



FASTING, BREAKFAST, CAFFEINE AND CAFFEINE WITHDRAWAL: EFFECTS ON ALERTNESS, RECALL AND ENCODING

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Article Received on 27/09/2020

Article Revised on 17/10/2020

Article Accepted on 07/11/2020

ABSTRACT

Background: Extensive research on the behavioural effects of consuming breakfast and caffeine has led to the identification of sensitive tests. It has been suggested that the effects of breakfast on memory and alertness may reflect removal of the negative effects of fasting. Similarly, it has been argued that beneficial behavioural effects of caffeine may be due to reversal of caffeine withdrawal. The aim of the present research was to examine these mechanisms using tests which are known to be sensitive to the effects of breakfast and caffeine. **Methods:** The present study examined the effects of fasting and caffeine withdrawal over the course of an 8 hour period during the day. The participants were 65 males and 65 females, age range 18-30 years, mean age 23.5 years. Participants carried out a baseline test session and were then given breakfast cereal and caffeinated coffee (100 mg caffeine). Volunteers were then assigned to groups formed by combining fasting (fast/no fast) and caffeine withdrawal conditions (withdrawn/non-withdrawn). The effects of fasting and withdrawal were tested 8 hours after breakfast. Following this test volunteers were given caffeine (100 mg) or placebo, and breakfast cereal or no cereal. A final test session was completed an hour later. **Results:** The results showed that fasting was associated with reduced pre-test alertness and poorer recall of a list of words. Caffeine withdrawal had no significant effects on tests of post-task alertness and encoding. In the final session, caffeine increased post-task alertness and encoding of new information. This was observed in both withdrawn and non-withdrawn volunteers. Breakfast cereal increased pre-task alertness in both those who had fasted and those who had not. However, breakfast cereal only improved recall in the fasted group. **Conclusions:** Use of sensitive tests demonstrated behavioural effects of breakfast cereal and caffeine. Fasting led to reduced alertness and poorer recall and the effect on memory was removed by consuming cereal. The effects of caffeine were observed in both withdrawn and non-withdrawn volunteers.

KEYWORDS: Fasting; Caffeine; Breakfast Cereal; Caffeine withdrawal; Encoding; Alertness; Free recall.

INTRODUCTION

Extensive research has shown that consumption of breakfast is associated with improved episodic memory.^[1,2] Effects of breakfast have been investigated using other performance tasks but the results are equivocal.^[2] Consumption of breakfast also leads to an acute increase in alertness.^[3] These behavioural effects have been found with different breakfasts, including breakfast cereals, and cereal bars. In the present study these sensitive outcome measures (immediate free recall of a list of words and ratings of alertness before beginning the cognitive test battery) were used to examine whether the beneficial effects of consuming breakfast reflected a reversal of the negative effects of fasting. In addition, these established effects of breakfast were used as a positive control in an investigation of effects of caffeine withdrawal and caffeine.

Recent research been concerned with intermittent longer term fasting and fasting in periods such as Ramadan.^[4]

Breakfast consumption, relative to fasting, has a short-term (same morning), positive domain-specific effect on cognition.^[5] Most of the studies of the effects of breakfast have followed an overnight fast, but there is research showing that morning fasting adversely effected recall of a word list. This could be reversed by consuming a glucose drink.^[6] The present study examined whether fasting over the day influenced these outcomes, and whether the effects of fasting would be reversed by consuming breakfast in the early evening.

Effects observed in caffeine challenge are well documented.^[7-14] A recent study^[14] demonstrated effects of caffeine on encoding of new information and post-task alertness, and these appeared to be robust in different contexts. Reversal of withdrawal has been put forward as a possible explanation of effects of caffeine on cognition and alertness.^[15-26] Many studies of caffeine withdrawal focus on symptoms such as headache^[27-31] and it has been suggested that they may reflect expectancies based on

perceptions of withdrawal.^[32,33] Other researchers have argued that effects of caffeine on behaviour do not reflect reversal of caffeine withdrawal.^[34-42]

One possible reason for the different results could be that effects of caffeine may depend on the tasks used. What is desirable is to use tests which identify effects in a variety of different context. Recent research^[14] demonstrated effects of caffeine on encoding of new information and post-task alertness. These effects were observed at different times of day. Previous research has shown such effects in studies of non-consumers,^[43] after previous consumption^[44,45] and washout.^[46] No effects of caffeine withdrawal were observed for these tasks in these studies.

There were two main aims in the present study. The first aim was to examine effects of fasting and consumption of breakfast cereal after a fast, using measures of pre-test alertness and free recall of a list of words. The second aim was to investigate caffeine withdrawal and caffeine ingestion on post-task alertness and encoding of new information. By investigating these issues in a single study, one will have more confidence in specific findings observed in a context of replication of established effects.

MATERIALS AND METHODS

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

Design

A factorial between subjects design was used with participants being randomly allocated to conditions. The first grouping was fasting/no fasting and approximately half of the participants were in these groups. The second grouping factor was caffeine withdrawal/no withdrawal, and each of the fasting groups had approximately equal numbers in the withdrawal/no withdrawal conditions. The second set of manipulations were the drinks (caffeine v placebo) and meals (cereal v no food) in the early evening. These conditions were balanced across the fasting and withdrawal groups.

Sample size: In between subject designs adjusting for baseline differences, group sizes of 24 have been shown to be sensitive to effects of caffeine and breakfast. This suggests a minimum sample of 96 for the present study.

Volunteers: The participants were university students (65 males and 65 females, age range 18-30 years, mean age 23.5 years). Gender has been shown to have little effect on the effects of caffeine in this age group.^[47] They were paid £35.00 for participating in the study.

Exclusion criteria: Any current physical or mental illness; unable or unwilling to consume caffeinated coffee or breakfast cereal; unable to complete battery of

tests; unwilling to consent following provision of information about the study.

Familiarisation with procedures: Prior to the test day volunteers were familiarised with the tasks and procedures.

Baseline measurements: Baseline measurements were taken at the start of the test day (between 08.00 and 09.00) prior to the initial cereal and caffeinated coffee. These were used as covariates to remove any unwanted individual differences.

Measurement of mood^[14] Mood was assessed both before and after performance testing using 18 bi-polar visual analogue scales. These yield three factors: Alertness, Hedonic tone and Anxiety. The alertness scores were used in the analyses reported here.

Performance tasks

(a) Categorical Search Task^[48]

This task was developed to measure aspects of selective attention and choice reaction time. Each trial started with the appearance of two crosses in the positions 2.04 or 5.20 degrees apart. Volunteers did not know which of the crosses would be followed by the target. The letter A or B was presented alone on half the trials and was accompanied by a digit (1-7) on the other half. Again, the number of near/far stimuli, A versus B responses and digit/blank conditions were controlled. Half of the trials led to compatible responses (i.e. the letter A on the left side of the screen, or letter B on the right) whereas the others were incompatible. Interest here focused on responses which were either the same (repetitions) or different (alternations) from the previous one. A difference score (Alternation RT – Repetition RT) was calculated, with smaller scores reflecting faster encoding of new information. Volunteers were given ten practice trials followed by five blocks of 64 trials. In each block there were equal numbers of near/far conditions, A or B responses and equal numbers of the four distractor conditions. The nature of the previous trial was controlled.

(b) Free recall task^[14]

Volunteers were shown a list of 20 words, with each word being presented for 2 secs. At the end of the list they had 2 minutes to write down, in any order, as many words as they could remember.

Breakfast and caffeine after baseline tests

All volunteers were given breakfast cereal and caffeinated coffee after the baseline tests. Volunteers selected a cereal from a number of different varieties.^[49] They were allowed to consume as many small boxes of cereal as they desired but could only select one type and had to finish each portion completely. They were allowed to add sugar and semi-skimmed milk. The average energy provided by the cereal was 208kcal and the macronutrient composition was 2.8g protein, 49.5 g

carbohydrate and 0.3 g fat. All drinks were made with one rounded teaspoon of decaffeinated coffee in a 150 ml mug of boiling water. To this 60mg of caffeine was added. Milk and sugar were added in accordance with usual preference.

Fasting and withdrawal procedure

Volunteers stayed in the research unit all day and were free to read or use their laptop between test sessions. In the fasting condition there was no food until after end of experiment. The non-fasting group were provided with lunch. Coffee was provided at 11.00, and again at lunch time (13.00). In the withdrawal group only decaffeinated coffee was given. In the non-withdrawal group, 60 mg caffeine was added. The caffeine manipulations were double blind.

Each participant was provided with a sandwich based lunch (sandwich choice: chicken salad; prawn mayonnaise; cheese and salad; egg mayonnaise; tuna and sweetcorn; BLT) with a choice of various accompaniments (crisps, biscuits and fruit). This lunch was consumed at either lunch time (non-fasting condition) or given at the end of the test day upon departure (fasting condition). Those eating lunch were taken to a separate room to eat whilst those in the no lunch condition remained in the main test area. Those participants asked to abstain from lunch were informed that they would receive the lunch of their choice at the end of the final test session thus minimising induction of negative mood as a result of being asked to miss lunch.

Second test session

This was carried out to assess the effects of fasting and caffeine withdrawal, and took place at approximately 17.00.

Evening cereal and caffeine

The breakfast and coffee procedure was repeated after the second test session, with approximately half the participants in the fasting and caffeine groups being given cereal, the others abstaining, and half having caffeinated coffee (100mg caffeine), the others being given placebo.

Final test session

This was carried out one hour after consumption/non-consumption of the cereal and caffeine.

RESULTS

Effects of fasting

Results from the second test session revealed significant effects of fasting on pre-test alertness ($F_{1,125} = 10.55$ $p < 0.001$) and recall ($F_{1,125} = 5.43$ $p < 0.05$). Caffeine withdrawal had no significant effect on pre-test alertness ($F_{1,125} = 1.24$ $p = 0.27$) or recall ($F < 1$). These results are shown in Table 1.

Caffeine withdrawal

The results for post-test alertness and speed of encoding are shown in Table 2. There were no significant effects of caffeine withdrawal, fasting, nor interaction between the two (all F 's < 1 except for withdrawal and encoding: $F_{1,125} = 1.28$ $p = 0.26$).

Acute effects of caffeine and breakfast cereal

Results from the final session were analysed and the ANCOVA distinguished the between subject factors of fasting condition, withdrawal condition, evening cereal/no cereal and evening caffeine/placebo. Baseline measurements were used as covariates.

Fasting and cereal

In the analyses of the pre-test alertness, there were significant effects of fasting ($F_{1,113} = p = 0.006$) and cereal: ($F_{1,113} = 5.19$ $p = 0.02$). In the free recall task, there was a significant fasting x cereal interaction ($F_{1,113} = 6.88$ $p < 0.01$). These results are shown in Table 3. Alertness was lower in the fasting condition and higher in the cereal condition. Recall was improved by consumption of cereal in the fasting condition but not the no fasting condition. There were no significant effects of caffeine withdrawal or caffeine on these tasks.

Caffeine withdrawal and caffeine

Ingestion of caffeine after session 2 was associated with faster encoding of information ($F_{1,125} = 4.20$ $p < 0.05$), as revealed by smaller differences between alternations and repeats. There was no significant interaction between caffeine and prior withdrawal conditions ($F < 1$). There was no effect of fasting or consumption of cereal on speed of encoding. Post-test alertness was also significantly higher after caffeine ($F_{1,125} = 6.30$ $p < 0.05$), but again there was no interaction between caffeine and caffeine withdrawal ($F < 1$). These results are shown in Table 4.

Table 1: Fasting and caffeine withdrawal; cereal/fasting sensitive tests; scores are the adjusted means from the ANCOVAs (s.e.s in parentheses)

	Pre-test Alertness	Free recall, number correct
No fast, no caffeine over day	243.8 (8.4)	8.53 (0.36)
No fast, caffeine over day	250.4 (8.5)	8.61 (0.36)
Fast, no caffeine over day	213.2 (8.6)	7.81 (0.37)
Fast, caffeine over day	225.6 (8.6)	7.62 (0.37)

Table 2: Fasting and caffeine withdrawal: caffeine sensitive tests; scores are the adjusted means from the ANCOVAs (s.e.s in parentheses).

	Post-test Alertness	Encoding of new information
No fast, no caffeine over day	186.0 (7.3)	10.6 (3.7)
No fast, caffeine over day	183.5 (7.3)	6.0 (3.7)
Fast, no caffeine over day	184.8 (7.4)	8.8 (3.7)
Fast, caffeine over day	175.4 (7.4)	4.9 (3.8)

Table 3: Effects of fasting and breakfast cereal; scores are the adjusted means from the ANCOVAs (s.e.s in parentheses).

	Pre-test alertness	Free recall, number correct
Fast, no cereal	198.2 (8.8)	8.35 (0.4)
Fast, cereal	222.4 (9.0)	9.98 (0.4)
No fast, no cereal	228.7 (8.5)	10.05 (0.4)
No fast, cereal	242.8 (9.1)	9.51 (0.4)

Table 4: Effects of caffeine and caffeine withdrawal; scores are the adjusted means from the ANCOVAs (s.e.s in parentheses).

	Encoding of new information	Post-task alertness
Caffeine, no withdrawal	7.4 (4.4)	214.2 (7.9)
Placebo, no withdrawal	13.0 (4.5)	190.8 (8.0)
Caffeine, withdrawal	12.3 (4.3)	218.4 (7.9)
Placebo, withdrawal	24.7 (4.3)	201.9 (8.0)

DISCUSSION

The results of the present study confirmed that fasting was associated with lower pre-test alertness and poorer immediate recall of a list of words. Subsequent consumption of breakfast cereal removed the effect of fasting on memory, although the cereal led to increases in alertness in both fasted and non-fasted groups, and did not remove the effect of fasting. Previous research suggests that the effects of fasting and cereal consumption on memory may reflect changes in blood glucose.^[6] Glucose tolerance is also important^[50], and better memory has been associated with better glucose intolerance and meals that more slowly released glucose into the blood. Similarly, the effect of breakfast may be influenced by what is consumed the previous evening.^[51]

The present results confirmed that caffeine withdrawal has little effect of the encoding of new information and post-task alertness. In contrast, both measures were acutely changed by consumption of coffee containing 100 mg of caffeine. This effect was observed in both caffeine withdrawn and non-withdrawn participants. There are plausible biological mechanisms for these two effects of caffeine. Previous research shows that caffeine modulates attention network function^[52], and this has been linked to cholinergic changes.^[53-55] Other research^[56] has demonstrated that the effects of caffeine observed in low alertness states, such as after a battery of tests, are due to changes in the noradrenergic system.^[56]

CONCLUSION

The results of this study demonstrated the benefits of being able to select sensitive tests based on considerable previous research. It also showed that by combining investigation of established effects, one can have greater confidence in the results. Fasting impaired recall of a list of words and this effect was removed by consumption of breakfast cereal. The results also showed that fasting and cereal influenced pre-test alertness. Caffeine consumption, but not caffeine withdrawal, increased the speed of encoding of new information, and post-task alertness. This sensitive methodology can be used to investigate contextual factors associated with consumption of breakfast cereal and caffeine.

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