myers, Johnson, & McVey, 1999). There have been several biochemical mechanisms of caffeine described: the direct release of intracellular calcium has been suggested as one

mechanism, although this only occurs at millimolar concentrations. The inhibition of cyclic nucleotide phosphodiesterases has also been proposed, but this requires high concentrations in the micromolar to millimolar range, as well, and this cannot be attained during normal caffeine consumption (Fredholm, Battig, Holmen, Nehlig, & Zvartau, 1999). Currently, the antagonism of the adenosine receptors is the most widely accepted mechanism of action, as it is the only mechanism that is significantly affected at normal doses of human caffeine consumption (Nehlig, 2007).

Adenosine, a by-product of ATP metabolism and an important regulator of sleep, works on four main types of receptors: A1, A2a, A2b, and A3 (Fredholm et al., 1999). The A2b receptor is found in low levels throughout the brain and on blood vessels, but is thought to only be activated by pathologically high concentrations of adenosine (Fredholm et al., 1999). In humans and rats, the levels of the A3 receptors are low and are little affected by methylxanthines such as caffeine. Because of this, A1 and A2a are the most relevant in the study of caffeine.

The A1 and the A2A receptors are coupled to G-proteins. Specifically, the A1 receptor is coupled to the pertussis toxin-sensitive G-proteins G_{i-1}, G_{i-2}, G_{i-3}, G_{o1}, and G_{o2}. Activation of A1 receptors leads to inhibition of adenylyl cyclase and some voltage-sensitive Ca+ channels, as well as activation of K+ channels, phospholipase C, and phospholipase D. Activation of A1 receptors causes a large variety of cellular effects, ultimately by hyperpolarizing the neuron and reducing its firing rate (Greene & Haas, 1991; Nehlig, 2007). In contrast, A2a receptors are associated with G_s proteins, and activation will induce activation of adenylyl cyclase and L-type Ca2+ channels (Fredholm, 1999).

The adenosine receptors have different regional distributions in the brain. The A1 receptors are present throughout the brain, with highest levels in the hippocampus and lower

levels in the caudate nucleus, putamen and nucleus accumbens (Nehlig, 2007). Adenosine A1 receptors are colocalized with dopamine D1 in neurons of the striatum that contain GABA, substance P, and dynorphin, and project directly to the substantia nigra (Ferre, Fredholm, Morelli, Popoli, & Fuxe, 1997). Thus, adenosine blocks the stimulant effect of dopamine on behavior, thus decreasing locomotor activity, whereas *blockage* of adenosine A1 receptors increases the motor stimulation (Popoli et al., 1996).

Conversely, A2a receptors are mainly located in dopamine-rich regions and colocalized with dopamine D2 receptors, largely in the dorsal striatum, nucleus accumbens, globus pallidus, and olfactory tubercle (Nehlig, 2007). The A2a and D2 receptors interact, as the activation of A2a receptors decreases dopamine binding to D2 receptors. Adenosine also inhibits the release of other neurotransmitters, such as glutamate, GABA, acetylchonline, and monoamines, thus decreasing firing rate (Phillis & Edstrom, 1976). Caffeine, however, acts as a nonspecific antagonist of both A2 and A2a receptors at low concentrations, thus blocking adenosine and increasing dopaminergic transmission throughout the brain (Fredholm et al., 1999; Nehlig, 2007).

Health Concerns

The high incidence of caffeine use is significant because it is one of the most widely used psychoactive substances in the world, as it is found in many regularly-consumed foods and beverages, such as coffee, tea, soft drinks, energy drinks, chocolate, and many analgesics. An estimated 87% of the United States' adult population reports daily consumption, with 76% of US children reporting daily consumption. These figures are up from 82% of adults and 43% of children in 1977 (Frary, 2005). Daily mean intake for adults ranges from 2.4 to 4.0 mg/kg in North American countries and the United Kingdom, respectively, with slightly higher doses in

some European countries (Barone & Roberts, 1996). Although the most prevalent caffeine source in the United States remains coffee for adults, soft drinks are being consumed in increasing quantities and are the second leading source of caffeine in the United States (Frary, 2005). Coffee typically contains the largest amount of caffeine (65-110 mg per cup), while tea and soda carry an intermediate amount (40-60 mg per serving; Lieberman, 2003).

Caffeine has both acute and chronic effects on a wide range of health concerns. It works in the body by increasing physiological arousal, acting as a strong central nervous system and skeletal muscle stimulant. In addition, caffeine stimulates the cardiac muscle, increasing heart rate, and decreases cerebral blood flow in the cerebral cortex (Addicott et al., 2009; Nehlig 2007). At 300 milligrams, stimulation of the medulla, vagus, and vasomotor centers also occurs (Nehlig, 2007).

Caffeine intake increases plasma adenosine concentrations, and adenosine concentrations are lower than normal following withdrawal from chronic caffeine administration (Conley et al., 1997). This is because, in the normal caffeinated state, increased adenosine concentrations produce more competition with caffeine for receptor binding. Thus, the stimulant effects of caffeine could be diminished by repeated dosing in chronic users, and those who are withdrawn may be affected differently than those in a normal caffeinated state. For example, moderate levels of chronic caffeine use may reduce the effects of acute exposure to caffeine; however, high chronic levels can exacerbate the effects of acute exposure (Smith, 1994).

Caffeine Withdrawal

When discontinued, caffeine is reported to cause withdrawal symptoms in 11-22% of the population (Dews, O'Brien, & Bergman, 2002). Headaches, weakness, impaired concentration, fatigue, irritability, and withdrawal usually start 12 to 24 hours after caffeine cessation and reach

a peak 20 to 48 hours later (Nehlig, 2007). However, these symptoms are not generally present if caffeine consumption has been progressively decreased, suggesting that physical dependence is low compared to other drugs (i.e., cocaine, amphetamine, morphine, or nicotine; Griffiths & Mumford, 1996; Nehlig, 2007). Overall, there are no significant health risks are associated with moderate caffeine use, and although caffeine increases extracellular dopamine, caffeine is not considered to have addiction liability (Griffiths & Woodson, 1988).

The Effect of Caffeine on Subjective Experiences

At low doses, caffeine has a positive influence on mood. Some research has suggested that 20 to 200 mg causes individuals to feel "energetic, imaginative, efficient, self-confident, alert, able to concentrate, and motivated" (Nehlig, 2007, p. 50). At low to moderate doses (50 to 300 mg caffeine), caffeine ingestion results in mild subjective effects, such as increased self-rated feelings of well-being, calmness, alertness, energy, and ability to concentrate. Mumford and colleagues (1994) reported positive effects of single low doses of caffeine (56 mg) on measure of well being, alertness, and concentration. Smit and Rogers (2000) failed to demonstrate significant changes in mood following low does (12-50 mg), but were able to show changes in perceived levels of energetic arousal at slightly increased amounts (100 mg).

The influence of low doses of caffeine on mood correlates with the increase in cerebral functional activity in the locus coeruleus, serotoninergic median, and dorsal raphe nuclei, which are involved in the regulation of wakefulness, mood, and well-being (Nehlig & Boyet, 2000). Following caffeine absorption, serotonin is released in limbic areas and dopamine is released in the cortex. Thus, caffeine intake mimics the effects obtained through antidepressants (Acquas, Tanda, & Di Chiara, 2002; Casas, Ramos-Quiroga, Prat, & Qureshi, 2004).

High doses of caffeine (i.e., 400-800 mg) can result in short-term effects of anxiety, nervousness, jitteriness, and insomnia, particularly in those who do not routinely consume caffeine (Fredholm et al., 1999; Lieberman, Wurtman, Emde, & Coviella, 1987). Caffeine intake can also induce feelings of panic in those with or without panic disorder (Krystal, Deutsch, & Charney, 1996). These effects may result from the simultaneous block of adenosine A1 and A2a receptors (Jain, Kemp, Adeyemo, Buchanan, & Stone, 1995), although other mechanisms that block the antagonism of adenosine receptors have been proposed (i.e., via the noradrenergic system; Baldwin & File, 1989). Those who do not routinely consume caffeine are generally more sensitive to anxiogenic and psychostimulant effects (Nehlig, 2007).

While the effects of caffeine on anxiety have been found to be relatively consistent, the relationship between caffeine intake and depression remains more mixed. Caffeine influences sleep and sleep deprivation is a symptom of major depression, although it is not clear whether caffeine intake is related to depression. Because A2a and D2 receptors exert antagonistic effects in the ventral striatum, an antagonist such as caffeine may have antidepressant properties (Nehlig, 2007). It has been observed that caffeine reduces self-rated depression when administered in moderate doses (Lieberman et al., 2002).

The Diagnostic Statistic Manual (Fourth Edition; DSM-IV) currently recognizes Caffeine Intoxication, Caffeine- Induced Anxiety Disorder, and Caffeine-Induced Sleep Disorder, as well as recommends that more research be conducted on the validity of Caffeine Withdrawal as a diagnosis. Overall results appear to be mixed regarding the benefits of caffeine use and the potential negative effects of withdrawal (Smith, 2002; Smith et al., 2004).

The Effect of Caffeine on Cognitive Performance

Reports of the enhancing effects of caffeine have resulted in further investigation of the substance's effects. Studies have suggested that caffeine may have a significant impact on performance on a variety of cognitive tasks. For example, research on the impact of caffeine on the British workforce has suggested that caffeine may enhance workplace performance. Smith (2005) examined whether caffeine and improved cognitive function in a working sample in regular caffeine consumers who rated their alertness and carried out a simple reaction time task before and after work. Associations between caffeine consumption and frequency of cognitive failures were examined in a sample of 1,253 white-collar and 1,555 workers who were "especially at risk of having an accident." Those who had reported consuming high levels of caffeine reported significantly greater increases in alertness over the working day, with significantly less slowing of reaction time. After controlling for possible confounding factors it was found that higher caffeine consumption was associated with about half the risk of frequent/very frequent cognitive failures and a similar reduction in risk for accidents at work. However, this task did not manipulate caffeine dose in session, and thus the results assume that the differences are due to chronic effects.

Smith (2009) replicated this finding and found support for caffeine and improved cognitive function in a non-working sample. Participants completed measures about their caffeine consumption and survey items about how often they had problems with memory and attention. Results indicated that those with higher caffeine consumption reported fewer cognitive errors. However, most of the significant effects of caffeine disappeared when demographic and lifestyle factors were controlled for. Again, these findings should also be interpreted cautiously, as this work was based entirely on self-reported cognitive errors and caffeine intake. Other

studies have also shown that caffeine's benefits have real-world application. Brice and Smith (2001) demonstrated that 3 mg/kg of caffeine improved accuracy in a driving simulator, as well as showed improvement in mood measures and a sustained attention task.

These findings suggest that real-world cognitive performance improves after caffeine ingestion. However, it has been proposed that there is a negative quadratic relationship (i.e., U-shaped) between arousal and performance, as performance is optimal at medium levels of performance but impaired if too low or too high (Watters, Martin, & Schreter, 1997). For example, there is some evidence that fine motor control may be impaired as a result of high doses of caffeine (Smith, 2002).

Psychomotor Performance

The general belief that caffeine has a mild psychostimulant effect and improves a wide array of performance variables has lead to examination of various types of tasks. Psychomotor performance has generally been the most frequently studied. Psychomotor performance, which refers to measures of performance that combines some decision making with some form of a motor activity, has been measured with tasks such as tapping speed, simple and choice reaction time, and other tasks that require prolonged attention to stimuli that include a reaction time measure (Carroll, 1998).

Finger tapping tasks involve fast repetitious motor responses on a switch. This task has little cognitive load and is commonly included in task batteries as a measure of motor speed. This simple task has been used in many early examinations of caffeine's effects, resulting in reported enhanced response rates following administration (e.g., Hollingworth, 1912). More recent examinations have also shown an increase in tapping rate with caffeine (e.g., Fagan et al., 1988; Kaplan et al., 1997; Lieberman et al., 1987). Rees, Allen, and Lader (1999) demonstrated

that participants improved finger tapping rate, digit symbol substitution, and symbol copying following a 250 mg dose of caffeine. Swift and Tiplady (1988) found similar effects following 200 mg using a finger tapping task. Kaplan and colleagues (1997) also demonstrated improvements after both 250 mg and 500 mg doses on Digit Symbol substitution and finger tapping compared to participants not given caffeine.

In addition to tapping measures, several studies have included other motor tasks in performance batteries examining caffeine's effects. For example, grooved pegboard tasks (Liberman et al., 1997), measures of fine finger movements (i.e., Liebrman et al., 1987), and other standardized measures of hand steadiness (e.g., Bovim, Naess, Helle, & Sand, 1995) have been used to demonstrate caffeine's effects.

However, improved performance comes with an expense. Bovim, Naess, Helle, and Sand (1995) demonstrated that 300 milligrams of caffeine negatively influenced motor steadiness and reduced maze coordination performance in healthy participants, although finger tapping and grooved pegboard tasks were unaffected by this dose. The general conclusion in the literature is that caffeine can enhance motor response rate, but that the effect is small and hard to detect, and measures of steadiness may be more sensitive to the effects of caffeine.

The findings on these studies are complicated by specific task demands, as many tasks measuring attention or reaction time involve a psychomotor component and thus it may be difficult to determine whether it is simple attention, reaction time, psychomotor speed, or a combination of the three that are influenced by the chemical.

Simple and Choice Reaction Time

Measures of reaction time have been part of early investigations of caffeine and performance. For example, Hollingworth (1912) reported that caffeine was responsible for

enhancing typing speed in early studies. Reports of improvements on more standardized measures of reaction time followed soon afterward, although many studies found disparate effects on reaction time. A review of early literature in 1982 concluded that caffeine had real effects on returning degraded human performance toward optimum, although the effects were small and were produced by a variety of everyday arousing and alerting influences, including environment and noises (Dews, 1982). Since Dews' review, improvements in technology have permitted more accurate measurement of reaction time and better control of stimuli, and several more recent studies have reported improved reaction time (e.g., Lieberman et al., 1987; Swift & Tiplady, 1988). However, others still fail to find improvements (e.g., Foreman, Barraclough, Moore, Mehta, & Madon, 1989).

Attention

In addition to reaction time, attention is also one of the most consistently-demonstrated testing effects following caffeine intake, as these types of tests have been shown to be sensitive to caffeine's effects. Reviews of the literature have shown that caffeine improves various aspects of attention. Keleman and Creeley (2001) showed improvements on a sustained attention task following a large dose of caffeine (4 mg/kg). Others have shown improvements on a repeated digits vigilance task (detecting targets at irregular intervals) following varying doses of caffeine (e.g., Smith, Sutherland, & Christopher, 2005; Scholey & Kenney, 2004). Similarly, Hewlett and Smith (2006) and Haskell, Kennedy, Wesnes, and Scholey (2005) found that caffeine was related to the simple reaction time and sustained attention tasks. A few studies have demonstrated improvements on simple and choice reaction time with a computerized task that requires participants to tap a button at the sight of target stimuli (Smith, Sturgess, & Gallagher, 1999; Lieberman, 2002).

One study by Warburton and Bersellini (2001) examined the effects of an 80mg /250 ml energy drink among coffee drinkers with either minimal or no caffeine deprivation. Those who ingested the caffeinated drink showed improved attention and accuracy in recognizing computerized letter strings, as well as faster reaction time with a semantic verification task. These tasks require participants to decide if provided statements are true (e.g. *forks are manufactured goods*) or false (e.g., *dogs have wings*), and performance is measured by number of correctly identified statements and mean reaction time. Faster reaction times on semantic tasks have also been observed in other controlled examinations (e.g., Haskell et al., 2005; Warburton, Bersellini, & Sweeney, 2001; Smith, Sturgess, & Gallahger, 1999; Hewlett & Smith, 2006).

Taken together, the literature suggests that attention and reaction time are affected by acute intake of caffeine in moderate doses. Although some studies report no effects and others have found positive effects with only certain groups (e.g., the elderly, Swift & Tiplady, 1988), the most widely demonstrated findings in the literature are improvements in attention, reaction time, and psychomotor speed.

Memory

The most common effects of caffeine in the literature are increases in alertness and improvements in reaction time and vigilance. Nevertheless, caffeine is a nonspecific stimulant, and thus research has shown differences in various performance domains, including memory. However, the research examining the effects of caffeine intake on memory has been more inconsistent. Some studies have suggested that chronic caffeine intake can improve memory. For example, Hameleers and colleagues (2000) found cognitive changes using data from a longitudinal aging study in the Netherlands (The Maastricht Aging Study, MAAS). More than 1,800 adults were screened for habitual intake of coffee and tea and took part in extensive

cognitive testing. After controlling for age, sex, and demographic variables, habitual caffeine consumption was found to be significantly related to better long-term memory performance on a verbal learning task. However, there was no relationship between habitual caffeine consumption and short-term memory, and this study did not control for the acute effects of a controlled caffeine dose.

Most studies of caffeine and memory have not found positive effects related to caffeine ingestion. Following the ingestion of an 80 mg caffeine energy drink, Warburton, Bersellini, and Sweeney (2001) tested 42 participants with a number of cognitive measures, including verbal and nonverbal tasks. Although consumption of a caffeinated beverage produced improved attention, improved verbal reasoning, and reduction in the variability of attentional performance between subjects, there were no differences in verbal or non-verbal memory.

Similarly, Smith, Sturgess, and Gallagher (1999) examined the effects of 40 milligrams of caffeine in a double-blind study, and those who consumed caffeine did not demonstrate improvement on a free recall or delayed memory recognition task. The effects of caffeine were not affected by the drink presentation (i.e., coffee, tea, cola). Scholey and Kennedy (2004) examined college students following consumption of an energy drink. Although the caffeine drink (including other additives) resulted in increases in a composite "secondary memory factor," including immediate recall, delayed recall, and recognition, there was not a caffeine alone condition, and thus the specific effects of caffeine alone could not be examined.

Others studies have shown decrements in memory performance following an average caffeine dose. Terry and Phifer (1986) tested college students in a word list recall following 100 milligrams of caffeine. Participants given caffeine recalled fewer words than the control group, both after single presentations of lists and across repeated trials. These results suggest that

caffeine resulted in poorer performance, particularly in a recall of the middle to end portions of the list. However, this study was not rigorously controlled. Participants were allowed to consume caffeine prior to the study, and there was no mention of excluding tobacco users. These findings suggest that memory may not be sensitive to the effects of caffeine. It is also possible that the doses in these studies are not sufficiently robust to demonstrate differences and more examinations at either high or low doses may demonstrate stronger effects.

Working memory has also received some attention in the literature regarding caffeine. This is considered to be an executive function requiring individuals to mentally manipulate information. It has been proposed that working memory has at least three subcomponents: the visuospatial scratchpad, the articulatory loop, and the central executive (Baddeley, 1986). Haskell and colleagues (2005) showed group differences in only spatial working memory, with caffeine consumers performing better than non-consumers. One study found that consumption of 2mg/kg to 4mg/kg impaired the encoding of stimuli in working memory in women compared to controls (Erickson et al, 1980). However, Smith, Clark, and Gallagher (1999) found no effect of caffeine on working memory, although it did improve encoding of new information and counteracted the fatigue that developed over the testing session.

Executive Functions

Despite the large volume of literature concerning the role of caffeine and cognitive functioning, relatively little research has been published regarding the effect of caffeine intake on executive functions. Executive functions refer to the higher level cognitive skills that direct lower level abilities (Stuss & Levine, 2002), including the abilities to recognize future consequences resulting from current actions, to choose between good and bad actions, to override and suppress unacceptable social responses, and to determine similarities and

differences between things or events.. These are relevant in decision-making, planning, initiation of goal directed behavior, inhibition of inappropriate responses, sequencing, monitoring of behavior, and self-regulation (Royall et al., 2002; Stuss & Levine, 2002). The frontal lobes also play an important part in retaining longer term memories associated with emotions derived from input from the brain's limbic system.

A substantial body of neuropsychological evidence suggests that these diverse executive functions are the product of neural activity within the prefrontal cortex. The executive functions are primarily guided by the frontal lobes, with the dorsolateral prefrontal cortex associated with cognitive aspects and the ventromedial prefrontal cortex (including the orbitofrontal cortex and anterior cingulate cortex) associated with affective components (Stuss & Levine, 2002). Although these are the primary brain areas involved in the broad range of executive functions, the prefrontal cortex has extensive neural circuitry which allows for inputs from other brain regions to affect these processes, making it difficult to localize specific executive functions.

One aspect of executive functions involves the ability to inhibit prepotent responses. A common way to examine this skill is by testing the Stoop effect in individuals to see how well they can control more automatic responses. The Stroop effect is observed on tasks in which the brain experiences slowed processing time as it sorts through conflicting information. The traditional tasks measuring this phenomenon involve words of colors printed in a different colored ink, and individuals are challenged to inhibit the automatic reading response and, instead, name the color of the ink. This task required inhibitory control, as individuals must limit the reading response.

Some research has suggested an impaired Stroop performance as a result of caffeine intake. Foreman and colleagues (1989) examined performance on a modified, numeric Stroop

test following either a 125 mg or 250 mg of caffeine, or placebo. Participants who consumed caffeine demonstrated worse Stroop performance compared to control participants, suggesting that caffeine may hinder inhibitory processes. However, this variation of Stroop task is not a widely used measure, and the findings were based on a small sample size.

Other studies have used the Stroop task to examine caffeine's effects, however, two of these were part of a large aging study and caffeine dose was not controlled. As mentioned before, the chronic effects of caffeine are the independent variables in these studies, and one found improved performance (Hameleers et al., 2000), whereas another did not find a relationship between caffeine and Stroop performance (Van Boxtel et al., 2003).

Additionally, both Hasenfrantz and Battig (1992) and Killgore, Lipizzi, Kamimori, and Balkin (2007) used the Stroop task to examine the effects of caffeine following sleep deprivation. Neither study found enhanced executive function, however, caffeine may not be a powerful enough stimulant to counteract the fatigue imposed by the lack of sleep. Similarly, Westensen and colleagues (2005) failed to detect an effect of caffeine on the Stroop Color Word Task or Controlled Oral Word Association task following caffeine intake, although again, this investigation followed a period of significant sleep deprivation.

Another core component of executive functioning is decision-making, which has received little attention in the examination of how caffeine impacts cognition. This examination is relevant because of the dopaminergic neurotransmitter system affected by caffeine. As previously discussed, one of the effects of adenosine blockage is the increase in dopaminergric transmission, and research on the mesolimbic and mesocortical dopamine pathways suggest that the dopaminergic neurotransmitter system play a role in the decision-making process (Adinoff, 2004; Carlson, 2004). The mesolimbic pathway originates at dopaminergic cell bodies in the

ventral portion of the midbrain and terminates in the nucleus accumbens, amygdala, bed nucleus of stria terminalis, lateral septal area, and lateral hypothalamus (Adinoff, 2004; Carlson, 2004). This pathway is responsible for integration or learning of prospective positive and negative reinforcers and the promotion of goal-directed behavior. In contrast, the mesocortical pathway also projects its axons to the prefrontal cortex areas including the orbitofrontal cortex and the anterior cingulate (Adinoff, 2004; Carlson, 2004).

Functional brain imaging techniques have been used to help identify brain regions involved in different aspects of decision-making. Using PET scans, Ernst and colleagues (2002) found activation in the orbitofrontal cortex, dorsolateral prefrontal cortex, ventrolateral prefrontal cortex, anterior cingulate cortex, insula, parietal cortex, thalamus, and cerebellum during the decision-making process. The dopaminergic neurons within these structures influence the decision-making process because dopamine activation increases during times of reward uncertainty. Specifically, uninformed decision-making results in activation in the left amygdala, left middle prefrontal cortex, and left posterior parietal cortex, which are associated with emotional, sensory, and motor processes. This has been demonstrated in several primate studies. For example, Schultz, Tremblay, and Hollerman (2000) demonstrated that the response of dopamine neurons is dependent on the predictability of a reward. By examining the extracellular positions of single neurons in primates during a modified Go/No Go task, the authors showed that midbrain dopaminergic neurons were most highly activated when the primate was presented with an unpredictable reward. Informed decision-making, however, involves bilateral structures involved with memory (hippocampus and posterior cingulate), error learning (cerebellum), and motor control (striatum). The same primates in Schultz et al. (2000) examination showed no

activational response when presented with a predictable reward, and produced a depressed activation state when they received no reward.

Other studies have demonstrated similar findings. Fiorillo, Tobler, and Schultz (2003) found that midbrain dopamine neurons responded with a sudden increase in neural activity after an unpredictable reward. There was an increase in dopaminergic activity between the time of the stimulus and anticipated reward, with the peak of dopamine activation occurring at the time of expected reward (Fiorillo, 2004; Fiorillo, Tobler, & Schultz, 2003).

Research has shown that some of the same neural substrates activated during various aspects of decision-making are also impacted by caffeine intake. Nehlig, Armspach, and Namer (2010) provided typically low caffeine consumers and high caffeine consumers after ingestion of 3 mg/kg and demonstrated that, compared to controls, low caffeine consumers displayed neuronal activation bilaterally in inferior frontal gyrus, anterior insular cortex and uncus, left internal parietal cortex, right lingual gyrus, and cerebellum.

Caffeine intake may be particularly relevant to decision making and risk taking because of the proposed relationship between dopamine and decision-making. Caffeine is a competitive antagonist at adenosine receptors that stimulates dopaminergic activity. Behavioral studies show that caffeine produces behavioral effects similar to other stimulants, such as cocaine and amphetamine (Garrett & Griffiths, 1999). Similar to caffeine's effects, methylphenidate and *d*-amphetamine administration have been shown to improve attention and psychomotor performance (Silber, Croft, Papfotiou, & Stough, 2006). In addition, methylphenidate and *d*-amphetamine have been shown to reduce impulsiveness and inattentiveness in individuals with attention deficit/hyperactivity disorder, suggesting deficit in dopaminergic transmission. Brain imaging studies have shown that methylphenidate increased blood flow in striatal areas in

AD/HD patients (Lou et al., 1989). It is likely that caffeine will have similar effects on cognitive functioning, as well.

Dopamine is thought to play a key role in motivation and risky behaviors. However, most of the studies examining dopaminergic transmission that have explored how dopamine depletion or lesions in dopaminergic pathways have resulted in impairment of functioning (Nieoullon, 2002). There is increasing evidence suggests that both dopaminergic and serotonergic neurotransmitter systems are involved in the decision-making process, as they are related to brain-reward systems (e.g. Denk, Walton, Jennings, Sharp, Rushworth, & Bannerman, 2005). Activation of dopamine neurons has been associated with learning, periods of uncertainty or expectation, and novelty (Adinoff, 2004; Fiorillo, 2004; Fiorillo, Tobler, & Schultz, 2003). As such, ingestion of a stimulant such as caffeine would likely have an indirect effect on decision-making.

Mood state may also have an impact on decision making, which is particularly relevant given research has found that caffeine can alter mood. Although direct examinations of the impact between caffeine, mood, and decision-making have not been examined, research on dopamine levels may shed light on this hypothesized relationship. Changes in dopamine levels through dopamine depletion studies have resulted in decreases in mood. Specifically, consumption of an amino acid mixture lacking phenylalanine and tyrosine may increase the risk for depressed mood states. Consumption of such a mixture has been related to significant changes in mood, resulting in feelings of apathy (McLean et al., 2004), restlessness, and boredom (Leyton et al., 2000). Thus, it is possible that caffeine consumption may increase dopamine and improve mood. Studies using the Iowa Gambling Task as a risk-taking measure have shown that negative affect results in more risky decision making whereas positive mood

results in more conservative decisions (Suhr & Tsanadis, 2007). However, other studies have suggested the opposite effect (Schwarz, 2000; Yuen & Lee, 2003).

There is some evidence to support a relationship between caffeine intake and risk-taking in college students based on self-report. Jones and Lejuez (2005) examined the personality correlates of caffeine consumers, and found that self-report measures of sensation seeking and impulsivity were positively related to self-reported caffeine consumption. However, performance on a behavioral measure of risk-taking (BART) was not related to self-reported caffeine use. The limited findings may be attributed to the procedure, as caffeine intake was not controlled, nor were participants asked to "drink what is typical" on the date of the BART administration. The findings of this study suggest that there may be a relationship between level of caffeine consumption and risk-taking behavior, although the methodology limited interpretation to chronic rather than acute effects, which likely did not affect the behavioral measure.

Evidence from PET scans has suggested that reduced activity within the prefrontal cortex is associated with corresponding decrements in performance on tasks involving complex cognitive processing, such as the Iowa Gambling Task. However, most of the studies on caffeine and decision-making have examined this relationship following long periods of sleep deprivation. For example, Killgore, Lipizzi, Kamimori, and Balkin (2007) demonstrated that 75 hours of continuous sleep deprivation impaired a specific type of executive function involving the ability to make advantageous decisions under conditions of uncertainty on the Iowa Gambling Task (IGT). Although volunteers previously learned to avoid risky decisions that led to net losses, when sleep deprived, the same participants had difficulty making advantageous decisions. Despite previous success avoiding disadvantageous choices on the first half of the trials, they shifted their decisions away and adopted a more risky strategy for the second half of

the task. However, caffeine did not restore function during sleep deprivation. Other studies by Killgore and colleagues demonstrated the same effect with shorter sleep deprivation schedules. Caffeine demonstrated no symptom alleviation effect following 49 hours of sleep deprivation (Killgore, Balikin, & Westensen, 2006), nor after 61 hours (Killgore et al., 2008).

In a measure examining risk-taking following consumption of caffeinated alcoholic beverages, Roehrs, Greenwald, and Roth (2004) examined whether an alcohol/caffeine beverage concoction counteracted tiredness to influence decision making. The study utilized the Stop Light Task to investigate the impact on risky decision-making. The Stop Light Task is a measure of risk-taking in which participants to respond to a computerized "traffic signal" displayed on a video monitor and make decisions that result in actual money loss or gain. Participants choose whether to stop responding when a yellow light warning is presented or try to continue until the red light appears, at the risk of losing money. Participants were not sleep deprived, but those who reported that they were more tired demonstrated impaired decision-making on the Stop Light Task. Additionally, caffeine was able to reverse the impairments induced by ethanol, although it was never administered in isolation and therefore the acute impact of caffeine stimulation on decision-making cannot be determined.

The limited research about caffeine and decision making begs the question of whether there are observable effects of caffeine in the absence of sleep deprivation. Few studies have demonstrated the impact of caffeine on decision making in non-sleep deprived individuals. The few that have demonstrated an effect are poorly controlled (i.e., Jones & Lejuez, 2005) or only examined the impact of caffeine combined with other substances (Roehrs, Greenwald, & Roth, 2004). Overall, the relationship between decision making and caffeine use is not well understood.

Methodological Considerations of Caffeine Studies

Much research has focused on the impact of caffeine intake on human behavior and cognition, however, the results have been inconsistent and difficult to reconcile. A wide range of methodological factors can account for the variable nature of published effects on caffeine on performance across cognitive domains. A major source for the varying results may relate to methodological differences in caffeine dose, experimental design, protocol, and procedure of testing (van der Stelt & Snel, 1998). Specifically, inadequate sample sizes, short duration of tests, poor control for placebo effects, limited range of caffeine doses, and differences in testing conditions may account for some of the failures to find effects (Nehlig, 2007). The diversity in study design and execution seems to reflect a lack of consensus on the appropriate methods to employ when examining the influence of caffeine on behavior and mental performance.

The first major variable in caffeine research is the dosage at which tasks are performed and measured. The most common doses within studies range from 150-250 milligrams, or the equivalent of 2-3 cups of coffee, although several studies have examined more extreme doses. For example, Smit and Rogers (2000) compared low and high caffeine consumers and found that caffeinated participants have improved attention and response time, even at a low 12.5 mg dose. Similarly, Lieberman and others (1987) demonstrated effects in reaction time and auditory vigilance using a small dose of 32 mg. Kaplan and colleagues (1997) examined psychomotor functioning and mood following single doses equivalent to five times the amount found in an average cup of coffee (500 mg). The vast differences in the doses may explain some of the outcome variability within the literature. Overall, it is believed that there is a dose response relationship between caffeine and a variety of outcome measures.

A second concern regarding the variability between study procedures relates to whether there are differences between one large dose and several small doses that better mimic routine consumption patterns. Several of the examinations of caffeine intake and performance focus on one large dose, which may be unrealistic for regular consumers. To address this methodological shortcoming, Brice and Smith (2002) compared the effects after complete consumption of multiple, small doses of caffeine (4 x 65 mg) to the effects following a single large dose (200 mg), and found equivalent increases in alertness and anxiety, and improved performance on simple and choice reaction time tasks, and cognitive vigilance tasks. The results suggested that either administration procedure is appropriate, and further demonstrated the effects of caffeine on attention and reaction time.

The effects of caffeine on performance have been examined in both caffeine consumers and abstainers, however, the majority of the research on cognitive performance following intake has been completed on caffeine-deprived, habitual users (Haskell, Kennedy, Wesnes, & Scholey, 2005). Because most studies require a period of abstinence prior to caffeine administration, there is a concern about whether caffeine produces an absolute improvement in performance or if it simply lessens the effects of caffeine withdrawal. The most common symptoms of caffeine withdrawal include headache, drowsiness, lethargy, decreased energy, and decreasing concentration, which may indicate that abstinence from caffeine leads to sub-optimal performance, and intake simply restores performance to normal levels. James and Rogers (2005) argued that the effects of caffeine on performance and mood are almost wholly attributable to reversal of adverse withdrawal effects associated with short periods of abstinence from the drug. Similarly, Warbutron and Bersellini (2010) proposed that caffeine improves performance across tasks by stabilizing normal fluctuations in arousal. Fagen and colleagues (1988), however,

concluded that caffeine intake maintained levels of performance that may have otherwise declined over time, as they observed that caffeine-related improvements were evident in latter-stages of auditory vigilance testing.

Methods have been employed in order to determine whether improvements in performance following administration are evident without the confounding effects of withdrawal. Pre-dosing participants with standards amounts of caffeine, allowing *ad libitum* caffeine consumption, and withdrawing caffeine consumers from caffeine for a week or more to reduce the immediate effects of the drug have all been used to examine different effects. However, these methods present their own methodological problems, as pre-loading with standard doses does not account for the different levels of caffeine withdrawal prior to testing. *Ad libitum* consumption is confounded by individual differences in patterns of daily consumption, and does not control for individual differences in regard to caffeine withdrawal. Finally, the "washing out" method requires rigid compliance to the protocol and consistent monitoring of dietary habits (Haskell et al, 2005).

Another method of measuring the absolute effects of caffeine consumption in testing is to compare effects in overnight withdrawn consumers to non-consumers. Although this method carries its own methodological problems, such as locating non-consumers, the comparison between individuals allows direct comparison of improvements and can provide strong support in favor of alleviation model (if withdrawn consumers' performance is significantly lower than non-consumers) or absolute benefits (if there is no difference in benefit between the groups; Haskell et al, 2005).

Using this method, Rogers and colleagues (2003) found different effects for caffeine consumers and non-consumers, with regular consumers reporting less alertness, more tension,

and greater improvements in psychomotor performance from baseline following 100 mg of caffeine (Rogers et al, 2003). Smit and Rogers (2000) also found that chronic caffeine users had greater improvements on Rapid Visual Information Processing than non-consumers. Jarvis (1993) demonstrated a significant linear relationship between habitual caffeine consumption and memory performance and reaction time, although this study was limited to self-reported caffeine consumption, did not control caffeine intake during testing, and employed nonstandardized testing situations. Finally, Norman, Bardwell, Loredo, Ancoll-Israel, Heaton, and Dimsdale (2008) demonstrated that higher caffeine consumers were less impaired on measures of executive functioning. However, this study had an above-average level of impaired persons in the sample and may not be representative of a community sample. Additionally, Norman and colleagues (2008) did not manipulate caffeine doses.

Van Boxtel, Schmitt, Bosma, and Jolles (2003) and Hameleers, Van Boxtel, Hogervorst, Riedel, Houx, and Jolles (2000) did not find differences on a range of cognitive tasks between habitual users and nonusers. However, caffeine was not experimentally controlled in these studies and instead typical consumption patterns were compared. Other well-controlled studies also failed to find differences between caffeine and regular level of caffeine consumption on a range of cognitive tasks (e.g. Hewlett & Smith, 2006; Smith, Sturgess, & Gallagher, 1999; Smith, 2009). Haskell, Kennedy, Wesnes and Scholey (2005) did not find evidence for the alleviation of withdrawal model, as caffeine led to improvements in both consumers and non-consumers on diverse aspects of cognitive functioning.

Rapid tolerance may explain why there are few differences between habitual caffeine consumers and non-consumers. Judelson and colleagues (2005) examined performance on a variety of tasks, choice reaction time, mood state, and visual vigilance using a 5-day controlled

caffeine intake task to examine cognitive and psychomotor performance. There were few perceivable effects of varying levels of caffeine on cognitive and psychomotor performance, and the authors argued that chronic consumption may lead to a tolerance of caffeine's acute effects. Another study suggested that heavy coffee drinkers did not notice the subjective differences in their mood or behavior following an abrupt shift from caffeinated to decaffeinated coffee (Griffiths, Bigelow, Leibson, O'Keefe, O'Leary, & Russ, 1986). Given the methodological shortcomings of the studies suggesting major differences between users and nonusers, analysis of controlled research suggests that there are few differences between caffeine consumers and non-consumers.

Finally, claims about the negative effects of caffeine withdrawal require closer examination since they can often be interpreted in ways other than caffeine dependence (e.g. expectancy). Indeed, in most of the studies that have demonstrated increases in negative effects following caffeine withdrawal, the subjects have not been blind but have been told or even instructed to abstain from caffeine. This is clearly very different from the double-blind methodology typically used to study effects of caffeine challenge.

Another methodological weakness in caffeine literature is the lack of information regarding caffeine's effects in non-sleep deprived participants. Much of the current research on the effects of caffeine on cognitive performance is conducted following a period of sleep deprivation to determine whether caffeine alleviates the effects of fatigue. Some research has shown that moderate doses of caffeine may improve cognitive functions, such as vigilance, attention, reaction time, and mood state in non-sleep deprived individuals. These same benefits have been examined in those deprived of sleep for extended periods of time. For example, Lieberman and colleagues (2002) examined the influence of caffeine intake during United States

Navy SEALs training. Participants in the study received 100, 200, or 300 milligrams of caffeine or a placebo following 72 hours of sleep deprivation and were administered a battery of cognitive tests. Results indicated that, after these adverse conditions, caffeine mitigated the effects of the sleep and stress in a dose-dependent manner. Doses of 200-300 milligrams improved visual vigilance, reaction time, and alertness, and effects persisted for 8 hours. However, the severity of these stressors is unlikely to be experienced in day-to-day functioning, and is not generally problematic for neuropsychological interpretation.

Other research, however, demonstrated no such benefit, and no restorative properties following sleep deprivation. For example, James, Gregg, Kane, and Harte (2005) sought to determine whether chronic use of caffeine has net effects on performance and mood compared with sustained abstinence, and whether dietary caffeine restores performance and mood adversely affected by sleep restriction. Caffeine had no significant effects for either performance or mood when participants were non-sleep deprived, and produced no net restorative effects when performance and mood were degraded by sleep restriction. This result was likely because the participants developed a tolerance to the drug's effects, as they were maintained on a steady dose for a week prior to testing.

Summary

Overall, the ingestion of caffeine may improve general levels of performance in some cognitive domains, but the evidence available does not allow for a thorough understanding of the impact of caffeine on cognitive functioning. There have been few studies that have examined performance across an array of performance measures that have been well controlled. The few studies that have employed a within-subject design have either allowed for uncontrolled ad libitum consumption prior to the study (i.e., Smit & Rogers, 2000; Smith, Sutherland, &

Christopher, 2005), only examined performance at doses of caffeine without enough variance in the size of the doses to demonstrate an effect (i.e., Brice & Smith, 2002; Haskell, Kennedy, & Wesnes, 2005), or compared performance with unrealistic testing conditions (i.e., Killgore, Baltkin, & Westensen, 2006).

Furthermore, as the actions of caffeine stimulate the brain areas and neurotransmitters associated with decision-making (e.g., anterior cingulate cortex, parietal cortex, insula), it is possible that caffeine could impact performance on these tasks measuring higher level cognitive abilities without depriving participants of sleep. Although there is limited research examining caffeine's impact on risk-taking and impulsivity, several studies have investigated the direct manipulation of dopamine on these measures. Past research has shown that caffeine indirectly impacts dopaminergic function (Ferre, 2008), and thus it is possible that intake of caffeine could influence risk-taking in ways similar to direct dopamine manipulation. Results from behavioral measures of decision-making may shed light on the acute impact of caffeine on executive functions.

In addition, there is research to suggest that increases in mood may decrease risk-taking. That is, positive mood causes stronger reliance on affective signals in decision-making (de Vries, Hollad, & Witteman, 2008). Because caffeine has been demonstrated to improve affect in many past studies, a positive effect on mood following caffeine may result in more advantageous decision-making (i.e., less risk).

Current Study

The purpose of the current study was to expand on existing research regarding the acute impact of caffeine on cognitive tasks by addressing the methodological shortcomings of past examinations. This study employed a within-study design to determine how caffeine affects cognitive ability. Past research has been unclear about the effects of caffeine, and the few within-subject examinations did not control for caffeine levels. A within-subjects study that requires a wash-out period in non-sleep deprived participants has the best potential for yielding clearer findings. Additionally, the current study includes examinations of executive functioning tasks. Although much research on caffeine use exists, many of the findings are based on reaction time and attention. Tasks that have examined executive functions have been poorly controlled and do not allow for understanding of caffeine's effects under these conditions. Thus, the present study will improve understanding of the effects of caffeine by examining performance on cognitive tasks, while addressing methodological limitations of past research. The following hypotheses were proposed:

1. As demonstrated in past literature, caffeine is believed to have positive effects on reaction time, processing speed, attention, with mixed results on memory tasks. Following caffeine ingestion, it is anticipated that participants will demonstrate improvements on all domains of the computerized assessment tool.
2. Participants will show less risky decision making on executive function tasks (Angling Risk Taking) after consumption of caffeine compared to placebo trials.
3. The subjective effects of caffeine on mood may be a moderator in the relationship between caffeine and risk-taking. The subjective effects of caffeine are believed to be a

moderator in the relationship between caffeine and performance on the decision-making tasks.

CHAPTER II

METHOD

Participants

Students enrolled in psychology classes were recruited through Central Michigan University's psychology subject pool. Participants were be required to be between the ages of 18 and 30, and were only eligible to participate if they reported moderate amounts of caffeine use. In addition, participants were excluded if they had a history of loss of consciousness for more than 20 minutes, had a history of a learning disability or attention-deficit/hyperactivity disorder, were nicotine users, or were currently taking centrally acting medications that would alter catecholamine levels. The age of 30 was used as an upper cutoff to avoid a skewed distribution. Individuals participated in three separate research sessions: placebo dose (0 mg), moderate caffeine dose (100 mg), and high caffeine dose (300 mg).

A total of 66 (N = 66) undergraduate students at a large Midwestern university participated in all aspects of the study. Two individuals completed at least one session, but elected to withdraw from the study. Two participants were removed from the analysis because their computerized data were not properly saved (3%). Three participants (4%) were removed because they were currently taking psychotropic medication that could alter catecholamine levels, and another three participants (4%) were removed due to a history of head injury that resulted in a loss of consciousness.

The estimated daily average caffeine intake was calculated for each participant to ensure that the sample was approximately equal in their consumption. The average caffeine intake of participants was 270 milligrams per day (*SD = 179.21*). Three participants were removed from the analysis because they endorsed daily caffeine levels significantly higher (2 standard

deviations) than other participants in the study (4%). The estimated average daily intake of participants after this removal was 242 milligrams (*SD = 135.22*).

The removal of these ten participants resulted in a sample of 55 participants retained for analysis (20 males and 35 females, 18 to 22 years of age, M_{age} = 19.8 years). Ethnicity of the sample was fairly homogeneous: 78.2% Caucasian (*n =43)*, 10.9% African-American (*n* = 6), 3.6% Latino (*n* = 2), 3.6% Asian (*n* = 2), and 3.6% biracial (*n* = 2) (see Table 1).

Table 1. *Participant Demographics*

	N	**%**
Gender		
Male	20	36.4
Female	35	63.6
Racial Background		
Caucasian	43	78.2
African American	6	10.9
Asian	2	3.6
Latino	2	3.6
Biracial	2	3.6

Note: N =55

Materials

Heart Rate and Blood Pressure

Heart rate, diastolic blood pressure, and systolic blood pressure were monitored prior to administration of the caffeine or placebo and 30 minutes following consumption of the mixture. Difference scores (pre-post) were calculated for each session.

Caffeine Consumption Questionnaire

The Caffeine Consumption Questionnaire (CCQ) was constructed by Landrum (1992) and was modified for this study by making it more current with some additional categories (e.g. energy drinks). The CCQ measures individuals' average weekly caffeine consumption in milligrams by asking participants to fill in the number of times they typically eat or drink the specified items per week. The CCQ has proven to be reliable and effective for measuring caffeine consumption. Standard caffeine amounts for new items were taken from the Mayo Clinic's health website (Mayo Clinic, 2011).

Profile of Mood States (POMS; McNair & Heuchert, 2003)

The POMS consists of a list of 64 adjectives. Participants were asked to use a 5-point Likert scale ranging from 0 (Not at all) to 5 (Extremely) in order to rate how well each adjective describes how they felt. The POMS measures global distress (Total Mood Disturbance) as well as six subscales: Tension-Anxiety, Anger-Hostility, Fatigue-Inertia, Depression-Dejection, Vigor-Activity, and Confusion-Bewilderment. Factorial validity of the POMS has been replicated across several studies, and the construct validity has been demonstrated in a variety of research areas (McNair & Heuchert, 2003). Internal consistency estimates of the subscales, using coefficient alpha, range from .76 for the Confusion-Bewilderment subscale to .93 for the Fatigue-Inertia subscale. The POMS measure was administered twice; once prior to the caffeine administration and 30 minutes after the procedure. The difference score (post-caffeine values minus pre-caffeine values) was calculated for data analyses.

Immediate Post-Concussive Assessment and Cognitive Testing (ImPACT)

The ImPACT 2.0 neurocognitive test battery (Lovell, Collins, Podell, Powell, & Maroon, 2000) is a computer-based program for assessing neurocognitive function and concussion symptoms. The test battery consists of 6 computerized modules that evaluate attentional processes, verbal recognition memory, visual working memory, visual processing speed, reaction time, numerical sequencing ability, and learning. After demographic information and concussion history are entered, test subjects are permitted to begin the modules of the assessment.

Module 1 (Word Discrimination) evaluates attention processes and verbal memory using a word-discrimination paradigm. Participants are twice presented with a list of twelve target words for 750 milliseconds. After the second presentation, participants are provided 12 target and 12 non-target words. They are asked to click either the "yes" or "no" buttons on the screen about whether they remembered the word presented. After being presented with the other modules (about 15-20 minutes), they are asked to complete a delayed recall. The presentation of the delay condition is identical to the immediate recall condition. Scores are calculated for the number of correct "yes" and "no" responses. There are five parallel forms of this task for repeated administration.

Module 2 is a visual memory task (Design Memory) that evaluates visual recognition memory and attention using a design discrimination paradigm. Similar to the Word Memory task, twelve target designs are presented on the screen for 750 milliseconds, and then repeated to facilitate learning. At the end of the second presentation, participants are tested for recognition by identifying the correct figure from 24 designs. The 24 designs include both the 12 target designs and 12 non-target designs (target designs rotated in space). Participants are again asked to indicate "yes" or "no" at the end of the modules for a delay score. As with the Word Memory

task, scores are calculated for the number of correct "yes" and "no" responses, and there are five parallel forms of this task for repeated administration.

Module 3 (X & O) is a task that measures visual working memory and visual processing speed, and also includes a distractor task. Participants are asked to practice the distractor task once prior to beginning the memory task. The distractor is a choice reaction time task during which that participant is asked to click the "Q" button on the keyboard if a blue square is presented, and the "P" button if a red circle is presented. After this, a screen with a random assortment of X's and O's is presented for 1.5 seconds. For each trial, three X's or O's are highlighted on the screen, and the participants are instructed to remember their location. The arrangement of these designs is randomized by the computer for each trial and administration. Immediately after the presentation of the X's and O's, the choice reaction time distractor is again presented. Following the distractor, a screen with X's and O's is provided and participants have to click on the designs that were previously illuminated. Participants complete 4 trials of this task during each administration. Scores are calculated based on correct identification of the X's and O's (memory), reaction time for the distractor, and the number of errors made on the distractor task.

Module 4 (Symbol Matching) examines visual processing speed, learning, and memory. In this task, participants are first presented with a screen that displays 9 symbols, and directly under each is a number from 1 to 9. Below the grid, a symbol is presented, and the participant had to match the number as quickly as possible as well as remember the symbol/number pairings. After 27 trials, the symbols are removed from the grid, and the participants are again presented with a symbol and recall the correct symbol/number pairing by clicking the

appropriate button. This task yields an average reaction time score and a total correct score for memory of symbol/number pairs.

Module 5 (Color Match) is a choice reaction time task that evaluates impulse control/response inhibition. Participants are first asked to respond by clicking red, blue, and green buttons to demonstrate color recognition. They are then provided with a Stroop-like task in which words of colors ("red," "blue," or "green") are presented in either a red-, blue-, or green-colored font. Participants are asked to click the mouse as quickly as possible when they see that the color and the written word match, and inhibit that response when the color and font are dissimilar. This module provides both a reaction time score and a total error score.

Module 6 (Three Letters) examines working memory and visual-motor response speed. Participants are first introduced to the distractor task, which requires them to click numbered buttons in backward order beginning with "25." After this practice has been completed, participants are presented with three consonant letters on the screen. The numbered grid quickly reappears and the participant is instructed to click in backward order as soon as possible. After 18 seconds have elapsed, the numbered grid is removed and the participant is asked to recall the letters by typing them on the keyboard. This task consists of five trials for each administration. The number placement (1-25) on the grid and the three letters displayed are randomized for each trial. This module provides a memory score (total number of correct letters) and a score for the average number of correctly-clicked numbers in the distractor task.

In addition to the individual scores, the ImPACT also provides composite scores for Verbal Memory, Visual Memory, Reaction Time, and Impulse Control. The Verbal Memory Composite score is calculated by averaging the percent of correct total memory scores, total correct hidden symbols in Module 4 (Symbol Match), and total percent of letters correct of the

Three Letters task. The Visual Memory Composite Scores include the average of the total percent correct in Module 2 (Design Memory) and the total correct memory score in Module 3 (X's & O's). The Visual Motor Speed composite is calculated from the total number of correct responses in Module 3 (X's & O's) interference task and the average correctly counted numbers (25 to 1) from the Module 6 (Three Letters) distractor task. The Reaction Time composite score is comprised of the average correct reaction time of Module 3 (X's and O's), average correct reaction time of Module 4 (Symbol Match), and average correct reaction time of Module 5 (Color Match). The Impulse Control Composite is calculated from the total errors from the distractor condition of Module 3 (X's and O's) and the average commissions of counted numbers (25 to 1) of Module 6 (Three Letters).

In addition, a Cognitive Efficiency Index is provided, which is a measure of both speed and accuracy on the Symbol Match test (Module 4). This score is was developed on order to aid interpretation of other composites, as individuals with mild traumatic brain injuries often have difficulty maintaining high accuracy and fast speed (ImPACT Applications, 2011).

The ImPACT 2.0 has undergone extensive validation through multiple studies (Iverson, Lovell, & Collins, 2002; Lovell, & Collins, 2004; Iverson, Gaetz, Lovell, & Collins, 2005). The ImPACT is also not subject to the practice effects sometimes seen on pencil and paper tasks (Lovell et al., 2003). In addition, research has shown that the cognitive domains represented by the ImPACT have good construct validity with standard neuropsychological tests (Maerlender et al., 2010.) The methods of computerized testing provides accurate reaction time calculation, randomization of test trials, and automation of data collection and analysis. As the ImPACT is designed to be sensitive to even small cognitive changes across multiple domains, and was chosen because of its sensitivity. Additionally, this task was designed to measure baseline

performance and subsequent changes at retesting, which lends itself suitable for examining within subject differences following caffeine administration.

Angling Risk Task (ART)

The ART (Pleskac, 2008) is a measure of risk taking/decision. During this task, participants fish in a tournament for 30 rounds in a pond that has 1 blue fish and 128 red fish. Below the pond are two buttons: one button is labeled "Go Fish," and pressing it results hooking a fish. Each fish is equally likely to be caught on a given cast. With each attempt, there is a reduction of the total number of red fish in the pond, thus increasing the risk of catching a blue fish on the next cast. If a red fish is caught, $0.05 will be placed into the "Trip Bank." The participants will continue to cast the line into the pond for that round until they choose to either keep the money by pressing the "Collect" button to transfer the money to the "Tournament Bank" or until they catch a blue fish. If a blue fish is caught, the round will end and participants lose their accumulated money in the "Trip Bank." As this task requires participants to make a decision under clear probabilities (i.e., sampling-without-replacement), the ART is reliable way to measure an individuals' risk-taking under predictable conditions.

Mental Rotations Test (MRT-A)

The MRT-A (Peters et al., 1995) is a multiple choice test of mental rotation in which participants select two matrix figures from a series of four options. The two correct images reflect a rotated target, and the two incorrect figures are distractors. For each item, a large "X" is to be drawn through two figures that represent the rotated target. The MRT-A has adequate internal consistency (Peters et al., 1995). For the purpose of this study (6 questions per study

session), a total score was calculated by subtracting the number of incorrect choices from the number of correct choices.

Manipulation Check

At the end of each session, participants completed a Test Condition Questionnaire to determine the efficacy of the blinding procedure. This measure required participants to guess which dose they received during the session: placebo, stimulant, or sedative. The addition of the sedative as an option was provided in order to minimize the influence of suggestion on participants, and instead gather a more accurate assessment of objective experiences.

Procedure

To assess the effects of moderate amounts of caffeine intake on performance the current study utilized a randomized, placebo-controlled crossover administration procedure. Participants were blinded to their condition, and told prior to testing that they would consume a stimulant, sedative, or placebo. To help ensure that participants abstained from caffeine and nicotine for twelve hours prior to their participation, each participant was e-mailed by the primary investigator after the initial appointment time was scheduled, and again before each testing session. All participants were scheduled for three sessions at the same time of day (either 9;00 am or 11:00 a.m) and day of the week, exactly seven days apart. If participants indicated that they had consumed nicotine or caffeine, they were rescheduled for testing on a different day and were allowed a make-up session the next day at the same time

An approximate timeline of the procedure is outlined as follows:Upon arrival to the testing session, the investigator explained the rationale for the study, the procedures, potential risks, and benefits outlined on the consent form (9:00/11:00). Participants were then given

consent forms to sign. Baseline physiological measures (heart rate and blood pressure) were recorded at this time. Five minutes into the session (9:05/11:05), participants were provided with a bottle of water and an opaque white size #0 gelatin capsule with either placebo (crushed Smarties® candy) or caffeine (100 mg or 300 mg), and asked to wait for 30 minutes. During this waiting period, they completed the background questionnaire and a baseline POMS (9:10/11:10). Participants also completed the CCQ during their first session. In the remaining time, they were allowed to read magazines or study.

Following the 30 minute delay, participants were again asked to complete the physiological measures (9:35/11:35) and the POMS (9:40/11:40). They were then provided instructions about how to complete the ImPACT and were then asked to try their best to complete the measures as instructed on the screen. After completion (10:00/12:00), participants were read standard instructions and asked to complete the ART. To encourage effortful responding, participants were informed of the reinforcement system (competition for a gift card as a reward based on performance on tasks). They then completed the Spatial Rotation task (10:10/12:10) Finally, they were asked to complete the Test Condition Questionnaire (10:15/12:15) to determine the efficacy of the blinding. They were then provided with a reminder card for subsequent testing sessions, asked if they had any questions or concerns, and dismissed. After the third session, participants were provided with a debriefing form and thanked for their time. The entire session lasted approximately 75 minutes.

CHAPTER III

RESULTS

Physiological Changes

Since physiological responses change over time and depend on individual factors, change scores were computed for systolic blood pressure, diastolic blood pressure, and heart rate at each testing session. These were analyzed separately using one-way repeated measures ANOVAs. There were no significant effects of caffeine condition on changes in heart rate (Wilks' $\lambda = .98$, F (2, 53) = .596, $p = .555$), systolic blood pressure (Wilks' $\lambda = .98$, F (2, 53) = .424, $p = .657$) or diastolic blood pressure (Wilks' $\lambda = .93$, F (2, 53) = 1.99, $p = .146$) (see Table 2).

Table 2. *Descriptive Statistics for Physiological Difference Scores*

	Placebo		100 mg Caffeine		300 mg Caffeine	
	Mean	SD	Mean	SD	Mean	SD
Heart Rate	-2.27	14.23	-4.33	9.94	-4.78	11.22
Systolic BP	-3.09	8.87	-1.64	15.53	4.38	13.46
Diastolic BP	-1.56	12.96	-1.18	17.32	3.47	14.84

Note: $N = 55$. Means are difference scores (post-caffeine minus pre-caffeine values). *SD* = Standard Deviation.

Although participants were blind to the test condition, responses on the Test Condition Questionnaire revealed that many participants were able to correctly identify whether they had received the placebo or a stimulant. Forty percent of participants were accurate in the placebo and 300 milligram condition, but less accurate in their detection of 100 milligrams (see Table 3). However, only five individuals in the entire sample correctly guessed that they had a stimulant during both caffeine conditions, and only two participants correctly guessed all three conditions.

Table 3. *Descriptive Statistics for Correct Identification of Dose*.

	Condition guess		
	Placebo	Stimulant	Sedative
Placebo condition	**22 (40.0%)**	13 (23.6%)	19 (34.5%)
100 mg caffeine condition	22 (40.0%)	**16 (29.1%)**	16 (29.1%)
300 mg caffeine condition	13 (23.6%)	**25 (45.5%)**	16 (29.1%)

Note: $N = 54$. One participant was not included in analysis due to omitted data. Text in bolded font indicates correct estimate.

Mood Changes

The effect of caffeine on mood was measured by examining the change in POMS scores from pre-caffeine to post-caffeine values with a one-way repeated measures analysis of variance (ANOVA) (see Table 4). The impact on Total Mood Disturbance was not significant. However, a significant difference was found on the Depression-Dejection subscale. Individuals in the placebo group experienced the greatest decrease in Depression-Dejection, while those in the 100 mg and 300 mg groups experienced smaller decreases. However, paired samples *t* test indicate that these difference scores were not significant in any of the conditions, (100 mg - 300 mg, $t(54) = -1.81$, $p = 0.08$; placebo - 100 mg, $t(54) = -1.90$, $p = 0.06$; placebo - 300 mg, $t(54) = -1.08$, $p = 0.28$). The former finding suggests a relationship approaching significance. Since total mood was not related to caffeine condition, it was not controlled in further analyses.

Table 4. *Descriptive* Statistics *for Difference Scores on the POMS*

	Placebo	100 mg	300 mg		
	Mean (SD)	Mean (SD)	Mean (SD)	*F* (*p*)	η^2
Tension-Anxiety	0.05 (258)	0.31 (3.48)	-0.49 (3.25)	1.34 (0.27)	0.048
Depression-Dejection	1.84 (6.58)	0.16 (1.33)	0.80 (2.58)	3.47 (0.04)	0.116
Anger-Hostility	1.21 (4.85)	0.35 (1.09)	0.51 (1.80)	0.92 (0.40)	0.034
Vigor-Activity	2.07 (5.17)	0.98 (3.31)	-0.17 (5.09)	2.75 (0.07)	0.095
Fatigue-Inertia	0.91 (4.27)	1.49 (2.94)	1.25 (3.43)	0.34 (0.71)	0.013
Confusion-Bewilderment	-0.22 (2.18)	0.11 (1.93)	0.25 (1.92)	0.75 (0.48)	0.027
Total Mood Disturbance*	2.60 (5.64)	3.21 (6.78)	1.49 (6.77)	1.15 (0.33)	0.043

Note: $N = 55$; * = Total Mood Disturbance combines the 6 subscales (weighing Vigor negatively). Means are difference scores (post-caffeine minus pre-caffeine values). *SD* = Standard Deviation.

Hypothesis 1: ImPACT Cognitive Task Performance

The first hypothesis of the present study was that there would be significant differences in performance on three different trials of the ImPACT Neurocognitive Performance measure. In order to test whether performance in the caffeine conditions would improve relative to the placebo condition, a one-way repeated-measures ANOVA was conducted to compare mean scores. Descriptive statistics for participants' composite scores across each session are displayed in Table 5. There was a significant effect of caffeine on tasks of Visual Memory (Wilks' $\lambda = .82$, $F(2, 53) = 5.871$, $p = .005$), but there were not significant differences on the other index scores. Participants performed better on visual memory tasks under the placebo condition, and worse after consuming doses of caffeine. Examination of the data indicate that verbal tasks were more difficult for participants, as was evidenced by the percent of verbal and visual memory tasks correctly answered after a delay.

Table 5. *Descriptive Statistics for Scores on the ImPACT Composite Scores*

	Placebo	100 mg	300 mg		
	Mean (SD)	Mean (SD)	Mean (SD)	*F* (*p*)	η^2
Verbal Memory Composite	88.60 (9.78)	90.02 (7.92)	89.02 (7.93)	0.88 (0.42)	0.032
Visual Memory Composite	74.87 (14.75)	72.18 (11.42)	68.53 (13.48)	5.87 (0.01)	0.112
Visual Motor Speed Composite	42.89 (7.17)	43.39 (5.66)	43.63 (5.70)	0.40 (0.67)	0.015
Reaction Time Composite	0.57 (0.12)	0.55 (0.06)	0.55 (0.07)	1.46 (0.24)	0.052
Impulse Control Composite	5.13 (3.14)	5.02 (2.98)	4.55 (2.78)	1.03 (0.36)	0.038
Cognitive Efficiency Scale	0.39 (0.16)	0.42 (0.10)	0.42 (0.11)	1.11 (0.34)	0.040

Note: $N = 55$

Three paired-samples *t* tests were conducted to follow-up the significant change in Visual Memory Composite. Differences in mean scores between the three caffeine conditions were significant between 100 milligrams and 300 milligrams, $t\ (54) = 2.25$, $p = 0.03$, and placebo and 300 milligrams, $t\ (54) = -3.42$, $p = 0.01$. However, change scores were not significant between the 100 milligram and placebo doses, $t\ (54) = -1.60$, $p = 0.14$. Visual memory composite scores were significantly lower in the 300 mg condition than in the 100 mg or placebo conditions, suggesting that a high dose of caffeine may impair performance on visual memory tasks. Individual scores are discussed below.

Verbal Memory Composite. To examine participants' performance in greater detail, repeated-measures ANOVAs were used to evaluate differences in each of the four scores used to calculate the composite. The Verbal Memory Composite score is calculated by averaging the percent of correct words remembered both immediately and after a delay (Module 1), total correct hidden symbols in Module 4 (Symbol Match), and total percent of letters correct in Module 6 (Three Letters). Participants' performance on Module 1 (Word Memory) was not affected by varying doses of caffeine, as mean score changes on the number of correct words

(Immediate: Wilks' λ = .955, F (2, 53) = 1.250, p = .295; Delay: Wilks' λ = .993, F (2, 53) = .194, p = .825 and correct distractors (Immediate: Wilks' λ = .958, F (2, 53) = 1.148, p = .325; Delay: Wilks' λ = .999, F (2, 53) = .034, p = .967) were not significant.

Evaluation of the number of correct responses in Module 4 revealed no significant differences between participants' total correct responses while symbols were hidden (Wilks' λ = .976, *F* (2, 53) = 0.660, *p* = .521). There were no significant differences in the number of letters recalled on Module 6 (Wilks' λ = .982, *F* (2, 53) = 0.485, *p* = .619) (see Table 6).

Table 6. *Descriptive Statistics for Scores on the ImPACT Verbal Memory Composite*

	Placebo	100 mg	300 mg		
	Mean (SD)	Mean (SD)	Mean (SD)	*F* (*p*)	η^2
Mod 1. Hits (Immediate)	11.45 (1.60)	11.67 (0.72)	11.55 (0.92)	1.25 (0.30)	0.045
Mod 1. Hits (Delay)	9.96 (1.49)	10.15 (2.13)	9.95 (2.06)	0.19 (0.83)	0.007
Mod. 4 Total Correct (Hidden)	7.04 (2.02)	7.58 (3.06)	7.22 (1.64)	0.66 (0.52)	0.024
Mod 6. Total letters correct	14.24 (1.44)	14.33 (1.22)	16.67 (18.90)	0.49 (0.62)	0.018

Note: *N* = 55

Visual Memory Composite. The Visual Memory Composite includes the average of the total number of designs correct in Module 2 (Design Memory) and the total correct memory score in Module 3 (X's & O's). Overall there were no significant differences in Module 2 scores measuring the number of designs recalled immediately after presentation (Wilks' λ = .91, *F* (2, 53) = 2.715, *p* = .08) or following a delay (Wilks' λ = .98, *F* (2, 53) = .526, *p* = .59) (see Table 7). However, there were significant differences in identification of non-target images following a short (Wilks' λ = .72, *F* (2, 53) = 10.081, *p* = .00) and a long delay (Wilks' λ = .872, *F* (2, 53) = 3.905, *p* = .026) (see Table 7).

Three paired-samples *t* tests were conducted to follow-up the significant differences of correct identification of distracters between conditions in Module 2. Differences in mean scores were significant between the 100 and 300 milligram doses, t (54) = 4.36, p = 0.01, as well as between the placebo and 300 milligram doses, t (54) = -3.77, p = 0.01. This significant difference was not demonstrated between the placebo and 100 milligram doses, t (54) = -0.67, p = 0.50. There was also a significant difference in identification of non-targets after a delay between the placebo and 300 milligram doses, t (54) = -2.80, p = 0.01. These findings suggest that participants became more impaired in their ability to discern non-targets with increasing doses of caffeine, with significantly worsened performance at the high dose relative to placebo both immediately and following a delay.

Participants' performance on Module 3 did not vary as a function of caffeine in the number of correctly identified designs (Wilks' λ = .958, F (2, 53) = 1.163, p = .32) (see Table 7).

Table 7. *Descriptive Statistics for Scores on the ImPACT Visual Memory Composite*

	Placebo	100 mg	300 mg		
	Mean (SD)	Mean (SD)	Mean (SD)	F (p)	η^2
Mod. 2. Hits (Immediate)	10.02 (1.91)	9.69 (1.53)	9.27 (1.92)	2.72 (0.08)	0.093
Mod. 2. Distractors (Imm.)	10.00 (2.13)	9.82 (1.79)	8.67 (2.00)	10.08 (0.00)	0.276
Mod. 2.Hits (Delay)	9.91 (1.77)	9.78 (1.64)	9.64 (1.52)	0.536 (0.59)	0.019
Mod. 2. Distractors (Delay)	8.98 (2.59)	8.40 (2.08)	7.85 (2.48)	3.91 (0.03)	0.128
Mod. 3 Total (Memory)	8.13 (2.67)	7.80 (2.30)	7.56 (2.53)	1.16 (0.32)	0.042

Note: N = 55

Visual Motor Speed. The Visual Motor Speed composite is calculated from the total number of correct responses in Module 3 (X's & O's) interference task and the average correctly counted numbers (25 to 1) from the Module 6 (Three Letters) distractor task. Performance on

the interference component of Module 3 was examined, and there were no significant differences in the number counted correctly during the distractor task (Wilks' $\lambda = .968$, F (2, 53) = 0.864, p = .43). Additionally, there were no significant differences in the average of numbers counted correctly during the distractor task (Wilks' $\lambda = .933$, F (2, 53) = 1.893, p = .161) (see Table 8).

Table 8. *Descriptive Statistics for Scores on the ImPACT Visual Motor Speed Composite*

	Placebo	100 mg	300 mg		
	Mean (SD)	Mean (SD)	Mean (SD)	F (p)	η^2
Mod. 3 Total Correct (Inter.)	115.27 (6.92)	116.91 (5.83)	117.67 (6.19)	4.40 (0.17)	0.142
Mod. 6. Avg. counted correctly	18.26 (4.71)	19.18 (3.63)	19.28 (3.56)	1.89 (0.16)	0.067

Note: N = 55

Reaction Time. The Reaction Time composite score is comprised of the average correct reaction time during Module 3 (X's and O's), average correct reaction time during Module 4 (Symbol Match), and average correct reaction time during Module 5 (Color Match). Participants' reaction time did not vary as a function of caffeine during the distractor task of Module 3 (Wilks' $\lambda = .968$, F (2, 53) = 0.864, p = .43). Evaluation of performance on Module 4 indicated that participants differed significantly on the number of targets correctly matched while the symbols were visible (Wilks' $\lambda = .852$, F (2, 53) = 4.616, p = .014). On average, participants performed significantly better after consumption of 100 mg of caffeine than either the placebo or 300 mg dose. There were no significant differences between participants regarding reaction time (Visible: Wilks' $\lambda = .963$, F (2, 53) = 1.028, p = .365; Hidden: Wilks' $\lambda = .946$, F (2, 53) = 1.519, p = .228). On Module 5, participants failed to show changes in reaction time (Correct: Wilks' $\lambda = .962$, F (2, 53) = 1.033, p = .36; Commissions: Wilks' $\lambda = .967$, F (2, 53) = 0.907, p = .41). (see Table 9).

Table 9. *Descriptive Statistics for Scores on the ImPACT Reaction Time Composite*

	Placebo	100 mg	300 mg		
	Mean (SD)	Mean (SD)	Mean (SD)	*F* (*p*)	η^2
Mod 3. Avg. Correct – RT	0.38 (0.84)	0.40 (0.14)	0.38 (0.11)	0.86 (0.43)	0.032
Mod. 4. Avg. Correct RT (Visible)	1.52 (0.50)	1.42 (0.23)	1.44 (0.32)	1.03 (0.37)	0.037
Mod. 4. Avg. Correct RT (Hidden)	1.44 (0.37)	1.54 (0.44)	1.48 (0.38)	1.52 (0.23)	0.054
Mod. 5 Average Correct RT	0.72 (0.18)	0.71 (0.13)	0.69 (0.12)	1.03 (0.36)	0.038
Mod. 5 Average Commission RT	0.23 (0.84)	0.08 (0.18)	0.10 (0.23)	0.91 (0.41)	0.033

Note: $N = 55$

Impulse Control. The Impulse Control Composite is calculated from the total correct responses from the distractor condition of Module 3 (X's and O's) and the average correctly counted numbers (25 to 1) of Module 6 (Three Letters). One-way repeated measures ANOVA did not demonstrate differences in performance across doses for the number of incorrect responses during Module 3 interference (Wilks' $\lambda = .955$, F (2, 53) = 1.237, $p = .30$), or total errors of commissions in Module 6 (Wilks' $\lambda = .981$ F (2, 53) = 0.509, $p = .60$), (see Table 10).

Table 10. Descriptive Statistics for Scores on the ImPACT Impulse Control Composite

	Placebo	100 mg	300 mg		
	Mean (SD)	Mean (SD)	Mean (SD)	*F* (*p*)	η^2
Mod 3. Total Incorrect (Inter.)	4.87 (2.93)	4.84 (2.89)	4.29 (2.66)	1.24 (0.30)	0.045
Mod. 6. Total commissions	0.25 (0.52)	0.18 (0.39)	0.18 (0.38)	0.51 (0.60)	0.019

Note: $N = 55$

Hypothesis 2: Risk-taking

A one-way repeated-measures ANOVA was used to determine whether there were significant changes in risk-taking between each of the doses. The adjusted ART score represents the average number of casts participants made on fishing trips during a tournament for which they did not catch a blue fish. The data in Table 11 demonstrate the differences in performance, indicating that participants cast fewer times in the caffeine conditions (100 and 300) relative to the placebo condition (Wilks' $\lambda = .877$, F (2, 50) = 3.505, $p = .038$).

Three paired-samples *t* tests were conducted to follow-up the significant differences in ART scores. Differences in mean scores between the placebo and 300 milligram doses were significant, t (52) = -2.59, $p = 0.01$. However, the changes scores were not significant between the 100 milligram and 300 milligram doses, t (52) = 0.56, $p = 0.58$, or placebo and 100 milligrams, t (52) = -1.93, $p = 0.06$. The latter finding suggests a relationship approaching significance.

Table 11. *Descriptive Statistics for Scores on the Angling Risk Taking Task*

	Placebo	100 mg	300 mg		
	Mean (SD)	Mean (SD)	Mean (SD)	F (p)	η^2
Adjusted ART score	44.49 (17.46)	41.17 (17.30)	40.07 (14.83)	3.51 (0.04)	0.123

Note: N = 52. Data from three individuals were not properly saved, and thus were not included in this analysis.

Hypothesis 3: Mood as a Moderator

Given that previous analyses examining changes in mood were not significant, there is no moderation to be detected in the variables.

Additional Analyses

Mental Rotation

A repeated measures ANOVA was also computed for the MRT-A. Table 12 presents the findings, demonstrating that the differences in scores are not significant (*Wilk's Λ* = 0.93, *F* (2, 53) = 1.98, *p* = .148). As predicted, the spatial control task was generally unaffected by the caffeine condition.

Table 12. *Descriptive Statistics for Scores on the Mental Rotations Task*

	Placebo	100 mg	300 mg		
	Mean (SD)	Mean (SD)	Mean (SD)	*F* (*p*)	η^2
MRT-A	4.84 (4.69)	6.04 (5.28)	5.24 (4.81)	1.98 (0.15)	0.070

Note: *N* = 55

Order Effects

A two-way repeated measures analysis of variance was conducted to evaluate the effect of order on performance on the ImPACT domains. There were three patterns to which participants were assigned: 100 mg, 300mg, placebo (Pattern A), 300 mg, placebo, 100 mg (Pattern B), and placebo, 100 mg, 300 mg (Pattern C). The within-subjects factor was the order in which they completed each condition (Pattern A, Pattern B, or Pattern C). No significant interactions were found between order group and performance on ImPACT domains measuring verbal memory (*Wilk's Λ* = 0.88, *F* (4, 102) = 1.67, *p* = .162), visual memory (*Wilk's Λ* = .92, *F (4*, 102) = 1.10, *p* = .361), reaction time (*Wilk's Λ* = .94, *F* (4, 102) = 0.74, *p* = .566), or impulse control (*Wilk's Λ* = .93, *F* (4, 102) = 1.00, *p* = .414). However, there was a significant interaction for performance on Visual Motor Speed Composite (*Wilk's Λ* = .79, *F* (4, 102) = 3.14, *p* = .018), with those in Pattern A performing significantly better on each of the three conditions than those

in Patterns B or C. The Visual Motor Speed composite is composed of the total number correct of the interference component of Module 3 and the average numbers counted correctly in the distractor component of Module 6. In addition, there was no effect of order on risk taking (*Wilk's Λ* = .86, *F* (4, 96) = 1.89, *p* = .118).

Gender Differences

Gender differences were examined using a mixed 2 X 3 ANOVA in order to determine whether there were differential effects of caffeine on men compared to women. There was a significant interaction between verbal memory composite scores and sex, with men performing better on the verbal memory task (Module 1) than women (*Wilk's Λ* = 0.89, *F* (2, 52) = 3.17, *p* = .05), with a significant difference between the placebo and 100 milligram caffeine dose, *t* (19) = 2.59 *p* = 0.02. However, there was no significant main effect for sex on verbal memory performance. No significant main effects or interactions were found between sex and performance on any of the other ImPACT domains (visual memory (*Wilk's Λ* = 0.96, *F (2*, 52) = 1.21, *p* = .31), visual motor speed (*Wilk's Λ* = .95, *F* (2, 52) = 1.42, *p* = .251), reaction time (*Wilk's Λ* = .96, *F* (2, 52) = 0.98, *p* = .38), or impulse control (*Wilk's Λ* = .99, *F* (2, 52) = 0.40, *p* = .67).

Difference scores on the ART and Mental Rotations Task were also examined using a mixed 2 x 3 ANOVA to determine whether caffeine affected men and women differently. There was a significant main effect for sex on the Mental Rotations task, with men performing better than women on all three conditions (*F (1*, 53) = 6.89, *p* = 0.01), although no interaction effect was detected (*Wilk's Λ* = 0.99, *F (2*, 52) = .224, *p* = .800). No significant main effects or interactions were found between men and women's performance on the Angling Risk Task (*Wilk's Λ* = 0.90, *F (2*, 49) = 2.704, *p* = .077).

Influence of Correct Prediction

This current study blinded participants to their conditions, and at the end of each session they were asked to estimate which dose they believe they consumed. To examine whether knowledge of caffeine condition affected performance, the scores of participants who correctly assessed their performance in both caffeine conditions were evaluated. No significant interactions or main effects were found between those who correctly guessed when they consumed caffeine and performance on ImPACT domains measuring verbal memory (*Wilk's Λ* = 0.918, *F (4*, 100) = 1.09, *p* = .364), visual memory (*Wilk's Λ* = 0.96, *F (4*, 100) = 0.48, *p* = .751), visual motor speed (*Wilk's Λ* = .899, *F* (4, 100) = 1.368, *p* = .251), reaction time (*Wilk's Λ* = .979, *F* (4, 100) = 0.263, *p* = .901), or impulse control (*Wilk's Λ* = .855, *F* (4, 100) = 2.032, *p* = .096).

Furthermore, the scores of those who believed that they consumed caffeine were not significantly different from those who believed that they consumed a sedative or placebo. Although there were significant interaction effects for the Impulse Control domain (*Wilk's Λ* = 0.82 *F (4*, 102) = 2.595, *p* = .04), for those who believed that they consumed caffeine during the 300 milligram condition, there was no main effect (*Wilk's Λ* = 0.913 *F (2*, 51) = 2.443, *p* = .10). Further, there were no significant interactions or main effects on ImPACT domains measuring verbal memory (*Wilk's Λ* = 0.983, *F (2*, 51) = 0.441, *p* = .65), visual memory (*Wilk's Λ* = 0.960, *F (2*, 51) = 1.07, *p* = .349), visual motor speed (*Wilk's Λ* = .955, *F (2*, 51) = 1.21, *p* = .307), or reaction time (*Wilk's Λ* = .918, *F* (2, 51) = 2.269, *p* = .114).

Similarly, there were no significant main effects or interactions for verbal memory (*Wilk's Λ* =0.976, *F (2*, 51) = .619, *p* = .542), visual memory (*Wilk's Λ* = .962, *F (2*, 51) = 1.01, *p* = .369), visual motor speed (*Wilk's Λ* = .95, *F* (2, 51) = 1.341, *p* = .251), reaction time (*Wilk's Λ*

= .917, *F* (2, 51) = 2.32, *p* = .108), or impulse control (*Wilk's Λ* = .922, *F* (2, 51) = 2.151, *p* = .127) between those who believed that consumed caffeine in the 100 milligram condition and those who did not.

Caffeine Sensitivity

Because there were few effects of caffeine on physiological, mood, and neurocognitive measures, the data were further examined to better explain the findings. Separate one-way repeated measures ANOVAs were computed for individuals who demonstrated sensitivity to caffeine. These individuals were selected for analysis if they experienced increases in at least two of the three physiological reaction scores (i.e. heart rate, diastolic blood pressure, systolic blood pressure) following the 300 milligram dose (N= 24). Results indicated that there were no differences in mood or ImPACT domains. However, there was a significant finding for Visual Memory Composite, suggesting that individuals performed worse in the caffeine conditions (Wilks' λ = .66, F (2, 22) = 5.77, p = .01).

Similar results were found when the analyses were limited to individuals who experienced changes in all three of the physiological reaction scores following the 300 milligram dose (*N* = 7). There were no differences in the mood or ImPACT scores, although results of the one-way repeated measures ANOVA again indicated a significant effect on Visual Memory (Wilks' λ = .06, *F* (2, 5) = 42.83, *p* = .01), demonstrating that individuals performed worse in the caffeine conditions.

Summary of Findings

It appears that caffeine resulted in significant differences in performance on the risk-taking measure and visual memory composite score, suggesting that caffeine may have a mild

effect on performance. However, taken together the results of the current study suggest that there is not a consistently significant relationship between caffeine intake and cognitive abilities. In addition, caffeine did not have a considerable influence on mood or anticipated physiological measures. It appears that the effects of caffeine are mild, and the current findings suggest limited influence of stimulants on performance.

CHAPTER IV

DISCUSSION

In the present study, the ingestion of caffeine did not result in changes in anticipated domains, calling into question past findings that caffeine has an influence on motor speed, physiological measures and verbal memory. In addition, the subjective effects of caffeine seem minimal, as only five participants in the current study correctly hypothesized that they had a stimulant during both caffeine conditions, and only two participants correctly guessed for all three sessions. If participants are unable to correctly determine whether they have consumed a stimulant and do not display meaningful changes in mood or cognition, then the influence of caffeine may indeed be negligible at these levels.

The blinding of doses to participants was a unique component of this study that has been underutilized in much of the caffeine literature. Other research efforts that employed blinding also found no improvements in the anticipated domains (e.g. Smith, Sturgess, & Gallagher, 1999; Judelson et al., 2005). Taken together, the lack of findings in well-controlled studies may provide evidence for the minimal direct impact of caffeine, and instead suggests that perception may have an influence on performance. Kelemen and Creeley (2001) showed that expectancies about caffeine were more closely related to cognitive performance than actual dosage. Similarly, Fillmore and Vogel-Sprott (1992) found that participants who believed that caffeine would improve performance on a pursuit rotor task showed improved performance, but those who believed that it would impair performance showed slowed performance, although all participants unknowingly consumed decaffeinated beverages.

Present Study

The results of the present study suggest a modest relationship between caffeine in the domains of visual memory and risk taking. During the placebo condition of the visual memory tasks, participants were better at identifying non-target images than while in the caffeine conditions. However, the direction of the relationship was not as anticipated, as the results of the current study suggest that performance on visual memory tasks was impaired after consuming caffeine. Although most research has suggested improvements in functioning, some have demonstrated similar impairments in functioning as a result of caffeine, as well (e.g. Terry & Phifer, 1986).

Given the number of analyses involved in the present study, the meaning of significant differences in the Visual Memory Composite must be evaluated. Past research has demonstrated the high convergent validity of the Visual Memory Composite with the other ImPACT domains (e.g., Verbal Memory $r = .75$) (Iverson, Franzen, Lovell, & Collins, 2003). This correlation with other composites suggests that these are related constructs, and thus significant findings should be relating consistent across domains. Nevertheless, Visual Memory was the only significant cognitive composite throughout the study, suggesting that this difference may be attributed to error rather than true differences.

In addition, individuals made less-risky decisions on the Angling Risk task after consuming caffeine than placebo. It is possible that this finding is the result of increased dopaminergic neurotransmission following caffeine intake, which has been implicated in the decision-making process (Adinoff, 2004). This finding is consistent with past research that suggests that risky behaviors are reduced following caffeine (e.g. Killgore et al., 2007). However, the lack of research in this area demands for further investigation of decision-making,

as the few studies of caffeine and risk-taking have involved chronic caffeine intake or performance on tasks after long periods of sleep deprivation. Furthermore, this area of research seems to be limited to a military sample, and further understanding may be applicable to other populations.

Physiological and Mood Effects

Caffeine did not result in changes in mood or physiological measures in the current study. Past research has suggested that caffeine has a positive influence on mood at low doses (e.g. Mumford et al., 1994; Nehlig, 2007), whereas high doses can result in short-term effects of anxiety, nervousness, jitteriness, and insomnia (e.g. Fredholm et al., 1999; Lieberman et al., 1987). However, the physiological effects of caffeine are not well understood, as epidemiological studies have produced contradictory findings about the relationship between blood pressure and caffeine consumption (Nurminen, Niittynen, Korpela, & Vapaatalo, 1999). Research that has been carefully controlled and utilized placebo-controlled, crossover, double blind studies have not consistently demonstrated within-group differences on heart rate, systolic, or diastolic blood pressure (e.g. Seifert, Nelson, Devonish, Burke, & Stohs, 2011). Similarly, there were minimal changes in mood ratings following the caffeine doses. The differences on POMS scores did not suggest that the doses had an effect on mood. The findings of caffeine on mood are also mixed, as many studies failed to find differences in mood after consuming caffeine relative to placebo (e.g. Hewlett & Smith, 2006).

Aside from methodological disparities, it is unclear what causes these discrepancies. Past reports have suggested that regular caffeine consumers develop a rapid tolerance to caffeine that minimizes the effects on mood, blood pressure, and heart rate. The mechanism by which this believed to occur is adenosine receptor upregulation (e.g. increase in receptor numbers)

(Fredholm 1982). Given that participants were required to be regular consumers of caffeine, this mechanism may also explain the lack of significant findings between conditions.

Cognitive Research

In the present study, the ingestion of caffeine did not result in changes in cognitive domains, such as psychomotor speed, reaction time or verbal memory, contrary to much of the research that has demonstrated such effects (e.g., Fagan et al., 1988; Kaplan et al., 1997; Lieberman et al., 1987; Swift & Tiplady, 1988). However, the available research highlighting caffeine's effects are inconsistent at best, and this study was designed to address several methodological shortcomings of past research. For instance, much of the past research was purely correlational rather than experimental. In other words, several studies examined the co-occurrence of caffeine use with performance, but did not control for caffeine abstinence prior to the study and thus cannot establish a causal link (e.g. Jones & Lejuez, 2008; Lesk et al., 2009; Norman et al., 2008; van Boxtel, Schmitt, Bosma, & Jolles, 2003). Furthermore, many of these studies used self-report or non-blind administration of caffeine. Smith (2005) examined the impact of caffeine on work performance by simply examining self-reported daily intake with self-reported alertness and errors on the job. As previously discussed, there have been reports of expectancy effects following consumption of caffeine that likely influence results.

Other studies have suffered from small sample size (e.g. Quinlan, Lane, Aspinall, 1997; Mumford et al., 1996; Brice & Smith, 2001, Scholey & Kennedy, 2004) and others have generated results by examining differences between subjects in between subjects designs (e.g. . Christopher, Sutherland, Smith, 2005; Gruber & Block, 2005; Haskell et al., 2005; Hewlett & Smith, 2006; Hewlett & Smith, 2007; Lesk et al., 2009). Finally, more recent studies of higher level executive functions have examined performance only under sleep deprivation, but not non-

sleep deprived conditions (e.g. Deslandes et al., 2006; Killgore et al., 2006, 2007, 2008; Lieberman et al., 2002; Westensen et al., 2005).

Furthermore, even under rigorous methodological control, the patterns of significant results are easily misinterpreted if not carefully examined. For example, Christopher, Sutherland, and Smith (2005) found improvement in reaction time and vigilance following caffeine intake. However, the differences in scores were negligible, as only one of the three subscores of the focused attention task suggested a significant difference. Similar interpretations were made for other tasks in the battery (e.g. categoric search task), suggesting that there were not robust differences between caffeine conditions.

The most consistent findings have been established in laboratories utilizing simple reaction time and vigilance tasks, which are basic measures that do not address caffeine's influence on global cognitive abilities. The measures of performance have varied greatly in past studies, ranging from simple psychomotor activities to complex higher order tasks. The more complex functions such as those measured by the ImPACT have been less responsive to caffeine than the simple and repetitive activities (James & Rogers, 2005). Those that have examined caffeine's influence on higher order abilities such as planning and mental manipulation have often failed to demonstrate a significant effect (e.g., Lesk et al., 2009).

In sum, previous studies had many methodological errors that may have resulted in false positives: Several did not employ a within-subjects design, and coupled with a small sample size, the findings may be attributed to variance between subjects. The current study lends support for the limited influence of caffeine on overall functioning in healthy young adults, as the methodology addressed several of these limitations by exploring performance on a complete neurocognitive battery while also employing a within-subject, placebo-controlled crossover

design. In addition, all participants were tested at the same time of day, were given blinded caffeine or placebo doses in capsules (rather than via beverage that may not mask the condition), and were removed from analyses if they were taking medications that might interfere with caffeine's hypothesized effects. These precautions were taken to reduce the likelihood of erroneous findings.

Limitations

Given the lack of significant differences in physiological arousal between caffeine and placebo conditions, the procedure of the current study must be examined. As increases in blood pressure and heart rate are well-established effects of caffeine ingestion, it is likely that individuals may have certainly demonstrated these changes, but not before the second readings were completed. As caffeine reaches peak absorption between 40 and 70 minutes after ingestion (Mumford et al., 1995), a longer interval before the second physiological measurement and subsequent commencement of cognitive tasks may have yielded different results. As there is individual variance in this influence, it may have been wise to delay cognitive testing until each person demonstrated a certain degree of change from their baseline measurement. Although there would be other considerations if this methodology were adopted (e.g. determining the length of delay in the placebo condition), this is worth deliberation. More robust results might be demonstrated in this study if it was evident that caffeine was in the system. Furthermore, a third physiological reading at the end of this study may have determined the extent of physiological effects.

It is possible that the findings from the current study may have been the result of caffeine levels too low to result in significant changes in mood, blood pressure, heart rate, and cognitive performance. It is possible that a higher dose would have resulted in more robust differences

between sessions. However, this dose was selected because of its replication in the literature, as well as to mimic levels that are easily attained by participants over the course of normal testing conditions. Although it is possible to increase the amount of caffeine consumed in one setting, the findings may not be generalizable to other normal testing conditions.

In addition, doses were selected based on caffeine level without adjustments for individual body weight or sensitivity to caffeine. Although individuals were selected for these measures only if they endorsed regular caffeine consumption and removed if they routinely consumed high doses, it is impossible to control for individual variation in reactions. Few individuals demonstrated expected physiological arousal, which may contribute to the lack of findings. Only seven participants in the current sample demonstrated anticipated changes in both blood pressure and heart rate after consuming the high dose of caffeine. Evaluating their data in isolation still failed to demonstrate significant effects of caffeine on cognitive performance.

It was particularly difficult to estimate caffeine intake for participants, as many were unsure about the size of typical caffeinated beverages and were uncertain about the number of caffeinated drinks they consumed per day or per week. More accurate recordings would have been beneficial for permitting and dismissing a homogenous sample.

Participants were excluded if they indicated that they had consumed caffeine prior to testing, but it is possible that participants were not forthright about consumption or did not realize that their beverages or foods contained caffeine. Similarly, it is also possible that participants slept poorly (or not at all) or consumed other types of medication and stimulants, and were not aware of their consequences on the outcome of the study. Although efforts were made by the primary examiner to reduce this possibility (e.g. reminder emails), the results may have been affected by such factors.

Another potential weakness could lay in the selection of tests. Past researchers have suggested that negative findings were due to measures not sensitive enough to detect changes in performance, and thus the ImPACT was selected because it was designed to be repeated and sensitive to detect even minimal changes in performance. These neurocognitive tasks may not have the appropriate sensitivity to detect changes due to caffeine. However, the finding that the ImPACT was generally not sensitive to changes in caffeine intake suggests that caffeine intake is unlikely to significantly alter performance on cognitive tasks. This finding is important for interpretation in many areas, including computerized neurocognitive testing as well as neuropsychological testing, as it is such a widely consumed stimulant. If significant differences were consistently detected, the results would have widespread implications on future interpretation. Furthermore, changes in cognitive scores would have consequences for ImPACT test results, and the current examination further validates this measure as an accurate assessment of cognitive functioning without interference from routinely consumed stimulants.

Directions for Future Research

The current study detected significant differences in visual memory performance and risk-taking in participants on different levels of caffeine. These findings should be explored further to determine whether caffeine is responsible for individual variation in task performance. Furthermore, this relationship may have widespread application for practitioners who have nonverbal tasks of verbal memory in test batteries, and do not otherwise consider caffeine intake to contribute to performance.

The current research study utilized a blinded within-subjects design with a test battery developed for repetitive administration. Few studies to date have used this method, and future research should employ such rigid methodology to reduce the proliferation of erroneous results.

Given the mixed findings about caffeine in the literature, it is necessary that future studies maintain such control in order to understand whether and how this stimulant affects human cognition. Such information would have important implications for neurocognitive testing to be sure that interpretations and recommendations are based on accurate data, and ensure that the data generated resemble the most accurate assessment of functioning.

APPENDICES

APPENDIX A

Adult Consent Form

CMU
CENTRAL MICHIGAN UNIVERSITY

Study Title: The Acute Effects of Caffeine on Psychomotor, Memory, and Executive Functioning
Investigator: Adrienne L. West, Psychology Department (Telephone: 585-520-0286)

Introduction
You are invited to take part in a study that examines how individuals are affected by different doses of a stimulant or sedative. In order to participate, it is necessary that you routinely consume caffeine and have no current health conditions that preclude you from consuming stimulants. It is also necessary that you are a native speaker of English. Please tell the researcher now if this is not the case. The research assistant can answer any further questions you may have after reading this form.

What is the purpose of this study? This research examines how consumption of herbal supplements affects performance on memory and decision-making tasks.

What will I do in this study? This study involved *three separate testing sessions*. Before each testing session, you will be asked to refrain from caffeine and nicotine for 12 hours prior to the testing session. The study will require meeting in the morning to complete baseline measures and ingest the supplement that may or may not contain a mild stimulant, sedative, and/or placebo. After providing consent, you will take the supplement, wait a short period (30 minutes), and then perform two computer-based tasks and complete brief surveys. You will then be scheduled for two other testing days. Thus, you will be asked to perform the same tasks on three different days, and the testing will be the same on each of the three days.

How long will it take me to do this? Each of the three sessions will last approximately 70 minutes.

Are there any risks of participating in the study? In the current study you will be asked to consume a substance which may result in some physical side effects or mood changes for less than an hour. Some people may experience mild jitteriness as a side effect. Your blood pressure and heart rate will be monitored throughout testing to ensure that you are okay.

You will be asked to answer questions regarding basic demographic information and potentially illegal behavior (substance use). Privacy will be maintained by ensuring anonymity. The data from questionnaires will be converted to a research database and any identifying information will be coded to ensure privacy and confidentiality. An ID number will remain in the research

database, but it is an arbitrary number. Questionnaires and other related material will be kept separate from identifying information and will be destroyed upon the completion of the study. Some of the questions may be upsetting to some individuals. If any participant feels emotional distress, then the graduate student conducting the study can attend to that individual or can direct him/her to the on-campus psychology or counseling center clinic. The Counseling Center may be reached at (989) 774-338. The Psychological Training and Consultation Center can be reached at (989) 774-2824.

What are the benefits of participating in the study? There are no direct benefits to be gained from participating in this experiment. You will receive 3 SONA credits for each session you attend (i.e., 9 credits total). A single $100 gift card prize will be chosen randomly from all individuals who complete the entire study (all 3 sessions). In addition to the possibility of the $100 prize, you will receive extra credit for the various portions of the study. As an alternative to participating in the study, you may also earn extra credit by reading and summarizing an article provided by the experimenter. You have the right to withdraw from the study at any time; however, if you choose to discontinue participation your name will not be included in this raffle.

Will anyone know what I do or say in this study (Confidentiality)? The participant number you are assigned helps to protect the confidentiality of your reading test score. Confidentiality of your research records will be strictly maintained and will not include identifying information such as your name or student ID. The data and this consent form will be kept confidentially on computers and in a locked cabinet that is accessible to authorized investigators only. In any sort of report we might present or publish, we will not include any information that will make it possible to identify you. Data from the session will only be viewed by researchers for research purposes. All data will be destroyed after five years.

Will I receive any compensation for participation? You will receive SONA credits total for your participation in this experiment. Credits will be awarded after you complete the third session.

Is there a different way for me to receive this compensation or the benefits of this study? Contact your instructor for information about alternative ways to earn extra credit in your class.

Who can I contact for information about this study? A verbal and written explanation of the study will be provided to you. If you have any questions at this time, please do not hesitate to ask. If any additional questions occur please feel free to contact Dr. Reid Skeel (989-774-6485) or Adrienne West (585-520-0286).

You are free to refuse to participate in this research project or to withdraw your consent and discontinue participation in the project at any time without penalty or loss of benefits to which you are otherwise entitled. Your participation will not affect your relationship with the institution(s) involved in this research project.

If you are not satisfied with the manner in which this study is being conducted, you may report (anonymously if you so choose) any complaints to the Institutional Review Board by calling

989-774-6777, or addressing a letter to the Institutional Review Board, 251 Foust Hall Central Michigan University, Mt. Pleasant, MI 48859.

My signature below indicates that all my questions have been answered. I agree to participate in the project as described above.

_____

Signature of Subject Date Signed

A copy of this form has been given to me. _____Subject's Initials

_____

Signature of Responsible Investigator Date Signed

APPENDIX B

CAFFEINE CONSUMPTION QUESTIONNAIRE (CCQ)

Adapted from Landrum (1992)

Please answer the following questions about your typical caffeine usage. Respond to items that you consume <u>at least once a week</u>.

COFFEE	MORNING	AFTERNOON	EVENING	NIGHT
(8 oz. servings/week)	6am – 12pm	12pm – 6pm	6pm – 2am	2am – 6am
<u>Caffeinated</u>				
Regular Brewed	_____	_____	_____	_____
Drip-Brewed	_____	_____	_____	_____
Instant	_____	_____	_____	_____
Percolated	_____	_____	_____	_____
<u>Decaffeinated</u>				
Regular Brewed	_____	_____	_____	_____
Drip-Brewed	_____	_____	_____	_____
Instant	_____	_____	_____	_____
Percolated	_____	_____	_____	_____
TEA				
(5 oz. servings/week)	_____	_____	_____	_____
COCOA				
(5 oz. servings/week)	_____	_____	_____	_____
CHOCOLATE				
(8 oz. servings/week)	_____	_____	_____	_____
SOFT DRINKS	MORNING	AFTERNOON	EVENING	NIGHT
(12 oz. servings/week)	6am – 12pm	12pm – 6pm	6pm – 2am	2am – 6am
Coca-Cola	_____	_____	_____	_____
Diet Coca-Cola	_____	_____	_____	_____
Dr. Pepper	_____	_____	_____	_____
Diet Dr. Pepper	_____	_____	_____	_____
Mountain Dew	_____	_____	_____	_____
Diet Mountain Dew	_____	_____	_____	_____
Mr. Pibb	_____	_____	_____	_____
Diet Mr. Pibb	_____	_____	_____	_____
Pepsi Cola	_____	_____	_____	_____
Diet Pepsi Cola	_____	_____	_____	_____
RC Cola	_____	_____	_____	_____
Mello Yello	_____	_____	_____	_____
Diet Mello Yello	_____	_____	_____	_____

Root Beer	_____	_____	_____	_____
Red Bull	_____	_____	_____	_____
Other Energy Drinks	_____	_____	_____	_____

OVER-THE-COUNTER DRUGS

(Tablets/week)				
Vivarin	_____	_____	_____	_____
NoDoz	_____	_____	_____	_____
Excedrin	_____	_____	_____	_____
Vanquish	_____	_____	_____	_____
Anacin	_____	_____	_____	_____
Dristan	_____	_____	_____	_____
Dexatrim	_____	_____	_____	_____

APPENDIX C

BACKGROUND INFORMATION/MEDICAL HISTORY QUESTIONNAIRE

Subject Number: _____

Name _____

Indicate an address where you will be at the end of this semester so we can contact you if you win the $100.

_____

_____

Age: _____

Education (indicate your highest level of education attainment, for example, 3rd year college education): _____

Handedness (check one): Right-handed _____ Left-handed _____

Race: _____

Siblings (indicate the number of siblings and their ages):

_____

Is English your native language? (check one): Yes ____ No _____

Do you smoke? (check one): Yes _____ No _____

Have you ever been a smoker?

If yes, have you smoked more than ten cigarettes in your lifetime?

Yes _____ No _____

Have you ever been hit in the head hard enough to lose consciousness for more than 20 minutes?

If so, please describe.

_____

_____

Do you have any history of learning disabilities? If so, please describe.

_____

_____

Are you currently taking any prescription medications (*including oral contraceptives)*? If so, please list them below

_____

_____

Are you currently pregnant or trying to become pregnant? Yes ____ No _____

Have you recently had a child? Yes ____ No _____

If yes, are you breastfeeding? Yes ____ No _____

Do you have any medical problems (e.g., high blood pressure, heart problems, respiratory problems, diabetes)? If so please list below.

_____

_____

Even if you do not currently have medical problems, have you ever had any medical problems (e.g., high blood pressure, heart problems, respiratory problems, diabetes)? If yes, please list below.

_____

_____

APPENDIX D

PROFILE OF MOOD STATES

McNair & Heuchert (2003)

Describe HOW YOU FEEL RIGHT NOW by circling one space after each of the words listed below:

Feeling:	Not at all	A little	Moderately	Quite a bit	Extremely
Friendly	1	2	3	4	5
Tense	1	2	3	4	5
Angry	1	2	3	4	5
Worn Out	1	2	3	4	5
Unhappy	1	2	3	4	5
Clear-headed	1	2	3	4	5
Lively	1	2	3	4	5
Confused	1	2	3	4	5
Sorry for things done	1	2	3	4	5
Shaky	1	2	3	4	5
Listless	1	2	3	4	5
Peeved	1	2	3	4	5
Considerate	1	2	3	4	5
Sad	1	2	3	4	5
Active	1	2	3	4	5
On edge	1	2	3	4	5
Grouchy	1	2	3	4	5
Blue	1	2	3	4	5
Energetic	1	2	3	4	5
Panicky	1	2	3	4	5
Hopeless	1	2	3	4	5
Relaxed	1	2	3	4	5
Unworthy	1	2	3	4	5
Spiteful	1	2	3	4	5
Sympathetic	1	2	3	4	5
Uneasy	1	2	3	4	5
Restless	1	2	3	4	5
Unable to concentrate	1	2	3	4	5
Fatigued	1	2	3	4	5
Helpful	1	2	3	4	5
Annoyed	1	2	3	4	5
Discouraged	1	2	3	4	5
Resentful	1	2	3	4	5
Nervous	1	2	3	4	5
Lonely	1	2	3	4	5

Miserable	1	2	3	4	5
Muddled	1	2	3	4	5
Cheerful	1	2	3	4	5
Bitter	1	2	3	4	5
Exhausted	1	2	3	4	5
Anxious	1	2	3	4	5
Ready fo fight	1	2	3	4	5
Good-Natured	1	2	3	4	5
Gloomy	1	2	3	4	5
Desperate	1	2	3	4	5
Sluggish	1	2	3	4	5
Rebellious	1	2	3	4	5
Helpless	1	2	3	4	5
Weary	1	2	3	4	5
Bewildered	1	2	3	4	5
Alert	1	2	3	4	5
Deceived	1	2	3	4	5
Furious	1	2	3	4	5
Effacious	1	2	3	4	5
Trusting	1	2	3	4	5
Full of pep	1	2	3	4	5
Bad Tempered	1	2	3	4	5
Worthless	1	2	3	4	5
Forgetful	1	2	3	4	5
Carefree	1	2	3	4	5
Terrified	1	2	3	4	5
Guilty	1	2	3	4	5
Vigorous	1	2	3	4	5
Uncertain about things	1	2	3	4	5
Bushed	1	2	3	4	5

APPENDIX E

TEST CONDITION QUESTIONNAIRE

Subject Number _____

In which of the following test conditions do you think you participated?

Place a check mark next to one of the following conditions.

_____ Placebo

_____ Stimulant

_____ Sedative

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