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CAFFEINE, MEMORY, IMPULSIVITY AND TIME OF DAY

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ABSTRACT

Background: Despite the substantial research on the effects of caffeine on behaviour, there have been relatively few investigations of individual differences and the impact of time of day. **Aims:** The present study tested the model of Humphreys and Revelle (1984) which regards caffeine as a source of arousal which interacts with baseline physiological arousal, as measured by the personality trait of impulsivity and time of testing. **Methods:** The experimental design included the between-subject factors of impulsivity (high/low), time of day (morning/evening) and caffeine (4mg/kg caffeine/placebo). Ninety-six participants completed the study. Testing was carried out on two consecutive days and the participants rated their mood and performed semantic processing, logical reasoning and levels of processing memory tasks. **Results:** The results showed that caffeine increased alertness and improved performance on sematic processing and logical reasoning tasks. Performance of these tasks was also influenced by time of testing. Low impulsive participants reported higher alertness in the morning compared to the evening, whereas high impulsive participants showed the opposite profile. There was little evidence of interactions between caffeine and impulsivity, or caffeine x impulsivity x time of day. **Conclusions:** The present study showed that alertness, logical reasoning and semantic processing change after caffeine ingestion. Time of day and impusivity also influence some of these outcomes. However, the effects appear to be largely independent and there was little evidence of interactions between caffeine, impulsivity and time of day.

KEYWORDS: Caffeine, Memory, Semantic processing, Logical reasoning, Alertness, Impulsivity, Time of day.

INTRODUCTION

There has been extensive research on the behavioural effects of caffeine.[1-7] Much of this research has been on attention and psychomotor performance.[8-9] There has been less research on caffeine and memory,[10] but research has shown that caffeine improves logical reasoning and semantic memory tasks.[11-15] This has recently been confirmed in a study that tested several other hypotheses.[16] The study examined whether caffeine led to state-dependent memory effects and showed no evidence. The effects of caffeine were reliable in that they were replicated on the second day of testing. The analysis examined whether there was a relationship between the effects of caffeine on semantic memory and logical reasoning tasks and whether the effects on the tasks were mediated by a common mechanism(s). The results showed little evidence of a strong relationship between the effects of caffeine on the two tasks, as no significant correlations were found between corresponding measures of speed or accuracy. The study also investigated a more global issue in caffeine research: task-specific interaction between caffeine, impulsivity and time of day as predicted by Humphreys and Revelle's model of arousal and cognitive performance.[17] Results from these analyses are reported here.

The study tested the models of arousal and performance proposed by Humphreys and Revelle[17] and Smith[18] which regards caffeine as a source of arousal which interacts with baseline physiological arousal (as measured by the personality trait of impulsivity). Several attempts have been made to investigate the interaction between caffeine and impulsivity[19] and between caffeine, impulsivity and time of day,[20] but findings are often conflicting and inconclusive. The present study investigated interactions between caffeine, impulsivity and time of day on various memory tasks using a between-subjects design.

In order to test whether the effects of caffeine are mediated by individual baseline arousal (and hence the time of day), a between-subjects design was used, which tested equal numbers of high and low-impulsive participants. Investigation of the interaction between caffeine and impulsivity also necessitated the testing of participants in the morning and the evening as there is considerable evidence to suggest that the arousal states that characterise impulsivity are subject to distinct circadian rhythms.[21,22]

The following hypotheses were tested

A) In high-impulsive participants only, caffeine (4mg/kg) will significantly improve recall of acoustically encoded words and impair recall of semantically encoded words. Caffeine will not affect the recall performance of low-impulsive participants.

B) High-impulsive participants will have peak cognitive performance in the evening and a relative impairment in cognitive performance in the morning. Low-impulsive people will have peak cognitive performance in the morning and a relative impairment in cognitive performance in the evening.

C) Caffeine (4mg/kg) will improve the cognitive performance of high-impulsive volunteers in the morning and low-impulsive volunteers in the evening.

D) Caffeine (4mg/kg) given to high-impulsive people in the evening and low-impulsive people in the morning will cause 'over-arousal' leading to a decrement in cognitive performance for tasks with a high short-term memory component but not in tasks with a high throughput of information.

Method

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

Design

The experiment had a mixed design, with the time of testing (morning vs evening), impulsivity (High vs low) and caffeine condition as the between-subjects factors and performance on day one and day two as within-subjects factors. The participants were divided into two equally sized groups; one with high impulsivity and the other with low impulsivity. From each group, three males and three females were picked randomly for each of the eight experimental conditions such that eight groups would be formed, each comprised of 6 high and six low-impulsive people. The caffeine administration was double-blind to eliminate a potential demand characteristic.[23]

Participants

Ninety-six participants were used in the experiment, 48 low-impulsives (EPI Impulsivity < 5) and 48 high-impulsives (EPI Impulsivity > 5), with 24 males and 24 females within the low and high impulsivity sub-groups. All were non-smokers and regular daily consumers of caffeinated coffee or tea. The demographics of the sample are shown in table 1.

Exclusion criteria

One study has described a differential effect of caffeine on males and females.[19] Therefore, despite theoretical differences in male and female metabolism of caffeine, both male and female participants were used, as they have been in the majority of similar studies. Participants were excluded if they were smokers, as studies have shown that inhaled tobacco smoke accelerates caffeine metabolism and can increase serum caffeine levels by as much as 200%.[24,25]

Informed consent

All the participants were provided with written details of the experiment, stating that they were free to withdraw from the study at any time and that any data collected would be strictly anonymous. They signed the consent form before starting the study.

Payment

Participants were paid £20 on completion of the study.

Table 1: Participant demographics and personality characteristics by High and Low impulsivity (means, SEs in parentheses).

Variable	Low impulsive group (EPI-I < 5)	High Impulsive group (EPI-I ≥ 5)
Age (years)	21.44 (0.32)	21.40 (0.45)
Mean caffeine consumption (mg/24h)	156.04 (17.21)	195.31 (17.58)
EPI: Impulsivity (0-low to 9-high)	2.85 (0.14)	6.21 (0.14)
EPI: Sociability (0-low to 12-high)	6.56 (0.35)	8.54 (0.26)
EPI: Extroversion (0-low to 23-high)	10.08 (0.45)	15.00 (0.38)

Test procedure

Morning testing

2200 Begin abstinence from alcohol until the end of the experiment

Test day 1:

0030 Begin abstinence from self-administered caffeine

0830 Present for testing after typical breakfast

0850 Test battery (Baseline)

0915 Expectancy effects questionnaire, administration of caffeine or placebo, eating and sleeping questionnaire, caffeine discrimination questionnaire

1015 Test battery (Post-drink)

1045 Participants were allowed to resume regular caffeine intake

Test day 2:

0030 Begin abstinence from self-administered caffeine

0915 Present for testing after typical breakfast, administration of caffeine or placebo, eating and sleeping questionnaire, caffeine discrimination questionnaire

1015 Test battery (Post-drink)

1115 Debriefing and participants were allowed to resume regular caffeine and alcohol intake

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 dissolved or, in the placebo condition, sterile water only. A disinterested third party held the code for the solutions and this was not revealed until after all the data analysis had been carried out.

Test battery

This is described in detail in the earlier report. In summary, the participants rated their mood, which gave scores relating to alertness, hedonic tone and anxiety.[16] The mood was rated before and after the memory tests. Semantic processing[26] and logical reasoning were examined on both days. The test battery[27] also included levels of processing and immediate and delayed recall.[16] All tasks were presented on a microcomputer.

RESULTS

Individual differences in the effect of caffeine

In the earlier paper, the analysis focussed solely on the main effects of caffeine on memory, but a body of literature, which suggests that arousal has additive properties, predicts that caffeine may interact with an individual's baseline arousal.[17] The present analysis attempted to investigate this proposed interaction by introducing arousal as a further between-subjects factor (as baseline arousal is dependent on the time of day, this factor was also included). The analysis will only deal with measures of cognitive performance as Humphreys and Revelle's model makes no predictions concerning mood states such as anxiety and sociability.[17] The exception to this rule will be subjective alertness as Humphrey and Revelle suggest that alertness and arousal refer to the same construct ('Arousal is the state of the organism that in everyday term means alertness, vigour.[17]

Effects of Impulsivity and Time of testing

The interaction between impulsivity and time of day should be present, according to Humphreys and Revelle's model,[17] in the absence of any additional source of physiological arousal, such as caffeine. Therefore, the effects of impulsivity and time of day were tested in the baseline condition using a series of between-subjects ANOVAs with impulsivity and time of day as between-subject factors.

Subjective alertness

For the alertness pre-memory test, a significant 2-way interaction was found between impulsivity and time of testing, $F(1, 92) = 4.93$, $MSe = 2889.86$, $p < 0.05$. A Newman-Keuls test failed to reveal any significant differences between means, but the pattern confirmed the Humphreys and Revelle's model.[17] For low impulsives, self-rated alertness was 223.83 (SE 10.97) in the morning but was lower in the evening, 207.63 (10.97), whilst for high impulsives, alertness was lower in the morning, 210.00 (SE 10.97) than the evening 242.58 (10.97). No other significant interactions or main effects were found for the subjective alertness pre-memory test. The mood ratings after the memory tests showed no interactions or main effects which approached significance.

Memory performance

For semantic memory, logical reasoning and recall, there were no 2-way interactions between impulsivity and time of day for any performance parameter. The only significant effects were the main effects of time of day for the number of trials correct for semantic memory and executive function.

Semantic memory

For semantic memory, the only significant effect was the main effect of time of day, with participants attempting 113.79 trials in the morning (SE = 4.18) and 126.67 trials in the evening (SE = 4.22), $F(1, 91) = 4.70$, $MSe = 837.47$, $p < 0.05$.

Logical reasoning

The only statistically significant effect was the main effect of the time of day. Participants tested in the morning attempted 53.08 trials (SE = 2.47), and those tested in the evening 60.26 trials (SE = 2.49), $F(1, 91) = 4.19$, $MSe = 291.55$, $p < 0.05$.

Recall

No statistically significant results were found for the total number of words recalled, the percentage of words correct or the number of intrusions.

Effects of caffeine, Impulsivity and Time of testing

The interaction between impulsivity and time of day for subjective alertness gave Humphreys and Revelle's model limited support.[17] The next stage of the analysis tested the prediction that on tasks with a high STM component caffeine will impair cognitive performance in the morning in low impulsives but improve it in the evening and that caffeine will be beneficial to high impulsives in the morning but impair performance in the evening.

Subjective alertness

Pre- and post-memory tests showed no 3-way interactions between caffeine, impulsivity and time of testing for subjective alertness. For alertness prior to the memory tests, there was a significant interaction between impulsivity and time of testing, $F(1, 87) = 4.05$, MSe = 1024.81, $p < 0.05$. It was found that for low impulsives, self-rated alertness in the morning was 234.37 (SE 9.58), whilst in the evening, it was marginally lower, 231.42 (SE 8.18), with the adjusted means being 233.02 (SE 6.54) and 237.83 (SE 6.59) respectively. In high impulsives, alertness in the morning was 235.83 (SE 7.39) and was also lower in the evening 229.25 (SE 8.03). The non-adjusted means were 241.11 (SE 6.57) in the morning and 218.91 (SE 6.67) in the evening. This means the pattern bears little resemblance to what Humphreys and Revelle predicted, as the high impulsive participants tested in the evening had the lowest self-reported alertness.[17]

Post-memory test, caffeine significantly increased self-rated alertness (F[1, 87] = 5.59, MSe = 1233.65, $p < 0.05$. Alertness in the caffeine condition was 225.81 (SE 5.07), whilst it was 208.86 (SE 5.07) in the placebo condition; non-adjusted means were 226.23 (SE 7.51) and 208.44 (SE 7.51), respectively. Post-memory test, there was again a significant interaction between impulsivity and time of testing on the measure of alertness, $F(1, 87) = 4.80$, MSe = 1233.65, $p < 0.05$. For low impulsive participants, self-rated alertness was 213.38 (SE 11.24) in the morning and was higher in the evening, 217.46 (SE 11.25), with non-adjusted means of 201.41 (SE 7.26) and 222.38 (SE 7.19) respectively. For high impulsive participants self-rated alertness was 223.04 (SE 10.15) in the morning and 215.46 (SE 217.14) in the evening. Non-adjusted means were 228.14 (SE 7.19) in the morning and 217.41 (SE 7.17) in the evening. Again, the pattern of means obtained showed little resemblance to Humphreys and Revelle's model and appeared to be the reverse of what might be expected, with low impulsives having higher self-rated alertness in the evening and high impulsives having greater self-rated alertness in the morning.[17]

Memory tasks

For tasks with a high STM component (e.g. the logical reasoning task), Humphreys and Revelle's model predicts 3-way interactions between caffeine, impulsivity and testing time.[17] No interactions between caffeine, impulsivity and time of day were found for any parameter of memory performance, and the only statistically significant effects were the main effects of caffeine and impulsivity, which offer little support for Humphreys and Revelle's model.[17]

Semantic memory

For the number of trials attempted, there was a highly significant main effect of caffeine, $F(1,86) = 8.53$, MSe = 89.22, $p < 0.005$ with 134.77 (SE 1.39) trials attempted by the caffeine group and 129.02 (SE 1.37) attempted by the placebo group. The non-adjusted means were 130.42 (SE 3.97) for the placebo group and 133.19 (SE 3.93) for the caffeine group. The ANCOVA also revealed a significant main effect of impulsivity for the number of trials attempted, $F(1, 86) = 5.59$, MSe = 89.22, $p < 0.05$. As might be expected, high impulsives attempted more trials than low impulsive subjects; adjusted means were 134.19 (SE 1.3) for the high impulsive group and 129.60 (SE 1.36) for the low impulsive group. Non-adjusted means were 135.38 (SE 4.27) and 128.40 (3.90), respectively. For the percentage of trials correct, there was a significant main effect of caffeine, $F(1,86) = 5.35$, MSe = 8.68, $p < 0.05$. In the caffeine condition, 94.60 (SE 0.43) per cent of trials were verified correctly as opposed to 93.20 (SE 0.43) in the placebo condition; non-adjusted means were 94.67 (SE 0.73) and 93.14 (SE 0.72), respectively. Analysis of MRT for correctly answered trials revealed a significant main effect of impulsivity, $F(1,86) = 10.11$, MSe = 16491.52, $p < 0.005$. As might be expected, high impulsives proved faster at completing trials than low impulsives, with MRT (msec) for high impulsives being 1241.04 (SE 57.26) compared to 1358.34 (SE 37.47) for low impulsives. Non-adjusted means were 1257.89 (SE 18.76) for high impulsives and 1341.84 (SE 18.55) for low impulses. For MRT for correct trials, there was also a main effect of caffeine, $F(1,86) = 7.00$, MSe = 16491.52, $p < 0.05$, with MRT (msec) being 1264.43 (SE 18.90) in the caffeine condition and 1335.30 (SE 18.68) in the placebo condition. Non-adjusted means were 1317.71 (48.23) in the caffeine condition and 1283.43 (SE 47.69) in the placebo condition.

Logical reasoning

For the number of trials attempted, no main effects or interactions were significant at the 5% level, but the main effect of caffeine approached significance, $F(1, 86) = 3.86$, MSe = 49.91, $p = 0.053$, with more trials being attempted in the caffeine condition than in the placebo condition. Caffeine was found to increase the percentage of trials correct, $F(1,86) = 4.15$, MSe = 18.54, $p < 0.05$. In the caffeine condition, 92.90 (SE 0.67) per cent of trials were verified correctly compared to 91.08 (SE 0.62) in the placebo condition with non-adjusted means of 92.06 (SE 1.16) and 91.85 (1.14), respectively. For MRT for correct trials,, no main effects or interactions approached significance.

Recall

There were no main effects or interactions that approached significance for the total number of words written recalled or for the percentage of words recalled correctly, but for the number of commission errors, there was a main effect of impulsivity, $F(1, 84) = 4.43$, $MSe = 5.16$, $p < 0.05$, with high impulsives making more commission errors than low impulsives. The mean number of commission errors (adjusted) was 1.96 (SE 0.27) in the low impulsive group and 2.87 (SE 0.40) in the high impulsive group, with non-adjusted means of 1.91 (SE 0.34) and 2.77 (SE 0.33) respectively.

A further ANCOVA was carried out with the level of processing as a within-subjects factor to determine if caffeine has a differential effect on shallow and deep processing in high and low impulsives. According to Gupta, it would be expected that in the placebo condition, low impulsives would recall more shallow processed words than their high impulsive counterparts and high impulsives recall more semantically processed words than low impulsives.[28] After caffeine, however, for high impulsives, recall of semantically acquired words would be impaired and recall after shallow processing facilitated. As this interaction was predicted two t-tests with bonferroni adjustment were performed to compare the effects of caffeine and placebo on shallow processing in high impulsives and on deep encoding in high impulsives.

It was found that, as expected, there was a main effect of level of processing, $F(1, 84) = 19.44$, $MSe = 55.59$, $p < 0.0001$, with 19.93 per cent of words recalled correctly after deep processing compared to 15.40 per cent recalled correctly after shallow processing. Non-adjusted means were 20.44 (SE 1.04) and 14.89 (SE 1.06), respectively. A significant interaction between caffeine, impulsivity and level of processing was also found, $F(1, 84) = 5.22$, $MSe = 58.58$, $p < 0.05$ (see Table 2).

Visual inspection of the means suggested that the results were similar to those of Gupta.[28] A series of t-tests with bonferroni adjustment were used to check all pair-wise comparisons and it was found that that although there were several significant pair-wise differences relating to level of processing none of the effects for high impulsives reached statistical significance. In the placebo condition, low impulsives favoured shallow processing and high impulsives deep processing, but, in high impulsives, only caffeine appeared to impair the recall of deeply processed words and facilitate the recall of words processed at a shallower level.

Table 2: Recall, day 1: Adjusted and Non-adjusted percentage of words recalled correctly using Shallow and Deep processing encoding by high and low impulsive participants in caffeine (4mg/kg) or placebo conditions (SEs in parentheses).

	Impulsive	Level of processing	Mean
Caffeine	Low	Shallow	12.46 (2.13) **13.47**
		Deep	21.27 (2.09) **21.10**
	High	Shallow	17.29 (2.08) **17.07**
		Deep	18.13 (2.04) **17.56**
Placebo	Low	Shallow	15.80 (2.13) **17.05**
		Deep	21.33 (2.09) **20.36**
	High	Shallow	13.98 (2.13) **14.00**
		Deep	21.02 (2.09) **20.97**

Summary of caffeine, Impulsivity and Time of day analyses

For self-rated alertness, there was limited evidence of an interaction between impulsivity and time of day that conforms to Humphreys and Revelle's model.[17]

There was no evidence of the interaction between impulsivity and time of day predicted by Humphreys and Revelle for any index of memory performance.[17]

For semantic memory and logical reasoning, there was a time of testing effect with performance being worse earlier in the day.

There was no evidence for an interaction between caffeine, impulsivity and time of testing as predicted by Humphreys and Revelle for any memory performance index or subjective alertness.[17]

For semantic memory and recall, there were main impulsivity effects consistent with the behaviour predicted by Eysenckian theory, i.e. compared to low impulsives high impulsives attempt more trials, have a faster MRT and make more errors.

In high impulsives, caffeine impaired recall of semantically acquired words and facilitated recall after rhyming acquisition.

DISCUSSION

The primary objective of the present study was to replicate previous studies that found the effects of caffeine on semantic memory and executive function. The study also aimed to provide further data on the interaction between caffeine, impulsivity and time of day suggested by Humphreys and Revelle's model of arousal and cognition[17] and to reproduce the interaction between caffeine, impulsivity and levels of processing described by Gupta.[28] The other objective of the study was to investigate the phenomena of state-dependent learning and recall, as these have been studied extensively for other centrally acting drugs but only once to date with caffeine.

The central theme of the present article was to investigate the interaction between caffeine and impulsivity (and hence the time of day due to the circadian rhythms associated with impulsivity) using Humphreys and Revelle's model.[17] The model suggests that physiological arousal is additive and that caffeine and impulsivity, both sources of arousal, may interact to influence cognitive performance. Specifically, the model predicts that in low impulsive participants, caffeine will be the most significant benefit to cognitive performance in the evening when baseline arousal is decreasing and that in high impulsive participants, the benefit of caffeine will be most significant in the morning when basal arousal is at its lowest. The model also predicts high arousal will damage performance on tasks with a high STM component. When the between-subjects factors of impulsivity and time of day were used to analyse the baseline data, there was no evidence of a consistent interaction between impulsivity and time of day for the positive control or the memory tasks. Data from test day one also failed to reveal any consistent interaction between caffeine, impulsivity and time of day that conformed to the predicted pattern. In general, caffeine, impulsivity and time of day effects were independent, and significant interactions that did occur failed to yield meaningful differences between means on post-hoc Newman-Keuls analysis. The data would then appear to suggest that there is little evidence to support Humphreys and Revelle's model,[17] and the independence of main effects noted in some of the tasks would suggest that sources of arousal are not additive and that arousal as a concept requires a much more concise definition. Seven previous studies have analysed caffeine-impulsivity interactions, and three have also failed to report any pattern of interactions.[13,19,29] More support for the model has been provided by Gupta[28] and Smith et al.[30] They have described decrements in recall and recognition memory in high impulsives given caffeine. However, the only interaction between caffeine and impulsivity that fully conforms to the model has been carried out by Anderson and Revelle.[20] It is acknowledged that the present study did not use particularly extreme groups of high and low impulsives compared to other studies.[28] However, as there was very little evidence of a caffeine-impulsivity interaction one can suggest that future research uses alternative approaches to Humphrey and Revelle's theory when examining individual differences in the behavioural effects of caffeine.[17]

In summary, the study has successfully replicated known caffeine effects on semantic memory and executive function, including improvements in accuracy on both tasks, which suggests that caffeine does not simply increase cognitive processing speed. No evidence was found that caffeine effects interact with the physiological parameter of baseline arousal or impulsivity.

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