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High Doses of Caffeine Impair Performance of a Numerical Version of the Stroop Task in Men

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FOREMAN, N., S. BARRACLOUGH, C. MOORE, A. MEHTA AND M. MADON. *High doses of caffeine impair performance of a numerical version of the Stroop task in men.* PHARMACOL BIOCHEM BEHAV 32(2) 399–403, 1989.—The effects of caffeine ingestion on mid-morning cognitive performance were investigated in thirty-two male subjects. These were given drinks containing either no caffeine, 125 mg caffeine (mean dose: 1.38 mg/kg), or 250 mg caffeine (mean dose: 3.45 mg/kg) and were tested on three tasks: 1) free recall of supraspan word lists, 2) a response time (pointing) task and 3) a numerical Stroop task. There were no significant group differences on the recall task or in response times, but subjects having the higher caffeine dose were seriously impaired on the Stroop test, making particularly slow responses. Caffeine may have a deleterious effect on the rapid processing of ambiguous or confusing stimuli, and this may account for its clearer effect on the Stroop test than on other cognitive tests used hitherto.

Caffeine   Cognitive performance   Stroop test (numerical)   Word recall   Response time   Attention

CAFFEINE (1,3,7 trimethylxanthine) is a widely used stimulant substance, available in coffee, tea, soft drinks, confectionery, and in over-the-counter remedies for colds and fatigue (17,36). In quantities regularly consumed by the public, caffeine has often been thought to enhance vigilance and mental alertness, producing a faster, clearer flow of thought (22, 29, 32). Yet this is not always the case, since it has been reported to induce anxiety (20) and locomotor hyperactivity (15), and depress performance, particularly in tasks that make high demands on memory, hand-eye coordination or complex responses (1, 16, 28, 39). Enhancement of performance tends to occur in simpler tasks, particularly those requiring speedy responses (8, 21, 27, 33).

But in many studies, mixed results are reported [(2, 13, 19, 23, 40); see (34) and (38) for reviews)] which fail to support any universal or systematic effect of caffeine on cognitive performance. Such ambiguity may arise because caffeine effects interact with many other situational and personal variables (2,3). In addition, the range of tasks employed hitherto may not have included any that makes sufficiently high cognitive processing demands to demonstrate a clear, caffeine-induced deficiency. Humphreys and Revelle (21) argue that short-term memory load needs to be high if caffeine-induced deficits are to occur, but they also hint, in a footnote (p. 160), that such factors as stimulus-response compatibility might also be important.

To investigate task parameters further, the present study employed three tasks of differing types and complexities. Two were of a kind frequently used to assess caffeine effects in the past (see references cited above), with variable results: first, free recall of supraspan word lists, and second, a response time (pointing) task, the latter involving three levels of difficulty (these making mildly increasing demands on attention, but a constant demand on hand-eye coordination). The third task was a numerical version of the Stroop test, which requires sustained vigilance and intense cognitive effort if fast responses are to be made and confusion errors avoided (14).

In the present study, factors such as caffeine tolerance, which may depend upon daily intake (9,24), sex differences (2) and diurnal variation (31) in caffeine sensitivity were controlled as far as possible; subjects' usual daily caffeine intake was estimated, only male subjects were used, and all subjects were tested mid-morning, as in an earlier study of word recall (2).

METHOD

Subjects

Subjects consisted of 32 male undergraduate students (mean age: 21 years) weighing between 60 and 95 kg. Prospective subjects were advised not to take part in the study if they suffered from high blood pressure. Subjects were requested not to eat or drink methylxanthine-containing sub-

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stances from 9.00 p.m. on the evening preceding the study, to get at least 5 hr sleep that night, and not to drink methylxanthine-containing drinks for at least two hours after completion of the study. A list of foodstuffs and drinks containing methylxanthines was provided for them.

Apparatus and Procedure

On arrival for testing, between 10.00 a.m. and 11.30 a.m., subjects were weighed in stocking feet and randomly allocated to a drug group (A: 0 mg caffeine, B: 125 mg caffeine, or C: 250 mg caffeine). Groups A and B had 11 subjects each, group C, 10. They were each given a cup of decaffeinated coffee into which had been thoroughly mixed the appropriate quantity of caffeine ("Proplus" caffeine tablets, powdered). They drank the coffee mixture and were then given a questionnaire to complete, detailing their usual daily intake of methylxanthine-containing foods and drinks, and daily alcohol consumption.

Thirty min after ingestion of their drink, subjects were taken to three test cubicles in each of which they performed a cognitive task. The order in which the tasks were performed was counterbalanced as far as possible.

1) Free recall of supraspan word lists: Fifteen lists, each containing 15 randomly-chosen words, were listed vertically on separate sheets of paper. Subjects were given 20 sec to read each word list silently and then 45 sec to write down as many words as they could remember, in any order, on a response sheet.

2) Response time (pointing) task: This was programmed and run on an IBM-AT computer with an RGB monitor and touch-sensitive screen. Instructions appeared on the screen. On each of 24 trials, one or more concentric circles appeared centrally on the screen. On 8 trials, there was only one circle presented (dia. 8.0 cm), on a further 8, three circles (dia. 5.5, 8.0 and 10.5 cm), and on a further 8, five circles (dia. 3.0, 5.5, 8.0, 10.5 and 13.0 cm). These 24 trials were presented in a predetermined, pseudorandom order. On every trial, an arc (0.5 cm in length) was missing at some point on the circumference of one of the circles. The subject was initially instructed to raise the index finger of their preferred hand toward the screen, and on each trial to touch the missing arc as quickly as possible. (A single, one-circle trial was presented as an example to the subject before the main trials began; data from this practice trial were discarded.) Response time (msec), target position, and mispointing errors were recorded and printed our automatically when all 24 test trials were completed.

3) Numerical "Stroop" test (6): This was run on an Apple computer. Instructions were displayed on screen. Ten practice trials were followed by 220 experimental trials in 4 counterbalanced blocks of 55. Two of the blocks were experimental trials, two were control trials. In each experimental trial, a line of 1, 2, 3 or 4 digits appeared at the centre of the screen, e.g., three "2"s, four "3"s etc. The control condition involved 1–4 geometric symbols in a row on the screen (e.g., ***). The subject was required to place the fore and middle fingers of their left hand over numbers 2 and 1 respectively on the keyboard, and the fore and middle fingers of their right hand over the numbers 3 and 4. Each time a series was displayed on screen, the subject had to press the number corresponding to the number of digits or symbols on screen, i.e., ignoring the numerical value of individual digits. The subject's response activated the next stimulus presentation. Average reaction time and number of errors for each group of trials was automatically calculated and displayed on screen when the trials were completed.

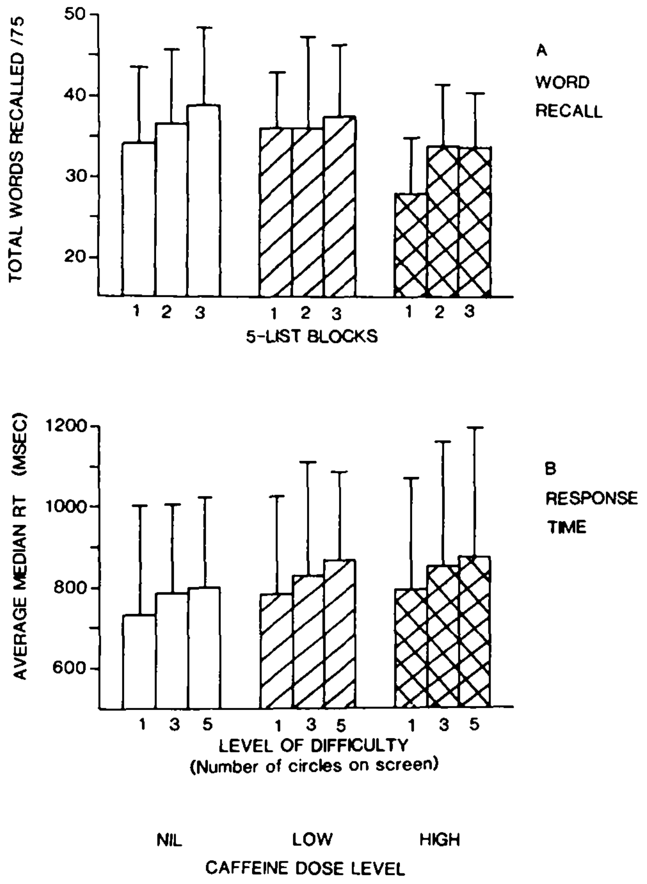

FIG. 1. Performance of high-caffeine (cross-hatched), low-caffeine (hatched) and nil-caffeine (unhatched) groups on two tasks. (A) Word recall task (mean number of words recalled in each block of 5 word lists), and (B) response time (pointing) task (group averages of median response times in 1-, 3- and 5-circle conditions). Vertical bars represent 1 sd from the mean.

RESULTS

From subjects' weights, actual dosages of caffeine were calculated and averaged within groups. The 125 mg group had, on average 1.38 mg/kg (sd: 0.17; range: 1.06–1.67) and the 250 mg group, 3.45 mg/kg (sd: 0.28; range: 3.03—3.97).

Daily Intakes

Daily alcohol intake was measured by translating subjects' reported quantities and types of alcoholic beverage into consumption "units," i.e., 1 unit=one-half pint of a long drink (beer, cider), one short drink (whisky, rum), or one vermouth or fortified wine. Daily methylxanthine consumption was calculated in milligrams from the estimated content of foodstuffs and drinks, as consumed, reported previously (17,36).

The average daily intakes of alcohol and methylxanthines in the three groups did not differ significantly. The number of units of alcohol consumed per week by the nil-, low- and high-caffeine groups in the present study were 20.36 (sd:

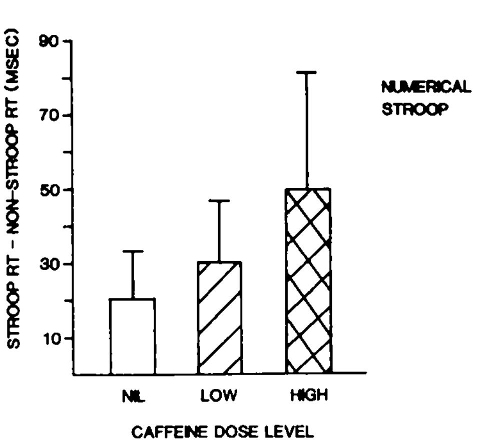

FIG. 2. Performance of high-caffeine (cross-hatched), low-caffeine (hatched) and nil-caffeine (unhatched) groups on the numerical Stroop task: group means of absolute RT differences between the Stroop and non-Stroop conditions. Details as for Fig. 1.

20.1), 15.82 (sd: 12.2) and 15.95 (sd: 13.0) respectively. Daily methylxanthine intake for the respective groups were 245.30 mg (sd: 75.8), 298.70 mg (sd: 100.5) and 241.10 mg (sd: 115.0). The highest methylxanthine consumption recorded was 438 mg/day, taken mostly in tea.

Task Performance

The mean number of words recalled by each subject in the supraspan memory test was computed separately for three blocks of five lists: 1–5, 6–10 and 11–15. Data were subjected to a two-way parametric analysis of variance (ANOVA: 3 drug groups × 3 blocks of lists). There was no main effect of caffeine dose, $F(2,29)=1.10$, $p>0.2$; performance improved across successive blocks of lists, $F(2,58)=7.16$, $p<0.002$. There was a clear trend in the data for the high-caffeine group to recall fewer words, particularly in early lists (Fig. 1A), but this was not significant since the list blocks × caffeine dose interaction did not achieve significance, $F(4,58)=1.57$, $p>0.1$.

Mispointing errors in the response time (pointing) task were totalled for all conditions and analysed with a one-way ANOVA. No group differences emerged, $F(2,29)=0.99$, $p>0.05$. Median latencies (Fig. 1B) were computed separately for each level of difficulty (i.e., 1-, 3- and 5-circle conditions). These scores were entered into a two-way analysis of variance (3 drug groups × 3 levels of difficulty). No group differences were obtained in response latency, $F(2,29)=0.20$, $p>0.05$, although latencies were longer when several circles appeared on the screen than when only a single circle appeared, $F(2,58)=8.52$, $p<0.001$; median 3-circle latencies were on average 7.8% longer, and 5-circle latencies 10.4% longer, than 1-circle latencies. This effect occurred equally in all drug groups, since there was no significant interaction between drug group × level of difficulty, $F(4,58)=0.06$, $p>0.05$.

For the Stroop test, median response times (RTs) and error scores were obtained for (a) the Stroop condition (where the numerical value of digits, and the number of digits on screen were incongruous) and (b) the non-Stroop condition (where geometric symbols were used). For each measure (response times, errors), the absolute differences between the values obtained in (a) and (b) were used as an index of the power of the Stroop effect (14). Absolute difference data are shown in Fig. 2. The relative values were then also calculated, i.e., (a−b)/b. Results were analysed using one-way ANOVAs. Significant group differences emerged on absolute RT differences, $F(2,29)=5.37$, $p<0.01$, and relative RT differences, $F=4.06$, $p<0.03$. Post hoc Tukey tests revealed that the high-dose caffeine group made slower responses than the nil-caffeine group on both measures of performance (both p's<0.05). The low-dose group failed to differ significantly from either of the other two. There were no significant group differences in error commission.

DISCUSSION

The main findings of this study, namely an absence of significant caffeine effects on the recall and response time tasks, coupled with a clear, significant deficit on the Stroop task, may help to explain some of the variability in previous caffeine studies. In particular, caffeine has previously been said to have its greatest impairing effect on tasks in which cognitive processing demands are high (1, 2, 21, 39), yet tasks such as word recall may not make sufficiently high demands for clear caffeine-induced deficits to emerge in every case. A trend toward poor word recall was seen in the high-caffeine group, but this did not reach significance; statistically significant deleterious effects on word recall are perhaps only obtained when very large subject groups are used (2), or when a repeated measures design is used, which is more powerful than the independent groups design used in the present study.

The Stroop task, however, arguably makes considerable demands on cognitive capacity, requiring the rapid processing of ambiguous and confusing stimuli (14), and this aspect of performance may be particularly sensitive to high levels of caffeine. It is unlikely that the potentially stressful "continuous" (subject-paced) presentation format used here in the Stroop test was crucial to obtaining a deficit, since Bättig and Buzzi (4) found that caffeine enhanced performance on a digit memory/classification task despite the use of such a presentation format.

The absence of caffeine effects on the response time (pointing) task is perhaps surprising, since reaction time has often been reported to be speeded by caffeine (30). However, manual dexterity and hand-eye coordination can be adversely affected by caffeine at doses similar to those given to the present "high dose" group (7,27). This may have created difficulties in response control and thus counteracted any enhancing caffeine effect on stimulus processing or movement speed. Note that caffeine effects on the present recall and response time tasks are unlikely to have been "masked" by task insensitivity, in view of the highly significant, subtle within-subject effects that were obtained, namely the list-block effect in the recall task and the effect of task difficulty in the response time task.

Thus, the Stroop task may prove a useful measure in future methylxanthine studies, particularly clinical studies in which small subject samples are involved [cf. (30)]. It would be of further interest to know whether the conventional color version of the Stroop task (14,37) would be as affected by high doses of caffeine as the numerical version.

Time of day may remain a crucial variable in tests such as word recall in man, and our results might have been different had we tested subjects in the early morning. Enhancing caffeine effects may be greatest where subjects are fatigued, under-aroused, or under the influence of tranquillising medication (8, 13, 19, 21, 25). The influences of caffeine upon receptor function, particularly adenosine inhibition (5, 11, 12, 35), would be expected to result in metabolic and psychomotor stimulation, which may be most advantageous when a subject is fatigued [(3), though see (4)]. Nevertheless, such stimulation might produce greater agitation and thus have a predominantly disruptive effect on psychomotor performance in mid-morning, when subjects' arousal baseline is higher.

Personality variables (extraversion—in particular, impulsivity) have been found to interact with drug condition in determining performance in previous caffeine studies (10, 18, 26), although it is unlikely that the present results were influenced by group differences in personality in view of the random allocation of subjects to groups.

In conclusion, while the subjective effect of caffeine ingestion is one of increased alertness and clarity of thought, mid-morning performance on some tasks is likely to be seriously impaired by high doses of caffeine (about 3.5 mg/kg, or 4 cups of strong coffee). This may apply especially to tasks involving potentially confusing stimuli or the resolution of ambiguity.

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