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CAFFEINE, SEMANTIC PROCESSING, LOGICAL REASONING, IMPLICIT MEMORY, RECOGNITION MEMORY AND ALLOCATION OF MEMORY RESOURCES

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ABSTRACT

Background: Research has shown that caffeine improves the performance of semantic processing and logical reasoning tasks. The present study aimed to confirm the positive effects of caffeine on these tasks and to investigate other aspects of memory, namely implicit memory, recognition memory and allocation of memory resources. **Methods**: Participants (University students, N=48) completed two laboratory sessions on consecutive days. Separate groups either received caffeine or a placebo on each day or had a different condition on each day. The caffeine dose was 4mg/kg and was carried out double-blind. On day one, the participants carried out memory tests investigating semantic processing, logical reasoning, immediate recall and recognition, implicit memory and allocation of memory resources. On day two, delayed recall and recognition were tested, and a word fragmentation completion task was carried out. **Results**: The performance of the semantic processing and logical reasoning tasks was significantly better in the caffeine condition, as were implicit memory and word fragmentation completion. Caffeine also led to resources being directed away from low-priority task components. Caffeine had no significant effect on immediate recall or recognition. On day two, delayed recall and recognition were not influenced by caffeine. **Conclusion**: The results from this study confirm the effects of caffeine on semantic processing and executive function. Recall and recognition were not influenced by caffeine, but there were new effects on the implicit memory and allocation of memory resources tasks. These results extend our knowledge of caffeine and memory and show that semantic processing and logical reasoning tasks can be used as positive controls in future research on this topic.

KEYWORDS: Caffeine; Semantic processing; Executive function; Immediate and delayed recall and recognition; implicit memory; Allocation of memory resources.

INTRODUCTION

The effects of caffeine on behaviour have been extensively reviewed[1-8], and much of the literature has been concerned with alertness, sustained attention and psychomotor speed. This profile has been confirmed in recently published results.[9-12] The effects of caffeine on memory have been less widely studied[13], but reliable improvements have been found with semantic processing and logical reasoning tasks.[14-20] The present study used the semantic processing and logical reasoning tasks as positive control tasks, where effects of caffeine were expected, in a study which also involved aspects of memory where little is known about the effects of caffeine.

One of the major objectives of the present study was to investigate the effects of caffeine on recognition memory which, along with recall, has been a significant focus of caffeine and memory research to date. The literature suggests that caffeine only has an effect on recognition memory where there may be factors which decrease attention when the stimuli lists are being learnt. For example, Anderson and Revelle[21] gave participants 4 mg/kg of caffeine or a placebo before performing four recognition memory tasks of differing lengths. These tasks consisted of the presentation, at 2.7 sec per word, of a 24- or 80-word list followed by an immediate forced-choice recognition task. The order of the list presentation was a 24-word list followed by two 80-word lists, followed by a final 24-word list. It was found that there was a significant main effect of caffeine for the two 80-word lists and for the second 24-item lists only. The authors argue that this is suggestive of a caffeine effect in the encoding of the stimuli as factors which affect attention and initial encoding of stimuli are known to mediate recognition memory performance.[22] The positive effects of caffeine on sustained attention are well documented, and the effects of caffeine described in their experiment may have arisen because encoding the longer 80-word lists and second 24-word list (when the participant would be more fatigued) would require a higher level of sustained attention than the first 24-word list. Generally, in studies where the word list has been shorter (e.g. 40-48 words,[23-25]), no effect of caffeine has been found. The present study attempted to replicate the results described by Anderson and Revelle[21] in order to provide further evidence that caffeine can also have an effect on recognition in specific circumstances, such as where the encoding task requires a high level of sustained attention. It is unknown whether attention at encoding might also mediate recall and the present study also investigated the possible interaction of caffeine and attention at encoding on a free recall task.

Another major aim of the study was to determine whether caffeine has any effect on implicit memory. Implicit memory refers to a form of memory whereby performance on a retrieval task is mediated by a previous and seemingly unrelated experience.[26] The phenomenon is the subject of two main theoretical interpretations, one of which suggests it reflects data-driven, as opposed to conceptual processing[27] and the other that suggests that it results from the operation of pre-semantic perceptual subsystems.[28] The phenomenon is, however, easily demonstrable, and there are several reasons why the effects of caffeine on this form of memory may be of interest.

Firstly, despite the interest in caffeine and memory in general, the effect of caffeine on implicit memory has not been thoroughly investigated in any studies to date. Research has demonstrated that the effects of caffeine on human memory are task-specific, and it may be the case that implicit memory is sensitive to caffeine. Secondly, implicit memory studies usually use incidental encoding tasks in order that participants do not perceive any association between the encoding and retrieval parts of the test. The use of an incidental encoding task gives participants no reason to use deliberate (and highly efficient) encoding or rehearsal strategies which might potentially optimise memory performance to such an extent that relatively subtle effects such as those produced by caffeine might be obscured. It is noteworthy that the three caffeine studies which have used incidental encoding prior to explicit recall have all described caffeine effects.[29-31] Our recent study[20] of immediate free recall on which deliberate encoding or rehearsal strategies could have been used was found, as is usually described in the caffeine literature, to be unaffected by caffeine. Main effects of caffeine were found, however, on semantic memory, logical reasoning, and the (unexpected) delayed recall task, which were not amenable to the use of deliberate encoding or rehearsal.

The dichotomy between implicit and explicit memory can also be considered in terms of the allocation of memory resources, where implicit memory would reflect the limited allocation of cognitive resources to memory, and explicit memory would reflect the intentional, strategic encoding of material. Such a conception would be compatible with Baddeley's[32] suggestion that the difference between implicit and explicit memory may be rather artificial, with implicit memory reflecting the use of '…an array of learning mechanisms that have in common only the fact that they are incapable of generating recollective memory.' (p. 351). Previous research has suggested that the allocation of memory resources is mediated by arousal (e.g. noise,[33]), where heightened arousal shifts resources toward prioritised memory tasks and away from non-prioritised memory tasks.[34] No previous research has considered the potential effects of caffeine on the allocation of memory resources, and the present experiment attempted to redress this balance using a task previously shown to be sensitive to the effects of noise.[35] Semantic memory and executive function were used as positive control tasks.

The measurement of implicit memory is the subject of considerable debate, and it would appear that there are several legitimate methods by which it can be measured, including priming (where exposure to a stimulus has an effect on subsequent performance), skill acquisition and classical conditioning.[36] Of these paradigms, priming is arguably the easiest to use experimentally, and two of the most commonly used forms, word stem completion and word fragment completion, were used in the present study. These two measures of implicit memory have been shown to produce equivalent results[26] and therefore enabled a repeated-measures design to be used whilst revealing as little as possible about the true nature of the test to the participant.

Hypotheses

Main effects of caffeine.

A) Caffeine (4 mg/kg) will significantly improve semantic memory performance; the number of trials attempted will be increased, the accuracy of responses will be increased, and mean reaction time (MRT) for correct responses will be decreased.
B) Caffeine (4 mg/kg) will significantly improve central executive function; the number of trials attempted will be increased, the accuracy of responses will be increased, and MRT for correct responses will be decreased.
C) Caffeine (4 mg/kg) prior to recall will significantly decrease the number of words correctly recalled in a delayed recall task (caffeine at encoding will have no effect on recall).

Interactions between caffeine and task parameters

Caffeine (4 mg/kg) will significantly increase performance on the longer immediate recognition task (80-word stimuli at encoding) but not on the shorter immediate recognition task (20-word stimuli at encoding). The increase in performance under caffeine will be greater under conditions of fatigue, i.e. at the end of the test battery.

METHOD

The study was carried out with the approval of the ethics committee School of Psychology and the informed consent of the participants. A mixed design was employed with caffeine condition and order of long and short recognition and recall tasks (80 items then 20 item test vs 20 items then 80 item test) as between-subjects factors and performance on day one and day two as a within-subjects factor. The 48 participants were then randomly subdivided into eight groups comprising the same number of males and females to give the experimental groups shown in table 1. The administration of caffeine was double-blind.

Participants

Forty-eight participants were used in the experiment, 24 males and 24 females; all were non-smokers and regular consumers of caffeinated coffee or tea. The demographics of the sample are shown in table 2.

Table 1: Experimental groups: caffeine condition on day one and day two and order of recognition and recall tasks.

Group	Caffeine condition on day 1 of testing	Caffeine condition on day 2 of testing	Order of recognition/recall tasks within batteries
1 (n = 6)	Caffeine	Caffeine	1. Short (20-word) list 2. Long (80-word) list
2 (n = 6)		Placebo	
3 (n = 6)	Placebo	Caffeine	
4 (n = 6)		Placebo	
5 (n = 6)	Caffeine	Caffeine	1. Long (80-word) list 2. Short (20-word) list
6 (n = 6)		Placebo	
7 (n = 6)	Placebo	Caffeine	
8 (n = 6)		Placebo	

Table 2: Participant demographics and personality characteristics (means, S.E.s in parentheses).

Age (years)	21.44 (0.32)
Mean caffeine consumption (mg/24h)	156.04 (17.21)
EPI: Impulsivity (0-low to 9-high)	2.85 (0.14)
EPI: Sociability (0-low to 12-high)	6.56 (0.35)
EPI: Extroversion (0-low to 23-high)	10.08 (0.45)

Informed consent

Participants were asked to sign a consent which gave brief details of the experiment and confirmed the fact that they were free to withdraw from the study at any time.

Payment

Participants were paid £25 on completion of the study.

Procedure

Familiarisation

Participants were given practice with the test battery no more than one week prior to their first test session to ensure that they were familiar with the tests. The familiarisation session presented the tests in identical order to those used on the test sessions but used truncated versions of the tasks that lasted for approximately one minute each. The word fragment completion task and the word stem completion tasks both used sets of words which had not been presented during the word rating exercise in order to maintain the illusion that these tasks were completely unrelated. During the familiarisation session, participants were allowed to ask questions as necessary in order to clarify instructions and objectives. Following the demonstration of the computer tasks, participants were weighed without shoes or coats so that the amount of caffeine they were to receive could be calculated. At familiarisation, participants were also given a sheet of written instructions which advised them that during testing, normal sleeping patterns and meal times should be adhered to as much as possible and that there were prescribed periods during which they should not consume alcohol or caffeine.

Test procedure

Participants were tested in sessions beginning at either 0900 or 1400 hrs.

Morning testing

2200 Begin abstinence from alcohol until the end of the experiment

Test day 1: 0030 Begin abstinence from self-administered caffeine

0900 Present for testing after normal breakfast

0905 Test battery (baseline)

0945 Expectancy effects questionnaire, administration of caffeine or placebo, eating and sleeping questionnaire, caffeine discrimination questionnaire

1045 Test battery (post-drug)

1145 Participants were allowed to resume normal caffeine intake

Test day 2: 0030 Begin abstinence from self-administered caffeine.

0900 Present for testing after normal breakfast; begin test battery (baseline)

0945 Administration of caffeine or placebo, eating and sleeping questionnaire, caffeine discrimination questionnaire

1045 Test battery (post-drug)

1145 Debriefing and participants were allowed to resume normal caffeine and alcohol intake.

Afternoon testing

Where participants were tested in the afternoon, the same procedure was used with baseline testing on day one starting at 1405 and the post-drink test battery on days one and two starting at 1545. Participants were again expected to refrain from alcohol from 12 hours prior to the beginning of the experiment until the end of the experiment and also to abstain from self-administered caffeine for 8 hours prior to each test session.

Experimental Beverages

All drinks were made with one rounded teaspoonful of decaffeinated coffee in 150ml of boiling water with milk and sugar added to each participant's taste. To this was added the appropriate amount of either solution A or solution B (each potentially carrying 20mg/ml of caffeine) such that in the active condition, participants would consume 4mg/kg of caffeine or, in the placebo condition, sterile water only. The code for the solutions was held by a third party and was not revealed until after all the data analysis had been carried out.

Measures

Questionnaires

At the familiarisation session prior to the demonstration of the computer tests, participants were asked to complete two questionnaires, one relating to demographic details, health-related behaviours and personality characteristics and another measuring the participants' beliefs about the cognitive effects of caffeine. Prior to each post-drug test session, two further questionnaires were administered. The first recorded eating and sleeping behaviour in the hours prior to the test session, and the second recorded whether participants thought they had consumed a caffeinated or placebo beverage.

Performance tasks

All tasks were presented on a microcomputer. For the long and short free recall, order-case, order-location and implicit memory tasks, additional response sheets were provided as detailed in the descriptions of the test.

Semantic memory

This test was devised by Baddeley[37] and is described more fully by Nguyen-Van-Tam and Smith.[20]

Logical reasoning task

This task was devised by Baddeley[38] and is again described more fully by Nguyen-Van-Tam and Smith.[20]

Allocation of resources (1) Order-case

Both allocations of resource tasks were based on those used by Smith[35] and used the same stimuli lists. Participants were given written instructions on the computer screen that they were going to be shown eight words, 4 in upper case and 4 in lower case, and that their task was to remember both the order of the words and the case in which they were presented. One group of participants (group A) was instructed to prioritise the order of the words, and a second group (group B) were asked to prioritise the case of the words. Words were presented for two seconds each, and after the presentation of the words, participants were required to perform three written tasks. The first task was to simply recall all the words that they could and write them down in any order. After this had been completed, participants were shown two lists of the words in random order and lowercase; on the first list, they were asked to indicate the order in which the words had been presented with the numbers 1-8, and on the second list the case in which the words were presented with a U or an L. Smith[35] did not use an initial recall task or presentation of all the words in random order prior to the order and case tasks, but in the present study these were used so that the order and case task reflected allocation of resources only and was not confounded by individual differences in the recall. The exclusion criteria were failure to order 25% of the word stimuli correctly or failure to identify the correct case of less than 25% of the word stimuli.

Allocation of resources (2) Order-location

Participants were again given written instructions on the computer screen and were again informed that they would be presented with eight words which would this time be presented in one of 4 places on the computer screen (the four corners), with the task this time being to remember the order of the words and the location in which they were presented. One group of participants (group B) was instructed to prioritise the order of the words, and a second group (group A) were asked to prioritise the location of the words. Words were presented for two seconds each, and after the presentation of the words, participants were required to perform a free recall task in which participants were asked to simply recall all the words that they could and write them down in any order. Participants were then shown a list of the words in random order and asked to indicate the order in which they had been presented with the numbers 1-8. Participants were also shown a map of the computer screen and, referring to the randomly ordered list of words, asked to indicate on the map where the word had appeared on the screen during the presentation. The exclusion criteria were failure to order 25% of the word stimuli correctly or failure to assign less than 25% of the word stimuli to the correct location.

Immediate recall

This task was similar to that used by Smith et al.[18]: a list of words was displayed (at two seconds per word), and participants were then asked to write down all the words they could recall, in any order, on a response sheet. Two immediate recall tasks were incorporated into each test battery, one of 80 words and one of 20 words. Participants in Group A completed the 20-word battery before the 80-word battery, whilst those in group B did the tasks in the opposite order. Word lists were balanced for word length and word frequency according to the Kuçera and Francis[39] norms. The indices of performance were the total number of words written down and the percentage of the words from the stimulus list that were recalled correctly. The exclusion criteria for the free recall task was a change of ± 4 S.D. from baseline in the total number of words written down so that participants showing inconsistent motivation would be excluded.

Immediate recognition

The recognition task followed the immediate free recall task and consisted of the random presentation of the words shown in the free recall task and a similar number of foils matched for length and frequency using the Kuçera and Francis[39] norms. Participants were then required to decide, as quickly as possible, whether each word had been seen previously and respond by pressing a true or false key on the computer response box. Indices of performance were the percentage of target words identified correctly, the percentage of foils identified incorrectly (i.e. the number of intrusions) and MRT for target words recognised correctly.

The exclusion criteria for the task were failure to correctly recognise at least 25% of the target words or to incorrectly identify more than 75% of the foils in the baseline condition.

Implicit memory

The implicit memory task was based very closely on the task used by Roediger et al.[26] and employed the same stimulus sets. Initially, on day one, incidental learning was used to encode a list of 60 target words. Equal numbers of high and low-frequency words were included in the list, with 30 of the words having a frequency higher than 50 per million according to the Kuçera and Francis[39] norms. Each word was presented on the computer screen for 7 sec, and during this time, participants were asked to rate the word from 1 (dislike very much) to 7 (like very much). After completing a ten-minute filler task (in this case, the semantic memory and logical reasoning tasks), participants were shown a list of 60-word fragments, each consisting of a word with 2, 3 or 4 letters missing. Included in the list were half of the target words and a similar number of non-studied words matched for length and frequency using the Kuçera and Francis[39] norms. Each fragment was shown for 12 seconds, and participants were asked to simply complete the fragment with the first word that came into their head and to write down the completed word on the response sheet provided.

On day two of testing, 24 hours after encoding, participants were shown 60 three-word stems comprised of the 30 encoded words not included in the word fragment completion task and a further 30 length and frequency-matched foils. The word stems were presented at a rate of one every 5 sec, and, without reference to the initial encoding of the targets in any way, participants were asked to think of a word that would complete the stem and write it down on the response sheet. Completed word fragments were judged to be correct if they fitted exactly into the spaces provided and were in the Oxford English Dictionary. Words were judged to have come from the studied list only if they exactly matched the words on the list. Participants were excluded if they failed to complete at least 10% of both the studied and non-studied word fragments correctly.

Delayed recall

For the delayed recall task, participants were asked to write down on day two all the words they could remember, in any order, from the corresponding free recall task on day one. The delayed recall tasks were in the same position in the test batteries as they had been on the previous day, and explicit instructions were given to recall only the words from the correct list (e.g. participants were asked to recall any words from the long list of words presented to them 'after their coffee').

Delayed recognition

Delayed recognition was tested after the delayed recall tasks on day two and was identical to the recognition task on day one except for a difference in the use of a different set of length- and age-matched foils.

Order of test battery

Familiarisation

The battery of tests in the familiarisation session included shortened versions of all the tasks in the order in which they were described.

Baseline

Group A	*Group B*
1. Immediate recall (20 words)	1. Immediate recall (80 words)
2. Immediate recognition	2. Immediate recognition
3. Allocation of resources: order*-case	3. Allocation of resources: order-case*
4. Semantic memory	4. Semantic memory
5. Logical reasoning	5. Logical reasoning
6. Allocation of resources: order-location*	6. Allocation of resources: order*-location
7. Immediate recall (80 words)	7. Immediate recall (20-words)
8. Immediate recognition	8. Immediate recognition

* = prioritised task

Post-drug day 1

The order of tasks was as the baseline with the addition of the implicit memory encoding task after the allocation of resources and the implicit memory word stem completion task after the logical reasoning task.

Post-drug day 2

As for baseline with the addition of the implicit memory word fragment completion task after the logical reasoning task and the substitution of the immediate recall and recognition tasks for delayed recall and recognition tasks (using the stimuli from the previous day).

Analysis of the memory data

Throughout the analysis, individual differences in performance were controlled for by using ANCOVA with the relevant index of performance from the baseline condition as the covariate. Where covariates were not constant across levels of a factor, only non-adjusted S.E.s were reported. For the analysis of the allocation of resources, recall and recognition tasks, which were carried out twice in each battery, the position of the task in the battery was used as an additional within-subjects factor.

Analysis of the data proceeded in two main stages

1. Determination of the effects of caffeine on day one so that a direct and straightforward comparison with other similar studies could be made.
2. Investigation of the effects of caffeine on delayed recall and recognition and implicit memory 24 hours after the presentation of the stimuli or priming.

RESULTS

Main Effects of caffeine on day 1

Semantic memory

Forty-eight data sets were analysed; no participants were excluded for meeting the exclusion criteria. A series of ANCOVAs were performed on the three indices of performance, the number of trials attempted, the percentage of trials correct and MRT for correct trials. For each analysis, the relevant index of performance from the baseline condition was used as a covariate. It was found that there was a significant main effect of caffeine on the number of trials attempted, $F(1, 45) = 4.12$, $MSe = 92.89$, $p < 0.05$, on the percentage of trials correct, $F(1, 45) = 4.35$, $MSe = 9.46$, $p < 0.05$ and for MRT for correct trials, $F(1, 45) = 3.03$, $MSe = 16983.89$, $p < 0.05$ (one-tailed; table 3).

Table 3: Effects of caffeine on the semantic processing task.

The number of trials completed.

Mean	*Caffeine (4 mg/kg)*	*Placebo*
Adjusted (S.E.)	130.27 (1.97)	124.61 (1.97)
Non-adjusted (S.E.)	132.54 (6.02)	122.33 4.97)

Per cent Correct

Mean	*Caffeine (4 mg/kg)*	*Placebo*
Adjusted (S.E.)	96.00 (0.63)	94.18 (0.63)
Non-adjusted (S.E.)	95.84 (0.53)	94.31 (0.83)

Mean reaction time (MRT) in msec

Mean	*Caffeine (4 mg/kg)*	*Placebo*
Adjusted (S.E.)	1263.20 (19.95)	1336.55 (19.74)
Non-adjusted (S.E.)	1217.55 (45.95)	1283.43 (52.28)

Logical Reasoning

Thirty-nine data sets were analysed as 9 participants met the exclusion criteria. ANCOVA using the relevant indices of performance at baseline as a covariate revealed that caffeine significantly increased the number of trials attempted, $F(1, 36) = 4.92$, MSe = 37.38, $p < 0.05$ and significantly decreased MRT for correct trials, $F(1, 36) = 3.74$, MSe = 126528.92, $p < 0.05$ (one-tailed; table 4). For the percentage of trials correct, the difference between caffeine and placebo conditions did not approach statistical significance. In the caffeine condition, 88.97 (S.E. 1.38) per cent of trials were completed correctly as opposed to 92.08 (S.E. 1.49) per cent in the placebo condition. Non-adjusted means were 90.18 (S.E. 2.26) and 90.67 (S.E. 1.49), respectively.

Table 4: Effects of caffeine on logical reasoning.

Number completed

Mean	*Caffeine (4 mg/kg)*	*Placebo*
Adjusted (S.E.)	58.68 (1.34)	54.32 (1.44)
Non-adjusted (S.E.)	59.52 (3.12)	53.33 (2.62)

Mean R.T. (msec)

Mean	*Caffeine (4 mg/kg)*	*Placebo*
Adjusted (S.E.)	3117.67 (77.77)	3339.53 (84.03)
Non-adjusted (S.E.)	3058.50 (145.19)	3408.56 (222.11)

Recall

Forty-five complete data sets were analysed.

Caffeine effects

A series of ANCOVAs were performed using caffeine condition and order of task length as between-subjects factors and position of the task in the test battery as a within-subjects factor. Measures of performance in the first and last recall tests of the baseline battery were used as covariates to control for individual differences. For the total number of words written down and the percentage of words from the stimulus, lists recalled there were no main effects of caffeine. The total number of words written down was 11.33 in the caffeine condition compared to 11.14 in the placebo condition. Non-adjusted means were 11.30 (S.E. 0.70) in the caffeine condition and 11.16 (S.E. 0.72) in the placebo condition. The percentage of words from the target lists recalled correctly was 25.21 in the caffeine condition and 25.51 in the placebo condition, with non-adjusted means of 25.46 (1.92) and 25.23 (S.E. 1.96), respectively.

For the total number of words written down and percentage of words correctly recalled, and the number of intrusions, it was found that there were statistically significant interactions between position in battery and order of short and long tasks ($F[1, 40] = 45.79$, $MSe = 7.60$, $p < 0.0001$, $F[1, 40] = 18.72$ and $MSe = 65.86$, $p < 0.0025$ respectively). The means relevant to all of the interactions clearly indicated the effects of task length. More words were written down, and more intrusions were made after the presentation of an 80-word list rather than a 20-word list and a higher percentage of words were recalled correctly from the shorter 20-word lists. No significant interactions between task length and caffeine were found.

Serial position – caffeine effects

An ANCOVA was then performed on the post-drug data using block and position in the battery as within-subjects factors and caffeine as a between-subjects factor. The covariates (not constant across levels of factors) were the percentage of words recalled correctly in each block at baseline. It was found that the main effect of caffeine and the interaction between caffeine and blocked serial position did not reach statistical significance at the 5% level.

Recognition

Forty-eight data sets were analysed, as no participants met the exclusion criteria.

Caffeine effects

A series of ANCOVAs were performed on the percentage of target words recognised correctly, the percentage of foils incorrectly recognised and the MRT for correctly recognised targets. Ingestion of caffeine or placebo and order of task length were used as between-subjects factors, and the position of the task in the test battery was used as a within-subjects factor. The covariates were the relevant indices of performance from the baseline condition. For the percentage of correctly identified targets, the percentage of incorrectly recognised foils and MRT for correctly recognised targets, there were no main effects of caffeine nor interactions between caffeine, the position of the task in the test battery or order of short and long tasks that approached significance at the 5% level.

In the caffeine condition, 42.26 per cent of target words were recognised correctly compared to 42.59 per cent in the placebo condition; non-adjusted means were 41.91 (S.E. 1.93) and 42.94 (S.E. 1.93), respectively. The percentage of incorrectly recognised foils was 9.87 per cent in the caffeine condition and 12.27 in the placebo condition. Non-adjusted means were 9.84 (S.E. 1.54) in the caffeine condition and 12.29 (S.E. 1.54) in the placebo condition. MRT for correctly recognised targets words was 882.88 msec in the caffeine condition and 900.18 msec in the placebo condition, with non-adjusted means of 884.18 (S.E. 32.53) and 898.88 (S.E. 32.53), respectively.

For the number of foils incorrectly identified as being in the studied list and for MRT for correctly recognised targets, there were statistically significant interactions between position in the battery and order of the short and long tasks ($F[1, 43] = 5.12$, 58.20, $p < 0.05$ and $F[1, 43] = 4.74$, MSe = 16909.45, $p < 0.05$ respectively). Inspection of the relevant means appeared to indicate that in the shorter 20-word tasks, the percentage of foils incorrectly recognised was greater and the MRT for correctly recognised targets slower than for the 80-word tasks.

Allocation of resources: order-case

No participants were excluded, and forty-eight data sets were analysed.

Caffeine effects

The first part of the task required participants to simply recall any of the words they had been presented with. An ANCOVA was performed for correctly recalling using caffeine condition and prioritisation of order or case as between-subjects factors and performance at baseline as a covariate. No main effects or interactions were observed.

A further ANCOVA was then performed using performance in the baseline condition as the covariate in order to ascertain whether caffeine on day one of testing would modify the pattern of allocation of resources observed in the baseline condition. As before, the number of words ordered correctly and the number of words assigned to the correct case were within-subjects factors and instruction to prioritise order or case was a between-subjects factor.

The analysis revealed that there was no main effect of caffeine and no interactions involving caffeine and allocation of resources. The only statistically significant effect was the main effect of the task, with 56.28% of words being ordered correctly (non-adjusted S.E. 3.93) and

69.50% of words being assigned to the correct case (non-adjusted S.E. 2.62), F(1, 43) = 5.07, MSe = 486.04, $p < 0.05$ (table 5). No other main effects or interactions reached significance at the 5% level, including the interaction between task performance and prioritisation instruction observed at baseline.

Table 5: Allocation of resources: order-case: percentage of words correct in caffeine (4mg/kg) or placebo conditions for participants asked to prioritise order or case in order and case tasks (S.E.s in parentheses).

Condition	Instruction	Task	Adjusted mean	Non-adjusted mean
Caffeine	Prioritise order	Order	**49.06**	41.67 (10.02)
		Case	**62.07**	68.75 (4.22)
	Prioritise case	Order	**59.73**	55.21 (8.07)
		Case	**70.73**	73.96 (5.21)
Placebo	Prioritise order	Order	**52.26**	46.88 (6.19)
		Case	**72.95**	80.21 (5.44)
	Prioritise case	Order	**64.07**	60.42 (6.51)
		Case	**72.24**	76.04 (6.06)

Allocation of resources: order-location

No participants were excluded; 48 complete data sets were analysed.

Caffeine effects

A preliminary analysis was carried out to see if there was any effect of caffeine on the correct free recall of the word stimuli. An ANCOVA, using performance in the baseline condition as a covariate and caffeine and prioritisation instruction as between-subjects factors, revealed no main effects or interactions approaching significance at the 5% level. Another ANCOVA was then performed again using the relevant index of performance in the baseline condition as the covariate; the number of words ordered correctly and the number of words assigned to the correct case were within-subjects factors, and instruction to prioritise order or the case was a between-subjects factor. It was found that post-drug, the only significant effect was a three-way interaction between task, prioritisation instruction and caffeine, F(1, 43) = 4.70, MSe = 289.50, $p< 0.05$ (table 6).

Table 6: Allocation of resources: order-location: percentage of words correct in caffeine (4mg/kg) or placebo conditions for participants asked to prioritise order or location in order and location tasks (S.E.s in parentheses)

Condition	Experimental instruction	Task	Adjusted mean	Non-adjusted mean
Caffeine	Prioritise order	Order	**60.52**	58.33 (6.41)
		Location	**50.86**	51.04 (5.21)
	Prioritise location	Order	**34.38**	34.38 (6.38)
		Location	**48.46**	47.92 (7.03)
Placebo	Prioritise order	Order	**53.44**	54.17 (8.20)
		Location	**55.83**	57.29 (5.21)
	Prioritise location	Order	**60.10**	59.38 (7.25)
		Location	**56.20**	57.29 (7.46)

A series of Bonferroni t-tests used to test all possible pairwise differences revealed that in the caffeine condition, performance was better on the ordering task when the instruction was given to prioritising order. There were no differences between means in the placebo condition, indicating that in this condition, there was no effect of prioritisation instruction.

Implicit memory

Forty-five data sets were analysed as three participants met the exclusion criteria for the task. A preliminary analysis was carried out to see if the expected implicit memory effect was present and if there was any main effect of caffeine on word fragment completion. The analysis used a mixed ANOVA with the percentage of words completed with primed or non-primed words as a within-subjects factor and caffeine as a between-subjects factor. The analysis revealed that, as expected, there was a very highly significant priming effect; 20.25 % (S.E. 0.81) of fragments were completed with primed words as opposed to 16.16 % (S.E. 0.72) completed with non-primed fragments, $F(1, 43) = 26.26$, MSe = 14.31, $p < 0.0001$. There was also a main effect of caffeine on fragment completion as a whole; in the caffeinated condition, 19.67% (S.E. 0.91) fragments were completed correctly, whereas, in the placebo condition, this fell to 16.74 % (S.E. 0.93), $F(1, 43) = 5.06$, MSe = 38.22, $p < 0.05$. The interaction between priming and caffeine proved to be non-significant, but as differences between certain pairs of means were of specific interest, two planned comparisons were carried out. These comparisons revealed that for primed words, caffeine significantly improved performance compared to placebo ($t = 2.47$, df = 43, two-tailed $p < 0.05$ with Bonferroni adjustment). For fragments completed with non-primed words, however, there was no statistically significant difference between the caffeine and placebo conditions (t = 1.31, df = 43, p > 0.05 with Bonferroni adjustment; table 7).

Table 7: Effects of caffeine on primed fragment completion.

% of the fragments completed with:	*Caffeine (4 mg/kg)*	*Placebo*
Primed words (S.E.)	22.24 (1.29)	18.26 (0.95)
Non-adjusted (S.E.)	17.10 (1.08)	15.23 (0.95)

Summary of Day 1 results

- Caffeine improved performance on semantic memory and logical reasoning tasks replicating the results of previous studies.
- Caffeine had no effect on immediate free recall.
- Caffeine had no effect on immediate recognition memory
- Caffeine affected a specific allocation of resources task (order-location) where it served to re-focus memory resources away from the non-prioritised task.
- Caffeine improved implicit memory.
- There was a positive main effect of caffeine on word fragment completion generally, which may also be evidence of an improvement in semantic memory.

Effects of caffeine on delayed recall, delayed recognition, and implicit memory 24 hours after priming

In order to determine whether caffeine had any effect on delayed recall, recognition or implicit memory performance, these tasks were tested 24 hours after initial encoding or priming. The potentially different effects of caffeine at encoding or priming were investigated by administration of a second dose of caffeine to a subset of participants. This gave rise to four possible caffeine conditions formed by the 2 x 2 combination of caffeine or placebo on day one and day 2 of testing. Delayed recall and recognition were considered to be qualitatively different tests from immediate recall and recognition, so ANOVAs were used in the analysis of these tasks as it was considered that there were no acceptable covariates from the baseline condition. ANOVA was also used in the analysis of the implicit memory data, as implicit memory was not tested at baseline. In all cases, caffeine on day one and caffeine on day two formed separate between-subjects factors.

Delayed recall

The position of the task in the battery was used as a within-subjects factor, and the order of the short and long tasks, caffeine condition on day one and caffeine condition on day two, were used as between-subjects factors. It was found that delayed recall performance was generally much worse than immediate recall, with fewer than 10 % of the stimulus words recalled correctly. The only statistically significant effect involving caffeine was for the total number of words written down where there was a two-way interaction between caffeine condition on day one and day two, $F(1, 37) = 7.45$, $MSe = 33.17$, $p < 0.05$ (table 8). A Newman-Keuls test revealed no significant differences between means, but it was noted that fewer words were recalled when a placebo had been given on both days.

There were, however, a number of significant effects that involved task parameters. There was a main effect of position in the test battery for the total number of words written down ($F[1, 37] = 4.60$, $MSe = 25.58$, $p< 0.05$), with 8.58 per cent of words being recalled on the second test compared to 6.29 per cent on the first (S.E.s were 0.93 and 0.67 respectively). The reason for this effect is unknown. A statistically significant interaction between the order of short and long tasks and position in battery for the total number of words written down, $F(1, 36) = 12.17$, $MSe = 26.24$, $p < 0.0025$, indicated that as of day 1, participants wrote down more words from the long 80-word lists than from the shorter 20-word lists.

Table 8: Delayed recall, day two: recall performance in caffeine (4mg/kg) or placebo on day one and day two (S.E.s in parentheses)

Index of performance	Condition on day 1	Condition on day 2	Mean
Number of words written down	Caffeine	Caffeine	6.79 (1.23)
	Caffeine	Placebo	8.71 (1.18)
	Placebo	Caffeine	8.93 (1.23)
	Placebo	Placebo	5.31 (1.23)
Percentage of words from the stimulus list recalled correctly	Caffeine	Caffeine	4.51 (1.40)
	Caffeine	Placebo	7.14 (1.33)
	Placebo	Caffeine	4.39 (1.40)
	Placebo	Placebo	4.50 (1.40)

Delayed recognition

As for the delayed recall, position in the battery was used as a within-subjects factor and order of short and long tasks, caffeine condition on day one and caffeine condition on day two, were used as between-subjects factors. There was only one significant effect involving caffeine, and this was for the percentage of targets correct, where it was found that the interaction between caffeine on day one and caffeine on day two was statistically significant, F(1, 40) = 6.87, MSe = 163.81, p < 0.025. A Newman-Keuls test failed to reveal any significant differences between means, and the pattern of means appeared difficult to interpret theoretically (table 9). There were, however, a number of effects involving task parameters. For the percentage of targets correct, the two-way interaction between position in battery and order of short and long tasks also reached significance at the 5% level (F[1, 36] = 5.96, MSe = 110.38, p < 0.0001 and the relevant means revealed that, as has been found previously, a higher percentage of targets were correctly recognised from the short task with a 20-word stimuli list than the long task with an 80-word list. For the percentage of foils incorrect, there was a main effect of position in the battery, F(1, 40) = 4.28, MSe = 81.04, p < 0.05, with a lower number of foils being recognised in the first recognition task test of the battery compared to the second. The interaction between position in the battery and order of short and long tasks again proved to be statistically significant, F(1, 39) = 26.52, MSe = 76.69, p < 0.0001, with the means indicating that more foils were recognised incorrectly from the 20-word lists than from the longer 80-word lists.

Table 9: Delayed recall, day two: recognition performance in caffeine (4mg/kg) or placebo on day one and day two (S.E.s in parentheses).

Index of performance	Condition on day 1	Condition on day 2	Mean
Percentage of targets correct	Caffeine	Caffeine	25.73 (2.61)
	Caffeine	Placebo	32.92 (2.61)
	Placebo	Caffeine	35.89 (2.61)
	Placebo	Placebo	29.53 (2.61)
Percentage of foils incorrect	Caffeine	Caffeine	19.12 (2.66)
	Caffeine	Placebo	23.49 (2.66)
	Placebo	Caffeine	24.53 (2.66)
	Placebo	Placebo	19.43 (2.66)
MRT for targets correct	Caffeine	Caffeine	906.48 (73.04)
	Caffeine	Placebo	1054.49 (73.04)
	Placebo	Caffeine	1095.38 (73.04)
	Placebo	Placebo	1052.01 (73.04)

Implicit memory 24 hours after priming

As in the analysis of implicit memory on day one, an initial analysis was carried out to ascertain if there were main effects of priming or caffeine or interactions between the two. The analysis used caffeine on day one and caffeine on day two as between-subjects factors to enable investigation of potentially different caffeine effects at priming and at encoding and the percentage of words completed with primed or non-primed words as a within-subjects factor.

It was found that there was a main effect of priming, $F(1, 44) = 96.86$, $MSe = 44.05$, $p < 0.0001$, but that, contrary to the theoretical expectations, 36.67 % (S.E. 1.24) of words were completed with non-primed words as opposed to 23.33 % (S.E. 0.79) completed with primed words. This finding strongly suggests that 24 hours later, the effects of priming had dissipated and that there was no longer any implicit memory for the primed words. As found in the earlier word fragment completion test, there was a main effect of caffeine, $F(1, 44) = 8.09$, $MSe = 46.46$, $p < 0.01$. As before, caffeine served to improve performance, with 31.86 % (S.E. 0.98) of word stems completed correctly after caffeine compared to 28.02 % (S.E. 0.98) after placebo.

Summary of day two results

- There was no evidence that caffeine produces any effects on the percentage of words correctly recalled in a delayed recall paradigm at either encoding or retrieval.
- There is no evidence that caffeine produces any effects on delayed recognition memory at encoding or retrieval.
- For both recall and recognition tasks, caffeine did not interact with stimulus list length or participant fatigue.
- Caffeine produced a positive main effect on word stem completion, possibly providing further evidence of a caffeine effect on semantic memory.

DISCUSSION

The primary objective of the study was to investigate the effects of caffeine on recognition memory and recall and the possibility of interactions with experimental parameters such as list length and time on the task, which might impair attention at encoding. The study also considered two areas of memory where the effects of caffeine are largely unknown: implicit memory and allocation of memory resources. The study used an experimental design which allowed caffeine effects at encoding or priming to be investigated independently from effects on retrieval and used measures of semantic memory and executive function as positive control tasks, as these have proven to be reliably improved by caffeine.

As expected, the usual effects of caffeine were found on the semantic memory and logical reasoning tasks, where caffeine was found to increase both speed and accuracy of performance for the semantic task and speed of performance of the executive function task. These results are consistent with those reported in our previous study[20] and those described in the literature. It should be noted that both tests rely heavily on the encoding of written information, and it would also seem possible that the speed at which this written information can be read and encoded may underlie the effects of caffeine, particularly effects on reaction time.

No main effects of caffeine were found on any of the parameters of immediate or delayed recognition, and this finding is consistent with previous research, which strongly suggests that caffeine has no main effects on recognition. The present study, however, also manipulated factors, such as list length and position of the test within the cognitive test battery, as previous research has found that caffeine mediates recognition memory performance when attention at encoding is impaired. When these factors were considered, it was found that there were effects of list length and position in the battery that appeared to conform to the theory that recognition is a function of attention at encoding but that these factors did not interact with the caffeine condition. No main effects of caffeine were found on immediate or delayed recognition, nor was there any evidence of the interaction between caffeine and attention at encoding described by Anderson and Revelle[21] and it is concluded that caffeine has no reliable effect on recognition memory.

The study also investigated whether caffeine would have effects on immediate free recall when the amount of attention at encoding was manipulated. Using the manipulations of experimental parameters described by Anderson and Revelle[21] to impair encoding, it was found that the expected effects of stimulus list length were observed with a higher percentage of words being recalled from the shorter 20-word list than from the 80-word lists as well as the usual primacy and recency effects. No main effects of caffeine were found, nor were there any interactions with experimental parameters that mediated attention at encoding, and the findings would therefore seem compatible with previous research where the majority of studies have reported that there was no effect of caffeine on immediate free recall. The present study also failed to find a statistically significant effect of caffeine on blocked serial position, and although the interaction between caffeine and serial position was approaching significance, the lack of clear-cut effects is not entirely unexpected as studies which have looked at caffeine and the serial position curve previously have produced conflicting results or else have found no effects. In our recent study[20], it was found that caffeine impaired performance on a delayed free recall task when given immediately before retrieval. The design of the present study also allowed investigation of the effects of caffeine at retrieval independently of effects at encoding, but it was found that in the present study, the effects of caffeine did not approach significance. Overall, the present study did not find any evidence of caffeine effects on immediate or delayed recall or any interaction with experimental parameters which mediated attention at encoding. The study was also unable to reproduce the impairment in delayed recall after acute ingestion of caffeine that was reported in our previous study[20], and it is concluded that, like recognition, recall is an area of memory where caffeine has little overall effect.

Although previous studies suggest that there are no reliable caffeine effects on recall and recognition, these tasks do appear to be sensitive to other pharmacological manipulations. Impairments in recall and recognition memory have, for example, been reported for lorazepam[40, 41] and midazolam.[42] Given the sensitivity of recall and recognition tasks to pharmacological manipulations, it seems that there may be a range of possible reasons why recall and recognition are not affected by caffeine. Firstly it may be that caffeine, like other drugs, has specific neurochemical mechanisms and actions[7] that affect only specific memory processes. In the case of caffeine, where the effect size is smaller than many clinically prescribed drugs, it could also be argued that effects on recall and recognition may be obscured using mnemonic strategies such as elaboration, imagery or rhyme. It is noted that on the semantic memory and logical reasoning tasks, where the effects of caffeine appear to be reliable and consistent, there are no such mnemonic strategies which can be used to facilitate performance.

Implicit memory has received very little attention in relation to caffeine. Turner[43] used a relatively unproven implicit memory task and a very poorly controlled method of caffeine administration. The present study used more proven implicit memory tasks (word fragment completion and word stem completion) and a methodology that was rigorous enough to produce caffeine effects on other memory parameters. It was found that 10 minutes after incidental encoding, there was a highly significant priming effect on a word fragment completion task and that more fragments were completed with primed words in the caffeine condition than in the placebo condition. For the implicit memory task administered on day two, 24 hours after encoding, there was, however, no priming effect, and it is assumed that the priming effect had dissipated, possibly due to interference effects from other tasks. The effects of caffeine on implicit memory reported in the present study have not been reported previously and require replication before any further conclusions can be drawn. On both implicit memory tasks, word-fragment and word-stem completion, there were statistically significant main effects of caffeine. In both cases, more words were successfully completed in the caffeine condition than in the placebo condition, and although the tasks are not generally acknowledged to be indices of semantic memory, the results are taken to be additional evidence that caffeine has a positive effect in this area.

The allocation of resources is another area of memory which has never been previously investigated in relation to caffeine, but unfortunately, findings on the tasks related to this area were rather unclear. There were no significant effects of caffeine in the order-case task. For the order-location task, however, caffeine effects were present, with participants given caffeine appearing to assign more resources to the prioritised task than those given placebo. If caffeine is taken to be a source of arousal, this finding is consistent with previous research where it has been found that heightened arousal (e.g. in the form of noise) shifts memory resources away from the low priority task and toward high-priority tasks.

The results for the allocation of resources tasks are difficult to interpret. It is unclear why only the caffeine effects were confined to the order-location task, but it would seem likely that in the order-case task, the unexpected but highly significant effect of task type obscured the relatively subtle caffeine effects. In the order-location task, the lack of effects of prioritisation instruction at baseline may mean that the significant three-way interaction between caffeine, prioritisation instruction and task performance simply reflects greater compliance with the experimental instructions after caffeine and not a re-allocation of memory resources per se.

In summary, the study failed to find any convincing evidence of caffeine effects on recall or recognition despite, in the case of the present study, manipulation of experimental parameters to produce impaired levels of attention at encoding. This result is consistent with most of the literature regarding the effects of caffeine on recall and recognition. The study did, however, find an effect of caffeine on implicit memory using a well-proven word-fragment paradigm where implicit memory was found to be significantly better in the caffeine condition than in the placebo condition. As this was the first study to examine the effects of caffeine on implicit memory, future research should attempt to replicate this effect, and if this proves possible, then subsequent studies must investigate the effect in more detail.

For the allocation of resources task, the results were problematic to interpret but potentially showed an effect of caffeine in the re-allocation of memory resources in the same way as other sources of arousal (e.g. noise), and further experimental investigation may be warranted. As for implicit memory, further research must replicate the effects of the present study before the effect is considered in more detail.

As expected, the present study also found the usual profile of caffeine effects on measures of semantic memory and executive function that were being used as positive control tasks. These effects are clearly reliable, and further research should investigate the mechanisms which underlie such effects and also consider the use of word-fragment completion as an alternative means of measuring semantic memory.

REFERENCES

1. Lieberman HR. Caffeine. In: Handbook of Human Performance, Vol.2: Health and performance. (eds) A. P. Smith & D. M. Jones. London: Academic Press, 1992: pp. 49-72.
2. Smith AP. Effects of caffeine on human behavior. Food Chem Toxicol, 2002; 40: 1243-55.
3. Smith AP. Caffeine. In: Nutritional Neuroscience. Edited by H. Lieberman, R. Kanarek and C Prasad, 2005; 335-359. London: Taylor & Francis.
4. Glade M.J. Caffeine – Not just a stimulant. Nutrition, 2010: 26: 932-938.
5. Smith AP. Caffeine: Practical implications. In: Diet, Brain, Behavior: Practical Implications. Eds: R.B. Kanarek & H.R. Lieberman. Taylor & Francis, 2011; 271-292.
6. Doepker C, Lieberman H, Smith AP, Peck J, El-Sohemy A, Welsh B. Caffeine: Friend or Foe? Annual Review of Food Science and Technology, 2016; 7: 6.1–6.22. DOI: 10.1146/annurev-food-041715-033243.
7. Smith AP The psychobiological processes underpinning the behavioural effects of caffeine. In: P. Murphy (ed), Routledge International Handbook of Psychobiology. London, New York: Routledge. ISBN: 978-1-138-18800-6 (hbk) ISBN: 978-1-315-64276-5 (ebk), 2019; 239-250.
8. Killgore WDS, Kamimori G. Multiple caffeine doses maintain vigilance, attention, complex motor expression, and manual dexterity during 77 hours of total sleep deprivation. Neurobiology of Sleep and Circadian Rhythms, 2020. doi.org/10.1016/j.nbscr.2020.100051.

9. Smith AP. Caffeine and long hours of work: Effects on alertness and simple reaction time. World Journal of Pharmaceutical Research, 2021; 10(2): 79-89. DOI: 10.20959/wjpr20212-19694.
10. Smith AP. Caffeine and ratings of alertness in the early morning. World Journal of Pharmaceutical and Medical Research, 2021; 7(3): 53-57. https://www.wjpmr.com/home/article_abstract/3334
11. Smith AP. Caffeine, alertness and simple reaction time: A study of free choice of beverages. World Journal of Pharmaceutical Research, 2021; 10(5): 149-159. DOI: 10.20959/wjpr20215-20442
12. Smith AP. Caffeine, chocolate, performance, and mood. World Journal of Pharmaceutical Research, 2021; 10(14): 180-188. Doi: 10.20959/wjpr202114-22277
13. Nguyen-van-Tam, DP, Smith AP. Caffeine and human memory: a literature review and some data. 19th International Scientific Colloquium on Coffee, 2001. Trieste. Association Scientifique Internationale du Café
14. Smith AP, Kendrick AM, Maben AL. Effects of breakfast and caffeine on performance and mood late in the morning and after lunch. Neuropsychobiology, 1992; 26: 198-204.
15. Smith AP, Brockman P, Flynn R, Maben AL, Thomas M. Investigation of the effects of coffee on alertness and performance and mood during the day and night. Neuropsychobiology, 1993; 27: 217-223.
16. Smith AP, Kendrick AM, Maben AL, Salmon, J. Effects of breakfast and caffeine on cognitive performance, mood and cardiovascular functioning. Appetite, 1994; 22(1): 39-55.
17. Smith AP, Whitney H, Thomas M, Perry K, Brockman P. Effects of caffeine on mood, performance and cardiovascular functioning. Human Psychopharmacology-Clinical and Experimental, 1997; 12(1): 27-33.
18. Smith AP, Sturgess W, Gallagher J. Effects of low dose caffeine given in different drinks on mood and performance. Human Psychopharmacology-Clinical and Experimental, 1999; 14: 473-482.
19. Warburton DM. Effects of caffeine on cognition and mood without caffeine abstinence. Psychopharmacology, 1995; 119(1): 66-70.
20. Nguyen-Van-Tam DP, Smith, A.P. Caffeine, mood, verbal reasoning, semantic processing and levels of processing: An investigation of state-dependent memory. World Journal of Pharmaceutical Research, 2022; 11(13): 2166-2190. Doi: 10.20959/wjpr202213-25780.

21. Anderson KJ, Revelle W. Impulsivity and time of day: Is rate of change in arousal a function of impulsivity? Journal of Personality and Social Psychology, 1994; 67: 334-344.
22. Underwood BJ. Recognition memory as a function of length of study list. Bulletin of the Psychonomic Society, 1978; 12: 89-91.
23. Smith AP, Kendrick AM, Maben AL. Effects of breakfast and caffeine on performance and mood late in the morning and after lunch. Neuropsychobiology, 1992; 26: 198-204.
24. Loke WH, Hinrichs JV, Ghoneim MM. Caffeine and diazepam: separate and combined effects on mood and memory and psychomotor performance. Psychopharmacology, 1985; 87: 344-350.
25. Loke WH. Effects of caffeine on mood and memory. Physiology and Behavior, 1988; 44(3): 367-372.
26. Roediger HL, Weldon MS, Stadler ML, Riegler GL. Direct comparison of two implicit memory tests: word fragment and word stem completion. Journal of Experimental Psychology: Learning, Memory and Cognition, 1992; 18(6): 1251-1269.
27. Roediger HL. Implicit memory: Retention without remembering. American Psychologist, 1990; 45: 1043-1056.
28. Schacter DL. Implicit memory; history and current status. Journal of Experimental Psychology: Learning, Memory and Cognition, 1987; 13: 501-518.
29. Gupta U. Differential effects of caffeine on free recall after semantic and rhyming tasks in high and low impulsives. Psychopharmacology, 1991; 105(1): 137-140.
30. Gupta U. Effects of caffeine on recognition. Pharmacology, Biochemistry and Behavior, 1993; 44(2): 393-396.
31. Jarvis MJ. Does caffeine intake enhance absolute levels of cognitive performance? Psychopharmacology, 1993; 110(1-2): 45-52.
32. Baddeley AD. Human memory: Theory and practice. (2nd ed.). 1997. Hove: Psychology Press.
33. Hockey GRJ, Hamilton, P. Arousal and information selection in short-term memory. Nature, 1970; 226: 826-827.
34. Eysenck MW. Human Memory. 1977. Oxford: Pergamon Press.
35. Smith AP. The effects of noise and task priority on recall of order and location. Acta Psychologica, 1981; 51: 245-255.
36. Roediger HL, McDermott KB. (Eds.). Implicit memory in normal human subjects (Vol. 8). 1993. Amsterdam: Elsevier.

37. Baddeley A.D. The cognitive psychology of everyday life. British Journal of Psychology, 1981; 72: 257-269.
38. Baddeley AD. A three-minute reasoning test based on grammatical transformation. Psychonomic Science, 1968; 10: 341-342.
39. Kuçera H, Francis WN. Computational analysis of present-day American English. Providence, RI: Brown University Press, 1969.
40. Scharf MB, Khosla N, Lysacght R, Brocke N, Moran J. Anterograde amnesia with oral lorazepam. Journal of Clinical Psychiatry, 1983; 44: 362-364.
41. File SA, Bond AJ, Lister RG. Interaction between effects of caffeine and lorazepam in performance testing and self-rating. Journal of Clinical Psychopharmacology, 1982; 2: 102-106.
42. Reitan JA, Porter W, Braunstein M. Comparison of psychomotor skills and amnesia after induction of anaesthesia with midazolam or thiopental. Anaesthesia and Analgesia, 1986; 65: 933-937.
43. Turner J. Incidental information processing: effects of mood, sex and caffeine. International Journal of Neuroscience, 1992; 72(1-2): 1-14.