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CAFFEINE AND ICONIC MEMORY

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ABSTRACT

Background: Research has examined the effects of caffeine on many aspects of memory. One area where there has been little research is sensory memory, and the present study examined the effects of caffeine on iconic memory (short-term visual memory). **Methods**: Participants (University students, N=24) completed a laboratory session in the morning or afternoon. Separate groups either received caffeine or a placebo. The caffeine dose was 4mg/kg and was carried out double-blind. The tasks involved either full or partial reports of a string of letters with varying inter-stimulus intervals (ISIs). **Results**: At baseline, the results were consistent with previous research, with recall performance in partial report conditions being superior to full report up to an ISI of 300 msec. There was no significant main effect of caffeine nor significant interactions between caffeine and report conditions. **Conclusion**: The results show that iconic memory is another aspect of memory that shows little effect of caffeine. Future research should use more sensitive tasks, such as those measuring semantic memory and executive function.

KEYWORDS: Caffeine; Memory; Sensory Memory; Iconic Memory.

INTRODUCTION

Previous research has considered the effects of caffeine on all of the major memory structures and processes identified in mainstream memory research, with the exception of sensory memory.[1-20] The purpose of the present study was, therefore, to investigate the effects of caffeine on iconic memory, a short-term visual store characterised by high capacity but extremely short duration. Early descriptions of a visual store of very short duration date back to the 18th century with the work of Sir William Hamilton[21], but the phenomena were first demonstrated convincingly by Sperling[22] in a classic experiment investigating the duration of briefly presented letter arrays.

In Sperling's experiment, participants were given a series of 50 msec presentations of a 3 x 4 or 3 x 3 array of letters and asked to recall all the letters that they could. Typically 3-4 letters of the 12-letter display could be recalled correctly and in the correct place in the array. In a second condition, participants were asked to learn that each row of letters was associated with a specific tone. The array of three rows of stimulus items with a tone was again shown for 50 msec, which was followed by a single tone a short time after the visual array was displayed. It was found that when the time limit between the offset of the stimulus items and the tone (the interstimulus interval or ISI) was short, e.g. 100 msec, the participant was able to report 75% of the row in question. This finding implies, however, that because the row to be remembered was not known beforehand, 75% of the entire display was available, i.e. nine letters of a 12-letter display. The superiority of partial report was found to gradually disappear as the ISI approached 250 msec, implying that the phenomena were of extremely short duration. Sperling's[22] experimental manipulations also suggested that the effect is independent of exposure duration over a range of 15 to 500 msec but is affected by the post-stimulus exposure field. Using Baxt trials, where the pre-exposure field is dark, and the post-exposure field is light, it was found that partial-report superiority declined to such a point where performance was no longer superior to full-report.

The results of the experiments led Sperling[23] to propose that two distinct memory systems are involved in reporting briefly presented visual displays. The first of these is a very short-term store, characterised by high capacity and rapid decay (this was given the name iconic memory by Neisser[24]). The duration of this store can be measured using a partial report, and using a bright post-exposure field, was estimated at 250-300 msec. A store with a duration of 300 msec is obviously not durable enough to report from, and Sperling[23] also suggested that information from iconic memory would be selectively transferred to a more durable store after the cue and reported from there. Coltheart[25] suggests that this store is acoustically coded STM, which within the framework of the working memory model is probably the phonological loop.

Such an explanation, however, is probably over-simplistic as there is a serious shortcoming in Sperling's explanation concerning the transfer of information from iconic memory to the more durable STM. Specifically, Sperling fails to explain why partial-report performance after a very long cue delay (longer than the persistence of iconic memory) is still at a level comparable to full-report. If the cue was not visible until after the iconic memory had dissipated, it would be expected, according to Sperling's explanation, that no items from the array could be retrieved accurately. This, in fact, has been reported by von Wright[26], but the majority of studies have found that a partial report under such conditions is roughly equivalent to a full report. It is suggested, therefore, by a number of authors[25, 27, 28] that there may be two types of transfer from iconic memory; 'nonselective' transfer that begins immediately and 'selective' transfer that begins once the cue has been seen or heard. When a brief stimulus is then presented to the observer, the nonselective transfer will begin immediately (guaranteeing a minimum level of input to STM); then, when the cue is registered, the nonselective transfer is switched to selective transfer and only cued information is transferred into STM. Several studies suggest that when participants are aware that the onset time of the cue is going to be excessive, they may consciously choose actively to abandon selective transfer in favour of a strategy which is nonselective with regard to the cue. Sperling[22] and Sakitt[29] for example describe participants who, in blocked trials with a standard ISI, employ particular nonselective strategies, such as reporting only the top line of an array when cue delay will be too long for selective transfer to be effective.

Since Sperling's initial experiments, a number of studies have found that partial-report superiority can be obtained by using a number of physical dimensions of the stimuli as cues, such as colour[30], shape[26] and brightness.[26] Stimulus properties which are not physical, e.g. whether an item is a digit or a letter[22,26] or whether a letter contains the phoneme 'ee'[31] do not, however, appear to lend themselves to partial-report superiority. This suggests that iconic memory is a pre-categorical store and does not contain any semantic information.[25]

It is noted that, although there is a considerable amount of evidence for the existence of a precategorical short-term store of high capacity and short duration, iconic memory is still questioned in some quarters on the basis that the partial-report paradigm is flawed.[32] Foremost amongst the objections are arguably those put forward by Holding[33,34], who suggests that partial-report superiority is due to output interference (there are more stimulus items to report in the full-report condition) or is an artefact of cue anticipation. On closer examination, both alternative explanations do not stand up well to the criticism as neither offers any explanation as to why the partial report is always found to be a linear function of cue delay.[25]

Despite the controversy concerning the validity of the partial-report paradigm, the balance of evidence still suggests that the paradigm represents an accurate index of iconic memory performance. The aim of the present experiment was to use the paradigm, in a relatively standard form, to investigate the effects of ingestion of caffeine on iconic memory using a between-subjects design and performance in a baseline condition as a covariate to control for individual differences in performance.

Methodological Considerations

The design of the experiment was identical to our previous studies, i.e. a between-subjects design with a baseline condition to provide a covariate to control for individual differences and was therefore known to be sensitive to the effects of caffeine. As it was intended to run the study on micro-computers using untried, bespoke software, a pilot study was performed prior to the main study to ensure that the usual partial-report superiority could be obtained and that the results were compatible with those reported in previous studies. No previous research has looked at the effects of caffeine on iconic memory, and the sample size required to produce a statistically significant effect, should there be one, was therefore largely unknown. Previous research has shown, however, that significant between-subjects differences in iconic memory performance can be detected using relatively small samples (e.g. differences between participants with normal and borderline low IQ with 10 per group[35]). The present study, therefore, used 12 participants per condition with the intention that should the results fail to reach but approach significance, the experiment could be replicated after power calculations to determine a satisfactory sample size.

RESEARCH OBJECTIVES

To date, there is no literature concerning the effects of caffeine on iconic memory, and the present study therefore aimed to investigate the effects of 4mg/kg caffeine on the well-established partial-report paradigm. It was expected that caffeine effects might manifest themselves in one of two different ways. Firstly, there could have been a main effect of caffeine over several differing ISIs such that the recall-ISI function would be displaced but not modified in shape. There could also potentially have been an interaction between caffeine and the length of ISI such that caffeine would have an effect limited to certain cue delays, thus altering the shape of the recall-ISI function.

Pilot Study

As partial-report superiority is known to be a function of post-stimulus luminosity[27], a pilot study was carried out to ensure that a partial-report superiority could be obtained with the computer screens and test software that were going to be used in the main study. The experimental parameters were the same as those used by Sperling[22], experiment 3, and by Averbach and Coriell[27], i.e. a 3 x 4 letter array that was presented for 50 msec and, where indicated, a 50 msec row indicator duration. Six student participants were asked to take part in the pilot study, and each was given a block of 30 full-report trials followed by blocks of 30 partial-report trials with ISIs of 50, 300 and 800 msec. It was found that in all six cases, there was a partial-report superiority which decreased as the ISI increased. At 800 msec, partial-report performance approximated closely to performance in the full-report condition in the manner described by Sperling.[22]

Method

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

The study used a mixed design with report condition as a repeated-measures factor and caffeine condition and order of partial-report condition as between-subjects conditions. The report conditions comprised a full-report task, three different partial-report conditions (with ISIs of 50 msec, 300 msec and 800 msec), followed by a further full-report task. The partial-report conditions were counterbalanced for order (see table 1). Performance at baseline was used as a covariate to control for individual differences. Administration of caffeine was again double-blind to eliminate potential demand characteristics.

Participants

Twenty-four participants were used in the experiment, and all were non-smokers, regular caffeine users, and not taking any psychoactive drugs. Participant demographics are shown in table 2. Participants were paid £20 on completion of the study.

Table 1: Experimental groups: caffeine condition, order of partial-report conditions.

Group	Caffeine condition	Order of partial-report conditions
1 (n = 4)	Caffeine	ISI 50 ISI 300 ISI 800
2 (n = 4)	Placebo	
3 (n = 4)	Caffeine	ISI 80 ISI 50 ISI 300
4 (n = 4)	Placebo	
4 (n = 4)	Caffeine	ISI 300 ISI 800 ISI 50
4 (n = 4)	Placebo	

Table 2: Participant demographics and personality characteristics (means, SEs in parentheses).

Age (years)	19.75 (1.52)
Mean daily caffeine consumption (mg)	179.25 (31.92)
EPI: Impulsivity (0-low to 9-high)	5.11 (0.39)
EPI: Sociability (0-low to 12-high)	7.72 (0.47)
EPI: Extroversion (0-low to 23-high)	12.50 (0.86)

Procedure

Familiarisation

Participants carried out a familiarisation session using a shortened test battery no more than one week prior to the testing to make sure that they understood what was required and were actually able to perform the task. At the familiarisation session, approximately 15% of participants were noted to be performing the full and partial-report tasks to a very much lower standard than the majority of participants. In order to avoid any floor effects, these participants were eliminated from the study using an exclusion criterion of an average of 1.5 or fewer letters correct per block of 20 3 x 4 arrays presentations. The reason why these participants performed at a much lower rate than the others is unknown though Sperling (1960; experiment 1) also reported large differences in individual abilities on recall of briefly presented stimuli. It is noted that the majority of iconic memory studies have used very small samples (e.g. Sperling[22] n = 5; Averbach and Coriell[27] n = 3), and it is possible that individuals with poor performance on these tasks would have been discovered if larger samples had been used.

Following the familiarisation session, participants who were going to take part in the remainder of the study were weighed without coats or shoes so that the amount of caffeine they were to receive could be calculated. They were also given a sheet of written instructions which advised them that during testing, they should keep to normal eating, drinking and sleeping patterns and that they should not consume any alcohol or caffeine during the prescribed hours. Participants were also asked to complete a questionnaire booklet that recorded demographic details, health-related behaviours and personality traits.

Test Procedure

Participants were tested in sessions beginning at 1000 and 1400hrs. The time taken to complete the baseline and post-drug test batteries varied as the tasks within the batteries were all self-paced, but the timing of the procedures was approximately as follows.

Morning testing

2200 Begin abstinence from self-administered alcohol

0000 Begin abstinence from self-administered caffeine

1000 Present for testing after normal breakfast

1010 Briefing

1020 Test battery (baseline)

1050 Administration of caffeine or placebo, break

1150 Test battery (post-drug)

1220 De-briefing and participants were allowed to resume their usual caffeine and alcohol intake.

Afternoon testing

Where participants were tested in the afternoon, the same procedure was used, but the baseline test battery began at 1420 and the post-drug test session at approximately 1550.

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. 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.

Iconic memory tasks

Iconic memory performance was measured using the partial-report paradigm pioneered by Sperling[22], with a full report of briefly presented stimuli used as a control. Both full and partial-report tasks were presented on a microcomputer. To view an array of letters, participants pressed the spacebar on the computer and, exactly two seconds later, were given a 50 msec presentation of a 3 (row) x 4 (column) array of letters. The letters were all in upper case and 2.0 cm high and approximately 1.5 cm wide, and presented in yellow on a mid-blue pre- and post-exposure background. There was 2cm between each column of letters and 1.5 cm between rows making the letter array approximately 7 cm high and 13 cm long. The letters of which the array was comprised were all consonants picked randomly by the computer program and therefore differed in each trial. All the combinations of letters were checked by two postgraduate psychology students to ensure that no combination of letters within a row or column formed meaningful abbreviations which may have a biased recall.

Participants completed a battery of five blocks of 30 trials at baseline and five blocks of 30 trials post-drug. The first and last blocks of each battery were always comprised of full-report trials. The remaining three blocks were composed of partial report trials with one block with ISI 50 msec, one block with ISI 300 msec and one block of ISI 800 msec. The order of presentation of the blocks of partial-report trials was counterbalanced for order (see table 1).

Full-report

In the full-report conditions, participants were simply required to write down any of the letters they could remember from the array on a 3 x 4 response grid corresponding to the layout of the display before going on to the next trial. In order to correct for guessing error, i.e. the participant guessing that items would be contained in the array, the study followed Sperling[22] in only scoring letters placed in the correct position in the response grid. This made it impossible for participants to achieve spurious scores by guessing the letters presented in the knowledge that, by chance, they might have appeared somewhere in the array. In the full report condition, the score was simply the number of letters recalled correctly, in the correct place, giving a minimum score of zero and a maximum score of 12.

Partial-report

In the partial-report conditions, the presentation of the letter array was followed by the 50 msec presentation of an asterisk adjacent to one of the rows of the array. The time between the offset of the array and the onset of the cue (the interstimulus interval or ISI) was 50 msec, 300 msec or 800 msec, depending on the block. When participants had seen an array followed by a row cue, they were required to write down all the letters only from the row which was adjacent to the cue; as in the full report, condition letters were only counted as correct if they were placed in the correct place in the response grid. As the row-cue appeared after the offset of the stimulus array, the number of correct responses on any cued line indicated that three times that number of letters were potentially available. The results of each trial were therefore corrected for a partial report by multiplying the number of letters correctly recalled in each cued line by three (as there were three lines per array). As for the full report, this gave a minimum score of zero and a maximum score of 12 per partial report trial. The exclusion criterion for this task was the failure to achieve an average of fewer than two words correct in the baseline condition.

Analysis

ANOVA was used to determine differences in performance at baseline. ANCOVA was used to determine differences in performance post-drink using the relevant index of performance in the baseline condition as a covariate. Where covariates, used to control for individual differences, were not constant across levels, only non-adjusted SEs were reported.

Analysis proceeded in two stages

1. Investigation of performance at baseline to determine whether there was a partial-report superiority for ISIs of 300 msec or shorter, i.e. whether the presence of iconic memory could be demonstrated.
2. Investigation of the effects of caffeine on iconic memory performance, i.e. performance in partial-report conditions

RESULTS

Investigation of performance at baseline to determine whether there was a partial report superiority

No participants were excluded; twenty-four complete data sets were analysed.

Effects at baseline

A repeated-measures ANOVA was used to determine whether there was any difference in performance across the recall conditions and whether there was any effect of the order of presentation of recall condition. It was found that, as might be expected, that there was a highly significant effect of the recall condition, $F(4, 84) = 35.73$, $MSe = 0.41$, $p < 0.0001$ (table 3).

Table 3: Recall performance, baseline: number of letters recalled correctly in full and ISI 50, 300 and ISI 800 msec partial-report conditions (SEs in parentheses).

Statistic	Full-report (1)	Partial-report			Full report (2)
		ISI 50msec	ISI 300msec	ISI 800msec	
Mean	**3.06**	**5.06**	**3.98**	**3.54**	**3.36**
SE.	0.11	0.28	0.23	0.16	0.11
Maximum	2.17	7.10	7.00	1.90	2.36
Minimum	4.13	2.60	2.20	5.10	4.73
Range	1.96	4.50	4.80	3.20	2.37

A series of planned Bonferroni t-tests revealed that there were no significant differences between the performance in the full-report conditions, between the full-report conditions and ISI 800 condition and between recall in the ISI 300 and ISI 800 condition. All other pair-wise comparisons were significantly different. This pattern of results is consistent with those reported by Sperling[22] in his original experiments, i.e. that recall performance in partial-report conditions is superior to recall in full-report conditions up to an ISI of approximately 300 msec.

There was no effect of the order of partial-report conditions, $F(2, 21) = 1.33$, $MSe = 2.73$, $p > 0.05$ but the interaction between recall condition and order of presentation of the three partial-report conditions was found to be statistically significant, $F(4, 84) = 2.66$, $MSe = 0.41$, $p < 0.05$. Due to the small cell size (maximum cell size 8), this interaction was not subjected to formal posthoc testing though it would appear that performance in each condition increased the later it was encountered in the test battery.

Investigation of the effects of caffeine on iconic memory performance

In order to investigate the effects of caffeine on iconic memory, a mixed ANCOVA was used to determine performance in the post-drink battery for partial-report conditions only. ISI was the within-subjects factor (with three levels; 50, 300 and 800msec) and caffeine condition and order of conditions were the between-subjects factors. It was found that there was no statistically significant main effect of caffeine and no interaction between caffeine and partial-report condition (table 4).

Table 4: Recall performance, number of letters recalled in the correct place: adjusted and non-adjusted means in caffeine (4mg/kg) and placebo conditions in ISI 50, 300 and 800 msec partial-report conditions (SEs in parentheses).

Caffeine condition	Partial-report condition		
	ISI 50msec	ISI 300msec	ISI 800msec
Caffeine	**4.58** 4.60 (0.42)	**4.89** 4.30 (0.29)	**4.45** 3.69 (0.26)
Placebo	**4.60** 5.67 (0.41)	**4.70** 4.88 (0.31)	**4.24** 3.99 (0.23)

As at baseline, there was a significant main effect of partial-report condition, $F(1, 21) = 5.52$, $MSe = 0.35$, $p < 0.01$. In the ISI 50 msec condition, 4.59 words were recalled correctly as opposed to 4.80 when the ISI was 300 msec and 4.34 when the ISI was 800 msec. Non-adjusted means were 5.23 (SE 0.31), 4.64 (0.22) msec and 3.86 (0.17) msec, respectively. A series of Bonferoni adjusted t-tests revealed that the only statistically significant pair-wise difference was the superiority of recall in the ISI 300 condition over recall in the ISI 800 condition.

DISCUSSION

A review of the literature showed that, despite the interest shown in caffeine and memory generally, the effects of caffeine on sensory memory have not been investigated to date. The objective of the present study was to redress this balance by investigating effects of caffeine on iconic memory using the partial-report paradigm developed by Sperling.[22] The paradigm has been the subject of some criticism[34,37], but without reference to a very short-term, high-capacity memory store, the phenomenon of partial-report superiority is very difficult to explain, and the existence of iconic memory is now accepted by most memory researchers.[21]

The study found that, as reported by Sperling[22], there were large individual differences in performance. Full-report varied between 2.17 and 4.73 letters correct with a mean of 3.21, and this was found to be comparable with the results obtained by Sperling[22], where immediate memory for arrays of varying sizes was found to be constant within individuals and to vary from 3.90 to 4.70 with a group mean of 4.30 letters correct (n = 5). In the partial-report tasks, performance was similarly variable, with between 2.60 and 7.10 letters being available in the partial-report condition with ISI 50 msec (mean 5.06). Despite variations in individual performance, it was found that there was a highly significant effect of report condition ($p < 0.0001$), and posthoc analysis confirmed that in accordance with the literature, there was a clear partial-report superiority up to an ISI of approximately 300 msec which decreased to the level of full-report performance by 800 msec. At baseline, there was no evidence of a time-on-task effect, as no statistical difference was found between performance on the first full-report task and the second full-report task.

In the post-drink test session, it was found that numerically the means in the caffeine and placebo conditions were very similar at an ISI of 50 msec but that in the ISI of 300 and 800 msec conditions, performance in the caffeine condition was superior. Statistical analysis, however, showed that there were no main effects of caffeine and that, importantly, the interaction between caffeine and partial-report condition did not approach significance. The lack of main effect suggests that there are no global caffeine effects on iconic memory, and the lack of effects at specific ISIs implies that caffeine does not significantly alter the duration of the store or the rate at which information in iconic memory dissipates.

In summary, the study suggests that caffeine has no effects on iconic memory and furthermore that it is, therefore, also unlikely that iconic memory effects mediate any other caffeine effects on cognition. Our research so far has now considered the effects of caffeine on the most important subcomponents of the human memory system identified in mainstream cognitive psychology. It has been found that there is no global effect of caffeine on memory and that caffeine effects are limited to relatively few reliable and replicable effects (table 5).

Table 5: Components of human memory or memory processes that are reliably affected by caffeine, where the effects of caffeine are unclear and where there are no effects.

Reliable caffeine effect	Possible caffeine effect	No effect of caffeine
Semantic memory (+) Executive function (+)	Implicit memory (+) Delayed free recall (-)	Recall; Recognition; Allocation of memory resources; Iconic memory; State-dependent memory; Different levels of processing

Future research should focus on semantic memory and executive function where reliable effects of caffeine have been found and specifically investigate these functions with regard to regular consumption of caffeine, caffeine withdrawal and caffeine-related expectancy effects.

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