4-2018

Caffeine Rush! Examining the Effects of Caffeine on Spatial Working Memory

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Abstract

Past research concerning caffeine and its effects on memory have yielded varying results. One study found that a 3-mg/kg dose of caffeine decreased reaction time during a selective attention task. However, this improvement was only found during a low display load, with no effect on reaction time occurring within a high display load (Lorist, Snell, Kok, & Mulder,1996). As such, the effects of caffeine may be dependent on a variety of other factors, such as the difficulty of the task at hand (Nehlig, 2004). This present study aimed to explore further the potential memory-enhancing qualities of caffeine with respect to spatial working memory. In order to test for any possible effects, a matched-pairs design was conducted to compare the number of errors committed, amount of moves taken, and time till task completion between a placebo and experimental group as the participants completed a series of levels within a computerized version of the popular puzzle game, *Rush Hour* (Di Vece, 2001). Repeated-measures ANOVAs (N=20) showed no significant effects of condition for any of the variables of performance studied. However, a trend analysis to examine potential changes over time with respect to condition was not conducted. A separate measure to assess any stress incurred (Dundee Stress State Questionnaire) was also used in this study. Further analysis using the data collected from this questionnaire is set to be conducted at a later date.

Acknowledgements

I would first like to thank Taylor Chambers, Scott Wonderly, and Tessa Jatczak for dedicating some of their free time towards helping collect the data that are used in this study, as well as, assisting with whatever else was needed. I would also like to thank Mark Matthew, B.A., for his help in running the data analysis and interpreting the accompanying results. Last, but certainly not least, I would like to thank Dr. Susan Davis, Ph.D., for her guidance and unending support throughout this entire thesis project. Without any of these individuals, this thesis project would not be possible.

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Caffeine Rush! Examining the Effects of Caffeine on Spatial Working Memory

What do coffee, chocolate, tea, soda, ice cream and energy drinks have in common? They all contain the most widely-consumed drug in the world: caffeine. A study conducted in 2014 found that about 85% of American adults consumed some form of caffeine daily, with the average intake being 164 mg (Mitchell, Knight, Hockenberry, Teplansky, & Hartman, 2014). Caffeine's immense popularity should come as no surprise. Unlike many other psychoactive substances, such as alcohol or marijuana, caffeine is generally recognized as safe by health organizations like the US Food and Drug Administration (Food and Drugs, 2017), thus, eliminating the need for any sort of strict governmental regulation. In fact, a lethal dose of caffeine is considered to be 10 g, according to Jennifer Temple, Ph.D. (as cited by Radcliffe, 2017), which is roughly equivalent to 100 ordinary cups of coffee (Radcliffe, 2017). A thorough review of the past 60 years of drug overdoses in which caffeine was present within the bloodstream found 51 cases in which caffeine was the main psychoactive agent responsible for death (Jones, 2017).

However, despite the fact that caffeine is considered relatively benign and safe to consume (Food and Drugs, 2017), there continues to be some uncertainty about the full effects of the popular stimulant on our bodies, with new discoveries constantly changing our view of the drug (La Motte, 2018). One branch of psychology that has begun to receive attention, recently, regarding the study of caffeine is cognitive psychology. Researchers have been interested in examining the potential 'cognitive enhancing' qualities of the drug (Nehlig, 2010). In other words, scientists have begun looking at whether caffeine could improve some of our fundamental cognitive processes, such as memory. The present thesis study takes inspiration from previously established research (e.g. Borota, et al., 2014) to add to this ongoing discussion.

Caffeine and Memory

According to Nehlig's extensive reviews of the literature (2004, 2010), a majority of the research (e.g., Erikson et al., 1985; Loke, Hinrichs, & Ghoneim, 1985; Terry & Phifer, 1986: Arnold, Petros, Beckwith, Coons, & Gorman, 1987; Foreman, Barraclough, Moore, Mehta, & Madon, 1989; Barraclough & Foreman, 1994) done on caffeine and memory has focused on short-term memory, where information is retained in the brain and retrievable over the brief time span of 15 to 30 seconds (Atkinson & Shiffrin, 1971). One popular short-term memory task that is often used in these studies is an unrelated word list. During this task, participants are shown a series of words and then later asked to recall as many of the words as possible, in any order. Typically, words that are placed towards the beginning and the end of the list are recalled more often due to what are called the primacy and recency effects, respectively (Deese & Kaufman, 1957; Murdock, 1962). Short-term memory is most directly responsible for the latter effect (Murdock, 1962). Of the 23 studies looked at in a meta-analysis by Snel, Lorist, and Tieges (as cited in Nehlig, 2004), 6 observed some improvement on recall (Arnold, et al., 1987; Barraclough & Foreman, 1994; Rogers & Dernoncourt, 1998; Schmitt, 2001a,b; Ryan, Hatfield, & Hofstetter, 2002), 3 observed some impairment on recall (Erikson et al., 1985; Terry & Phifer, 1986; Loke, 1992), and 14 observed no effect on recall (Loke, et al., 1985; Loke, 1988, 1992; Foreman, et al., 1989; Smith, Rusted, Savory, Williams, & Hall, 1991; Smith, Kendrick, & Maben, 1992; Smith, Brockman, Flynn, Maben, & Thomas, 1993a; Smith, Maben, & Brockman, 1993b; Smith, 1994a; Smith, Maben, &

Brockman, 1994b; Riedel, 1995; Warburton, 1995; Wright, Badia, Myers, & Plenzer, 1997; Rees, Allen, & Lader, 1999). Those studies that looked specifically at primacy and recency effects found no significant differences in recall performance between caffeine and placebo conditions (Erikson et al., 1985; Arnold et al., 1987; Smith et al., 1994b). Interestingly, one particular study by Barraclough and Foreman (1994) found that male participants who were given caffeine (either 2 mg/kg or 4 mg/kg) showed improved recall for words that appeared in the middle of the list. A similar study conducted by Smith, Davidson, and Green (1993) noted a difference in the recall performance of a digit list in relation to the sex of the participant, with female participants performing better than their male counterparts after the consumption of 300 mg of caffeine.

Similar to short-term memory, and sometimes used interchangeably, is working memory, readily-available information that is used for performing complex cognitive processes (Baddeley, 1992). Working memory has also been briefly examined in a few studies (Lorist, Snell, Kok, & Mulder, 1996; Smillie, & Gökçen, 2010) relating to caffeine. One common method of testing working memory involves a selective attention task. In selective attention tasks, participants are asked to find a target item among a series of alike lures. Lorist et al. (1996) found that participants who were given a 3-mg/kg dose of caffeine tended to show quicker reaction times than those given a placebo when there were few items on screen to differentiate between. However, this effect did not transfer to instances in which there were many items on screen to differentiate between. In other words, caffeine seemed to aid in quickly finding the target among the lures only when there were fewer lures. This indicates that caffeine’s positive effects on working memory may be limited by the difficulty of the task at hand, with more complex tasks naturally placing more strain on the overall memory process.

Another popular working memory task is the n-back test, in which participants are asked to indicate when a stimulus matches the one from a pre-defined number of items seen earlier. For example, a 2-N test requires a participant to identify when a stimulus matches from two items back (e.g., in the case of a series of letter-stimuli, F K L D E <u>D</u> R E I <u>E</u> –, the underlined letters match a stimulus two letters back in the series). A study conducted by Smillie and Gökçen (2010) noted better performance on this task from extraverted individuals who received 200 mg of caffeine as compared to participants who received a placebo and participant-introverts who received the same dosage of caffeine. The researchers’ conclusion was that there might be an interaction with dopamine functioning that is more likely to occur within extraverts due to biological differences (Reuter, Netter, Toll, & Hennig, 2002).

The effects of caffeine on long-term memory have also been studied, but to a far less extent. Long-term memory involves the lasting retention of information which is often thought to be stored indefinitely. The few studies (e.g., Herz, 1999; Bororta et al., 2014) that have chosen to examine long-term memory have been similar to many previous short-term memory studies (e.g., Erikson et al., 1985; Arnold et al., 1987; Barraclough & Foreman, 1994; Smith et al., 1994b) using the same unrelated word task. The key difference is that the participant is asked to recall the words after a longer retention interval. In a study by Herz (1999), some participants received a 5-mg/kg dose of caffeine before they learned the words and before they were asked to recall the words, 2 days later. There was no significant effect of caffeine on memory.

Regardless of the timing of the test, it may be that caffeine does not have any sort of effect on long-term memory, at least for information that is intentionally learned. However, caffeine may help encode information that is incidentally learned as indicated by a recent study by Borota et al. (2014). During this study, some participants were given 200 mg of caffeine immediately after the initial encoding of a series of pictures. When tested a day later, those participants who received caffeine correctly identified lures as similar more often than those who received a placebo (Borota et al., 2014). There was no difference in the recognition of targets between the two conditions which is consistent with Herz's (1999) findings.

Such conflicting results are difficult to interpret and are only further complicated by the differences within the methodological approaches used and the variable(s) of interest considered. Even those studies that seemed to indicate some sort of improvement of memory recall after caffeine administration often had other results that indicated otherwise. Adding to this issue is that the body of literature pertaining to examining the effects of caffeine on memory is still fairly new (Hollingworth, 1912; Blaise Park, Bellas, Gitchell, & Phan, 2018), having received greater attention within the past couple of decades. Due to the recency of the literature and the conflicting results that research into the field has produced, it is difficult to find a clear, definitive answer as to whether caffeine improves, hinders, or has no effect on the memory process. It appears that due to the complexities of the overall memory process, the answer may depend on a variety of factors including, but not limited to, the type of memory involved, the dosage of caffeine given, the sex of the participant, and the complexity of the task.

The Present Study

Since most of the extant research on caffeine has centered on relatively simplistic tasks often involving short-term memory, there is a glaring gap in the literature when it comes to examining how caffeine may interact with other, more involved types of memory (Nehlig, 2010). The present study partially aims to fill this gap by looking at spatial working memory, the utilization of spatial information, such as orientation and environmental cues, processed by the brain to carry out cognitive functions (Baddeley, 1992). Since the working memory process, as defined by Baddeley's model, depends heavily on attention and concentration, areas that moderate caffeine doses (~200 mg) have been shown to improve (Garrett & Griffiths, 1997; Griffiths et al., 1990), I hypothesized that those participants who were given caffeine would perform better on the spatial working memory task than those given a placebo. However, since it appears that the difficulty of the task may influence performance, I hypothesized that this increase in performance would not transfer to the more difficult version of the task. Further research, will examine caffeine's interaction with stress using the results of a subjective measure of stress.

Method

Participants

Twenty-two students (9 men and 13 women), from the University of Dayton, participated in this experiment either to fulfill a requirement for an introductory psychology course, or to receive extra credit in an upper-level psychology class. All participants were reimbursed $10 at the end of the study, for their time. The age of the participants ranged from 18 to 23 years old. Individuals who were pregnant, breastfeeding, had known heart arrhythmias, or had a hypersensitivity to caffeine were prohibited from participating in this study. To minimize risk and eliminate a potential confound, all participants were asked to abstain from caffeine prior to coming into the lab.

Materials

There were two questionnaires and a computerized puzzle game used in the experiment.

Intake Survey: This seven-question survey (see Appendix A) was designed by the researcher to serve two purposes. The first was to examine a participant's regular caffeine consumption habits. As such, it asked questions about the different types of caffeinated products that the participant consumed on a regular daily basis and the typical amount consumed of each product. The second was to serve as a method to exclude any participant who may have been deemed unfit to participate due to prior caffeine consumption upon coming into the lab, having one or more of the previously-mentioned health conditions, or being on a medication that could negatively interact with caffeine (e.g., anti-anxiety medications).

Dundee Stress State Questionnaire (DSSQ): This questionnaire was used with permission from its creator, Gerald Matthews Ph.D., University of Central Florida (Matthews et al., 1997). The DSSQ is a two-part, self-report questionnaire that examines stress that has occurred because of the completion of a task. The first part of this questionnaire is to be distributed before the task is completed and measures how the participant feels in the current moment. The second part of the questionnaire is to be distributed after the task is completed and measures how the participant felt while completing the task. Both parts of the DSSQ are divided into four sections: Mood and

Affect, Motivation, Thinking Style, and Thinking Content. Each of these sections vary in length (Mood and Affect: 29 items, Motivation: 15 items, Thinking Style: 30 items, Thinking Content: 16 items). Each section of the DSSQ is derived from a factor analysis of characteristics tested for their relation to stress. Based on the results of this analysis, it was found that certain characteristics could be clustered together due to their statistical correlations into three, dimensional categories: task engagement, distress, and worry (Matthews, Szalma, Panganiban, Neubauer, & Warm 2013).

Rush Hour: *Rush Hour*® is a sliding-block puzzle game that was first invented in the 1970's, by Nob Yoshigahara. In 1996, *ThinkFun*™ (then Binary Arts) brought the game over to US audiences. Since then, *Rush Hour*® has remained one of the company's most popular games to date ("The Evolution of ThinkFun's *Rush Hour*", 2018). The main objective of each level within the game is to move a red 'target car' to the exit of a 6 x 6 block grid. Blocking the path to the exit are other obstructing vehicles that can only be moved either horizontally or vertically, depending on the direction that they are facing. Each level (one 6 x 6 block grid) contains a unique layout of cars and trucks among which the participant must maneuver. In total, there are 40 levels within the original board game. The difficulty continually rises the more levels the player completes (Levels 1-10 are easy, Levels 11-20 are intermediate, Levels 21-30 are advanced, and Levels 31-40 are expert). The version of *Rush Hour*® used during this study is a computerized adaptation of the original board game. This computerized version was developed by Mario Di Vece, of ByteDive Entertainment, in 2001. See Appendix B for in-game screenshots.

Procedure

The present study was divided into two different phases separated by a 60-minute intermission period. Before beginning the study, participants were asked to read and sign an informed consent. Once again, they were reminded of the restrictions placed on participation, and that they could be asked to withdraw from the study if they were deemed unfit to participate. After reading and signing the informed consent, participants completed the intake survey. A researcher collected and examined their individual responses to this survey. If a participant was deemed fit to participate, he/she could transition on to Phase 1 of the study, known henceforth as the familiarization phase. One participant was excluded from continuing with the study due to having consumed caffeine prior to coming into the lab.

During familiarization, participants completed a basic demographic questionnaire asking about their sex, age, year in school, and race. Once finished, they were instructed to complete Part 1 of the DSSQ. The responses to this part of the questionnaire would serve as a baseline measure of stress for later analysis. Soon after, participants were given their first introduction to the game *Rush Hour*®. They were told how to play this particular version of the game using the mouse and keyboard, and that they would be completing five easy levels (as defined by the original board game) in order to get used to the controls. After the successful conclusion of a level, a researcher recorded the participant’s number of moves and the time it took to complete that level before giving the participant permission to advance to the next level. As soon as all participants had completed the five easy levels, they were instructed to complete Part 2 of the DSSQ.

Responses to this part of the questionnaire would be used later to examine stress incurred while first completing the memory task.

While participants answered the questions on Part 2 of the DSSQ, researchers matched participants based on performance. Performance, in this case, was defined by the recorded number of moves and the time required to complete the five easy levels. After being successfully matched with a participant having a relatively equal skill level, the two participants were randomly assigned to different conditions (either caffeine or placebo). This process was to ensure that each condition would have an equal number of participants of varying degrees of skill. Once all participants had finished the second part of the DSSQ, they were told to follow the main researcher out into the hallway. One by one, each participant was called by name to step into a second lab room and receive either a 200 mg caffeine pill or a placebo pill, depending on the condition to which they were assigned. The brand of caffeine pill used was Vivarin™, due to its use in previous research (Klein, Bennett, Whetzel, Granger, & Ritter, 2010; Scott et al., 2002; Wesensten, Killgore, & Balkin, 2005). All participants were unaware of the type of pill that they received. After each participant had received the assigned pill, the researcher escorted him/her back into the primary lab room. This began a 60-minute intermission period. The mean amount of time it takes a caffeine pill to reach maximum efficacy is 85-120 minutes; however, participants were expected to begin to feel the effects of the caffeine pill within an hour (Kamimori et al., 2002). Given the additional time for instructions, participants were expected to be completing the memory task well within the range of time that caffeine has an effect.

During this intermission period, participants were free to work on any homework or other paper work that they may have brought with them to the experimental session. The only restriction during this time was that they were not allowed to leave the room, unless it was to use the restroom or to get a drink of water. This was done as a safety precaution so that the researchers could continuously monitor the participants for any negative, unwanted side effects. In case a participant did experience an unwanted side effect, a researcher was on-hand to escort that participant to the university health center for treatment. Once the hour had passed, the second phase of experimentation began, henceforth known as testing.

During testing, participants were once again told to complete Part 1 of the DSSQ. The responses to this part of the questionnaire were later used to examine any stress felt while under the effects of the placebo or caffeine pill. After all participants completed this part of the DSSQ, they were again instructed to play levels within *Rush Hour*®. This time they were faced with finishing 12 levels, 6 of which were considered to be of easy difficulty while the other 6 were considered to be of medium difficulty. The easy levels were interspersed with the medium levels to prevent mental fatigue from having to complete 6 noticeably harder levels in a row. Participants were told to try to complete all of the levels; however, if they were unable to finish a level within 5 minutes, they were to raise their hand so that a researcher could advance them to the next level. Once more, each participant's number of moves and time to completion were recorded. Errors indicated by recursions, instances in which the participant moved a car back and forth, were also recorded, but were counted after the experiment was over. All three of these factors were used to define a participant's performance for later data analysis. As soon as participants had managed to get through all 12 levels, they were told to complete Part 2 of the DSSQ, again. The responses to this part of the questionnaire would be used later to examine stress incurred by the memory task while under the effects of either the caffeine or placebo pill. Once the participants had filled out this part of the DSSQ, they were led back into the room in which they had originally received either the caffeine or placebo pill. The participants were then informed of the type of pill that they had received earlier. If the participant had received caffeine, a researcher read a side effects check list that detailed some possible negative side effects from caffeine consumption. If the participants said that they were not experiencing any of the mentioned side effects, and it was deemed safe to release the participants, they were formally debriefed. Participants who received the placebo did not have to experience the side-effects check list.

Results

Of the 22 participants that took part in this study, the data of 20 participants were used for data analysis. Two participants were excluded due to different reasons. As previously mentioned, one participant was asked to withdraw from the study before the familiarization phase and, therefore, had no data to analyze. The other participant failed to complete all the levels within the familiarization phase and, as such, could not be matched to another participant. The remaining participants were evenly divided between the two conditions.

In order to test for any potential effects of caffeine on performance of the spatial working memory task, the mean number of moves used, amount of time taken, and number of errors committed (”recursions”) were calculated for the six easy levels and the five medium levels. One medium level was excluded as it was deemed too difficult to be grouped with the other medium levels (only 5 participants were able to complete the level within the time limit), and its inclusion severely inflated the means. The means for each of the variables of performance as well as their standard deviations are included at the end of the result section in graphical form for easy viewing (see Figures 1, 2, and 3).

Three separate, repeated-measures ANOVAs were conducted with the calculated means. Level difficulty was the within-subjects factor and condition (caffeine or placebo) was the between-subjects factor. As expected, there was a significant effect of level difficulty for each variable (moves: F (1, 18) = 103.75, $p < .0005$, time: F (1, 18) = 95.65, $p < .0005$, error: F (1, 18) = 37.98, $p < .0005$). However, none of the variables of performance showed a significant effect of condition (moves: F (1, 18) = .55, $p = .468$, time: F (1, 18) = .02, $p = .884$, error: F (1, 18) = .13, $p = .724$).

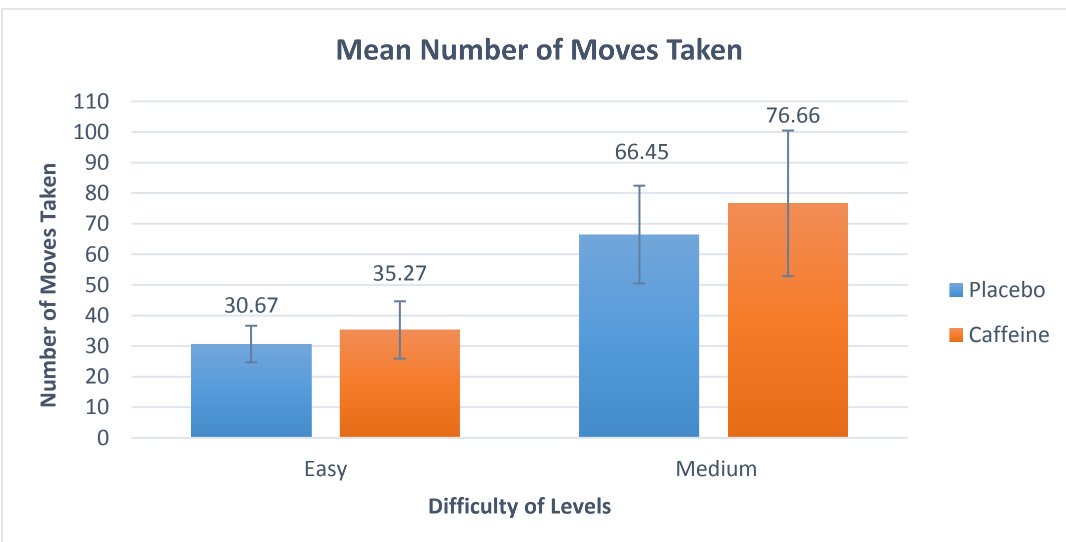

***Figure 1*. Mean number of moves taken during the series of easy and medium levels separated by condition.**

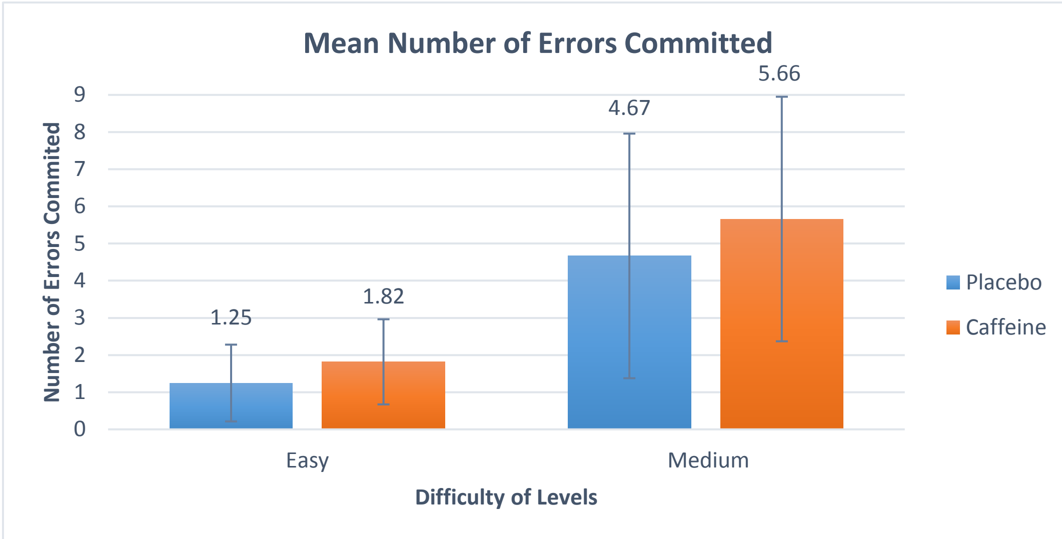

***Figure 2*. Mean number of errors (recursions) committed during the series of easy and medium levels separated by condition.**

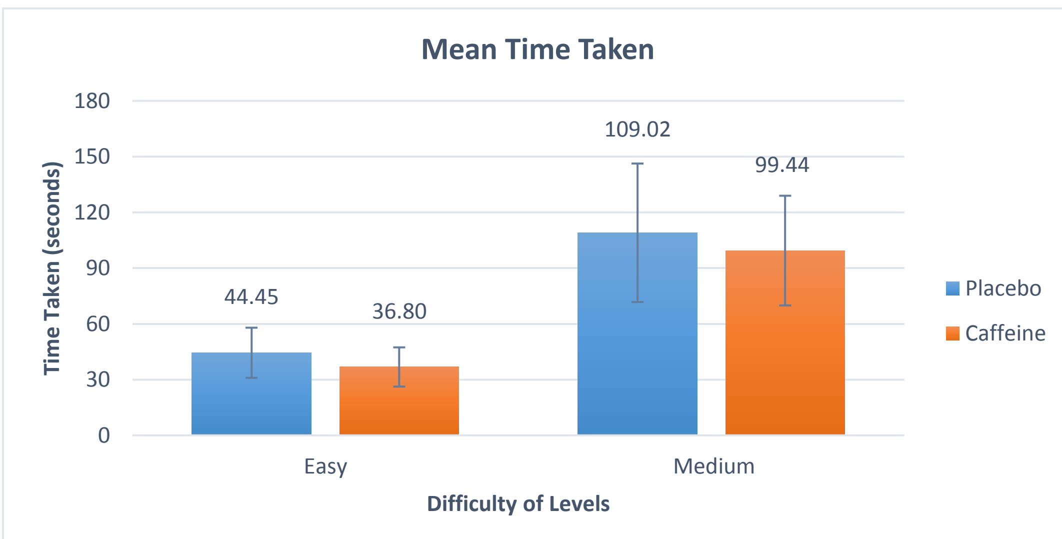

***Figure 3*. Mean amount of time taken during the series of easy and medium levels separated by condition.**

Discussion

As indicated by the results, participants in both the caffeine and placebo conditions completed the levels within the testing phase in a similar amount of moves and time while committing a similar amount of errors. This was the case regardless of the difficulty. That there were no significant differences in performance between the two conditions is contradictory to the research hypothesis that those who received caffeine would perform better than those who received the placebo, at least on the easier levels. However, these results are consistent with some of the extant research that has found no effect of caffeine on long-term (Herz, 1999) nor, in some cases, on working memory (Smillie, & Gökçen, 2010).

One factor that may have affected the results is the small sample size. Due to time constraints, only 20 sets of useable data were collected. That is, each condition only contained 10 participants. As such, the amount of variability within each condition was fairly high, particularly in regard to the medium levels. Given enough time, a larger sample size could be obtained, leading to results that would have more statistical power.

It does appear from Figures 1, 2, and 3 that there is a slight difference between the two conditions. Those participants in the caffeine condition appear to be completing levels in more moves and with more errors but doing so in less time. For this very reason, it is possible that this study may continue with the process of data collection soon. The aim of future data collection would be to produce a larger sample.

Another possibility for the near future would be analysis of the self-reported stress scores collected from the DSSQ. Due to the time constraints and low sample size of the present study, analysis of these data was not conducted at this time. Nonetheless, it is predicted that the scores on the DSSQ should be statistically different between the two conditions with those participants who received caffeine tending to self-report lower levels of stress.

Regardless of the outcome, research into the effects of caffeine on memory is an important avenue of study that should be examined to a greater extent by other researchers. Caffeine is highly popular around the world and plays a role in many daily lives. The drug’s interactions with our basic cognitive functions, such as memory, should be better understood to truly appreciate the underlying interactions between our brain and the substances that we consume on a regular basis.

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Appendix A: Caffeine Intake Survey

Please answer the following questions as honestly as possible….

1. Which of the following products do you consume on a regular basis (for example, once or twice a week)? (Check all that apply)

- ☐ Coffee (excluding decaf)
- ☐ Espresso
- ☐ Tea
- ☐ Iced Tea
- ☐ Hot Chocolate
- ☐ Carbonated Soft Drinks
- ☐ Energy Drinks
- ☐ Energy Shots (i.e. Five Hour Energy)
- ☐ Dark Chocolate (candy products)
- ☐ Milk Chocolate (candy products)
- ☐ Caffeine Pills

2. During an average day, how often do you consume the following products?

Coffee (cups):
- ☐ 1-2 times a day
- ☐ 3-4 times a day
- ☐ More than 4 times a day
- ☐ I don’t drink coffee

Carbonated Soft Drinks (cans):
- ☐ 1-2 times a day
- ☐ 3-4 times a day
- ☐ More than 4 times a day
- ☐ I don’t drink soda

Tea (cups):
- ☐ 1-2 times a day
- ☐ 3-4 times a day
- ☐ More than 4 times a day
- ☐ I don’t drink tea

Energy Drinks (cans):
- ☐ 1-2 times a day
- ☐ 3-4 times a day
- ☐ More than 4 times a day
- ☐ I don’t drink energy drinks

3. In the past 24 hours, have you consumed any of the products mentioned in Question 1?

- ☐ Yes
- ☐ No

4. If you answered yes, to the best of your abilities, check the products that you consumed and list the approximate time(s) that you consumed these products and the approximate amount(s) of each. (i.e. 1 cup of coffee at 8:00 P.M.)

- ☐ Coffee (excluding decaf)
- ☐ Espresso
- ☐ Tea
- ☐ Iced Tea
- ☐ Hot Chocolate
- ☐ Carbonated Soft Drinks
- ☐ Energy Drinks
- ☐ Energy Shots
- ☐ Dark Chocolate
- ☐ Milk Chocolate
- ☐ Caffeine Pills

Amounts + Time Consumed:

5. Are you currently taking any medications that may negatively interact with caffeine, such as anti-anxiety medications (e.g. Ativan, Valium, Xanax), stimulants (e.g. Adderall, Ritalin, Vyvanse), etc.? **Please ask your researcher if you are unsure.**

- ☐ Yes
- ☐ No

6. If you answered yes to question 5, please list any medications you are currently taking in the space below:

7. For personal safety concerns, please indicate whether any of the following apply to you:

- ☐ I am pregnant
- ☐ I am breastfeeding
- ☐ I have heart arrhythmias
- ☐ I have a hypersensitivity to caffeine

Appendix B: Screenshots of *Rush Hour*®