Effects of Caffeine on Lexical Decision Performance

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Undergraduates (4 men, 4 women) at a midwestern university participated in a study of the effects of caffeine on lexical decision making. The study also examined the effect of the medium in which caffeine was consumed, that is, water versus cola. Using a within-subjects design counterbalanced for order of presentation, the experimenters compared 4 treatments: caffeinated water, caffeine-free water, caffeinated cola, and caffeine-free cola. Contrary to expectation, caffeine slowed reaction times when consumed in either water or cola. However, caffeine improved lexical decision accuracy when it was consumed in a water-based beverage (Water Joe®); yet, accuracy was also marginally higher relative to control (spring water) after participants drank both caffeinated and decaffeinated cola. These unexpected results may be due to confounds arising from inadequate time to absorb the caffeine. Classical conditioning, whereby participants may come to associate cola taste with caffeine-induced enhancement of mental function, may also explain some of the unexpected results.

Considered the world's most widely used drug (Rogers & Dernoncourt, 1998), people consume caffeine in beverages such as coffee, tea, and soft drinks, medications such as appetite suppressants, and foods such as chocolate. Although most people presume that caffeine improves thinking and mood, laboratory studies conducted over several decades have yielded inconsistent findings. In fact, laboratory studies indicate that caffeine may improve, decrease, or have no effect on memory and other mental functions. As Table 1 shows, the literature on caffeine's psychostimulant effects provides little consistent evidence that regular caffeine use benefits mood or performance, and some studies show caffeine can actually hinder performance. However, because more studies report an increase of mental functioning with caffeine, we expected caffeine to improve accuracy and decrease reaction times in a cognitive task.

The lexical decision task involves measuring accuracy and reaction time of long-term memory retrieval. Researchers have used lexical decision tasks to measure the effects of drugs on mental functioning. Maylor, Rabbitt, and Kingstone (1988) found that alcohol increased lexical decision reaction times, whereas other researchers (Gentry, Hammersley, Hale, Nuwer, & Meliska, 2000; Hale, Gentry, & Meliska, 1999) report that nicotine and cigarette smoking improved lexical decision performance. To our knowledge, the present study is the first to examine caffeine's effects on lexical decision making. We expected that caffeine consumption would reduce reaction times and increase lexical decision accuracy in people deprived of caffeine for 4 hr.

Method

Participants

The participants were 4 female and 4 male undergraduates at a midwestern university, aged 18 to 22, selected from a pool of respondents to flyer

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TABLE 1

Caffeine Studies on Cognitive Functioning

I. Studies related to memory

Mental task	Caffeine improved	Caffeine inhibited	No effect
Short-term memory	Hindmarch et al., 1998; Warburton, 1995		Buffalo et al., 1993 (rhesus monkeys)
Recall of words acquired from rhyming	Gupta, 1991 (in high impulsives)		Gupta, 1991 (in low impulsives)
Recall of words acquired semantically		Gupta, 1991 (in high impulsives)	Gupta, 1991 (in low impulsives)
Delayed recall	Warburton, 1995		
Immediate recall			Warburton, 1995
Recognition after hearing	Gupta, 1993 (in high impulsives)		
Conceptual recognition		Gupta, 1993 (in high impulsives)	
Recall of word lists (fast presentation)			Erikson et al., 1985
Recall of word lists (slow presentation)		Erikson et al., 1985	
"Memory"			Loke, 1988
Operant learning	Buffalo et al., 1993 (rhesus monkeys)		
Color and position discrimination	Buffalo et al., 1993 (rhesus monkeys)		

and newspaper advertisements. Potential participants completed a brief phone screening concerning substance habits, health, and commitment to participate. To be a participant, a person had to be a student attending the University of Southern Indiana, be a nonsmoker, not be using any psychoactive medication (except caffeine), have no major physical or psychological illnesses, and have a history of caffeine consumption. Those persons selected to participate read an informed consent form explaining the physical and pharmacological conditions incompatible with caffeine consumption. The experimenters paid the participants $25 for participating in five sessions.

Apparatus and Surveys

The equipment used included an IBM-compatible personal computer with standard VGA monitor, the Micro-Experimental Laboratory (MEL) lexical decision task (Psychology Software Tools, Inc., Pittsburgh, PA), the Sternberg memory task (from MEL), and the Profile of Mood States (POMS, Educational and Industrial Testing Service, San Diego, CA) questionnaire. The POMS measures six different mood scales (Tension/Anxiety, Depression/Dejection, Anger/Hostility, Fatigue/Inertia, Confusion/Bewilderment, and Vigor/Activity); Total Mood Disturbance is calculated by subtracting the Vigor/Activity score

TABLE 1 (continued)

Caffeine Studies on Cognitive Functioning

II. Studies related to other cognitive functions

Mental task	Caffeine improved	Caffeine inhibited	No effect
Stroop task			Edwards et al., 1996
Reaction time	Hindmarch et al., 1998; Durlach, 1998		
Critical flicker fusion	Hindmarch et al., 1998		
Attention	Warburton, 1995		Buffalo et al., 1993 (rhesus monkeys)
Problem solving	Warburton, 1995		
Mental rotation	Smith & Oscar-Berman, 1990		
Mental speed tasks	Mitchell & Redman, 1992		
"Psychomotor performance"			Lane, 1997
Auditory attention	Linde, 1994 (after sleep deprivation)		Linde, 1994 (normal sleep)
Addition and multiplication	Loke, 1988		
Vigilance			Loke & Meliska, 1984

from the sum of the five remaining negative mood factors. The cola-based beverage containing caffeine was Diet Coke®. The commercially available, water-based beverage containing caffeine was Water Joe®. The noncaffeinated "placebos" were Caffeine-Free Diet Coke® and bottled spring water, respectively.

Procedure

The Institutional Review Board of the University of Southern Indiana approved all procedures. Using a double-blind, within-subjects design, we tested each participant with each of four lexical templates, under each of the four caffeine conditions. For 4 hr before the start of each session, participants abstained from ingesting caffeine. Each participant performed the lexical task on four separate occasions, separated by 48 hr. To minimize trial, sequence, and learning effects across the four test sessions, the experimenters used four independent sets of 98 paired letter strings. Gentry et al. (2000) describe in detail the construction of these letter string sets. To control for possible effects of testing order, we administered caffeine treatments according to a counterbalanced, Latin square order of administration. Prior to the first session, the participant read and signed the informed consent form; then the experimenter gave the participant either a cola-based or a water-based beverage which contained either caffeine or no caffeine. Across sessions, each participant received all four beverages, a different one at each session. Both participant and experimenter were blind with respect to caffeine content of the beverage. To control for differences in average body size, male participants consumed 12-oz beverages (48 mg caffeine) and female participants consumed 8-oz beverages (32 mg caffeine).

To provide time for caffeine absorption, each participant walked with the experimenter in the testing building for 5 min after drinking the beverage. After returning to the laboratory, the participant completed the POMS followed by the lexical decision task and the Sternberg memory task. Because the Sternberg and POMS yielded no significant effects, the remainder of this report focuses solely on the results of the lexical decision task.

For the lexical task, the participant viewed two letter strings on a computer monitor, then decided whether *both* strings were real words or not. The participant viewed five combinations of paired letter strings: word/related word, word/unrelated word, word/non-word, non-word/word, and non-word/non-word. In this task, a "+" appeared in the center of the screen; then one string of letters would appear above and one below the "+." Participants pressed the "1" key if both letter strings were words and the "2" key if one or both letter strings were non-words. The researcher remained in the room with the participant to ensure that the instructions were followed. The computer automatically measured accuracy and reaction time with respect to the type of combination.

Dependent Measures

There were two dependent measures: accuracy (percent correct) in determining whether both letter strings were words, and reaction time (in milliseconds)—the average time between the appearance of the letter strings and the participant's response.

Data Analyses

The experimenters analyzed reaction time and accuracy data separately, using within-subjects analysis of variance (ANOVA). Interaction effects were analyzed with paired-samples t tests. We used directional (one-tailed) tests to test the main effects of caffeine versus placebo, and nondirectional (two-tailed tests) for the mode effect (water vs. cola) and the Mode × Drug interaction, because differences in mode of caffeine delivery were not expected. Because this was exploratory research, we used lenient standards of statistical significance in which $p < .10$ was considered "marginally significant" and interpreted as a result warranting further data analysis and interpretation.

Results

The ANOVA showed a significant main effect of caffeine on reaction time. Contrary to expectation, mean reaction time was substantially longer, across lexical decision types, in the caffeine conditions (combined) than in the placebo conditions, $F(1, 7) = 13.16$, $p = .008$; see Figure 1. Thus, participants responded more slowly after drinking the caffeine beverages than they did after drinking the placebo beverages.

The ANOVA on accuracy scores showed a significant (one-tailed) main effect of beverage type (i.e., whether the beverage was cola-based or water-based), $F(1, 7) = 4.22$, $p = .038$. However, the Drug × Beverage Type interaction approached marginal significance, $F(1, 7) = 3.49$, $p = .104$. Due to the exploratory nature of the study, we felt this interaction warranted further analysis. Paired-samples t tests showed, as expected, that accuracy was significantly higher after consuming caffeinated water (Water Joe®) than after consuming placebo (spring) water, $t(7) = 2.19$, $p = .039$ (one-tailed; see Figure 2); however, accuracy was also marginally higher after consuming the Caffeine-Free Diet Coke® (placebo) than after placebo water, $t(7) = 2.07$, $p = .064$ (two-tailed). Caffeine-Free Diet Coke® and Diet Coke® did not differ significantly.

Discussion

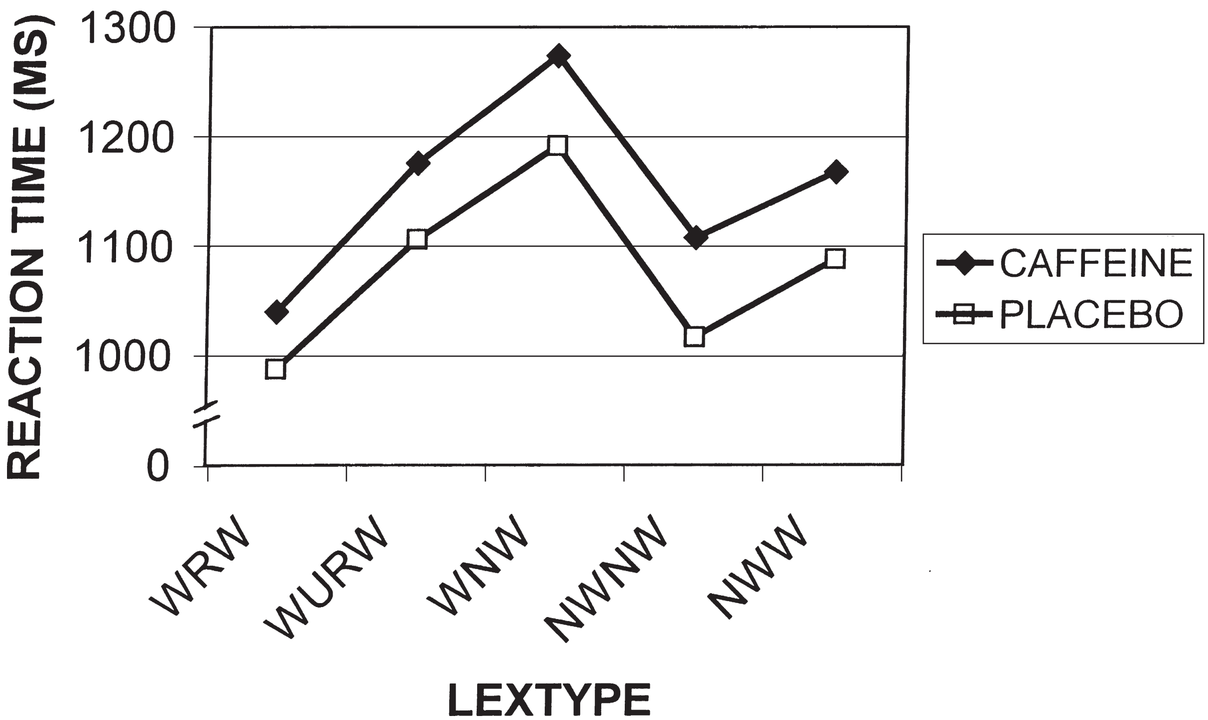
Most of the previous studies we reviewed showed, as expected, that caffeine reduced reaction time on various cognitive tasks (Hindmarch, Quinlan, Moore, & Parkin, 1998; Mitchell & Redman, 1992). These previous results conflict with the present findings, which indicate that caffeine, whether in cola or water, slowed lexical decision response times substantially for all five lexical decision types. This finding suggests that caffeine ingestion may actually reduce response speed with some kinds of cognitive tasks, while increasing response speed with others.

If the slower responding with caffeine occurred because participants were contemplating the stimuli more carefully, prior to responding, then caffeine drinkers might be expected to display greater accuracy than placebo drinkers. Our findings partially support this interpretation. Participants responded more accurately, relative to placebo, when they consumed caffeine in the water-based beverage, Water Joe®; however, consuming caffeine in cola did not improve accuracy, relative to the caffeine-free cola. Furthermore, consuming the caffeine-free cola unexpectedly produced marginally higher accuracy than did consuming spring water. Although the presence or absence of caffeine could account for the differences in the water groups, it cannot explain why caffeine had no effect in the cola-based beverages, or why placebo cola produced marginally greater accuracy than spring water. Only the beverage characteristics and experimental confounds can explain the later two findings.

A possible confound exists due to not enough time being allowed to elapse between drinking the

FIGURE 1

Reaction time (in milliseconds) with each of the five lexical decision types: word/related word (WRW), word/unrelated word (WUW), word/non-word (WNW), non-word/non-word (NWNW), and non-word/word (NWW). Caffeine slowed reaction times (*p* < .05) for all lexical decision types, regardless of mode of consumption (water vs. cola).



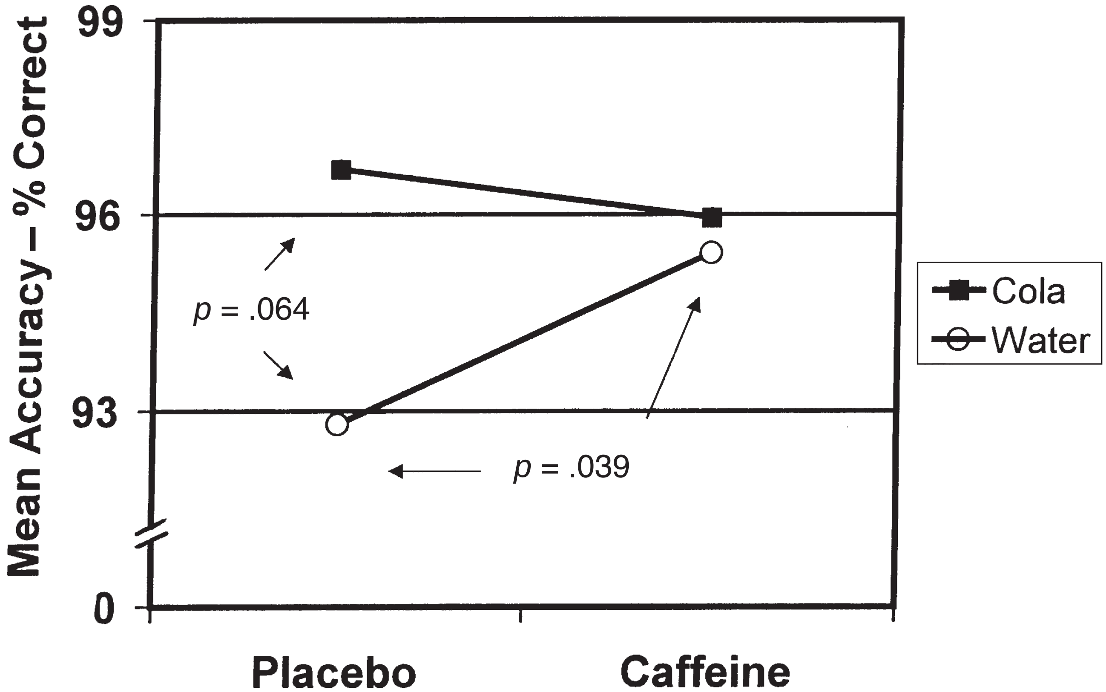
caffeinated beverage and performing the lexical task. The 10 min allowed (the 5-min walk plus about 5 min to complete the POMS) may not have been adequate, because absorbing significant blood levels of caffeine may require 30–45 min (Julian, 1998). Had the experimenters allowed more time for absorption, the effects of the caffeine might have been greater. Nevertheless, Hindmarch et al. (1998) found caffeine enhanced performance 10 min after oral ingestion (in tea), suggesting that caffeine is capable of producing detectable effects within 10 min or so of oral ingestion.

Another plausible explanation involves a classically conditioned placebo effect. Suppose caffeine improves decision accuracy in some domains, and this effect can be measured in lexical decision task accuracy. Whenever someone drinks a caffeinated cola, that individual might experience an increase in some aspects of cognitive functioning. Caffeine would be an unconditioned stimulus leading to the unconditioned response: improved cognitive functioning. However, the person would also experience the taste of cola. In this way, the cola taste would be paired with the caffeine-induced cognitive enhancement, making the taste a conditioned stimulus, eventually leading to a conditioned response: improved cognitive functioning. This form of conditioning might explain why we found no significant difference in accuracy between the Diet Coke® and the Caffeine-Free Diet Coke®. The Caffeine-Free Diet Coke® has nearly the same taste as Diet Coke®, leading to the conditioned response: increased cognitive functioning, leading to a higher accuracy score. This effect would also explain why caffeine in water produced a rise in accuracy, up to the level obtained in both cola conditions, but spring water did not.

To test this idea, one could add ingredients to caffeine-free cola to alter its taste, to determine whether accuracy after consuming the beverage is still on par with accuracy after drinking diet cola. One could attempt to recreate the hypothesized classical conditioning: Two drinks could be made to taste dif-

FIGURE 2

Accuracy (percent correct) with respect to condition (placebo vs. caffeine). The two lines represent different modes of consumption (water vs. cola). Caffeine improved accuracy relative to placebo (p = .039) when consumed in water, but not when consumed in cola. However, the placebo cola condition also produced marginally higher accuracy (p = .064) than the placebo water condition.



ferently by, say, adding a little salt to the caffeinated water but not to the spring water. After many trials, the participant would be tested with salted spring water. The hypothesis predicts that after consuming salted spring water, participants will be more accurate than after unsalted spring water.

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