The Effects of Caffeine on Human State Dependent Learning

Nicole Miller
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Abstract

The effect of caffeine on state dependent learning for memory using a word list was investigated. On day 1 60 students were administered a beverage containing either 0 or 200 mg of caffeine and given a list of 18 words to memorize until criterion. On day 2 the students were administered either the same or a different level of caffeine and asked to recall the words learned on day 1. The number of words recalled correctly by those individuals receiving the same amount of caffeine on both days was significantly more than those who received differing amounts of caffeine. This finding supported previous studies that suggested same state dependency can improve cognitive performance.
The Effects of Caffeine on Human State Dependent Learning

Caffeine is the most widely used psychoactive substance in America and has been considered at times as a drug of abuse. A large percentage of avid caffeine consumers are college students. The reason caffeine has become so popular among the college student population results from the overall effects caffeine has on stimulating the central nervous system. By stimulating the nervous system caffeine can alleviate fatigue and drowsiness, enhance rapid and clear thought, and improve performance on cognitive tasks such as memory. Caffeine has been found to increase self-rated happiness, well-being, calmness, and alertness. Small doses of the substance (20 mg) have shown to produce positive feelings, higher energy, and an increase in the ability to concentrate (Herz, 1999).

Some studies have shown interactive effects between caffeine and mood enhancement (Smith, 1994) and caffeine and memory improvement (Hertz, 1999). Other considerations such as individual characteristics may alter the effects of caffeine. For example, habitual use, amount of caffeine consumed, and age (James, 1998).

A study performed by Loke (1988) engaged 95 undergraduate students screened for daily caffeine consumption, that were administered either 0, 200, or 400 mg of caffeine and an hour later were asked to carry out a wide variety of assessments including mood evaluation (happy, sad, anxious, etc.), multiple-trial immediate free recall, and delayed free recall. He found that higher levels of caffeine increased mood items (nervousness, anxiety, and restlessness) however, there was no significant improvement on the cognitive portion of the test (cancellation tasks, free recall, and delayed free recall). In fact, higher levels of caffeine were shown to have a significant decrease in the
cognitive performance of the participants. When Herz (1999) performed a similar study with 48 students, she also found that while 5mg/kg of body weight of caffeine caused an increase in arousal, alertness, and vigorousness it did not reveal a significant improvement on memory. The students were given either a 5 mg sugar pill or 5 mg caffeine pill and asked to memorize a list of 16 words. Two days later they were asked to return to the study, administered the same level of caffeine and asked to recite the words learned on day 1. No significant difference in the amount of words correctly recalled between the caffeine and sugar pill groups was found.

Another study on caffeine and memory was performed in order to support the idea of remote excitatory tendencies (tremors, increased arousal, anxiety, and cognitive recall) reported by Ebbinghaus while learning nonsense syllables (Hull, 1985). Hull (1985) conducted a study using 5mg/kg of body weight on 80 male university students. Students were given either the caffeine or placebo and learned a series of nonsense syllables. The next day they recited the word list. Results for this study revealed that while learning done under the influence of caffeine made encoding slightly easier (students in the placebo group recalled fewer words at retrieval) this tendency did not produce a statistical significance.

It has been previously suggested that while caffeine may stimulate performance on tests of vigilance and attention (Herz, 1999), it impairs performance on tests of short-term memory (Loke, 1988). Terry and Phifer (1986) chose to measure performance on the Auditory Verbal Learning Test (AVLT) 40 minutes after caffeine consumption to detect if caffeine had an effect on verbal memory, memory span, learning, interference, and delayed recall. Thirty-three undergraduate students were engaged in this study and
divided into two groups, one that ingested 100 mg of caffeine in a beverage and another that received no caffeine in their beverage. The results indicated that even in small amounts caffeine could have an adverse effect on memory performance. Those in the caffeine group recalled fewer words in all 5 trials and experienced a greater deficit in recalling the middle-to-end portions of the test in comparison to the control group (Terry & Phifer, 1986).

While the latter study focused on the immediate effects of caffeine on short-term memory, few sought to emphasize the consequences of abrupt caffeine withdrawal on cognitive performance. James (1998) found that while caffeine did not improve short-term performance in young and middle aged adults, performance was significantly impaired when caffeine was withdrawn following habitual use. This experiment, in which 36 habitual caffeine consumers participated, involved the ingestion of caffeine or placebo (1.75mg/kg of body weight) 3 times a day for 6 days. Those given the placebo recalled fewer words as a whole than those whose diets included caffeine. This finding suggests that abrupt withdrawal of caffeine has an impact on cognitive performance.

A similar study that lent support to the long-term effects of caffeine consumption and memory was employed by Hameleers, et al. (2000). A group of 1875 adults were screened for habitual caffeine intake and tested on a variety of cognitive abilities. While short-term memory, information processing, and Stroop testing were not significantly related to habitual use, long-term memory performance (reading speed and delayed free recall) was significantly related to caffeine consumption. This study suggests that habitual caffeine intake is related to better storage or retrieval from the long-term memory as earlier hypothesized by Loke (1988).
Furthermore, differential effects on memory were found in a study that examined the effects of caffeine on memory performance in young, middle, and older adult participants (Hogervorst, Riedel, Schmitt, & Jolles, 1998). Caffeine (225 mg) was administered to the 60 individuals in a placebo-controlled parallel groups design. Caffeine had no effect on memory performance (immediate and delayed free recall for word lists) of the young and older adult participants, but a significant improvement was found in the middle adult age group. A survey taken prior to the experiment found that middle aged adults consumed more caffeine daily than the other two groups suggesting that long term use of caffeine (those middle aged adults consumed 225 mg of caffeine or more daily) was a determinant of such findings.

While previous studies examined the effects that caffeine had on memory, few have sought to determine if performance is related to the means by which the caffeine is administered. Prior to a study by Smith (1994), very few experiments were conducted that sought to examine the type of drink the caffeine was administered in leaving room for debate as to whether or not the improvement in cognitive performance was due to the caffeine or the beverage itself. That is, do the ingredients contained in the beverage aside from the caffeine (flavoring, sugar, carbonation) influence cognitive performance? Smith (1994) had 144 university students consume coffee, tea, water, or soda that either contained caffeine (40 mg) or did not. One hour later the students were assessed on mood and performance (recall, memory, and verbal reasoning). Results revealed a significant increase on memory improvement for those administered the caffeine. However, the nature of the beverage had no bearing on the performance of the individuals involved.
Studies mentioned previously (Loke, 1988) and (Hogervorst et al., 1998) sought to examine the effect large amounts of caffeine consumption has on cognitive performance (memory, delayed free recall, free recall, and attention). These large amounts (150 mg or more) are often unrealistic determinants of real life caffeine intake (the average cup of coffee contains 60 mg of caffeine). Smith, Clark, and Gallagher (1999) examined the changes in performance, mood, and physical functioning in the early morning associated with cereal and low dose caffeine consumption. A total of 144 students were engaged in this study. The students were divided into two groups, one group that received breakfast cereal and another that received caffeinated coffee. Forty-five minutes after ingestion of the coffee or cereal the participants were assessed on mood, memory and learning, and cardiovascular functioning. They found that the breakfast cereal was associated with greater positive mood and spatial memory than caffeine consumption however, no effect on the speed of encoding information was found. Caffeine consumption was found to increase blood pressure, mental alertness, and the encoding and retrieval of new information.

Another study performed by Warburton (1995) also supported increased memory performance by caffeine consumption. A double blind procedure was used to administer 75-150 mg of caffeine in a decaffeinated cup of coffee to 18 undergraduate male students. Cognitive performance was tested 45 minutes after ingestion to ensure peak plasma levels of caffeine. The tests administered measured attention, verbal memory, nonverbal memory, problem solving, and mood. Caffeine increased improvement on attention, problem solving, and mood in proportion to the level of the drug. This study’s
findings illustrated that even small amounts of caffeine could have a positive effect on cognitive performance.

A study performed by Jarvis (1993) examined the effect of habitual caffeine intake on cognitive performance. Nine thousand and three randomly selected adults from the United Kingdom participated in this study. A health and lifestyle survey was administered to record the participant’s diet, health, amount of exercise, and caffeine consumption. Individuals were assigned to groups based upon daily caffeine consumption. A weight of 1 was assigned for each cup of coffee consumed and .5 for each cup of tea. Individuals consuming 1-2 cups of coffee were scored as 1.5, those who consumed 3-4 as 3.5, 5-6 as 5.5 and more than 6 cups as 6.5. Cognitive tests measuring reaction time, verbal memory, and visio-spatial reasoning were administered in order to determine if differing levels of habitual caffeine consumption would correlate with cognitive performance. The results revealed that as the amount of caffeine consumption increased among the participants so did the level of cognitive performance on the tests.

Previous research examined failed to include gender as a confound in caffeine consumption and memory performance. Erickson, Hager, Houseworth, Dungan, Petros, and Beckworth (1985) studied the effects of caffeine on memory performance on 107 university students and found little effect of caffeine on cognitive performance. Participants in this study were divided into groups according to impulsivity (as measured by the Eysenck Personality Inventory), sex, and the amount of caffeine administered (0, 2, or 4 mg per kg of body weight) at learning. The participants were shown a list of words (nine lists of twelve words) to be memorized and asked a day later to recall the words they had learned. An ANOVA revealed that caffeine had no effect on the oral
recall of the word lists for the male students but that it did have an adverse effect on the
cognitive performance of the female students.

The interaction between social stimulants (caffeine and nicotine) and improved
cognitive performances is now a widely tested phenomenon (Lowe, 1988). The question
is, "Does caffeine itself cause an improvement in memory performance or is it the state
the individual is in at time of encoding and retrieval that determines the performance?"
Drug-induced state dependent memory has been demonstrated in humans using a variety
of drugs (nicotine, caffeine, and alcohol) (Lowe, 1987). The term, drug induced state
dependency, is used to illustrate the findings that learning is improved when the
information is encoded and retrieved in the same drug state. Lowe (1988) performed a
study to determine if a combination of caffeine and alcohol has an effect on state
dependent learning. Sixteen undergraduate students (8 male and 8 female) ages 18-24
participated into this study. Day 1 of the double blind experiment consisted of
administering a caffeine/alcohol combination to the experimental groups and a
nonalcoholic/decaffeinated combination to the comparison group. Forty minutes later the
students were then administered the learning tests. On day 2, the day of recall,
participants were given either the same conditions as day 1 or a different combination of
caffeine/alcohol and found dissociation decrements (inability to recall words learned) in
both the double placebo (mean 0.25) and alcohol only conditions (mean 3.55) which
suggests the cognitive improvements on the tasks were a direct result of the caffeine and
not the alcohol.

State dependency can be altered with various conditions (drug induced, mood
induced, etc) in order to determine if same state dependency has an effect on cognitive
performance. Schare, Lisman, and Spear (1984) examined the idea that when affective states are consistent during both encoding and retrieval performance is enhanced. Three different experiments were performed using 198 undergraduate students. Students were given statements to be memorized that were of a neutral subject manner or one of depressing content. Experiments 1 and 2 altered the mood states of the participants during retention and encoding and no state dependence was revealed. However, experiment 3 did not alter the mood states from day 1 to 2 but employed an interference paradigm (the participants learned a dual word list, one in a depressed mood and one in an elated mood) and found that those who were administered the same state dependency on both days had a 30% higher accuracy in the recall of words learned than those with altered states indicating that state dependency may have an effect on learning in specific situations.

Alcohol was used as the substance of drug state dependency in two different experiments conducted by Lowe (1987). Lowe examined the effects of alcohol and nicotine and alcohol and caffeine on state dependency. Twenty-four undergraduate students volunteered in the alcohol/nicotine combination experiment. Participants in this group were administered vodka and tonic water 4.4 ml per kg of body weight or tonic and tap water (4.4 ml per kg of body weight). Nicotine was administered to the subjects by having them smoke two Benson and Hedges Pure Gold cigarettes within a 12-minute period. Those in the comparison group received two “Honey piece” herbal cigarettes (nicotine free). On day 1 all subjects received the same treatment of alcohol plus nicotine and on day 2 the individuals were randomly allocated to four conditions: drugs, nicotine and placebo, alcohol and placebo, or no drugs. The largest dissociation decrements
(inability to recall words) were found in the groups with both the double placebo and the nicotine. This suggests the major state dependent learning (SDL) was due to alcohol with a slight influence of nicotine. The second experiment, which relates more to the study currently, included 16 undergraduate students who underwent the same conditions as those in experiment one except nicotine was replaced with caffeine. An ANOVA revealed the largest dissociation decrements in the double blind placebo and alcohol only conditions. Little dissociation was found when caffeine only was ingested suggesting that caffeine was the major determinant of the SDL effect.

It is worthwhile to investigate drug state dependency of caffeine on learning in the college population in order to determine if learning that occurs in one drug induced state effects performance later when in the same state or in another state. It is reasoned that if memory is dependent, returning to the original mood or state helps remind participants of what they were thinking when in that mood and memory performance can be enhanced. The researcher is interested in understanding what processes mediate mood-congruent memory. There are two possible explanations regarding the phenomenon of mood-congruent memory. The first possibility is that mood congruency is directly produced by changes in arousal that are associated with the presence of an emotional state. The second possibility is that mood congruence is the result of cognitive processes activated as a result of the emotional state experienced (Varner & Ellis, 1998). The idea behind state dependency is that when one learns information in a particular state or mood and is asked to recall that information at a later date, the information will be retrieved with greater ease and accuracy if the state or mood is congruent with the original state in which the material was learned.
In light of the conflicting studies on caffeine and state dependency on memory, the present study is interested in examining if state dependency on caffeine increases performance on memory for word lists. The hypothesis for this study is: Individuals who receive the same level of caffeine on both day 1 and day 2 will recall more words than those who receive differing levels of caffeine on both days, supporting the notion that caffeine state dependency fosters improved memory performance.

Method

Participants

Participants for this study included 60 undergraduate students from developmental psychology classes at Messiah College, a Christian liberal arts college in the middle Atlantic states, ages ranging from 18-24 years of age. Students were asked to voluntarily participate in this investigation and were awarded extra credit points by their professors. Students were excluded if they had reported a history of diabetes, hypoglycemia, hyperglycemia, high blood pressure, or heart disease, conditions that might be compromised by the ingestion of caffeine.

Materials

A detailed consent form (see appendix A) was issued at the beginning of the study for the participants to read and sign. The students were then administered a 200 ml plastic cup of generic caffeine free cola that contained 0 or 200 mg of crushed caffeine in tablet form in order to determine if a large amount of caffeine had a greater effect on state dependent learning than no caffeine. The tablets were over the counter No Doz tablets. A random word list (see appendix B) containing 18 words was presented to the students
on an 8x11 inch sheet of paper. The researcher kept a record sheet in order to track the number of words recalled on day 2.

Procedure

A 2 (level of caffeine at encoding) x 2 (level of encoding at retrieval) all-between design was used. On both days the levels of caffeine were a high dose (200 mg), or a no dose (0 mg) of caffeine. Students were asked to refrain from caffeine consumption 12 hours prior to their scheduled time period and for the duration of the study, 24 hours after day 1 testing. This measure was taken to ensure that outside consumption of caffeine would not interfere with the results of the study. Students were tested between 11:00am and 4:00 pm on both testing days. Prior to testing, the students were made aware of the nature of the study and the benefits he or she would receive (see appendix C). On day 1 the students were asked to sign a consent form verifying their voluntary participation and made aware of the confidentiality of the study.

After completion of the consent form the students were administered 0 or 200 mg of caffeine depending upon the cell group for which he or she was randomly selected. Thirty names were selected for the 0 mg caffeine cell and the remaining thirty were placed in the 200 mg caffeine cell. The student was then asked to leave the study (students were able to go to any location on campus) and return to the study 30 minutes later to ensure peak plasma levels of caffeine and issued a list of randomly selected words to be memorized. Participants were given as much time as they needed to study the list. They understood that they would be taking a test on the words the next day, which guided them in their study time.
On day 2 the student was administered the same or a different amount of caffeine in his or her beverage and tested one half hour later on the same word list that was memorized the previous day in order to determine if state dependency on caffeine had an effect on memory. The group that received the caffeine and the group that did not, were randomly divided into two more groups on the second day with half of each group receiving caffeine and half not, prior to recall of the words. Once the student completed the second portion of the experiment he or she was thanked for his or her participation and debriefed on the nature of the study.

Results

The mean number of words recited during the recall portion of the experiment (Day 2) can be found in Table 1. A 2 x 2 all between ANOVA (level of caffeine at encoding x level of caffeine at recall) was performed and no main effects for either encoding or recall was found. In other words, there was not a significant difference in words recalled between the group that received the caffeine on the first day and those that did not receive caffeine on the first day. Likewise, there was no significant difference between the groups that received caffeine on the second day with those who did not receive caffeine on the second day. However, an interaction was found between the two variables $F (1, 56) = 5.37, p < .05$ (See Figure 1) showing that depending on the condition, there were differential effects.

Discussion

The present data did lend support to the researcher’s hypothesis of caffeine on state dependency for memory of word lists. Students given the same amount of caffeine on both testing days did out-perform students given differing levels of caffeine on both
days. Participants who received either 0 mg of caffeine or 200 mg of caffeine on both
days recalled a significantly higher number of words at the time of recall than those who
received two different levels of caffeine. These findings suggest that it is not merely the
presence or absence of caffeine that influences memory, but the state of the individual at
the time of encoding and recall. If the state of arousal at the time of encoding is matched
at recall, this study would suggest memory performance would be optimized.

Despite results that revealed higher levels of caffeine decreased cognitive
performance in recall (Lowe, 1988), this study did find increased cognitive performance
with a high (200 mg) level of caffeine. However, this increase was over groups that did
not have matched levels of caffeine at encoding and recall. In addition, this study lent
support to previous studies that revealed caffeine alone had no effect on the number of
words recalled (Hull, 1985). Due to the fact that the group that received no caffeine at all
during the testing performed as well as the group that received caffeine at encoding and
recall, these results are indicative that state dependency is the variable that influences
memory and not the caffeine.

This study offers some initial insights and confirms the nature of state dependency
in an area of cognitive performance (memory). The results indicate that state dependent
learning can occur with or without the addition of a stimulant (caffeine). This study lends
support to the notion that similar mood states at the time of encoding and retrieval have a
greater impact on learning performance than the stimulant used.

In short, there is a relationship between state dependency and memory function.
Future research should focus on short-term memory and state dependence in order to
determine if similar results would be found. In addition, it may be important to include
more information about specific aspects of caffeine such as gender, age, and time of day of consumption.
Reference


Appendices
Caffeine Levels and Words Recalled (Mean)

Encoding (EY=Caffeine the First Day, EN=NO Caffeine the First Day)

EN

EY

Number of Words Recalled on Second Day

0

5

10

15

20

13.36

15.44

12.5

15.5

(1st day) anale the no catterine the (2nd day) catterine the
<table>
<thead>
<tr>
<th>Retrieval-Caffeine</th>
<th>Encoding-Caffeine</th>
<th>Encoding-No Caffeine</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.50</td>
<td>13.36</td>
<td></td>
</tr>
<tr>
<td>12.50</td>
<td>15.44</td>
<td></td>
</tr>
</tbody>
</table>
Appendix A

Consent to participate in Research Study

Title of Study: The Effects of Caffeine on Human State Dependent Learning

Investigator: Nicole Miller, Messiah College, Phone: 939-2855

You are being asked to participate in a study examining the effects of caffeine consumption and state dependent memory.

Procedure: You will be given a beverage and then asked to return to the study one half hour later. Once you return, you will be asked to study a list of eighteen words until criterion. Once you feel you have memorized those words to perfection you may leave the study and return tomorrow at the same time. Day two will follow the same procedure as day one except on day two you will be asked to recite the words you learned the previous day. Once you have been tested you will be free to leave. Thank you for your participation.

Risks and Benefits: The method of research creates no potential risk to you as a participant. It is a minimal risk study. You will be receiving extra points in the amount of 6 points for your participation.

Confidentiality: Testing will be analyzed using a number system, no names will be used and the information will not be given to anyone else.

Costs and Compensation: There is no cost or compensation for participation in this study.

Right to refuse or withdrawal: You have the right to refuse to participate at any time during this study. You also have the right to leave the study at any time.

Please sign your name on the line below indicating your voluntary consent.

_________________  ___________________  ___________________
_________________  ___________________  ___________________
_________________  ___________________  ___________________
_________________  ___________________  ___________________
_________________  ___________________  ___________________
_________________  ___________________  ___________________
Appendix B

Word List

Wax
Smile
Arithmetic
Ocean
Teaberry
Slave
Calf
Lips
Strange
Aquatic
Ledge
Goose
Apple
Bike
Chair
Essay
Malice
Dream
Appendix C

Debriefing

You were just involved in a study testing state dependent learning (in this case levels of caffeine 0 or 200 mg) and cognitive performance on memory for word lists. Numerous studies have been performed that report a greater ability to recall words learned when the individual has the same state (same amount of caffeine) at both encoding and retrieval of words learned. The purpose of my study was to determine if those of you who received the same amount of caffeine on both testing days would out-perform those who received differing levels of caffeine on both days. Did you feel the words were easier or harder to memorize or recite on either day? How did you feel while taking the test (jittery, nervous, apprehensive?) How do you feel now that the study has been performed? Can you think of any possible improvements? Do you feel this study to be valuable to college students in general?

Do you have any further comments or questions? If not, thank you for your participation. Please do not discuss the nature of this study with anyone else as it may bias the results. If you are interested in receiving the results of this study please leave me your e-mail address and I will send you a copy once the data has been analyzed. Thank you!