The Effects of Caffeine and Exercise on Implicit and Explicit Memory Performance in Younger Adults: an Investigation of Physiological Arousal

By
Timothy Buckley

A Thesis Submitted to the University of Arizona Honors College
In Partial Fulfillment of the Bachelors degree
With Honors in
Psychology

THE UNIVERSITY OF ARIZONA
May 2013

Approved by:

[Signature]
Dr. Lee Ryan
Department of Psychology
The University of Arizona Electronic Theses and Dissertations
Reproduction and Distribution Rights Form

The UA Campus Repository supports the dissemination and preservation of scholarship produced by University of Arizona faculty, researchers, and students. The University Library, in collaboration with the Honors College, has established a collection in the UA Campus Repository to share, archive, and preserve undergraduate Honors theses.

Theses that are submitted to the UA Campus Repository are available for public view. Submission of your thesis to the Repository provides an opportunity for you to showcase your work to graduate schools and future employers. It also allows for your work to be accessed by others in your discipline, enabling you to contribute to the knowledge base in your field. Your signature on this consent form will determine whether your thesis is included in the repository.

<table>
<thead>
<tr>
<th>Name (Last, First, Middle)</th>
<th>Buckley, Timothy, Paul</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree title (eg BA, BS, BSE, BSB, BFA):</td>
<td>Psychology BS</td>
</tr>
<tr>
<td>Honors area (eg Molecular and Cellular Biology, English, Studio Art):</td>
<td>Psychology</td>
</tr>
<tr>
<td>Date thesis submitted to Honors College:</td>
<td>5/1/13</td>
</tr>
<tr>
<td>Title of Honors thesis:</td>
<td>The Effects of Caffeine and Exercise on Cognitive Performance in Younger Adults</td>
</tr>
<tr>
<td>The University of Arizona Library Release Agreement</td>
<td></td>
</tr>
</tbody>
</table>

I hereby grant to the University of Arizona Library the nonexclusive worldwide right to reproduce and distribute my dissertation or thesis and abstract (herein, the “licensed materials”), in whole or in part, in any and all media of distribution and in any format in existence now or developed in the future. I represent and warrant to the University of Arizona that the licensed materials are my original work, that I am the sole owner of all rights in and to the licensed materials, and that none of the licensed materials infringe or violate the rights of others. I further represent that I have obtained all necessary rights to permit the University of Arizona Library to reproduce and distribute any nonpublic third party software necessary to access, display, run or print my dissertation or thesis. I acknowledge that University of Arizona Library may elect not to distribute my dissertation or thesis in digital format if, in its reasonable judgment, it believes all such rights have not been secured.

☑ Yes, make my thesis available in the UA Campus Repository!

Student signature: Timothy Buckley Date: 5/1/13
Thesis advisor signature: [Signature] Date: 5/1/13

☐ No, do not release my thesis to the UA Campus Repository.

Student signature: Date: 

Last updated: 04/01/13
Abstract

Memory performance is best during an individual’s optimal time-of-day, when physiological arousal is naturally highest, and decreases significantly during their non-optimal time of day when arousal declines. Previous research suggests that the time-of-day at which a memory task is completed may contribute to age related disparities in memory performance. Ryan et al. (2002) found that this deficit could be eliminated in older adults by administering caffeine during their non-optimal time of day, the late afternoon. However, there are no benefits of caffeine if administered during an individual’s optimal time of day. It remains unclear whether the same patterns of effects of caffeine would be seen in younger adults. Experiment 1 examined whether caffeine enhanced memory in the early morning. Thirty minutes after consuming a cup of coffee (caffeinated or decaffeinated), participants completed implicit and explicit versions of a word stem completion task. Young adults who consumed caffeinated coffee demonstrated significant improvements in explicit memory, but no implicit memory. Experiment 2 examined the effect of caffeine in younger adults during their optimal time of day, where results show that caffeine had no effect on memory performance. This suggests that that caffeine serves a compensatory role, aiding time-of-day deficits. Finally, experiment 3 examined whether exercise would also ameliorate time-of-day deficits. Young adults completed 15 minutes of either cardiovascular exercise or gentle stretching. Heart rates were taken throughout the experiment to measure physiological arousal. While exercise clearly increased physiological arousal, exercise had no effect on either explicit or implicit memory. Taken together, these results suggest a unique mechanism for caffeine-induced arousal that compensates for time-of-day memory deficits.

Keywords: caffeine, exercise, explicit memory, implicit memory, time of day, younger adults
1. Introduction

Prior research has shown that time of day can influence cognitive performance. Memory performance is best during an individual’s optimal time-of-day, when physiological arousal is naturally highest, and decreases significantly during the non-optimal time-of-day, when arousal declines (May, Hasher & Foong, 2005). Recent research by Fabbri et al (2013) tested participants that were either morning and evening types on a memory test during three times, the morning, afternoon, and evening. Results showed that memory was affected by the natural circadian rhythm and task performance is best during periods of highest physiological arousal. Research has correlated physiological changes such as heart rate, skin conductance, and body temperature during with an individual’s non-optimal time of day. Some researchers speculate that memory performance is affected by this decrease in physiological arousal (Baily et al., 2001). Therefore, time of day deficits could be alleviated by stimulants which increase physiological arousal. Yet research is just starting to elucidate stimulants that ameliorate these time-of-day memory deficits.

Research by May, Hasher, and Fong’s study found a relationship between implicit memory, explicit memory and time-of-day. Implicit memory refers to information that is encoded without conscious awareness while explicit memory refers to information that is consciously recalled from learned material. Results found that explicit memory is lowest during non-optimal times-of-day while implicit memory is highest. In contrast, explicit memory is highest during optimal time of day when implicit memory is traditionally low.

Further, time of day preference generally varies across age groups, with older adults tending to have an optimal time of day in the morning and non-optimal time of day in the
evening. Young adults, on average, have a non-optimal day in the morning, and optimal time of day in the evening.

Ryan, Hatfield, and Hofstetter (2002) examined the use of caffeine to remove the explicit memory deficit in older adults. The experiment found that in older adults explicit memory performance during non-optimal time of day can be improved by the administration of caffeine. In this study older adults were tested two times, once during their optimal time of day in the morning, and once during their non-optimal time of day, the evening. At testing, participants were either given either caffeinated or decaffeinated coffee. Participants who tested in the morning showed no difference in explicit memory scores independent of the type of coffee they received. However, participants tested during the non-optimal time of day in the caffeinated condition showed significantly improved explicit memory performance. In the experimental condition, participants who consumed caffeine during their non-optimal time of day showed an increase in explicit memory performance, possibly compensating for the time-of-day deficit.

Although time of day preference tends to vary across age groups, it remains unclear whether younger adults will benefit from caffeine consumption. The first goal of the current experiment was to study the same types of episodic memory in younger adults during their optimal and non-optimal time of day. Experiment 1 examined whether caffeine can enhance explicit memory performance in the young adult population during their non-optimal time-of-day, the early morning. The initial hypothesis was that caffeine will improve explicit memory performance in younger adults when tested early in the morning. Experiment 2 investigated the effect of caffeine on memory performance during the optimal time of day of younger adults. Past research has shown that older adults do not benefit from caffeine during their optimal time of day.
(Ryan, et al. 2002). Based on these findings, we expected that caffeine serves a compensatory role, and the effect would only be observed in the presence of a cognitive deficit.

Research by Szabo, McAuley, Erickson, et. al.(2011) found that regular exercise can have long term benefits on cognition and memory performance. They performed an analysis of lifestyle patterns and memory performance suggested that improved memory performance may be a result of preservation of hippocampal volume that occurs following physical activity. A follow up study examined this claim using Magnetic Resonance Imaging (MRI), and found that maintaining exercise regiments in late adulthood was associated with preservation of hippocampal volume, which led to increased memory preservation (Erickson, Voss, and Prackish 2011).

While these experiments involve habitual exercise and gradual changes to neurological structures, they show that exercise clearly affects the brain, particularly the hippocampus. In addition, the benefits of caffeine could be attributed to caffeine increasing physiological arousal, thereby improving explicit memory performance. Experiment 3 examined whether mild exercise can act similarly to caffeine, and cause short term improvements to explicit memory during an individual’s non-optimal time of day. This aims to help elucidate whether caffeine works by increasing general arousal or through its own specific mechanism. Physiological arousal induced by exercise is predicted to have beneficial effects similar to caffeine and increase explicit memory performance during non-optimal time of day.

2. Experiment 1

2.1 Methods

2.1.1 Participants
Sixty participants (36 female) were recruited from the Psychology 101 subject pool (see table 1). Participants were screened to ensure that their optimal time of day was in the evening, were free of any confounding conditions that may affect memory performance such as a recent switch in medications or persisting symptoms from head trauma. Time of day preference was assessed through an abbreviated version of the Morning and Evening Questionnaire (MEQ). All participants were assessed as “strongly evening type” or “neither morning nor evening type.” Participants were instructed not to eat or drink anything besides water immediately before the experiment. All procedures in the study were approved by the University of Arizona Human Subject’s Committee. Participants gave informed consent and were given course credit for their participation in the study.

Table 1

<table>
<thead>
<tr>
<th>Participant Data</th>
<th>Experiment 1 (caffeine: non-optimal time-of-day)</th>
<th>Experiment 2 (caffeine: optimal time-of-day)</th>
<th>Experiment 3 (exercise: non-optimal time-of-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>Caffeinated</td>
<td>Caffeinated</td>
<td>Exercise</td>
</tr>
<tr>
<td>Number of Participants</td>
<td>30</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Age (Years)</td>
<td>18.7 (.92)</td>
<td>18.9 (.75)</td>
<td>18.5 (.95)</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>10/20</td>
<td>7/11</td>
<td>17/3</td>
</tr>
<tr>
<td>MEQ scores</td>
<td>43 (6.65)</td>
<td>45 (6.39)</td>
<td>43 (4.76)</td>
</tr>
<tr>
<td>Average HR Increase (bpm)</td>
<td>-</td>
<td>-</td>
<td>58.7 (15.3)</td>
</tr>
<tr>
<td>Implicit Performance</td>
<td>.20 (.147)</td>
<td>.12 (.131)</td>
<td>.18 (.128)</td>
</tr>
<tr>
<td>Explicit Performance</td>
<td>.44 (.140)</td>
<td>.21 (0.096)</td>
<td>.36 (.116)</td>
</tr>
</tbody>
</table>

Note. Standard deviations are in parentheses.

2.1.2 Materials

Seventy-two unique three-letter stems and completions (e.g. cal____; calcium) were chosen from a large normative word-stem completion data set (Ryan et al., 2001). Stems and completions were chosen by the following criteria: the stems could be completed with a minimum of 5 words, each completion was at least five letters long (5-9 letters), and the
completion was not the most frequent completion for the stem. The completions were randomly divided into three lists of 24 words each. Two lists were used during the study and test phase. Half of the words from the third list (12 words) were used during the stem completion task as fillers. The lists were counterbalanced across tasks and conditions.

2.1.3 Procedure

All participants were randomly assigned to receive caffeinated or decaffeinated coffee and the experiment was scheduled for either 6AM or 7AM. The study was a double blind experiment: all participants were informed that they were receiving caffeinated coffee, and research assistants were not aware of which condition they were administering. Participants were given 30 minutes to allow the caffeine to take full effect before beginning the cognitive tasks. Memory testing consisted of a word stem completion task. Cognitive testing begins with the study phase, where participants were shown 48 words (example BASEBALL) and asked to rate their pleasantness on a 1-5 scale. Following the study phase, the participants completed the full MEQ, a questionnaire regarding their usual sleep habits and their sleep the previous night. The questionnaire asked if the participants consumed anything before the experiment and again asked participants to rate their arousal. These questionnaires serve as a distracter task prior to the test phase. The test phase consisted of a word stem completion task and a cued recall task. During the word stem completion task, participants were presented with 36 word stems consisting of 3 letters (example BAS______). Twenty four of the stems can be completed with words from the study phase. Participants were instructed to complete the word stem with whatever word comes to mind first. The percentage of stems completed with words from the pleasantness task provides a measure of implicit memory performance. Implicit memory scores were calculated by taking the correctly completed word and subtracting the baseline completion rates previously collected.
following the word stem completion task, was the cued recall task. Participants were once again presented with 3 letter word stems and instructed to only answer if they recall the original word from the study phase. This discourages the participants from guessing for every word stem, and provides a measure of explicit memory performance. Memory tests were administered via computer using DMDX software, which is capable of displaying words and images.

2.2 Results

Data were analyzed using independent samples T-test. Throughout the experiment, participants are asked to rate how awake they felt using a point scale ranging from completely tired to wide awake. This provided a subjective measure of participants’ perceived arousal. Results show a non-significant trend that participants felt more awake after receiving caffeinated coffee t (58) =1.98 p=.079.

Results from Experiment 1 show a significant difference in explicit memory performance after the consumption of caffeinated coffee. Participants who drank caffeinated coffee had improved explicit memory performance (M= .44, SE= .02) compared to those who received decaffeinated coffee (M=.35, SE=.02); t (58) = 2.801 p< .05. As expected, caffeine similarly affected younger adults during their non-optimal time of day as was observed in older adults (see panel A of figure 1).
2.3 Discussion

In Experiment 1 the results show that the beneficial effects of caffeine are applicable to younger adults during their most cognitively deficient time-of-day. These findings provide scientific evidence suggesting that students should consume caffeinated coffee to help improve memory performance during morning testing sessions. While these results show that caffeine provides similar benefits to younger adults during their non-optimal time of day, it remains unclear whether the same pattern of affects will be observed during optimal time-of-day. The second experiment examined whether caffeine similarly has no effect on younger adults when administered during optimal time-of-day.

3. Experiment 2

3.1 Methods

3.1.1 Participants

Thirty-six college students (20 female) participated in this experiment. Participants had the same eligibility requirements as those in Experiment 1.

3.1.2 Procedure

The procedure used in this experiment was the same as used in experiment 1 with the modification that participants were scheduled for the afternoon, 2 PM to 4 PM. Younger adults typically experience their optimal time of day in the afternoon and evening.

3.2 Results
The results showed that there was no difference in explicit or implicit memory performance when younger adults were tested during their optimal time of day $t(34) = -1.35\ p = .185$. As hypothesized, these results are congruent with the finding in older adults (see panel B of figure 1).

### 3.3 Discussion

As observed in older adults, the benefits of caffeine only have a significant effect on memory performance when administered during participant’s non-optimal time of day. This information highlights that caffeine is most likely serving a compensatory role. However, it remains unclear whether improved explicit memory performance is caused by generalized physiological arousal from caffeine, or from a unique effect of caffeine’s a chemical compound.

### 4. Experiment 3

#### 4.1 Methods

##### 4.1.1 Participants

Forty-two college students (35 female) participated in this experiment. Participants had the same eligibility requirements as the past experiments. Participants, all evening-type individuals, were scheduled to arrive at either 6 AM or 7 AM, which ensured it was their non-optimal time of day. Participants were instructed not to eat or drink anything but water the morning of the experiment. All procedures in the study were approved by the University of Arizona Human Subject’s Committee. Participants gave informed consent and were given course credit for their participation in the study.

##### 4.1.2 Procedure
In order to determine whether physiological arousal from exercise has similar effects as caffeine, the experimental condition involved cardiovascular exercise designed to increase the heart rate. The control condition consisted of stretching exercises which would not significantly change the heart rate. In this experiment, change in heart rate served as a measure of physiological arousal. The experiments were again scheduled for 6 or 7 AM to ensure it was the non-optimal time of day for younger adults. Participants were randomly assigned to either the exercise condition, or the control stretching condition. They were then instructed on how to use an activity watch, which is used to measure heart rate. The activity watches were standard wristwatches with three sensors that allow the watch to detect heart rate in beats per minute. The watches were tested for accuracy prior to the experiment and gave reliable heart rate measurements, usually within 1 beat per minute. Participants were given several opportunities to practice obtaining a heart rate using the watches. Once they were comfortable obtaining their heart rate, they were given instructions explaining either the exercise or stretching condition and a baseline heart rate was taken. All participants were informed that they could withdraw from the experiment at anytime if they felt unable to continue with the exercise. The exercise condition consisted of 10-15 minutes of mild cardiovascular exercise induced by briskly walking a lap in the hallways of the psychology department with intermittent stairs. The stairs allowed a quick and enduring increase in heart rate. Most participants exhibited a heart rate increase of 60 beats per minute after the first flight of stairs. This rate was generally maintained for the duration of the exercise. The exercise included walking the length of the hallway to prevent the participants from becoming fatigued from constant stairs. To account for variability, the desired increase in heart rate was at least 20 percent of their resting heart rate. Research assistants were stationed at the start of each lap, in order to take the heart rate at regular intervals. Research assistants
recorded the heart rate data into a table. Following 10 minutes of exercise in the target heart rate zone, participants were instructed to return to the appropriate rooms for cognitive testing.

The stretching group was instructed through 10 minutes of simple stretching. Research assistants provided demonstrations for all the stretches, and recorded heart rates after every minute of stretching. Following either exercise or stretching, participants completed the same word stem completion task as the prior experiments.

4.2 Results

The data shows that participants in the exercise condition $M=58.74$ (SE=3.422) showed a significant difference in heart rate increase compared to the control condition $M=10.65$ (SE=2.18) $p<.001$. In addition, participants in the exercise condition reported an immediate increase in perceived wakefulness compared to the control condition ($p=.049$). However, the results of implicit and explicit memory performance showed no significant difference between the two groups ($p=.904$). Contrary to the expected results, the exercise condition did not experience the hypothesized increase in explicit memory performance (see panel C of figure 1).

4.3 Discussion

Results from this experiment show that physiological arousal was successfully increased in the experimental condition. In addition to a stark difference in change in heart rate in the exercise condition, participants also reported feeling more awake after exercise. Despite these differences, exercise had no effect on explicit memory performance, contrary to our initial hypothesis. These results suggest that caffeine has a unique mechanism that extends beyond generalized physiological arousal.
5.1 General Discussion and Future Research

The results from these experiments help to highlight the interactions of caffeine, physiological arousal, time-of-day and cognition. In addition, the second experiment repeats the findings observed in older adults: caffeine administered during optimal time-of-day had no significant effect on memory performance. This suggests that caffeine is mainly used as a compensatory substance, with the largest effects correlating with the largest deficits. Experiment 3 shows that exercise was an effective means of increasing physiological arousal, but this increased arousal had no effect on implicit or explicit memory performance. Possible explanations may be that exercise fatigued participants. However, this is unlikely since participants reported feeling more awake after exercise. These results suggest that there is a unique mechanism to caffeine induced arousal. While both exercise and caffeine lead to increased perceptions of arousal, the direct effect of caffeine as a chemical compound may be a unique remedy to time of day related cognitive deficits. This shows that there is an effect of caffeine that extends outside of physiological arousal, which effects cognitive performance.

Nehlig, Daval, and Derby (1992) provide information on the mechanism of action of caffeine and particularly the effects of memory. The main effect of caffeine is that serves as an antagonist for adenosine, an inhibitory neurotransmitter within the central nervous system. Combined with the rapid ability of caffeine to diffuse across the blood brain barrier, the chemical mechanism of caffeine provides a rapid and efficient solution to time of day deficits.

Lojovich (2010) provides information on how exercise may improve cognitive performance. Habitual exercise leads to increased calcium levels which are necessary for the metabolism of dopamine and norepinephrine. This has been associated with cognitive improvements. However, the increase in calcium is gradual, and requires habitual exercise. The
stark differences between exercise and caffeine in their respective flux of metabolites may explain why exercise could not provide significant short term effects on memory while caffeine did.

Past research has shown that implicit and explicit memory performances are inversely related relative to time-of-day. However, in the first experiment, there was no significant difference in implicit memory performance. The most likely explanation is that the word stem completion paradigm does not provide enough precision to detect the small changes in implicit memory performance. Additional research could more closely examine the effects of time-of-day and caffeine on implicit memory performance using tests more suitable to detect the subtle changes.
References


Marco Fabbri, Chiara Mencarelli, Ana Adan & Vincenzo Natale (2013): Time of day and circadian typology on memory retrieval, Biological Rhythm Research, 44:1, 125-142

