



FURTHER INVESTIGATION OF THE EFFECTS OF CAFFEINE ON IMPLICIT MEMORY, ALLOCATION OF MEMORY RESOURCES, SEMANTIC MEMORY AND EXECUTIVE FUNCTION

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ABSTRACT

Background: Research has shown that the performance of semantic processing and logical reasoning tasks improves after caffeine. There is also some evidence that implicit memory and allocation of memory resources are improved by caffeine. The aims of the present study were twofold; firstly, to attempt to replicate the effects of caffeine on implicit memory and allocation of memory resources and secondly, to investigate whether the effects of caffeine on semantic memory and executive function were mediated by the speed of reading and encoding of lexical information. **Methods:** Participants (University students, N=56) completed a laboratory session in the morning or afternoon. Separate groups either received caffeine or a placebo. The caffeine dose was 4mg/kg and was carried out double-blind. Tasks

measuring semantic processing, logical reasoning, implicit memory and allocation of memory resources were used. **Results:** The performance of the semantic processing and logical reasoning tasks was significantly better in the caffeine condition. These effects did not reflect the speed of encoding of the information. Previous findings on the effects of caffeine on implicit memory and allocation of memory resources were not replicated. **Conclusion:** The results from this study confirm the effects of caffeine on semantic processing and executive function. These effects did not reflect the speed of encoding the new information. In contrast, no reliable effects of caffeine on implicit memory and allocation of memory resources were found. These results confirm that semantic processing and logical reasoning tasks are good indicators of the beneficial effects of caffeine, whereas other aspects of memory show little effect.

KEYWORDS: Caffeine; Semantic processing; Executive function; Logical reasoning; Implicit memory; Allocation of memory resources.

INTRODUCTION

The effects of caffeine on behaviour have been widely studied [see 1-8 for reviews], and much of the literature has been concerned with sustained attention, psychomotor speed and alertness. This profile has been confirmed in our recently published results.^[9-12] The effects of caffeine on memory have received less attention^[13], but reliable improvements have been found in semantic processing and logical reasoning tasks following the consumption of caffeine.^[14-20]

Our previous study^[21] provided further evidence for the reliability of caffeine's effects on semantic memory and executive function and also suggested that caffeine has a positive effect on implicit memory and may also cause reallocation of memory resources in favour of highly prioritised tasks. The first objective of the present study was to extend previous findings regarding the effects of caffeine on semantic memory and executive function by investigating whether performance increases on the tasks are mediated by increases in the speed at which lexical information can be read and encoded. The second objective of the study was to attempt to replicate the effects of caffeine on implicit memory and the allocation of memory resources reported in the previous study.

Research has suggested that the effects of caffeine on semantic memory and executive function are consistent and easily replicable and that the effects are not mediated by subjective alertness. It was also found that performance on the two tasks after caffeine does not appear to be highly correlated, suggesting that the tasks do not measure a common cognitive construct or have a common underlying mechanism. Both tasks, however, require fast reading and encoding of lexical information (particularly the semantic memory task), and it would seem possible that this might be one of the mechanisms by which caffeine could mediate performance on one or other of the tasks (though probably not on both tasks since performance on the two tasks after caffeine does not appear to be related). Such a mechanism, while obviously accounting for differences in reaction time, could also plausibly affect the accuracy of performance as an increase in the percentage of trials correct may be the result of faster encoding of lexical information, allowing more time for a well-considered answer to be made. In order to test this hypothesis, the present study used modified versions of the semantic memory and executive function tasks in which the majority (but not all) of the

lexical information for each trial was presented for a fixed time before the presentation of the crucial information needed to actually answer the question or verify the statement. This allowed a generous and fixed amount of time for reading and encoding the majority of the lexical information needed to answer each trial so that an ability to read and encode information quickly would not confer many advantages in terms of performance on the task. Standard versions of both tasks were also included in the test battery so that performance with fixed encoding time and performance with free encoding time could be compared as a within-subjects factor.

The study also attempted to replicate the positive effects of caffeine on implicit memory following incidental encoding that was found in the previous study. Anagram completion rather than word-fragment or word-stem completion was used as a measure of implicit memory to see whether the effect could be generalised to other implicit memory paradigms, which are known to produce highly comparable results.^[22]

In our previous study^[21], it was found that there were unexpected main effects of task type in the order-case task but that on the similar order-location task, caffeine possibly led to a relative re-focusing of memory resources onto the high-priority task at the expense of the low priority task, i.e. caffeine acts in the same way as noise.^[23] The interaction of caffeine with priority instructions and task performance in the post-drug condition was possibly confounded by the lack of effect of priority on task performance at baseline, such that caffeine simply led to greater compliance with the experimental instructions rather than causing a reallocation of memory resources per se. In the present study, it was hoped to reproduce the effects of caffeine on the allocation of resources seen post-drug in the previous experiment but also to see if this effect could be reproduced in conjunction with a priority effect at baseline. The lack of compliance with priority instruction at baseline in the previous study may have been related to participant fatigue, so the order-location task was placed toward the start of each cognitive battery in the present experiment.

Finally, in the previous study, it was found that for word-fragment completion and word-stem completion tasks (used as indices of implicit memory), there were also main effects of caffeine, with participants who had consumed caffeine demonstrating better performance on both tasks irrespective of priming. This finding was taken to be indicative of further evidence of a caffeine effect on semantic memory, as both tasks require retrieval of general information without temporal associations from long-term storage. The present study aimed

to reproduce these effects using a simple word-fragment completion task without any priming in order to find out whether the effect was reliable.

Hypotheses

Main effects of caffeine

- A) Caffeine (4mg/kg) will significantly improve semantic memory performance; the number of trials attempted will be increased, the accuracy of responses will be increased, and MRT for correct responses will be decreased.
- B) Caffeine (4mg/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 (4mg/kg) will significantly increase the number of primed anagrams correctly deciphered in the implicit memory task. Caffeine will have no effect on non-primed word anagrams.
- D) Caffeine (4mg/kg) will significantly increase the number of word fragments completed correctly.

Interactions between caffeine and task parameters

Caffeine (4mg/kg) will modify performance on the allocation of resources task such that after caffeine, performance on the high-priority task will be better compared to placebo and performance on the low-priority task will be decreased compared to placebo.

METHOD

The study was approved by the ethics committee School of Psychology, Cardiff University, and carried out with the informed consent of the participants.

Experimental design

A mixed design was employed with caffeine condition and priority of order or location as between-subjects factors and order of standard and modified semantic and executive function task as a within-subjects factor. The 56 participants were randomly subdivided into four groups, each comprising the same number of males and females, to give the experimental groups shown in table 1. Administration of caffeine was double-blind to eliminate a potential demand characteristic, and the code describing which solution contained caffeine was not broken until after the analysis. The dose of caffeine (4mg/kg) and method of administration

used in our previous studies^[20,21] produced the expected profile of caffeine results on the positive control tasks and was therefore used in again the present experiment.

Table 1: Experimental groups: caffeine condition, order of standard and encoding time-controlled semantic memory and logical reasoning tasks.

Group	Caffeine Condition	Order of semantic memory and logical reasoning tasks within batteries
1 (n = 14)	Caffeine	1. Standard task
2 (n = 14)	Placebo	2. Encoding controlled task
5 (n = 14)	Caffeine	1. Encoding controlled task
6 (n = 14)	Placebo	2. Standard task

Participants

Fifty-six participants were used in the experiment, 28 males and 28 females; all were non-smokers and regular consumers of caffeinated coffee or tea. The demographics of the sample are shown in table 2.

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

Age (years)	22.32 (0.87)
Mean caffeine consumption (mg/24h)	100.00 (16.40)
EPI: Impulsivity (0-low to 9-high)	4.26 (0.28)
EPI: Sociability (0-low to 12-high)	7.19 (0.38)
EPI: Extroversion (0-low to 23-high)	11.87 (0.62)

Informed consent

Participants were asked to sign a consent form 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

Prior to the test session, participants were given a sheet of written instructions which advised them that during testing, normal sleeping patterns and mealtimes should be adhered to as much as possible and that there were prescribed periods during which they should not consume alcohol or caffeine.

Familiarisation

A familiarisation session was integrated into the test procedure to ensure that participants knew how to complete the cognitive performance tasks correctly. The familiarisation session presented the tests in identical order to those used on the test sessions but used shortened versions of the tasks that lasted for approximately one minute each. The anagram task was presented before the word-rating exercise in order to maintain the impression that these tasks were completely unrelated. None of the anagrams was derived from words that were in the word-rating exercise. During the familiarisation session participants were also asked to complete a questionnaire that recorded demographic details, health-related behaviours and personality traits.

Test procedure

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

Morning testing

2200 Begin abstinence from self-administered alcohol until the end of the experiment

0000 Begin abstinence from self-administered caffeine

0900 Present for testing after normal breakfast, weighing

0920 Familiarisation battery

0940 Break

0950 Test battery (baseline)

1020 Expectancy effects questionnaire, administration of caffeine or placebo, eating and sleeping questionnaire, caffeine discrimination questionnaire

1120 Test battery (post-drug)

1210 Debriefing and participants are allowed to resume normal caffeine and alcohol intake

Afternoon testing

Where participants were tested in the afternoon, the same procedure was used but with baseline testing beginning at 1450 and the post-drink test session starting at 1620. Participants were again expected to refrain from self-administered alcohol for 12 hours before the experiment and from self-administered caffeine for 8 hours prior to the 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, participants were asked to complete a detailed questionnaire that recorded demographic details, health-related behaviours, eating and sleeping habits and a profile of personality traits. The questionnaire was identical to that used in our previous studies.

Prior to the post-drug test session, two further questionnaires were given. The first measured participants' perceived expectancies with regard to caffeine and mood, attention and cognition using three bipolar scales. The second measured eating and sleeping behaviour the night before and on the day of the test procedure. Participants were also asked to complete a caffeine discrimination questionnaire prior to the post-drug test session in order to ascertain whether they were able to detect caffeine.

Performance tasks

All tasks were presented on a microcomputer. For the implicit memory task and word-fragment completion task, response sheets were provided as described in the descriptions of the individual tasks.

Semantic memory: standard task

This was based on Baddeley's^[24] semantic memory task and is described more fully in our previous studies.^[20,21]

Semantic memory: encoding time controlled

This was similar to the standard task, but the first part of each question (e.g. Do dogs have...) was presented for a fixed time period (2.0 seconds) prior to the presentation of the last word in the sentence (e.g. wings?). The indices of performance were the same as for the standard task, with reaction time being measured from the presentation of the last word.

The exclusion criteria for these tests were failure to attempt at least 50 trials at baseline and/or failure to get at least 80% of the trials correct.

Semantic memory: word-fragment completion

This task was based on the word-fragment completion task used in our previous task^[21], with the only difference being that in the present study, none of the words from which the fragments were derived had been primed beforehand.

Participants were excluded if they failed to complete at least 10% of the word fragments correctly.

Central executive function: standard task

This task was based on Baddeley's^[25] logical reasoning task and is described more fully described in our previous studies.^[21,22]

Central executive function: encoding time controlled.

This task was based on the standard central executive function test but presented the statement describing the letter pairs for 2.0 seconds (e.g. Does A follow B?) before showing the actual letter pair (e.g. B.A.). Indices of performance were the number of sentence verifications attempted in three minutes, the percentage correct and the MRT for correct verifications measured from when the letter pair first appeared on the screen.

The exclusion criteria for these tasks were failure to provide correct verifications for at least 50% of the simple active statements in the baseline condition.

Implicit memory

The anagram-completion task was based on a task devised by Roediger et al.^[22] Incidental learning was used to encode a list of 60 words. The encoding task consisted of the 7-second presentation of a word, after which participants were asked to rate their like or dislike of the word on a scale from 1 (dislike very much) to 7 (like very much) and to write their response on a response sheet.

After completing filler tasks (the semantic memory and executive function tests), participants were shown a series of 60 anagrams, each for 12 seconds. During this time, participants were asked to unscramble the letters to make a word and write it on a response sheet. The words from which 60 anagrams consisted of 30 words selected at random from the encoded list (i.e. half of the encoded list) and 30 non-studied words matched exactly for length and frequency.

Word anagrams were judged to be correct if they consisted of all the letters in the anagram and the word was 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 for failing to complete at least 10% of both the studied and non-studied anagrams correctly and for completing more than 10% of the anagrams with words that did not use precisely the letters available.

Allocation of resources task: order-location

This was the same task as described by Nguyen-Van-Tam and Smith [21]. Participants were 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.

Order of test batteries

* = *prioritised task*

Familiarisation battery

1. Implicit memory: anagram solution
2. Semantic memory
3. Semantic memory: controlled encoding
4. Semantic memory: word-fragment completion
5. Logical reasoning
6. Logical reasoning: controlled encoding
7. Allocation of resources: order-location*

- 8. Allocation of resources: order*-location
- 9. Implicit memory: encoding

Baseline battery

* = *prioritised task*

Group A

- 1. Allocation of resources: order-location*
- 2. Semantic memory
- 3. Semantic memory: controlled encoding
- 4. Logical reasoning
- 5. Logical reasoning: controlled encoding

Group B

- 1. Allocation of resources: order*-location
- 2. Semantic memory: controlled encoding
- 3. Semantic memory
- 4. Logical reasoning: controlled encoding
- 5. Logical reasoning

Post-drug

* = *prioritised task*

Group A

- 1. Allocation of resources: order-location*
- 2. Implicit memory: encoding
- 3. Semantic memory
- 4. Semantic memory: controlled encoding
- 5. Logical reasoning
- 6. Logical reasoning: controlled encoding
- 7. Implicit memory: anagram completion
- 8. Semantic memory: Word-fragment completion

Group B

- 1. Allocation of resources: order*-location
- 2. Implicit memory: encoding
- 3. Semantic memory: controlled encoding
- 4. Semantic memory
- 5. Logical reasoning: controlled encoding
- 6. Logical reasoning
- 7. Implicit memory: anagram completion
- 8. Semantic memory: word-fragment completion

Analysis

As in our previous studies, individual differences in performance were controlled for by using ANCOVA with the relevant index of performance from the baseline condition used as the covariate. If covariates were not constant levels of factors, only non-adjusted S.E.s are reported. ANOVA was employed where differences in performance were predicted in the baseline condition and for certain tasks where there was no baseline condition and hence no covariate. Performance on standard and modified versions of each task were analysed

together with control of encoding as a within-subjects factor. As in the previous studies, the data from the questionnaires was collated for later use.

RESULTS

Semantic memory

Fifty-four complete data sets were analysed; two participants met the exclusion criteria.

Effects at baseline

Two variations of the semantic memory task were carried out within each battery, and as encoding time was controlled in one of the tasks, it would be expected that there may have been some differences in performance at baseline, particularly in the amount of time taken to complete each trial. In order to investigate these differences at baseline, a series of ANOVAs were performed with the order of presentation of the tasks used as an additional between-subjects factor. As would be expected, it was found that on the semantic memory task where encoding was controlled, significantly fewer trials were attempted but that MRT for correct trials was significantly faster (because participants had encoded all but the last word of the trial in the previous two seconds). Where encoding time was controlled, significantly more trials were also answered correctly.

Caffeine effects

ANCOVAs were carried out 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 the covariate, with control of encoding time used as an additional between-subjects factor and order of presentation as a between-subjects factor.

It was found that there were no statistically significant interactions between caffeine and control of encoding time for any parameter of performance but that there were the usual main effects of caffeine. It was found that caffeine significantly increased the number of trials, $F(1, 49) = 3.61$, $MSe = 60.76$, $p < 0.05$ (one-tailed; table 3) and percentage of trials correct, $F(1, 49) = 3.19$, $MSe = 8.24$, $p < 0.05$ (one-tailed; table 3) and significantly decreased MRT for correctly answered trials, $F(1, 49) = 7.30$, $MSe = 16107.46$, $p < 0.01$ (table 3).

As at baseline, there was a highly significant effect of control of encoding for the number of trials attempted $F(1, 49) = 9.34$, $MSe = 48.19$, $p < 0.005$ with adjusted means being 101.80

trials without controlled encoding and 91.79 with controlled encoding. Non-adjusted means for the two conditions were 127.83 (S.E. 3.43) and 65.65 (S.E. 0.76), respectively. There was also a main effect of control of encoding for MRT for correct trials as there was at baseline, $F(1, 49) = 13.45$, $MSe = 7871.48$, $p < 0.001$. MRT was 1038.01 msec with encoding time not controlled and 938.21 msec with encoding time controlled. Non-adjusted MRT was 1304.88 (S.E. 40.64) for the uncontrolled encoding condition and 674.17 (S.E. 31.28) for the controlled condition.

Table 3: (a): Semantic memory: number of trials attempted in caffeine (4mg/kg) and placebo conditions on the standard task and task with controlled encoding (scores are the adjusted means, S.E.s shown as bars).

<i>Task</i>	<i>Mean</i>	<i>Caffeine (4 mg/kg)</i>	<i>Placebo</i>
Standard	Adjusted	103.95	99.66
	Non-adjusted (S.E.)	130.39 (4.77)	125.27 (4.93)
Controlled encoding	Adjusted	92.52	91.06
	Non-adjusted (S.E.)	66.43 (1.06)	64.89 (1.01)

(b) Semantic memory: percentage of trials correct in caffeine (4mg/kg) and placebo conditions on the standard task and task with controlled encoding (scores are the adjusted means, S.E.s shown as bars)

<i>Task</i>	<i>Mean</i>	<i>Caffeine (4 mg/kg)</i>	<i>Placebo</i>
Standard	Adjusted	96.60	95.18
	Non-adjusted (S.E.)	96.10 (0.59)	94.50 (0.61)
Controlled encoding	Adjusted	95.88	94.47
	Non-adjusted (S.E.)	95.73 (0.59)	95.00 (0.61)

© Semantic memory: MRT for correct trials in caffeine (4mg/kg) and placebo conditions on the standard task and task with controlled encoding (scores are the adjusted means, S.E.s shown as bars)

<i>Task</i>	<i>Mean</i>	<i>Caffeine (4 mg/kg)</i>	<i>Placebo</i>
Standard	Adjusted	1001.93	1074.11
	Non-adjusted (S.E.)	1269.97 (56.48)	1339.78 (58.46)
Controlled encoding	Adjusted	908.60	967.82
	Non-adjusted (S.E.)	649.76 (43.48)	698.59 (44.99)

Logical reasoning

Two participants were excluded, and 54 complete data sets were analysed.

Effects at baseline

As for the semantic memory task, it could be expected that control of encoding might exert an effect on task performance. In order to investigate this, ANOVAs were performed on the pre-drug baseline data using control of encoding as a within-subjects factor and order of presentation of the different tasks as a between-subjects factor. Similarly to semantic memory, the number of trials attempted was significantly decreased when encoding time was controlled, but MRT for correct trials was significantly faster. For the percentage of trials correctly answered there were no statistically significant effects of control of encoding.

Caffeine effects

To determine the effects of caffeine on the logical reasoning tasks, a series of ANCOVAs were performed using control of encoding as a within-subjects factor and order of presentation of the tasks as a between-subjects factor. In each case, the relevant index of performance from the baseline condition was used as a covariate. It was found that as for semantic memory, there were no interactions between caffeine condition and control of encoding but that there was a main effect of caffeine for the percentage of trials correct, $F(1, 49) = 4.64$, $MSe = 59.32$, $p < 0.05$ (table 4).

The main effect of caffeine did not reach statistical significance for the number of trials attempted or for MRT for correct trials, but on both parameters, there were slight numerical improvements in performance after caffeine. In the caffeine condition, 52.49 trials were attempted as opposed to 52.18 in the placebo condition. Non-adjusted means were 53.09 (S.E. 2.82) and 50.70 (S.E. 2.87), respectively. MRT for correct trials was 2636.88 msec in the caffeine condition and 2720.24 msec in the placebo condition with non-adjusted means of 2732.36 (S.E. 242.62) msec and 2808.87 (S.E. 247.07) msec, respectively.

Table 4: Logical reasoning: percentage of trials correct in caffeine (4mg/kg) and placebo conditions on the standard task and task with controlled encoding (scores are the adjusted means, S.E.s shown as bars).

<i>Task</i>	<i>Mean</i>	<i>Caffeine (4 mg/kg)</i>	<i>Placebo</i>
Standard	Adjusted	89.92	87.16
	Non-adjusted (S.E.)	90.39 (2.37)	87.53 (2.37)
Controlled encoding	Adjusted	92.51	88.97
	Non-adjusted (S.E.)	92.01 (2.24)	88.67 (2.24)

As in the baseline condition, there were statistically significant effects of control of encoding for the number of trials attempted, $F(1, 49) = 8.36$, $MSe = 42.02$, $p < 0.01$, and the MRT for correct trials, $F(1, 49) = 111.98$, $MSe = 116765.59$, $p < 0.0001$. The number of trials attempted was 51.13 when encoding was controlled and 53.53 in the standard logical reasoning task. Non-adjusted means were 46.05 (S.E 1.19) and 58.39 (S.E. 2.89), respectively. In the task with controlled encoding time average MRT was 2431.17 msec, whereas, in the standard logical reasoning task, it was 2925.94 msec. Non-adjusted means were 2057.25 (S.E 138.05) and 3313.93 (S.E. 155.70), respectively. No two- or three-way interactions were found involving caffeine condition, syntactic complexity or control of encoding.

Allocation of resources: order-location

Fifty-four data sets were analysed; two participants met the exclusion criteria and were excluded.

Effects at baseline

An ANOVA was performed on the baseline data with the number of words ordered and the number of words located correctly as within-subjects factors and prioritisation instruction as a between-subjects factor. It was found that there was a statistically significant effect of task with performance being superior on the order task than the location task. It was also found that the interaction between task and priority instruction was, as might be hoped, approaching significance, with the means indicating that when there was an instruction to assign priority to the order, performance on the order task was superior to performance on the location task and that when the instruction was given to prioritising location performance on this task was enhanced.

Caffeine effects

To determine the effects of caffeine on task performance, an ANCOVA was performed using the number of words ordered correctly and the number of words assigned to the correct case as within-subjects factors and instruction to prioritise order or case as a between-subjects factor. Two covariates were used; the number of correctly ordered words at baseline and the number of correctly located words at baseline.

It was found that post-drink, there were no statistically significant main effects or interactions (table 5).

Table 5: 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	65.39	66.07 (6.89)
		Location	63.55	63.92 (5.68)
	Prioritise location	Order	64.99	64.42 (7.13)
		Location	54.41	53.85 (7.13)
Placebo	Prioritise order	Order	56.12	57.14 (4.98)
		Location	53.32	52.68 (8.99)
	Prioritise location	Order	51.74	51.92 (6.78)
		Location	44.27	44.23 (6.88)

Implicit memory

Thirty-six data sets were analysed; 19 participants met the exclusion criteria. The majority of participants excluded attempted to use only a proportion of the letters available in each trial. 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 revealed, as would be hoped, a very highly significant priming effect, $F(1, 35) = 281.07$, $MSe = 44.91$, $p < 0.0001$. Of the anagrams derived from the 30 primed words, 46.72 % (S.E. 2.17) were completed correctly; for anagrams derived from non-primed words, only 20.59 % (S.E. 1.39) were completed correctly.

No main of caffeine was found, and caffeine did not interact with priming. For primed words, the percentage of anagrams completed correctly was 44.74 (S.E. 3.02) in the caffeine condition and 48.70 (S.E. 3.12) in the placebo condition. For non-primed words, the percentage of anagrams completed correctly was 18.77 (S.E. 1.93) in the caffeine condition and 22.41 (S.E. 1.99) in the placebo condition.

As in our previous study^[21], two planned comparisons were carried out, which looked specifically at the percentage of primed and non-primed anagrams that were completed in the caffeine condition and the placebo condition. Neither comparison revealed any statistically significant effect of caffeine; for primed anagrams, $t = 0.92$, $df = 35$, two-tailed $p > 0.05$, and for non-primed anagrams, $t = 1.31$, $df = 35$, two-tailed $p > 0.05$ (both with Bonferroni adjustment).

Semantic memory: word-fragment completion

Eight participants met the exclusion criteria, and 48 complete data sets were analysed.

The difference between the number of correctly completed word fragments in the caffeine and placebo groups was found to be approaching significance, $t = -1.38$, $df = 46$, $p = 0.087$ (one-tailed), with the mean percentage of word fragments completed correctly being 26.73 (S.E. 2.28) in the group given caffeine and 22.75 (S.E. 1.70) in the group given a placebo.

DISCUSSION

The purposes of the present study were twofold; firstly, to attempt to reproduce the effects of caffeine on implicit memory and allocation of memory resources and secondly, to investigate to what extent the effects of caffeine on semantic memory and executive function were mediated by the speed of reading and encoding of lexical information.

Analysis of the semantic memory and logical reasoning data suggested that the effects of caffeine are not mediated by the speed at which lexical material can be read and encoded. For the semantic memory task, it was found that, as in previous studies, there were main effects of caffeine on the number of trials attempted, the percentage of trials correct and the MRT for correct trials. Similar results were found on the logical reasoning task; caffeine was found to again lead to a significantly higher percentage of correct trials than placebo, and there were also numerical trends for caffeine to increase the number of trials attempted and to improve MRT for correct trials. On both tasks, the interaction between caffeine condition and control of encoding did not approach significance for any parameter of performance, suggesting that there was no difference in the effects of caffeine in the standard and controlled encoding versions of each task.

The lack of interaction between caffeine and controlled encoding time should not be interpreted as a lack of effect of caffeine on encoding per se but as a lack of effect on the speed of encoding. It may still be possible for caffeine to enable, for example, more associations to be made with the stimulus during encoding or in some other way to increase the quality of encoding, which would then lead to better performance. It is, of course, also entirely possible that the effect of caffeine is not related to the encoding of the question but might occur later in the chain of cognitive events that leads to the pressing of the response key. The data obtained in the present study does, though, strongly suggest that the effects of caffeine on semantic memory and executive function are not obtained solely by increases in

the speed of encoding of lexical material. Subsequent experiments should use only the standard semantic memory and logical reasoning tasks and investigate how practical, everyday factors such as interactions between acute ingestion of caffeine and long-term consumption of caffeine, expectancy effects and withdrawal from caffeine might affect these tasks.

Our previous study found a caffeine effect on the order-location allocation of resources task such that caffeine caused a relative re-focussing of attention from a low-priority memory task to a high-priority memory task. The study did not, however, find any effect of prioritisation instruction at baseline, and this was rather unsatisfactory as it may have indicated that the effects of caffeine on memory resource allocation may actually have been more accurately interpreted as greater compliance with experimental instruction than as reallocation of resources per se. The present study aimed to optimise compliance with experimental instructions so that the effects of prioritisation instruction would be present at baseline. This was done by presenting the task very early in each battery as in the previous experiment it was considered that participant fatigue might have influenced compliance with experimental instructions. It was found that at baseline, there were the expected effects of prioritisation instruction but that in the post-drug battery, there was now no effect of prioritisation instruction and no main effects or interactions involving caffeine. Overall, the results of the two studies suggest that the effects of caffeine on this task are not very robust and that the inconsistency reported may be mediated to a large degree by initial compliance with experimental instructions.

The present study also attempted to replicate the effects of caffeine on implicit memory that were found in the previous experiment, where caffeine was found to increase the correct completion of primed word fragments but not to have any effect on the completion of non-primed fragments. The present study used an anagram-solving task rather than the word-fragment task, as some participants had been previously exposed to this task, and the anagram task has been shown to produce equivalent results [22]. It was found that, unlike the previous study, there were no effects of caffeine on anagram solution for either primed or non-primed words, and in fact, the relevant means indicated that in absolute terms, implicit memory was actually worse after caffeine than after placebo. Given these conflicting results, it is suggested that there is little evidence for a robust effect of caffeine on implicit memory.

It is of note that the paradigms used to measure implicit memory have a particular weakness in that it is problematic to use a baseline condition so that a covariate can be used to control for individual differences. Implicit memory tests, by their very nature, do not ask participants for explicit, i.e. intentional recall of encoded material, but unfortunately, participants under certain circumstances realise the relation between the encoding task and the memory task and an ostensibly implicit test becomes contaminated by explicit retrieval [26]. Due to this potentially serious problem of implicit memory being contaminated with explicit retrieval, it was not considered plausible to run a baseline condition as this would allow more opportunity for the relation between encoding and memory task to be discovered. Consequently, the results are necessarily derived purely from a between-subjects design without a covariate to control for individual differences in performance.

In the previous study, it was found that for both word fragment and word-stem completion, there were statistically significant main effects of caffeine, with more words being correctly completed in the caffeine condition than in the placebo condition. These main effects were not expected but could be interpreted as further indicators of the effect of caffeine on semantic memory, as semantic memory would necessarily be drawn on extensively in order to complete the tasks. In the present study, it was decided to attempt to replicate the results using the word-fragment task but without any previous priming. It was found that the results were consistent with the previous study and that the main effect of caffeine was approaching significance, with performance being superior in the caffeine condition.

In summary, it has been found that the caffeine effects on semantic memory and on executive function have again been replicated successfully and that caffeine effects on these tasks are not mediated by an increase in the speed of encoding of lexical information. The effects of caffeine on these tasks are now taken to be firmly established, and subsequent studies should now centre on attempting to discover the exact action of caffeine on these tasks and on the relevance of the finding to semantic memory in real life. The attempts to replicate the effects of caffeine on implicit memory and allocation of memory resources have largely failed, and it is considered that any caffeine effects on these processes are not robust enough to warrant further investigation. This appears to be especially true in the case of implicit memory, where there also appear to be largely insoluble methodological problems.

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