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EFFECTS OF CAFFEINE, BELIEFS ABOUT WHETHER CAFFEINE WAS CONSUMED, AND BELIEFS ABOUT THE BEHAVIOURAL EFFECTS OF CAFFEINE: A SECONDARY ANALYSIS OF SEMANTIC MEMORY AND CENTRAL EXECUTIVE TASKS

Dominic P. Nguyen-Van-Tam*, PhD and Andrew P. Smith, PhD

Centre for Occupational and Health Psychology, School of Psychology, Cardiff University, 63 Park Place, Cardiff CF10 3AS, UK.

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***Corresponding Author**
Dominic P Nguyen-Van-Tam
PhD, Centre for Occupational and Health Psychology, School of Psychology, Cardiff University, 63 Park Place, Cardiff CF10 3AS, UK.

ABSTRACT

Background: There has been extensive research on the effects of caffeine on behaviour. Research has suggested that the effects of caffeine may vary depending on the ability to detect that caffeine has been administered and the expectancies about the effects of caffeine. These topics were examined here in analyses of semantic processing and logical reasoning (executive function) tasks. **Methods**: Secondary analyses of data from recently published studies are reported. One hundred and seventy-seven university students participated in the research. Baseline testing was carried out, and then separate groups either received a placebo or caffeine. The caffeine dose was 4mg/kg, and the manipulation was carried out double-blind. The dependent variables were the performance scores from semantic memory and logical reasoning tasks. Expectancies about the behavioural effects of caffeine and the ability to detect caffeine in a cup of coffee were measured by questionnaire. **Results**: The usual positive effects of acute caffeine were found for both the semantic processing and logical reasoning tasks. The ability to detect whether the coffee contained caffeine or not also had a significant effect. Expectancies about the effects of caffeine had no significant effect. There were no interactions between caffeine, correct detection of the caffeine and expectancies about the effects of caffeine. **Conclusion**: Acute effects of caffeine were observed for both tasks, confirming previous findings. Expectancies about the effects of caffeine had no significant effect. Those who could correctly detect whether the drink contained caffeine or placebo showed better performance, but this was an independent effect and did not modify the effects of the acute caffeine challenge.

KEYWORDS: Caffeine; Discrimination; Expectancies; Memory; Semantic processing; Executive functioning; Logical reasoning.

INTRODUCTION

Previous research[1-23] has examined the effects of caffeine on many aspects of memory, and in our recently published studies,[21-26] only the effects of caffeine on semantic memory and executive function have been replicable. This research has described reliable effects of caffeine on semantic memory and executive function, which do not appear to be mediated by alertness and level of regular caffeine consumption.[24-27] However, previous research has described behavioural effects caused by beliefs about the effects of drugs in participants actually given a placebo (expectancy effects) and also the ability to discriminate caffeine in beverages under experimental conditions. The effects of these two factors on semantic memory and executive function performance have not so far been investigated, and the purpose of the present analysis was, therefore, to investigate the possibility that caffeine effects on semantic memory and executive function are mediated by expectancy effects, possibly in combination with the ability to detect caffeine.

The basis of drug-related expectancy lies in the reliable association between the administration of a particular drug and specific behavioural effects[28,29], and Fillmore[29] has suggested that this may occur in a variety of ways. Most obviously, the association can occur with experience of a particular type of drug but also by observing the effect the drug has on others or from sources of information about the drug. Once these associations are acquired, a range of behavioural phenomena can then be elicited under placebo conditions. Research into drug-expectancy effects has been directed largely toward the placebo effects of alcohol, where it has been found that alcohol evokes strong, reliable placebo responses in both affective and social behaviour (including aggression, sexual arousal and social anxiety) but has little effect on psychomotor behaviour.[30,31]

A smaller body of research has described expectancy effects after consumption of placebo caffeine which appears to extend to psychomotor performance and subjective mood. These studies are exemplified by work carried out by Fillmore and Vogel-Sprott[32], which used a between-groups design to test the effect of expectancy and beliefs about caffeine on a pursuit rotor task. Participants were divided into four experimental groups, three of whom were led to believe that they would be given a caffeinated beverage but which was, in fact, a placebo. Of these groups, one was informed that caffeine would improve performance, the other was told caffeine would impair the performance, and the third group was not given any information about the effect of caffeine on performance. The fourth group received no beverage at all prior to testing. When a change from a baseline condition was calculated, it was found that those participants who had been told caffeine would improve performance displayed greater improvement than those who had also been given a placebo but no information about the effects of caffeine and that this group in turn performed better than those who were told caffeine would impair performance. The group given no placebo caffeine and no information about caffeine exhibited no change in performance from baseline. Similarly, for a measure of subjective alertness, it was found that there were strong correlations between the effect participants thought caffeine would have on alertness and self-rated alertness after the beverage.

Experimental evidence also indicates that expectancy effects, including those relating to caffeine, may be related to social acceptance of the drug. Fillmore et al.[33] were able to demonstrate that placebo caffeine could elicit responses on pursuit rotor tracking and that these were not only in accord with the information given about the expected effects of caffeine on the task but were also associated with social expectations. The study used a between-subjects design with participants with four conditions formed by the combination of placebo alcohol or placebo caffeine and the information that the drug would improve or impair performance. There was a statistically significant difference between the two caffeine placebo groups, with those who had been informed that caffeine would improve their performance increasing time on target by 5.47% compared to baseline, whilst those who were told that caffeine would lead to an impairment were found to have decreased their time on target by 0.80% compared to baseline. In the alcohol conditions, however, it was found both groups improved compared to baseline, with the group told that alcohol would impair performance returning a significantly better performance than those informed that alcohol would increase performance. This is taken by the experimenters to be an indication that effects that expectancies are drug-specific and may interact with factors such as the social desirability of certain drug effects.

Expectancy effects could arguably be encountered in any caffeine study, but if participants in a blind caffeine challenge experiment were to be able to reliably detect which experimental beverage contained caffeine, this would arguably magnify the confounding effects of expectancy. The issue of caffeine discrimination is largely ignored within the caffeine literature, where it is assumed that participants in double-blind trials will not detect caffeine in their experimental beverages. Where caffeine discrimination has been formally tested after double-blind administration prior to performance testing, no published research has reported any evidence of successful caffeine discrimination. Some evidence does exist that participants can be successfully trained to discriminate caffeine after repeated trials[34,35], but the number of trials taken to reach experimental criterion levels for discrimination appears to be consistently high. With a sample consisting only of the authors, who were all behavioural pharmacologists, Griffiths et al.[34] report that 4-9 sessions were needed to reach 80% correct discrimination on four consecutive trials, and using normal volunteers, Silverman and Griffiths[35] report that more than 20 sessions are needed. Given the number of trials necessary to attain a reliable level of caffeine discrimination, it would seem unlikely that untoward caffeine discrimination would constitute a confounding variable in studies using one or two caffeine challenges and normal volunteers.

Overall, it would appear that drug-related expectancies, possibly in combination with successful caffeine discrimination, have the potential to mediate, or at worst confound, the actual behavioural effects of caffeine. Fillmore[29] has, in fact, argued that drug-related expectancy effects may, in part, account for the 'equivocal findings of caffeine on behaviour' (p.63). The studies which have investigated caffeine-related expectancy have, however, left a number of important questions unanswered, which may mean that the expectancy effects may not have the serious implications for caffeine research that Fillmore[29,36] has suggested. Specifically, the studies have only attempted to prove the existence of expectancy effects and have not attempted to investigate the belief structures underlying such effects, the possibility of interactions with discrimination of caffeine and the extent to which the main effects of caffeine are attributable to expectancy. The studies have also used highly contrived, possibly transparent, procedures in order to lead participants to believe they were going to consume a caffeinated or non-caffeinated beverage[33], and it remains to be seen whether the effects could be produced in a more typical experimental design without such manipulation.

The purpose of the present analyses was, therefore, threefold. First, it attempted to confirm that participants are unable to discriminate caffeine in a standard, double-blind caffeine experiment. Secondly, it attempted to investigate the belief structures associated with the cognitive effects of caffeine, and thirdly, and most importantly, it attempted to determine the extent to which the effects of caffeine on semantic memory and executive function are mediated by expectancy and caffeine discrimination.

Methodological considerations

The study employed the data sets used in our recent studies[27] and, therefore, used a caffeine dose of 4mg/kg and methods of caffeine administration and measures of semantic memory and executive function that are known to produce consistent and replicable results

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 mean reaction time (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.

Caffeine discrimination

Participants will not be able to distinguish whether they had consumed an active (4mg/kg caffeine) or placebo experimental beverage.

Caffeine-related expectancy effects

There will be a statistically significant interaction between beliefs about the caffeine content of the beverage and beliefs about the cognitive effects of caffeine such that when participants believe that they have consumed caffeine, their performance will reflect their beliefs about the cognitive effects of caffeine.

Method

The ethics committee, School of Psychology, Cardiff University, approved the research, and it was carried out with the informed consent of the participants. The study employed a between-subjects design with beliefs about the caffeine content of the beverage, beliefs about the cognitive effects of caffeine and acute exposure to caffeine as between-subject factors. Participants were divided into groups with strong positive beliefs about the cognitive effects of caffeine and weak positive beliefs about the cognitive effects of caffeine by a median split of factor scores derived from factor analysis of questionnaire data relating to the cognitive beliefs about caffeine.

Participants

One hundred and seventy-seven participants, all university students, took part in the research. All were non-smokers and regular caffeine consumers. Participants were paid £20-25 for participation in the research.

Procedure

This is described in detail by Nguyen-Van-Tam and Smith.[27] The main points can be summarised as follows.

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. During the 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 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-drink)

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

Afternoon testing

When participants were tested in the afternoon, the same procedure was used but with baseline testing beginning at 14.50 and the post-drink test session starting at 16.20. 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.

Questionnaires

The questions used to measure caffeine-related expectancies with regard to concentration, reaction time and memory and to measure record caffeine discrimination are shown below:

Table 1: Caffeine-related expectancy.

Please draw crosses somewhere on the following lines at the points which best describe your answers.

Q1. What effect do you think caffeine has on *your* ability to concentrate?

Greatly--		Greatly
Impairs	No Effect	Enhances

Q2. What effect do you think caffeine has on the speed of *your* reactions?

Greatly--		Greatly
Impairs	No Effect	Enhances

Q3. What effect do you think caffeine has on *your* memory?

Greatly--		Greatly
Impairs	No Effect	Enhances

Table 2: Caffeine discrimination.

Do you think you have just drunk caffeinated or decaffeinated coffee? (please tick the appropriate box)

CAFFEINATED ☐

DECAFFEINATED ☐

Performance tasks

Both tasks were presented on a microcomputer.

Semantic Memory Task

This task was based on Baddeley's[37] semantic memory task and was described in detail by Nguyen-Van-Tam and Smith.[24-27]

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

Central executive function

This task was based on Baddeley's[38] logical reasoning task and was described in detail by Nguyen-Van-Tam and Smith.[24-27]

The exclusion criterion for the task was a failure to provide correct verifications for at least 50% of the simple active statements in the baseline condition.

Analysis

Chi-square tests were used for the analysis of the association between participants' perceptions of the caffeine content of the beverage and the actual caffeine content of the beverage. Exploratory factor analysis was used to reduce the number of variables describing participants' beliefs about the cognitive effects of caffeine. As in our previous studies, analysis of performance data was undertaken using ANCOVA and the relevant index of performance at baseline as a covariate.

Analysis proceeded in five stages

1. Investigation of caffeine discrimination in experimental beverages, i.e. the association between the consumption of caffeinated or placebo coffee and the participants' beliefs about whether the beverage was caffeinated or decaffeinated.

2. Investigation of the latent structure underlying participants' beliefs about the cognitive effects of caffeine using three measured variables; participants' perception of the action of caffeine on concentration, reaction time and memory
3. Description of the range and distribution of beliefs concerning the effects of caffeine on concentration.
4. Investigation of the 3-way interaction between participants' beliefs about the cognitive effects of caffeine, participants' beliefs about the caffeine content of their beverage and actual experimental condition on the semantic memory and logical reasoning tasks
5. Determination of the magnitude of caffeine effects on the semantic memory and logical reasoning tasks after controlling for participants' beliefs about the cognitive effects of caffeine.

RESULTS

Investigation of caffeine discrimination in experimental beverages

A chi-square analysis was used to determine whether participants' perceptions regarding the caffeine content of the beverage were associated with the actual caffeine content of their experimental beverage. It was found that for participants in the semantic memory data set, there was no statistically significant difference between the observed and expected frequencies of participants' perception of the caffeine content of the beverage in caffeine or placebo conditions, $\chi^2 = 2.54$, df = 1, $p > 0.05$ (table 1).

Table 3: Semantic memory data set: caffeine discrimination; count, expected count and percentage of participants perceiving the beverage to be placebo or caffeinated in caffeine and placebo conditions.

Caffeine condition		**Participants' judgement of beverage**		**Total**
		Placebo	**Caffeinated**	
Placebo	Count	39	49	88
	Expected count	33.90	54.10	88.00
	% of participants within the placebo condition	**44.30%**	**55.70%**	**100.00%**
Caffeine	Count	28	58	86
	Expected count	33.10	52.90	86.00
	% of participants within the placebo condition	**32.60%**	**67.40%**	**100.00%**

Analysis of the logical reasoning data set again found that there was no statistically significant difference between the observed and expected frequencies of participants' perception of the caffeine content of the beverage in caffeine or placebo conditions, $\chi^2 = 2.31$, df = 1, $p > 0.05$.

Investigation of the latent structure underlying participants' beliefs about the cognitive effects of caffeine

An initial principal component analysis (PCA) was carried out to determine the number of factors that could be extracted from three variables which measured participants' beliefs about the action of caffeine on concentration, reaction time and memory. Only one factor with an eigenvalue > 1 was found. It was also found that Bartlett's test of sphericity was highly significant, confirming the presence of high correlations between variables and that the Kaiser-Meyer-Olkin (KMO) test of sampling adequacy was 0.655, indicating that the variables have been measured adequately enough to proceed with exploratory factor analysis. The variables were then factor analysed using principal axis factoring (PAF) set to extract one factor. Variance explained by each variable and item loadings for the single-factor solution is shown in table 4. Very similar effects were found for both the semantic memory and logical reasoning data sets.

Table 4: Semantic memory data set: Factor analysis of variables measuring belief about the cognitive effects of caffeine: eigenvalues, % of variance explained, cumulative % of variance explained and item loading (extraction method: PAF).

Variable	Initial eigenvalue	% of variance	Cumulative % of the variance	Item loadings for one-factor solution
Caffeine effects on concentration	1.837	61.23	61.23	0.752
Caffeine effects on reaction time	0.648	21.60	82.82	0.616
Caffeine effects on memory	0.515	17.18	100.00	0.576

Investigation of the range and distribution of beliefs concerning the cognitive effects of caffeine

For both the semantic memory and logical reasoning data sets, factor analysis revealed that the variables describing beliefs about the effects of caffeine on concentration, reaction time and memory are intercorrelated and can be reduced to a single factor. The variable which loads most highly on this single factor is concentration, and the distribution of this variable will be described in more detail for the semantic memory and logical reasoning data sets as it is taken to be illustrative of the beliefs about the effects of caffeine on cognition generally. This is now shown for the semantic memory data set. A very similar profile was found in the analysis of the logical reasoning data set.

The distribution of participants' beliefs about the effects of caffeine revealed a very wide range that fully spanned the minimum and maximum values (table 5). The mean score was 65.37, and the distribution appeared to be negatively skewed, with very few participants believing that caffeine did not produce any positive effects on concentration.

Table 5: Semantic memory data set: Distribution of beliefs about the effects of caffeine on concentration (0 = maximum impairment, 100 maximum improvement; n = 174).

Mean	65.37
SE.	1.05
Median	65.00
Range	88
Minimum	12
Maximum	100
Interquartile range	15.25

Summary of results on expectancies about effects of caffeine

- Participants' beliefs about the cognitive effects of caffeine were generally positive.
- Participants' beliefs about the cognitive effects of caffeine are highly intercorrelated and can be reduced to a single factor that encompasses concentration, reaction time and memory

Investigation of the interaction between caffeine-related expectancy, caffeine discrimination and experimental caffeine condition

A series of ANCOVAs were carried out in order to determine whether expectancy has any effect on semantic memory and logical reasoning performance (either alone or in combination with the ability to detect caffeine or the actual caffeine condition). Beliefs about the caffeine content of the beverage, positive or negative thoughts about the cognitive effects of caffeine and actual caffeine condition were used as between-subject factors, and performance in the baseline condition was used as a covariate. A factor score was calculated for each participant using the factor loadings derived from the factor analysis. On the basis of this score, participants were divided into two groups by median split giving two groups of participants: one with strong positive beliefs about caffeine and one with weak positive beliefs, neutral or negative beliefs about the cognitive effects of caffeine.

Semantic memory

It was found that for semantic memory, caffeine significantly increased the number of trials attempted, $F(1, 165) = 12.37$, $MSe = 95.95$, $p < 0.0025$ and the percentage of trials correct, $F(1, 165) = 11.63$, $MSe = 8.86$, $p < 0.0025$ and significantly decreased the MRT for correct trials, $F(1, 165) = 9.61$, $MSe = 18934.30$, $p < 0.0025$ (table 6). For the number of trials correct, the main effect of perception of caffeine content reached one-tailed significance at the 5% level, $F(1, 165) = 4.57$, $MSe = 95.95$, $p < 0.05$ (one-tailed). Participants who thought they had consumed caffeine attempted 130.80 (SE 0.97) trials, whereas those who thought they had consumed a placebo attempted 128.19 (SE 1.22). Non-adjusted means were 129.78 (SE 2.70) and 130.07 (SE 3.44), respectively. The main effect of perception of beverage content also reached one-tailed significance, $F(1, 165) = 3.89$, $MSe = 18934.30$, $p < 0.05$ (one-tailed), in the MRT analysis. Participants who thought the beverage was caffeinated had an MRT of 1292.86 (SE 13.43) msec, and those who thought the beverage was placebo had an MRT of 1331.71 (SE 17.10) msec. The non-adjusted MRTs were 1299.82 (SE 32.12) and 1315.54 (SE 40.89), respectively. No other main effects or interactions approached statistical significance.

Table 6: Semantic memory: adjusted and non-adjusted means in caffeine (4mg/kg) and placebo conditions for participants perceiving the beverage to be placebo or caffeinated and holding strong or weak beliefs about the ability of caffeine to enhance cognitive performance (SEs in parentheses; * p < 0.05, one-tailed ** p < 0.0025)

Index of performance	Caffeine condition	Belief about caffeine condition	Belief about cognitive effects	Non-adjusted mean	Adjusted mean	Statistically significant effects
Number of trials attempted	Caffeine	Caffeine	Strong	130.36 (5.54)	132.43 (1.96)	Caffeine condition** Beliefs about caffeine condition*
			Weak	129.52 (4.82)	134.08 (1.71)	
		Placebo	Strong	129.93 (7.15)	129.34 (2.53)	
			Weak	133.85 (7.68)	133.02 (2.72)	
	Placebo	Caffeine	Strong	127.35 (5.43)	127.28 (1.92)	
			Weak	131.91 (5.77)	129.40 (2.04)	
		Placebo	Strong	130.00 (6.04)	125.69 (2.14)	
			Weak	126.50 (6.53)	124.70 (2.31)	
Percentage of trials correct	Caffeine	Caffeine	Strong	94.73 (0.87)	95.32 (0.60)	Caffeine condition**
			Weak	95.80 (0.76)	95.29 (0.52)	
		Placebo	Strong	95.32 (1.21)	95.05 (0.77)	
			Weak	94.74 (1.20)	95.05 (0.83)	
	Placebo	Caffeine	Strong	93.03 (0.85)	93.13 (0.58)	
			Weak	93.75 (0.91)	93.92 (0.62)	
		Placebo	Strong	95.12 (0.95)	94.56 (0.65)	
			Weak	92.26 (1.02)	92.68 (0.72)	
MRT correct trials (msec)	Caffeine	Caffeine	Strong	1360.57 (77.61)	1277.46 (27.59)	Caffeine condition** Beliefs about caffeine condition*
			Weak	1328.43 (71.85)	1255.63 (24.03)	
		Placebo	Strong	1255.76 (64.57)	1293.35 (35.53)	
			Weak	1302.74 (64.57)	1287.29 (38.17)	
	Placebo	Caffeine	Strong	1271.72 (91.32)	1320.62 (27.00)	
			Weak	1301.44 (85.01)	1317.72 (28.78)	
		Placebo	Strong	1307.52 (57.32)	1364.30 (30.05)	
			Weak	1333.28 (65.85)	1381.88 (32.44)	

Logical reasoning

For the number of trials attempted, participants who had consumed the caffeinated beverage attempted significantly more trials than those who had consumed a placebo, $F(1, 158) = 7.13$, $MSe = 45.00$, $p < 0.01$ (table 7). There were no main effects or interactions involving belief about the caffeine content of the beverage or strength of belief about the cognitive effects of caffeine.

Table 7: Logical reasoning: adjusted and non-adjusted means in caffeine (4mg/kg) and placebo conditions for participants perceiving the beverage to be placebo or caffeinated and holding strong or weak beliefs about the ability of caffeine to enhance cognitive performance (SEs in parentheses; * p < 0.01).

Index of performance	Caffeine condition	Belief about caffeine condition	Belief about cognitive effects	Non-adjusted mean	Adjusted mean	Statistically significant effects
Number of trials attempted	Caffeine	Caffeine	Strong	57.54 (3.23)	58.71 (1.32)	Caffeine condition*
			Weak	58.90 (3.06)	60.11 (1.25)	
		Placebo	Strong	54.53 (4.25)	60.90 (1.75)	
			Weak	59.31 (4.57)	59.67 1.86)	
	Placebo	Caffeine	Strong	60.04 (3.44)	56.79 (1.40)	
			Weak	60.83 (3.44)	57.94 (1.40)	
		Placebo	Strong	57.00 (3.68)	56.37 (1.50)	
			Weak	57.39 (3.88)	56.73 (1.58)	
Percentage of trials correct	Caffeine	Caffeine	Strong	94.08 (1.72)	92.60 (1.19)	-
			Weak	89.19 (1.63)	89.40 (1.12)	
		Placebo	Strong	91.07 (2.27)	93.11 (1.57)	
			Weak	91.61 (2.43)	91.77 (1.68)	
	Placebo	Caffeine	Strong	88.17 (1.83)	89.92 (1.27)	
			Weak	91.65 (1.83)	90.29 (1.26)	
		Placebo	Strong	91.62 (1.96)	91.27 (1.35)	
			Weak	91.08 (2.07)	90.96 (1.42)	
MRT correct trials (msec)	Caffeine	Caffeine	Strong	3307.69 (216.30)	3334.66 (106.09)	-
			Weak	3359.43 (204.80)	3121.70 (101.00)	
		Placebo	Strong	3367.06 (284.77)	3111.11 (140.13)	
			Weak	3110.17 (305.89)	3218.84 (150.10)	
	Placebo	Caffeine	Strong	3144.70 (229.97)	3416.32 (113.44)	
			Weak	3074.79 (229.97)	3238.96 (113.03)	
		Placebo	Strong	3450.66 (246.62)	3375.02 (121.00)	
			Weak	3263.69 (259.96)	3268.84 (127.50)	

Summary: Effects of caffeine, belief about caffeine content and belief about effects of caffeine on behaviour

- Those given caffeine showed better performance on semantic memory and logical reasoning tasks.
- Those who believed they had been given caffeine showed better performance on the semantic memory task, but the effects appeared to be limited to those parameters of performance that involve processing speed, i.e. the number of trials attempted and MRT for correct trials.
- The effects of believing that one had consumed caffeine were much smaller than the main effects of caffeine condition.
- Caffeine effects and beliefs about consuming caffeine appeared to be independent and did not interact.
- There were no effects of beliefs about the effects of caffeine on cognition (neither main effects nor interactions).
- There were no effects of beliefs about the nature of the drink or the effects of caffeine on performance in the logical reasoning task.

DISCUSSION

The objectives of the present analyses were to investigate the impact of beliefs about the caffeine content of the experimental beverage and the cognitive effects of caffeine on the performance of semantic memory and logical reasoning tasks which have been shown previously to be sensitive to the effects of caffeine. It was hypothesised that there would be an interaction between belief about the caffeine content of the beverage and beliefs about the cognitive effects of caffeine such that if participants believed that they had consumed caffeine, their performance would reflect their beliefs about the psychotropic effects of caffeine. The effects that discrimination and expectancy would have on the main effects of caffeine were unknown.

It was found that the experimental procedure for the administration of caffeine did not allow participants to successfully discriminate between the placebo and caffeinated beverages. This finding is compatible with existing research[35], which suggests that reliable levels of caffeine discrimination can only be attained after a much larger number of caffeine challenges that are carried out in typical caffeine studies.

The analyses also sought to describe the structure underlying lay beliefs concerning the cognitive effects of caffeine and, using factor analysis, this was revealed to be relatively simple with a single factor underlying beliefs about concentration, reaction time and memory. Factor loadings showed the highest caffeine effects on concentration and the lowest for beliefs about caffeine effects on memory. The range and distribution of beliefs about caffeine were described with reference to beliefs about concentration, as this was the item with the highest factor loading. For this item, it was found that the distribution of beliefs about caffeine was highly positively skewed, with less than 10% of students in both the semantic memory and logical reasoning data sets believing that caffeine had a negative effect on concentration.

A primary aim of the study was to ascertain whether expectancy effects could be obtained in a typical caffeine study without contrived disclosure of the caffeine content of the beverages. A series of ANCOVAs were performed with belief about the caffeine content of the beverage, belief about the cognitive effects of caffeine and actual caffeine condition as between-subjects factors and performance at baseline as a covariate. It was found that for the semantic memory task, there were the usual main effects of caffeine, but for indices of performance mediated by speed, i.e. the number of trials attempted and MRT for correct trials, there were also weak main effects of belief about the caffeine content of the beverage. The hypothesised interaction between belief about the content of the beverage and beliefs about the cognitive effects of caffeine was not found, which suggests that in the case of caffeine, the strength of belief about its positive effects is unimportant, and it would seem likely that this is because over 90% of participants believed the effects of caffeine were positive, and the distribution of beliefs was very positively skewed. For the logical reasoning task, the usual main effects of caffeine were found, but there were no effects or interactions involving belief about the caffeine content of the beverage or about the cognitive effects of caffeine.

These results suggest that the effects of the belief about the consumption of caffeine can be found using typical double-blind caffeine challenge paradigms but that the effect appears to be task-specific and considerably weaker than, and independent of, the main effects of the caffeine challenge. It is suggested for semantic memory and executive function, at least, there is little evidence for the claim that expectancy effects can confound the effects of a caffeine challenge.[29] It is further suggested that the robust caffeine-related expectancy effects described by Fillmore[29] may be the result of the overt (but supposedly unintentional) disclosure of the 'caffeine' condition leading to the expected behavioural effects being transparent to more sophisticated participants and leading to demand characteristics.

Another aim of the analysis was to investigate whether controlling for participants' beliefs about the cognitive effects of caffeine would have any impact on the main effects of caffeine condition or on the effect of perception of the caffeine content of the beverage. It was found that for semantic memory and logical reasoning, the use of the strength of belief about the positive effects of caffeine as an additional variable made the caffeine effects more significant and did not influence the belief about the caffeine content of the drink. This suggests that differing beliefs about the cognitive effects of caffeine may account for a proportion of the between-subjects variance in caffeine experiments and that controlling for this additional source of variance may lead to a clearer view of the main effects of caffeine.

In summary, the study has demonstrated several important points. Firstly, it has been shown that the double-blind procedure for the administration of caffeine is satisfactory in terms of drug discrimination, with no statistical evidence that the active beverage was detectable. Secondly, the study has shown that beliefs about caffeine content can be found in measures of semantic memory but not in measures of logical reasoning and then only on those indices of performance related to the speed of cognitive processing. The effects of beliefs about the caffeine content appeared to be much smaller and independent of the main effects of caffeine on semantic memory and were not related to the strength of belief about the cognitive effects of caffeine. In conclusion, the results reported here and our other recently published results[24-27] show that there are reliable effects of caffeine on semantic memory and logical reasoning, which do not appear to be due to subjective alertness, long-term regular consumption of caffeine, or beliefs about the consumption of caffeine and its behavioural effects.

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