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CAFFEINE, HABITUAL CAFFEINE CONSUMPTION, ALERTNESS AND COGNITIVE PERFORMANCE

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ABSTRACT

Background: There has been extensive research on the effects of caffeine on behaviour. People differ in the amount of caffeine they regularly consume, and there has been research comparing the effects of caffeine on low and high consumers. This issue was examined here, and the effects of caffeine withdrawal and caffeine (100mg) on alertness and cognitive performance were investigated. **Methods:** Two groups of caffeine consumers were recruited. The high consumers had an intake of more than 200mg caffeine daily, whereas the low consumers ingested less than 20 mg caffeine daily. A double-blind cross-over design was used with all participants carrying out caffeine and placebo conditions. Each session had the following features. After overnight abstinence, participants carried out a baseline session at 09.00 to examine the possible effects of caffeine withdrawal. During the session, they rated their alertness and performed cognitive vigilance and five-choice serial response tasks. After the baseline session, the participants were given either caffeinated or decaffeinated coffee. A post-drink testing session was carried out one hour later. **Results**: There were no significant differences between the low and high consumer groups at baseline. Both groups of participants reported significantly greater alertness after caffeine at the start and end of the test session. Caffeine was also associated with significantly more hits in the cognitive vigilance task and more responses in the five-choice serial response task. There were no differences between the two consumer groups in the effects of caffeine. **Conclusion:** These results demonstrate that caffeine increases alertness and improves sustained attention. These effects were observed for both low and high caffeine consumers. The two groups did not

differ at baseline, suggesting that caffeine withdrawal, which would be greater in the higher consumers, had little effect.

KEYWORDS: Caffeine; Caffeine Withdrawal; Habitual Caffeine Consumption; Ratings of Alertness; Sustained Attention.

INTRODUCTION

The effects of caffeine on behaviour have been studied for over fifty years, and there are many reviews of the area.[1-7] One line of research has shown that caffeine reduces impairments observed in low alertness states (e.g., when sleep-deprived,[8] when the person has a cold,[9] when working at night,[10], after lunch,[11] and after prolonged work,[12]). The alerting effects of caffeine have been shown to reflect blockade of the adenosine receptors,[13] which leads to its stimulant effects.[14] Adenosine antagonists, such as caffeine, also change the release of neurotransmitters. For example, caffeine increases the synthesis and turnover of central noradrenaline.[15] Smith et al.[16] have shown that caffeine removes the sedative effects of a low dose of clonidine which acts pre-synaptically to reduce the turnover of central noradrenaline. Other effects of caffeine have been observed when the person is not fatigued, which may reflect changes in the cholinergic neurotransmitter system.[17]

An alternative view is that caffeine withdrawal leads to impairments, and caffeine simply removes the adverse effects of withdrawal.[18] Research from different laboratories suggests that this theory is unlikely to be correct.[1,3,7,19-25] Indeed, caffeine influences the behaviour of non-consumers and animals[26,27] who do not experience withdrawal. Additionally, the effects of caffeine have been demonstrated after a seven-day washout period[28] when withdrawal effects should no longer be present. Significant effects of caffeine have also been found when the person is no longer deprived because of prior consumption.[29,30] The present study compared the effects of overnight caffeine abstinence on high and low caffeine consumers. If the withdrawal explanation is correct, the high consumers should experience more significant withdrawal effects, leading to differences from the low consumer group in tests carried out before caffeine consumption. Other research has found differences in the effects of caffeine given to high and low consumers, which do not reflect withdrawal.[22,31,32] The present study examined whether high and low caffeine consumers differ in personality and health-related behaviours. High caffeine consumers are more likely to be smokers. Both smoking and caffeine have cholinergic effects, and it has also been shown that smoking leads to faster

elimination of caffeine which could plausibly account for greater caffeine consumption by smokers.

One of the problems in reviewing the effects of caffeine on mood and cognitive performance is that many different tasks have been used in various studies. Using a small number of tasks reduces the possibility of chance effects. The present study continued the approach of Smith et al.[28] which used a small number of tasks that reflect both noradrenergic and cholinergic effects of caffeine. In the present study, the indicators of noradrenergic effects were post-task ratings of alertness and the number of responses on the five-choice serial response task. Cholinergic effects were measured by pre-task alertness and accuracy of cognitive vigilance.

Finally, a cross-over design was used with all participants carrying out both caffeine and placebo conditions in a counterbalanced order. Many studies of the effects of caffeine have used between-subject designs. The present design had a pre-drink baseline for each type of drink, and measures from this session were used as covariates in the analysis of the post-drink effects. Order of drink conditions was also included in the analysis. This procedure allows one to determine whether there are any transfer effects across drink conditions. It also removes practice effects from the error term, providing a better opportunity to obtain significant effects of drink conditions.

In summary, the present study examined the effects of caffeine withdrawal and caffeine challenge on the alertness and cognitive performance of high and low caffeine consumers. A cross-over design was used, and the pre-drink measures were analysed to compare differences between the two consumer groups. The pre-drink measures were used as covariates in the analyses of the post-drink variables. Inclusion of order of treatments in the analysis removed variation due to the different orders and eliminated practice effects from the error term, which provided a better indication of the significant effects of the within-subject caffeine variable. Cognitive tests were chosen that were known to be sensitive to changes in the noradrenergic and cholinergic neurotransmitter systems. Other measures included expectancies about the effects of caffeine and about whether caffeine was administered or not.

MATERIALS AND METHODS

The study described here was carried out with the approval of the ethics committee, School of Psychology, and carried out with the informed consent of the volunteers.

Design - A double-blind cross-over design was used with volunteers carrying out both caffeine and placebo conditions in a counterbalanced order. On recruitment, volunteers were familiarised with the procedure and performed a practice version of the tasks. The volunteers then carried out the two conditions approximately one week apart. Following overnight caffeine abstinence, volunteers carried out a pre-drink baseline, then consumed the coffee, followed by a post-drink test session. In order to detect medium size caffeine effects in a cross-over design, 24 participants are required.

Caffeine - In the caffeine condition, 100mg of caffeine in solution was added to decaffeinated coffee. In the placebo condition water was added to the decaffeinated coffee. The caffeine manipulation was double-blind.

Participants – All volunteers were recruited from the Health Psychology Research Panel. On joining the panel, participants completed a caffeine consumption questionnaire from which total daily caffeine consumption could be calculated (coffee: filter coffee 125mg per cup; instant coffee 70mg/cup; decaffeinated coffee 5mg/cup; tea 60mg/cup; cocoa/hot chocolate 5mg/cup; and colas 30mg/ca).[33] They were paid for participation. Participants were recruited if they consumed more than 200 mg/day of caffeine or less than 50mg/day. Thirty-seven participants (18 low consumers, 19 high consumers) completed the study (20 females, 17 males. Mean age of 21.7 years, range 18-34 years). The high consumers had a mean daily caffeine consumption of 284mg (sd = 90.9), and the low consumers had a mean daily caffeine consumption of 15.8 mg (sd=19.2).

Information about personality[34] was recorded when the participants registered for the panel. The scales used were the introversion, impulsivity, and sociability scales of the Eysenck personality inventory; the Spielberger Trait Anxiety Inventory; and the summary question from the Horne and Ostberg Morningness Questionnaire. Information on health-related behaviours (smoking, alcohol consumption and eating habits) was also recorded.

Exclusion criteria - Any current physical or mental illness; inability or unwilling to consume caffeinated coffee; consumption of >50mg and <200mg of caffeine a day; inability to complete the battery of tests; unwilling to consent to the following provision of information about the study.

Familiarisation with procedures - The participants were familiarised with the tasks and procedures before the study. They were also asked whether they considered caffeine improved mental efficiency, alertness, concentration and speed of reactions. They answered this using a 100mm scale ranging from greatly impairs to greatly improves.

Procedure – Participants were asked to abstain from caffeine from 21.00 on the evenings before testing. They attended the laboratory at 09.00 on two occasions. Baseline measurements were taken, after which they were given a cup of either caffeinated or decaffeinated coffee. The participants remained in the laboratory for an hour after drinking the coffee and then carried out the post-drink test session. Each test session involved two ratings of alertness, a five-choice serial response task and a cognitive vigilance task. At the end of the test day, the volunteers were asked to guess whether they had received a caffeinated or decaffeinated drink.

Tasks

Rating of alertness - This was assessed using bi-polar visual analogue scales[35] (e.g. Drowsy-Alert; Lethargic-Energetic; Attentive-Dreamy, and Incompetent-Proficient). Alertness was rated at the start and end of the test battery. Some scales were reversed scored so that high scores reflected higher alertness. The percentage of the maximum score was used in the analyses.

Performance battery

Five-choice serial response task – Five red buttons were arranged in a pentagon on a board. When a button was illuminated, the participant had to press that button with the fore-finger of their dominant hand. As soon as this was done, another button was illuminated, and this had to be pressed. The task lasted 8 minutes, and the number of responses made in that period was recorded.[35]

Cognitive Vigilance Task – The repeated digits vigilance task was used.[35] Three-digit numbers were shown on the screen at a rate of 100 minutes. Usually, one of the digits changed on successive trials. Occasionally, eight times a minute, the same number was presented in successive trials. The task was carried out for 8 minutes, and the percentage of targets detected was the variable of interest

Analysis strategy

Analyses of variance were carried out on the personality data and health-related behaviours data to determine whether there were significant differences between the low and high consumers. The pre-drink data of the low and high consumers were also compared to determine whether negative effects of caffeine withdrawal were observed in the high caffeine consumers. Similar analyses were carried out on the expected effects of caffeine score and the type of drink guesses.

Separate analyses of covariance with the pre-drink measure as the covariate were carried out for the alertness and performance scores. The analyses were carried out using the BMDP 2V statistical programme. Consumer group (low/high) and order of caffeine conditions were the between subject variables. Caffeine condition (caffeine v placebo) was the within-subject factor.

RESULTS

Personality

The high and low caffeine consumers did not significantly differ in their personality scores (see Table 1).

Table 1: Personality scores of the low and high caffeine consumers (scores are the means, S.D.s in parentheses).

	TAQ	IMP	SOC	EXT	OPQ	MORN
High consumers	37.5 (9.0)	3.9 (2.1)	6.8 (3.1)	11.1 (5.0)	3.0 (1.2)	2.1 (1.8)
Low consumers	39.9 (10.0)	4.6 (2.2)	6.8 (3.5)	12.5 (5.3)	2.4 (1.2)	2.9 (1.8)

TAQ: Spielberger Trait Anxiety Inventory

IMP: Impulsivity (Eysenck Personality Inventory)

SOC: Sociability (Eysenck Personality Inventory)

EXT: Extraversion (Eysenck Personality Inventory)

OPQ: Obsessional Personality Questionnaire

MORN: Morningness

Expectancy of the effect of caffeine and drink guessing

Both groups considered the effects of caffeine on performance to be positive, and this effect was greater in the high caffeine consumers ($F\ 1, 34 = 4.46\ p < 0.05$; high consumer rating: mean = 75.3 sd = 9.1; low consumer rating: mean = 66.9 sd =14.4 $p < 0.05$).

Guesses about the caffeine content of the drinks were at a chance level, and there was no difference in the accuracy of the guesses of the low and high consumers (high: 47.4% correct; low: 50% correct).

Caffeine withdrawal

The two groups' pre-drink alertness and performance scores were compared to examine whether there was greater withdrawal in the high consumers. No significant differences were found between the groups (see Table 2.

Table 2: Pre-drink scores for the low and high caffeine consumers (scores are the means).

	Pre-test alertness	Post-test alertness	Number correct five choice	Hits cognitive vigilance
High consumers	41.2%	38.6%	581	47.5%
Low consumers	42.7%	36.4%	561	49.6%

The alertness scores are the percentage of the maximum possible score.

Effects of caffeine

The effects of caffeine are shown in Table 3. Caffeine was associated with significantly greater pre-test alertness ($F_{1,33} = 5.94$ $p < 0.05$), post-test alertness ($F_{1,33} = 9.79$ $p < 0.05$), more correct responses in the five-choice serial response task ($F_{1,33} = 7.28$ $p < 0.05$) and more hits in the cognitive vigilance task ($F_{1,33} = 5.57$ $p < 0.05$). There were no significant main effects of consumer groups and no significant interactions between drinks and consumer groups.

Table 3: Effects of caffeine and consumer group on alertness and performance (scores are the adjusted means from the analysis of covariance).

	Pre-alertness Caffeine	Pre-alertness Decaff	Post-alertness Caffeine	Post-alertness Decaff	Five choice Caffeine	Five choice Decaff	Cognitive hits Caffeine	Cognitive hits Decaff
High	47.4%	43.8%	42.0%	36.3%	620	591	51.3%	47.2%
Low	44.0%	41.1%	38.2%	34.4%	612	599	49.2%	45.0%
Total	45.7%	42.4%	40.1%	35.3%	616	595	50.2%	46.1%

The alertness scores are the percentage of the maximum possible score

DISCUSSION

The present study used measures known to be sensitive to the effects of caffeine and thought to be changed by cholinergic (pre-test alertness, cognitive vigilance) and noradrenergic

mechanisms (post-test alertness, cognitive vigilance). The results confirmed caffeine's effects on these tasks, which were observed for both high and low caffeine consumers. In contrast, there was no evidence of different effects of overnight caffeine withdrawal in either group. The groups did not differ in terms of personality or their ability to detect whether the drink contained caffeine or not. The high consumers had a higher expectancy of a benefit from caffeine, which may be important in studies that detected differences between the low/high consumer groups given caffeine.

Overall, the present results support the view that removal of caffeine withdrawal is not the mechanism underlying the effects of caffeine on alertness and performance of sustained attention tasks. These results have been found using a methodology that will be important for future research on the behavioural effects of caffeine. First, the study used sensitive tasks rather than a general battery of tests, many of which may not be sensitive to a design aimed at detecting medium-sized effects. Secondly, a pre-drink baseline was recorded and then used as a covariate to remove unwanted individual differences. A cross-over design was used, and the order of testing was included in the analyses to examine the effects of possible asymmetric transfer between conditions and to remove effects due to practice from the error term. The sample size was also appropriate for the effect sizes of caffeine in studies using these tasks. The tasks used here are not the only ones that are sensitive to the effects of caffeine. Other research[35] has shown that the speed of working and semantic memory tasks is quicker after caffeine. However, these effect sizes are generally small and require a larger sample size. Other tasks, such as episodic memory tasks (e.g. recall or recognition of a list of words), are often not significantly changed following caffeine. Such results may reflect caffeine's selective effects on different personality types, leading to no overall change.[36]

CONCLUSION

A double-blind placebo-controlled laboratory study of the effects of caffeine demonstrated significantly better outcomes after caffeine for pre-and post-task alertness, five-choice serial response and cognitive vigilance. Effects of caffeine were observed in both high and low consumers of caffeine. This result, and the absence of differences between these groups after overnight withdrawal, suggest that the removal of adverse effects of withdrawal was not the mechanism responsible for the benefits of caffeine. The methodology used here is recommended for future research extending our knowledge of the behavioural effects of caffeine. Caffeine is known to produce neurotransmitter changes (cholinergic and

noradrenergic) that plausibly underlie the effects observed here. Other research has shown that these effects of caffeine seen in the laboratory can be observed in real-life settings.[37-40]

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