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Effects of Caffeine on Functional Asymmetry in a Posner Letter-Recognition Task

M. SUE BARRACLOUGH*[1] AND JOHN R. BEECH†

*Department of Psychology, Nene College, Northampton NN2 7AL, UK
†Department of Psychology, University of Leicester, Leicester LE1 7RH, UK

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BARRACLOUGH, M. S. AND J. R. BEECH. *Effects of caffeine on functional asymmetry in a Posner letter-recognition task.* PHARMACOL BIOCHEM BEHAV **52**(4) 731-735, 1995.—A Posner task was used to investigate whether caffeine, in common with other drugs, has an asymmetric effect on cerebral functioning. Subjects consumed decaffeinated coffee either with or without added caffeine at 2 mg/kg body weight. They were then required to identify letter-pairs as the same or different. Same was defined as two identical letters irrespective of case (AA, Aa); different was defined as two different letters irrespective of case (AB, Ab). Main effects of stimulus type were found for both accuracy and speed of response. In the noncaffeine condition pattern-matching was faster by the right hemisphere and phonologic matching was faster by the left hemisphere. These results replicate much previous work, but under caffeine, a previously unreported reversal in the balance of hemispheric processing efficiency was found. An explanation is offered in terms of the disruption of the normal, optimum, rate of cerebral processing for each hemisphere.

Caffeine Cerebral asymmetry Posner task Reaction time

CAFFEINE is the most widely available, self-administered psychoactive drug in use today, occurring both in a variety of foodstuffs and as a constituent of pharmaceutical preparations. In psychomotor tasks it has been generally regarded as helpful to rapid responding, especially where performance has been depressed (3) and in maintaining vigilance once a degree of fatigue has been reached (2); but consensus is lacking for its effects on cognitive functioning (7).

Asymmetry and fluctuation in the distribution of neurotransmitters have been demonstrated in the human brain for noradrenaline (12), acetylcholine (1), and serotonin (10). Mandell and Knapp (10) proposed that stabilisation of such fluctuating levels of serotonin was the basis for the efficacy of lithium in the control of affective psychosis. Caffeine is also known to affect the turnover of a number of neurotransmitters in brain tissue, and there is wide agreement that these effects are mediated by the competitive blockade of adenosine receptors (14). The present study tested the possibility that caffeine, in common with other drugs, may modify hemispheric neurotransmitter balance. The method used was comparison of performance on a task known to demonstrate clear asymmetry of response in the noncaffeine condition with the same subject's performance after consuming caffeine. The task was a reaction time (RT) paradigm, modified from Posner and Mitchell (13).

Posner and Mitchell presented subjects with tachistoscopic stimuli consisting of letter pairs, and found that when a pair of same-letter stimuli were physically identical (AA), the response time was 71 ms faster than when they were physically different (Aa). Using a similar task, Klatzky (8) and Klatzky and Atkinson (9) directed lateralized stimuli to specific hemispheres and found that physical comparisons were processed faster by the right hemisphere, whereas phonologic matches produced faster RTs from the left hemisphere. This suggests more efficient holistic processing in the right hemisphere and better sequential processing in the left hemisphere. Geffen et al. (4) modified Klatzky's study to include instructions for subjects to judge the stimuli as the same or different under three sets of rules. In the first condition, same was defined as physically identical (AA), and pairs similar in name only (Aa) were never included in the same stimulus set. In the second condition, same meant having the same name (Aa) and physically identical pairs were never included. In the third condition, both physical and name matched pairs were presented and both qualified as the same. Physically identical stimuli produced faster RTs when presented to the right hemisphere (509 ms) compared with those directed to the left (540 ms). Phonologic identity was recognised faster when stimuli were directed to the left hemisphere (626 vs. 641 ms). In contrast to the findings of the above studies, Nicholls and Cooper (11)

[1] To whom requests for reprints should be addressed.

found the left hemisphere to be more efficient in processing typically right-hemisphere stimuli (pi figures); comparing the speed of hemispheric processing of these stimuli they recorded an advantage of 16 ms. The division of labour in this type of task is clearly not as sharp as has been suggested by other studies.

The study reported here is a partial replication of Geffen et al. (4) but extends it to investigate the effect of caffeine on hemispheric processing. Several broad predictions were made based on previous findings. A basic expectation was that caffeine would shorten RTs to all of the stimuli. Further, it was assumed that stimuli would be initially analysed for physical match, and only later for phonologic identity. The superiority of the right hemisphere in spatial matching should then ensure that left visual field (LVF) presentation of this stimulus type would give faster RTs than right visual field (RVF) presentation. Interhemispheric transfer time (IHTT) to the more efficient hemisphere could account for any RT discrepancy between the two hemispheres after presentation with the same stimulus type. Stimuli not recognised as having a physical match (e.g., AN) should produce longer RTs, as phonologic analysis is needed after pattern match is discounted: such stimuli should thus be recognised faster by the left hemisphere. For the Aa condition there would be an extra delay in responding, because the tendency to make a different response (on the initial recognition of the physical dissimilarity of the pair) would need to be inhibited. The correct response would be to accept the nominally similar, but physically different upper- and lower-case letters as the same. The difficulty of this manipulation was also expected to result in the generation of the largest number of inaccurate responses. These simple predictions aside, there was no precedent for suggesting the precise influence of caffeine on functional asymmetry.

METHOD

Subjects

We recruited 10 subjects from students and staff of the Psychology Department at Nene College, Northampton. Two participants were male and eight were female; their ages ranged from 21–40 years. Only right-handers were included to maximize the uniformity of the dominant hemisphere; none relied on corrective lenses. Subjects were asked to abstain from caffeinated food and drink for 12 h before testing, as they would be given caffeine at some time during the course of the experiment. Potential subjects with heart conditions or a tendency to migraine, or who were pregnant, were excluded from the study.

All participants completed a questionnaire establishing their normal daily caffeine intake. Mean consumption was found to be 521.5 mg/day (range : 125–1040 mg).

Apparatus and Materials

A PS2 IBM computer and MEL (Pittsburgh, PA)[2] software provided the means of tachistoscopic presentation of stimuli and a good-quality graphic facility. These stimuli were pairs of letters in various combinations—A, a, E, e, N, n, R, and r—such that they fell into one of four categories: AA, Aa, AN, and An. Each of the four stimulus types was presented eight times in each of the right and left visual fields during any one block; therefore, each block consisted of 64 trials in total (four types × two fields × eight trials). On each of two separate occasions, three blocks of 64 trials were each preceded by a practice block of the same length and form as the experimental one. One of these test sessions was run under 2 mg/kg caffeine, and the other under 0 caffeine. The caffeine was supplied as crushed Pro-plus tablets (Ashe Consumer Products Ltd., Hertfordshire, UK) and was dissolved in 100 ml of Brooke Bond Red Mountain Decaffeinated coffee (Croyden, UK), and consumed without added milk or sugar.

Design and Procedure

The repeated measures design allowed for control of the acknowledged variability in physiologic response to caffeine (6). On arrival in the laboratory on the first occasion of testing, subjects were weighed in stockinged feet for caffeine doses to be calculated. The order in which subjects served was determined by drawing lots, and subjects were blind as to the test condition. We allowed 30 min to elapse after coffee administration for peak plasma concentration to be reached (5). Subjects were then seated on an adjustable chair so that head movements could be comfortably restrained by chin and forehead rests attached to a bench in front of the computer screen. The subjects' eyes were thus fixed at a distance of 49 cm from the centre of the screen.

Each subject was told that the experimental task required a response of either same or different to four types of stimuli, consistent with the following instructions: Stimuli consisting of pairs of the same letter, either both in the upper or lower case or in mixed case (e.g., AA or Aa), required a "same" response, as "the letters sounded the same." Stimuli in which the letters were not phonologically identical (AN, An) required a different response; case remained irrelevant. In both the "same" and different conditions there was a case mismatch on half of the trials, but subjects were not informed of this. Responses were made via the computer keyboard using both hands simultaneously. Both index fingers were used to indicate same, and both middle fingers to indicate different. This bimanual method was adopted from Geffen et al. (4) to minimize response asymmetry. The keyboard was positioned at right angles to the subject so that the index fingers of the left and right hands rested on keys 1 and 4, respectively, and the middle fingers were on keys 2 and 5.

At the beginning of each trial a central fixation cross (+) appeared on the screen for 1000 ms, followed by the letter pair, flashed to either the right or the left visual field in pseudorandomized order. A presentation time of 150 ms was chosen as optimum for the task after a pilot study had shown that shorter periods made the task too difficult and that longer presentations failed to inhibit lateral eye movements. Immediately after stimulus presentation, a backward mask of asterisks appeared on either side of the fixation cross (** + **) across the positions where it was possible for any stimulus to appear. The position of the subject's head ensured a visual angle of 2° between the centers of the two sets of asterisk positions. As soon as the subject had made a response via the keyboard, data were analyzed on-line to provide immediate performance feedback. This information replaced the mask and informed the subject of his RT (in milliseconds) for the trial and whether the response had been correct. It also showed the cumulative mean accuracy for the session. The next trial was initiated when the experimenter pressed the space bar on the keyboard. A brief rest period was offered between each of the three pairs of practice and test blocks.

[2] Schneider, W. (1990). MEL User Guide: Computer Techniques for Real Time Psychological Experimentation. Learning Research and Development Center, University of Pittsburgh, Pittsburgh, Pa.

RESULTS

Two 2 × 3 × 4 × 2 analyses of variance (ANOVAs) (caffeine condition × experimental block × stimulus type × presentation field) were carried out on mean accuracy and RT data. These values were computed for each combination of stimulus type and visual field of presentation. All data were taken into account in calculating the accuracy means, but latencies in excess of 4 s and those from inaccurate responses were excluded from the RT calculation.

Reaction times recorded in the caffeine condition were slightly faster than in the noncaffeine condition, but not significantly so [$F(1, 9) < 1$ (means: 834 vs. 862 ms)]. Conversely, accuracy of response was slightly better in the noncaffeine condition (84%) than in the caffeine condition (80%). Again, however, there was no significant difference between the two conditions [$F(1, 9) = 1.7$]. Speed of response was more uniform with caffeine than without it (SD: 125 vs. 244 ms), whereas accuracy was more uniform without caffeine than with it (SD: 11.0 vs. 18.2%).

Table 1 shows accuracy and RT data across the four stimulus types for each visual field of presentation. Accuracy was good for AA, AN, and An presentations to both fields, but for Aa it was at chance level. The four-way ANOVA on these mean accuracy values showed a significant main effect of stimulus type [$F(3, 27) = 14.57$, $p < 0.0001$]. Posthoc tests indicated that responses to Aa were significantly less accurate than those to all other stimulus types (Bonferroni t-test: Aa/AA, 4.54, $p < 0.001$; Aa/AN, 3.69, $p < 0.005$; Aa/An, 4.62, $p < 0.001$). Table 1 also shows that response time was fastest in the AA condition (mean, 711; SD, 204 ms) and slowest to AN (mean, 915; SD, 274 ms); intermediate values were found for Aa (mean, 890; SD, 281 ms) and for An (mean, 879; SD, 248 ms). The significantly faster responses to AA stimuli gave a main effect of stimulus type [$F(3, 27) = 17.69$, $p < 0.0001$ (Bonferroni t-test: AA/Aa, 4.06, $p < 0.01$; AA/An, 5.25, $p < 0.01$; AA/An, 6.37, $p < 0.001$].

The ANOVA carried out on the accuracy data revealed no further main effects or interactions. However, in the analysis of the RT data a significant effect of experimental block was found [$F(2, 18) = 7.87$, $p < 0.003$]. RTs decreased from Block 1 (mean = 889, SD = 257 ms) through Block 2 (mean = 847, SD = 233 ms) to Block 3 (mean = 810, SD = 227 ms). Posthoc tests showed the significance to rest on the improvement between the first and third sessions (Bonferroni t-test = 4.61, $p < 0.01$). There was no corresponding change in accuracy across the three blocks [$F(2, 17) = 1.66$, $p < 0.217$].

A significant and important interaction between caffeine condition, stimulus type, and field of presentation [$F(3, 27) = 3.53$, $p < 0.02$] was also found. The RT means for this interaction are shown in Table 2.

There was a right hemisphere advantage, shown by a negative LVF–RVF value, for pattern matching (AA) in the noncaffeine condition, but this reversed to give a left hemisphere advantage in the caffeine condition. In strong contrast, there was a left hemisphere advantage for AN and An stimuli in the noncaffeine condition, but this too was reversed in the caffeine condition. Aa stimuli were processed faster by the left hemisphere at both levels of caffeine. The corresponding three-way interaction in the accuracy analysis was nonsignificant [$F(3, 27) < 1$].

TABLE 1

ACCURACY OF RESPONSE AND REACTION TIMES TO STIMULI PRESENTED TO RIGHT AND LEFT HEMISPHERES

Stimulus Type	LVF	RVF
Accuracy (percent)		
AA	100	97
Aa	50	52
AN	72	87
An	100	99
Reaction Time (Milliseconds)		
AA	701	721
Aa	901	878
AN	928	903
An	889	869

DISCUSSION

Overall accuracy of response, calculated from pooled caffeine and noncaffeine data, was very good for all but the Aa stimuli. AA responses in particular were made at a very high level of accuracy (99.5%). Left hemispheric RTs were faster than right ones for AN and An stimuli, indicating that subjects were actually naming them. The poor accuracy for Aa stimuli had been predicted as a possible outcome resulting from the need to inhibit an initial, incorrect response of different in favor of the correct response of same. This process of inhibition and decision reversal is similar to the situation in the Stroop condition and may therefore be the common feature causing disruption in some conditions of both the Posner and Stroop tasks.

In the noncaffeine condition of the present investigation the reaction time data were in broad agreement with previous findings in the area of functional asymmetry. Our data support those of Posner and Mitchell (13) in that physically and phonologically similar stimuli (AA) were processed faster than those that were physically different but phonologically similar (Aa). However, their response times were shorter than ours (AA, 452 vs. 710 ms; Aa, 523 vs. 901 ms) and the difference between them was less marked (71 vs. 191 ms). Methodologic differences between the two studies may have contributed to the discrepancies. Posner and Mitchell did not direct stimuli to specific hemispheres, whereas we did; their stimuli were displayed on cards rather than on screen, and they were physically larger at 1 in. high, which may have made the task easier. Nevertheless, when a comparison was made across those stimuli common to the two experiments, an ordinal agreement of increasing RT was found as follows: AA < An < Aa < AN. Taking the procedural differences into account, the parallels are clear.

The direction for pattern and name matching in the noncaffeine condition also agreed with that found by Geffen et al. (4), in which physical matching was faster than name matching by the right hemisphere in the AA and Aa conditions. All of their RTs were once again considerably shorter than in the present study. This was not expected, as Geffen et al. had eliminated the size cue of upper and lower case in the letters of their stimuli—which should have made the task more difficult. However, the RT differences between LVF and RVF presentations requiring a same (AA, Aa) response were close to ours: a right hemisphere advantage of 31 ms for physical matches compared with 49 ms in the present study, and a left hemisphere advantage for name matches of 15 ms compared with 21 ms. Different (AN and An) data, on the other hand,

TABLE 2

REACTION TIMES: MEANS (SD) FOR THREE-WAY INTERACTION AMONG CAFFEINE CONDITION, STIMULUS TYPE, AND FIELD OF PRESENTATION

	Stimulus Type			
Caffeine Condition	AA	Aa	AN	An
Non-Caffeine				
LVF	685 (193)	911 (303)	1004 (399)	922 (284)
RVF	734 (239)	890 (255)	892 (210)	860 (245)
LVF-RVF	−49	21	112	62
Faster hemisphere	R	L	L	L
Caffeine				
LVF	717 (240)	892 (344)	852 (246)	855 (255)
RVF	708 (220)	867 (320)	913 (312)	878 (310)
LVF-RVF	9	25	−61	−23
Faster hemisphere	L	L	R	R
Mean RTs	711 (204)	890 (281)	915 (274)	879 (248)

produced opposite patterns in the two studies. Whereas the data of Geffen et al. indicated a slight right hemisphere advantage (right, 644 ms; left, 656 ms), our study showed a strong left hemisphere superiority (right, 876 ms; left, 963 ms). Geffen et al. noted, however, that three of 12 of their subjects actually did show a left hemisphere advantage that was hidden by averaging across subjects. This point will be revisited later.

The finding by Nicholls and Cooper (11) of faster left hemisphere RTs even for their nonverbal stimuli was not paralleled in our study. It might have been expected that the letter stimuli used in the present study as pattern matches (AA) would have been processed more efficiently by the left hemisphere compared with their more obviously nonverbal pi figures. This was not the case, and there was a definite right hemisphere advantage of 49 ms. The requirement of the Nicholls and Cooper task (to determine which leg of the figure was shorter) was actually different from that of the typical RT paradigm, in which the sequential-holistic cerebral dichotomy is premised, and may help to explain their finding. The two outcomes, therefore, are not necessarily as incompatible or challenging to the accepted view of functional asymmetry as Nicholls and Cooper intimated.

In the caffeine condition the overall mean RT was faster than in the noncaffeine condition (833 vs. 862 ms), but it also produced more errors (80% vs. 84% accuracy). A comparison with the data from the noncaffeine condition is consistent with the notion that caffeine simultaneously spoils the performance of what would be the more efficient hemisphere for any particular stimulus without caffeine and, at the same time, improves the performance in what would be the less efficient hemisphere without caffeine. Thus, presentations of AN and An to the left hemisphere gave the expected left hemisphere advantage in the noncaffeine condition, but this advantage was lost under caffeine. Conversely, the faster RTs under caffeine were mainly due to a substantial facilitation of RTs in the less efficient hemisphere when free of caffeine. This was markedly so for right hemisphere presentations of AN and An, where the mean RT to AN was 152 ms faster than without caffeine and where the mean RT to An was 67 ms faster. In a similar way, AA presentations to the right hemisphere were disadvantaged under caffeine (32 ms slower), whereas left hemisphere presentations were facilitated (26 ms faster). These data suggest that right and left hemispheres normally process verbal and spatial stimuli, respectively, at optimum speed and that the further arousal induced by caffeine is detrimental to their functioning. This differential effect of caffeine on the two hemispheres is the seat of the three-way interaction seen in the RT analysis, and therefore of the reversal of functional asymmetry.

The finding by Geffen et al. (4) of a right hemisphere advantage for the AN and An conditions in nine of their subjects and of a left hemisphere advantage in three is interesting in the light of the present finding that caffeine is able to reverse functional asymmetry. Geffen et al. did not require their subjects to abstain from caffeine before testing, so that there was no common base line during performance. It is therefore possible that the three participants showing the left hemisphere advantage were physiologically more like the present subjects under the noncaffeine condition (that is, they were low or nil caffeine consumers) and that the nine subjects who showed a right hemisphere advantage were more like our subjects under the caffeine condition (that is, the more usual caffeine consumers). The implication here is that the caffeine status of subjects taking part in such studies should be taken into account.

Certain of the original predictions were not fulfilled. First, caffeine did not cause a universal decrease in RT; on the contrary, it produced a slowing in certain conditions, as discussed earlier. Second, Aa stimuli did not provoke the slowest RTs; rather, these were found with AN stimuli in both the noncaffeine and caffeine conditions. It may be that the subjects initially tended to respond to AN as the same, because the letters were both in upper case, but later recognized that they did not have a physical identity. This recognition would entail reversal of the first tendency, a situation opposite that initially proposed for Aa, but incurring time penalties for the same reason. The large difference between these two types of stimuli on accuracy may be partially explained as a tradeoff against speed. Aa responses were only just above the chance level in accuracy (51%) compared with AN (80%), whereas the RTs were slower for Aa (890 ms) compared with those for AN (916 ms). This suggests more impulsive responding to the difficult Aa condition than to AN.

In summary, evidence from the noncaffeine condition of the present study agrees with that of previous work on functional asymmetry of response to different classes of stimuli. It

thus supports the existence of hemispheric specialization. The interesting finding is the reversal of functional asymmetry by caffeine, which has not previously been reported. The implication is that the consumption of caffeine has a more subtle effect on the way in which stimuli are processed by the brain than has previously been recognised. An explanation in terms of disruption to processing in the "correct" hemisphere and facilitation in the "wrong" hemisphere is suggested.

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