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CAFFEINE, BREAKFAST CEREAL AND TIME OF DAY: EFFECTS ON ALERTNESS, ENCODING AND RECALL

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ABSTRACT

Background: There is considerable literature on the effects of caffeine on cognition and alertness. However, there is no consensus on sensitive measures that can be used as positive controls in the studies of the effects of other changes in state. The present study examined whether encoding of new information and ratings of alertness after a cognitive test battery are indicators which demonstrate the effects of caffeine in different contexts. The changes in state investigated here were those observed after consumption of breakfast cereal. Previous research has identified sensitive tests, namely free recall of a list of words and pre-test alertness, that are reliably observed when breakfast cereal is consumed in the early morning. **Methods:** The present research examined contextual factors that may be important in these breakfast effects. The first study examined the effects of breakfast at lunchtime and the second examined the possible role of sleep inertia by studying night workers who had a sleep in the day and then had breakfast before starting their shift. **Results**: The results showed that caffeine led to faster encoding of information in both studies and also increased alertness after the performance tests. In contrast, there were no effects of consumption of breakfast cereal on the free recall task, although alertness before the test battery was increased following the consumption of cereal in both studies. **Conclusion:** These results demonstrate that caffeine can be used as a positive control when the sensitive tasks used in this study are included. The effects of breakfast cereal on memory observed in the early morning are not due to consuming breakfast per se nor to sleep inertia. Further research involving a longer fasting period is now needed to determine whether this is the crucial factor leading to cereal improving recall. The effect of cereal on pre-test alertness shows that there are reliable effects which may be due to eating per se rather than post-digestive changes in state.

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

INTRODUCTION

There has been extensive research on the effects of caffeine on human behavior.[1-7] These reviews are briefly summarised below. These reviews show that the effects of caffeine on behaviour are often positive unless the person consumes very large doses, or the individual has a sensitivity to caffeine. One review of the effects of caffeine[5] concluded that they are often most easily observed when alertness is already reduced (e.g., when working at night, when sleep-deprived, after lunch, when the person has a cold; after carrying out prolonged work). The American Academy of Sleep Medicine concluded that caffeine can increase alertness and improve performance after both acute and chronic sleep deprivation.[8]

The benefits of caffeine while working have been investigated in various settings. Lieberman et al.[9] reviewed the effects of caffeine in sustained military operations and concluded that "When cognitive performance is critical and must be maintained during exposure to severe stress, administration of caffeine may provide a significant advantage". Smith[10] investigated habitual caffeine consumption and performance and safety at work. The first study showed that higher consumers of caffeine (> 220mg/day) reported greater alertness and a smaller slowing of reaction time over the working day. Associations between caffeine consumption and cognitive failures (problems of memory, attention and action) were then examined, as were associations between caffeine consumption and accidents at work. Higher caffeine consumption was associated with a reduced risk of frequent/very frequent cognitive failures, and also a reduction in risk for accidents at work. Another review[11] has examined the effects of caffeine on injuries, errors, and cognitive problems caused by doing shift work. They concluded that "Based on the current evidence, there is no reason for healthy individuals who already use caffeine within recommended levels to improve their alertness to stop doing so." Similar results have been obtained in analyses of human error and accidents in a non-working sample.[12] Research has shown that caffeine can improve other tasks such as reducing the impairment in driving performance. This has involved studies using driving simulators and epidemiological studies.[13] Other research has examined caffeine and cognitive decline and risk of dementia in the elderly. Santos et al.[14] reviewed cohort and case-control studies examining associations between caffeine and cognitive impairment or dementia in the elderly. The review and meta-analysis showed a trend towards a protective effect of caffeine.

There remains some controversy related to potential adverse behavioral effects of caffeine. Adverse effects may include nervousness, anxiety, and sleep disturbances. Consumers often reduce consumption of caffeine later in the day to prevent sleep problems. Research also shows that caffeine mainly leads to sleep disruption when higher doses (> 300mg) are consumed just before bedtime.[15] One adverse effect, a potential psychiatric disorder, is "Caffeinism".[16] Caffeinism follows daily intake of 1000 - 1500 mg caffeine and is indistinguishable from severe chronic anxiety. Caffeinism is a specific condition, and there is little evidence of adverse effects of caffeine intake due to anxiety in non-clinical populations or psychiatric outpatients.[17] Moderate intake of caffeine has been associated with fewer symptoms of depression and a reduced risk of suicide.

Some researchers have argued that there are no direct benefits of caffeine on behaviour, and hypothesized that caffeine withdrawal leads to impairments and ingestion of caffeine simply removes these negative effects of withdrawal.[18] However, this theory is unlikely to be correct[4, 5] as caffeine influences the behaviour of animals and non-consumers who are not experiencing withdrawal. The behavioural changes after caffeine have been observed after a seven-day washout period, when effects of withdrawal should have diminished.[20] Behavioral effects of caffeine have also been observed after prior consumption (i.e., when the person is no longer deprived).[21]

One issue where there has been less agreement is whether there are benchmark tests that reliably show effects of caffeine in different contexts. Smith, Christopher and Sutherland[20] showed that four performance outcomes should be considered. Two measures, simple reaction time and lapses of attention in choice reaction time tasks, were often only sensitive to effects of caffeine when levels of alertness levels were low. Other effects of caffeine involving the speed of encoding of new information, digit target detection and the difference in reaction time to alternating or repeated stimuli, were observed even when the person was alert, which plausibly reflects caffeine influencing the cholinergic system. Reported alertness changes after a battery of tasks are also influenced by caffeine in a range of contexts.

The present study examined whether the sensitive behavioural changes induced by caffeine in alert individuals could be used as positive controls in studies examining the contextual factors in which other changes of state are observed. In this study, the changes of state examined were those observed following the consumption of high carbohydrate breakfast cereal. Extensive laboratory research, usually with young adults as volunteers, has shown that consumption of breakfast is associated with improved episodic memory.[22] Consumption of breakfast has been shown to lead to an acute increase in positive mood, such as alertness.[23] Such effects have been observed with different types of breakfast, a range of breakfast cereals, and cereal bars. In summary, research has identified sensitive indicators of the behavioural effects of breakfast cereal consumption and in the present study the outcomes chosen were immediate free recall of a list of words and ratings of alertness before beginning the cognitive test battery.

The current research was based on a study by Smith, Clark & Gallagher[24] which confirmed the effects of breakfast cereal and caffeine described above. This study was carried out at normal breakfast time, and the two studies described here were conducted at different times of day to determine whether effects of breakfast depended on the time of eating the meal and previous sleep inertia. Previous research suggested that consumption of breakfast improves aspects of memory. It has been argued that this reflects the beneficial effects of glucose following an overnight fast. However, it is possible that time of day is also an important factor and that sleep inertia may also play a role. The present studies were designed to examine (1) the effects of breakfast cereal at other times of day (Study 1: lunchtime; Study 2: early evening), and (2) the effects of breakfast cereal on nightshift workers following a daytime sleep. The rationale behind these manipulations was as follows. If the behavioural changes depended solely on consumption of breakfast cereal, then it should be found at times of day other than early morning. If recent awakening from sleep was crucial, then night workers sleeping during the day and having breakfast in the early evening should show benefits from consuming breakfast cereal. These alternative views were examined by studying both memory and mood, as it was quite plausible that different factors underlie these two aspects of behaviour. It was predicted that caffeine in both studies would lead to faster encoding of stimuli in a choice reaction time task and higher post-task alertness.

MATERIALS AND METHODS

The studies described here were carried out with the approval of the ethics committee, Department of Psychology, and carried out with the informed consent of the volunteers. Common features of the two studies are described in the next section.

1. **Volunteers** - in both studies the participants were males and females. Previous research [25] has shown that age and gender do not have a large impact on

the behavioral effects of caffeine. Similarly, effects of breakfast on behaviour have been demonstrated in both males and females and in age groups ranging from children to the elderly.

2. **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 studies.

3. **Information collected prior to studies** - all volunteers completed standardised questionnaires assessing demographics, health-related behaviours and psychosocial characteristics/personality: introversion and trait anxiety, recent physical and mental health: the profile of fatigue states measuring fatigue, somatic symptoms, emotional distress and cognitive difficulty) and current dietary intake.

4. **Familiarisation with procedures** - prior to both studies volunteers were familiarised with the tasks and procedures.

5. **Baseline measurements** - baseline measurements were taken prior to the meal/caffeine manipulation and used as covariates to remove any unwanted individual differences.

6. **Measures taken** - in both studies pre-test and post-test mood, memory and choice reaction time were measured.

7. **Measurement of mood -** 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.

8. **Performance tasks - (a) Categoric Search Task with a pattern mask** This task was developed by Broadbent et al. (1986) 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 target letter was ‘masked’ by a pattern mask. The stimulus quality was degraded to examine the encoding stage of the choice reaction time process. 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, and on the effects of S-R compatibility. 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 - 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.

9. **Details of breakfast/caffeine manipulations -** Those in the breakfast condition were supplied with a breakfast cereal and a cup of coffee. Those in the no breakfast condition received only a cup of coffee. Volunteers selected a cereal from a number of different varieties.[24] 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 either the placebo or caffeine solution was added. Drink conditions were administered double blind. The placebo condition consisted of preserved water and a 100 mg dose of caffeine was added to the coffee in the caffeinated condition. Milk and sugar were added in accordance with usual performance.

Experiment 1: cereal and caffeine at lunch time

This was similar to the study of Smith, Clark and Gallagher[24] except that the cereal and coffee were given at lunchtime. A between subject design was used with participants being randomly allocated to caffeine or placebo conditions, and cereal of no cereal conditions. The baseline session was carried out between 12.00 and 13.00. Following this, the cereal and drink manipulations were carried out. The test session was carried out approximately 1 hour after the cereal/caffeine ingestion.

The participants were 58 students (29 male, 29 female) with a mean age of 21.2 years (range = 18 to 30 years). Sample size calculations suggested that 24 participants per group would detect moderate size effects.

RESULTS

Analyses of variance of covariance were carried on the two measures that have been shown to be sensitive to caffeine in previous studies (encoding of information and post-task alertness) and the two that were sensitive to breakfast cereal (pre-task alertness and free recall). The pre-cereal/drink measures were used as covariates and the between subject factors were cereal condition and caffeine condition.

The effects of caffeine on encoding in a choice reaction time task and on alertness post-testing were replicated (see Table 1), with those given caffeine reporting greater alertness at the end of the experiment ($F_{1,53} = 3.07$ $p < 0.05$ 1-tail) and showing faster encoding of masked stimuli ($F_{1,53} = 2.82$ $p < 0.05$, 1-tail). There were no significant effects of cereal conditions or cereal x caffeine interactions for these variables.

Table 1: Experiment 1: Effects of caffeine on the encoding of masked target letters and on post-test alertness (smaller RTs = better performance; higher alertness scores = more alert; scores are the adjusted means from the analyses of covariance; standard errors in parentheses).

	RT masked targets (msecs)	Alertness after testing
Placebo no cereal	571 [13]	174.6 [16.3]
Placebo cereal	571 [13]	212.6 [15.7]
Caffeine no cereal	561 [13]	221.8 [16.9]
Caffeine cereal	550 [12]	205.2 [15.2]

The effects of breakfast cereal on memory were not replicated (see Table 2) although there were significant increases in pre-task alertness following consumption of the cereal ($F_{1,53} = 3.56$ $p < 0.05$, 1-tail). These results suggest that the mechanisms underlying the effects of breakfast cereal on mood and memory are different. There were no significant effects of caffeine nor caffeine x cereal interactions for the recall and pre-alertness variables.

Table 2: Experiment 1: Breakfast cereal, free recall and alertness prior to testing (scores are the adjusted means from the analyses of covariance, standard errors in parentheses; high score = better recall and alertness).

	Free recall (number correct)	Alertness before testing
Placebo no cereal	9.8 (0.8)	230.4 (11.8)
Placebo cereal	10.6 (0.8)	241.4 (11.4)
Caffeine no cereal	9.4 (0.9)	238.1 (12.3)
Caffeine cereal	9.9 (0.8)	258.1 (11.0)

The next study examined another time of day and whether sleep inertia might underlie the breakfast cereal/memory results. This was examined by studying night-workers who had slept during the day, and were having "breakfast" in the early evening.

Experiment 2: breakfast and caffeine following a day time sleep

Participants completed a familiarisation session and then were tested on two consecutive weeks. On one session they were given cereal and on the other no cereal. Order of cereal conditions was balanced across participants. Caffeine was a between subject variable with approximately half of the participants being given a caffeinated beverage and the rest placebo on both weeks. The baseline session was carried out between 17.00 and 18.00 and was followed by the cereal/drink consumption. The test session occurred approximately one hour after ingestion of the cereal/drink.

The participants in this study were 21 workers who were doing night shifts. They had a mean age of 45.7 years (range 31-62 years) and 17 were male and 4 female. They had jobs at the university (e.g. security) or the local hospital (e.g. nurses).

RESULTS

The effects of caffeine were again confirmed in this study (see Tables 3), with caffeine improving the speed of encoding of stimuli ($F_{1, 15} = 6.55$ $p < 0.05$), and increasing post-test alertness. ($F_{1,15} = 4.03$ $p < 0.05$ 1-tail). Again, there were no effects of breakfast or caffeine x breakfast interactions for these variables.

Table 3: Experiment 2: Effects of caffeine on speed of encoding masked stimuli and post-task alertness (smaller RTs = better performance; higher alertness scores = more alert; scores are the adjusted means from the analyses of covariance, standard errors in parentheses).

	RT masked targets (msecs)	Post-task alertness
Caffeine	643 (11)	247.7 (16.3)
Placebo	662 (14)	203.1 (14.2)

There were no significant effects of cereal consumption on memory (see Table 4), although alertness was greater after the cereal before the performance testing ($F_{1, 15} = 4.33$ $p < 0.05$, 1-tail). There were no significant effects of caffeine or caffeine x cereal interactions for these variables. These results confirm that effects of breakfast cereal on memory are not observed in the early evening. They also show that sleep inertia is not a factor determining whether episodic memory changes following consumption of breakfast cereal.

Table 4: Experiment 2: Breakfast cereal, free recall and alertness prior to testing (scores are the adjusted means from the analyses of covariance, standard errors in parentheses; high score = better recall and alertness).

	Free recall, number correct	Pre-test alertness
Cereal	5.82 (0.33)	261.1 (11.8)
No cereal	5.37 (0.60)	238.6 (10.3)

DISCUSSION

The present study had two main objectives. The first was to examine whether effects of caffeine could be used as a positive control and be observed at different times of day with both young adults and older shift workers as participants. The second aim was to determine whether the effects of breakfast cereal on episodic memory and pre-test alertness could be observed at two times of day (lunch and early evening) and after a day time sleep. The results of both studies confirmed that caffeine led to faster encoding of new information. This has frequently been observed before with different measures reflecting the encoding of new information. The first type of task that often shows beneficial effects of caffeine is a target detection test (e.g. the rapid serial visual processing task or the detection of repeated number task) where caffeine increases detection of targets and leads to faster reaction times to those targets.[3-7] The second measure involves calculating the difference between reaction times to different stimuli and those which are a repetition of the previous trial.[19-21, 24] Caffeine leads to a faster encoding of new information which yields a smaller difference in the alternation-repeat score. The present study manipulated encoding by making the target stimulus more difficult to identify by using a pattern mask. Any of these three measures can plausibly be used as benchmark tests of the effects of caffeine on encoding of new information. Results from a recent electrophysiological study support this view.[26] This type of effect may be due to caffeine changing the cholinergic system.[27] The other robust effect of caffeine was that it reduced the drop in alertness found after performing a battery of tests. Again, this is a robust effect which may reflect changes in the noradrenergic system.[28]

The second objective was to determine whether the effects of breakfast cereal depended on time of day. A previous study using a very similar methodology had shown that breakfast cereal consumed in the early morning was associated with better immediate recall of a list of words. Alertness prior to doing a cognitive test battery was greater after consuming breakfast cereal. The results of the two studies reported here showed that there was no improvement in memory at lunchtime or in the early evening following a day time sleep. This suggests that the effect of breakfast cereal may depend on fasting, although it is still unclear whether this also depends on the time of testing. A study involving fasting over the day followed by cereal in the early evening would answer this question. The pre-test increase in alertness following cereal consumption was observed in both studies. This probably reflects an effect of ingestion per se, whereas the memory effect plausibly reflects changes in glucose supply to the brain.

CONCLUSION

The present methodology can now be used to identify the specific conditions necessary to demonstrate an effect of breakfast cereal on memory. This methodology can also be used to address new topics, and the identification of tasks which are reliably sensitive to caffeine means that this can now be used as a positive control which will give greater confidence when investigating areas where there is little existing literature.

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