Pharmacology Biochemistry and Behavior, Vol. 59, No. 4, pp. 1039–1045, 1998

0091-3057/98 $19.00 + .00

ELSEVIER

PII S0091-3057(97)00515-7

Regular Caffeine Consumption: A Balance of Adverse and Beneficial Effects for Mood and Psychomotor Performance

PETER J. ROGERS AND CLAIRE DERNONCOURT

Consumer Sciences Department, Institute of Food Research, Reading Laboratory, Earley Gate, Whiteknights Road, Reading, RG6 6BZ, UK

Received 15 August 1997; Accepted 11 September 1997

ROGERS, P. J. AND C. DERNONCOURT. *Regular caffeine consumption: A balance of adverse and beneficial effects for mood and psychomotor performance.* PHARMACOL BIOCHEM BEHAV **59**(4) 1039–1045, 1998.—It has often been pointed out that caffeine is the most widely "used" psychoactive substance in the world, and accordingly, there is a very large amount of research available on the effects of caffeine on body and mind. In particular, a psychostimulant action of caffeine is generally accepted as well established; for example, caffeine has been found to quicken reaction time and enhance vigilance performance, and to increase self-rated alertness and improve mood. There is, however, a real difficulty in determining the net effects of caffeine. In a typical experiment the subjects have a history of regular caffeine consumption, and they are tested on caffeine and a placebo after a period of caffeine deprivation (often overnight). The problem with relying solely on this approach is that it leaves open the question as to whether the results obtained are due to beneficial effects of caffeine or to deleterious effects of caffeine deprivation. The present article briefly reviews this evidence on the psychostimulant effects of caffeine, and presents some new data testing the hypothesis that caffeine may enhance cognitive performance to a greater extent in older adults than in young adults. No age-related differences in the effects of caffeine on psychomotor performance were found. We conclude that overall there is little unequivocal evidence to show that regular caffeine use is likely to substantially benefit mood or performance. Indeed, one of the significant factors motivating caffeine consumption appears to be "withdrawal relief." © 1998 Elsevier Science Inc.

Caffeine   Caffeine withdrawal   Mood   Alertness   Age   Psychomotor performance   Drug reinforcement

BECAUSE it is so widely and regularly consumed (2,14) there is considerable interest in the effects of caffeine on human mental and physical functioning. However, while the scientific literature on this subject is vast, it is far from clear how the benefits and costs (in terms of possible adverse effects) of caffeine consumption balance out. In part, the answer will depend on whether this is viewed at an individual or population level. Acute or chronic caffeine intoxication, sometimes referred to as "caffeinism," is harmful for the individual, but is probably not a very common disorder (23). A full discussion of the health effects of caffeine and the vehicles in which it is consumed (tea, coffee, etc.) is well beyond the scope of the present article, and in any case, comprehensive reviews are available elsewhere [e.g., (13,18,25)]. Instead, our purpose is to examine the evidence concerning the psychostimulant effects of caffeine, because these are usually presumed to be the main benefits of caffeine use. Even within this narrower field we have been able to discuss only a small proportion of the published literature. Finally, we present new data from a study designed primarily to determine whether caffeine might have a greater beneficial effect on the performance of older individuals.

EVIDENCE CONCERNING THE NET BENEFIT OF CAFFEINE USE FOR MOOD AND PSYCHOMOTOR PERFORMANCE

Psychostimulant Effects of Caffeine—Acute Studies

Numerous placebo-controlled studies on the acute effects of caffeine on human behavior have been published. Although the results are varied, with many of studies showing that a majority of the dependent variables were unaffected by the drug [cf. (25)], taken together they confirm a psychostimu-

Requests for reprints should be addressed to Dr P. J. Rogers, Consumer Sciences Department, Institute of Food Research, Reading Laboratory, Earley Gate, Whiteknights Road, Reading, RG6 6BZ, UK.

lant action of caffeine. Specifically, caffeine vs. placebo has been found to increase self-ratings of alertness, to improve mood, and to enhance psychomotor and cognitive performance (e.g., effects on tasks measuring tapping speed, simple reaction time, sustained attention, memory, and logical reasoning, and on simulated driving) [e.g., (1,3,5,8,10,11,15,20, 28–30,32,34,35,40,43,45,48,51,52).

Some of the procedures used in these studies can be summarized as follows. First, the subjects were often young adults, that is, aged between 18 and 30 years. Second, they were, or can assumed to have been, at least low to moderate habitual consumers of caffeine. Third, there was invariably some restriction placed on the subjects' consumption of caffeine-containing drinks and other products prior to testing. Most often this involved overnight caffeine deprivation. Fourth, the amount of caffeine administered (up to 600 mg) was often considerably greater than that which is consumed in a single cup of tea or coffee (40 to 125 mg), although Lieberman et al. (29), for example, found significant effects of 32 mg of caffeine.

While all of these procedures to some extent limit the relevance of the research to understanding the effects of caffeine as consumed in everyday life, the second and third points are probably the most critical. In the typical study the subjects had a history of regular caffeine consumption and they were tested on caffeine and a placebo after a period of caffeine deprivation. The problem here is that if caffeine deprivation has adverse effects, for example it leads to fatigue, then it is uncertain whether the results obtained were due to beneficial effects of caffeine or to deleterious effects of caffeine deprivation. In other words, this research says little about the "net" psychostimulant effects of regular caffeine use [cf. (24)].

Accordingly, in the next two sections we outline the evidence concerning the subjective and performance effects of caffeine withdrawal.

Adverse Efects of Withdrawal of Caffeine—Fatigue and Headache

For many regular users, cessation of caffeine consumption is followed temporarily by adverse changes such as increased incidence of headache, and increased drowsiness, and fatigue [e.g., (7,16,19,21,22,36,42,49).

For example, in a study of the acute and chronic effects of caffeine withdrawal we compared morning mood in caffeine users and nonusers (36). The group of regular users, with a mean caffeine intake of 250 mg/day, was divided into three matched subgroups who avoided all significant sources of caffeine for either 1.5 h (given 70 mg caffeine after overnight abstinence from caffeine), 13 h, or at least 7 days, before beginning an intensive morning test session. Two patterns were apparent in the results. First, the 13-h deprived group showed markedly greater levels of tiredness and drowsiness, and were more angry and dejected compared with all of the other groups, including the nonusers, who did not differ significantly on these moods. The second pattern was less definite, but tended to be characterized by poorer mood (e.g., lower clearheadedness and cheerfulness) and more headache in both the 13-h and 7-day groups. Other data collected during the 7-day period, when subjects were given regular or decaffeinated tea and coffee to use ad lib, confirmed the different time courses of these adverse effects of caffeine withdrawal. That is, increased headache and depressed mood appeared to persist for at least 7 days during withdrawal, whereas the effects on alertness were relatively short-lived. These various adverse subjective symptoms resulting from caffeine abstinence cannot be explained as merely "expectancy" effects, because participants were blind to the administration of caffeine or placebo both during chronic withdrawal and after overnight withdrawal.

Over 25 years before this Goldstein et al. (16) carried out a similar experiment in which coffee drinkers and noncoffee drinkers (essentially caffeine users and nonusers) were challenged with caffeine or placebo after overnight caffeine abstinence. Again, when not given caffeine in the morning the users were less alert, less content, more sleepy, more irritable, and had more headache than the nonusers. Blind administration of caffeine (150 or 300 mg) removed these differences by increasing alertness and reducing headache, etc., in the users, but there were almost no positive effects of these fairly large doses of caffeine in the nonusers. Indeed, the main significant effects of caffeine in the nonusers were increases in a cluster of ratings labeled "jittery" (jittery, nervous, shaky) and ratings of "upset stomach."

It is possible that preexisting differences in personality or other factors unaffected by caffeine use could explain differences in mood between users and nonusers [e.g., (38,47). Thus, individuals who are relatively sleepy in the morning may have learned to use caffeine to increase their alertness and performance efficiency at this time of day, while nonusers may avoid caffeine because they have come to recognize that for them it is "overstimulating" or that it has adverse somatic effects. Our study (36), however, also found that increased tiredness, drowsiness, anger, and dejection were present in caffeine users after overnight (13 h) caffeine deprivation but not after prolonged deprivation. Therefore, the only factor that can reasonably account for the presence or absence of these particular symptoms is the subjects' recent history of caffeine consumption. Similar findings from a smaller study were reported by Bruce et al. (4), who found increased tiredness in 24-h compared with 7-day caffeine-deprived subjects. Although nonusers were not tested, a further result was that high doses of caffeine (250 and 500 mg) reduced tiredness, and also headache, only in the 24-h group.

Taken together, these results very convincingly show that caffeine withdrawal can have significant adverse effects, including tiredness, headache, and depressed mood. Moreover, this occurs after no longer than overnight caffeine deprivation and in individuals with rather moderate intakes of caffeine (equivalent to an average of 3 cups of instant coffee per day, and possibly less). In other words, adverse effects of caffeine withdrawal are a feature of the everyday life of the caffeine consumer. Or as a subject (a regular, moderate caffeine user) commented on one of our prestudy recruitment questionnaires, "I don't drink decaffeinated coffee because it always gives me a headache."

Net Effects of Caffeine Use on Psychomotor Performance

What then are the effects of caffeine withdrawal on psychomotor performance? The finding that caffeine withdrawal is associated with fatigue suggests that performance should also be adversely affected; however, there is less direct evidence to support this contention (38), in part because few relevant experiments have been published.

Bruce et al. (4) reported that 24-h caffeine-deprived subjects "tired" more quickly on a tapping task than did 7-day caffeine-deprived subjects. Nevertheless, although high doses of caffeine (250 and 500 mg) reduced self-ratings of tiredness and headache only in the 24-h caffeine-deprived subjects (see above), for tapping performance there was not a significant difference between the two groups in their response to caffeine. Similarly, we (36) found no differences in responses to caffeine administration among caffeine nonusers and users deprived of caffeine for 1.5 h, 13 h, and 7 days. A low dose of caffeine (70 mg) significantly speeded up the subjects' simple reaction time on a short duration task, although 250 mg of caffeine did not. On the other hand, both doses significantly impaired hand steadiness. In a study (17) of heavy coffee drinkers, an abrupt change to decaffeinated coffee gave rise to a number of adverse effects, including increased headache and decreased self-rated alertness, which peaked during the first and second days of caffeine deprivation and remitted thereafter. Performance on a short-duration psychomotor test was also somewhat impaired on these days, but not reliably so. A critical factor here and in our study (36) may be the duration of the task, because the beneficial effects of caffeine administration, and therefore, possibly the adverse effects of caffeine withdrawal, tend to be greater as performance deteriorates with extended testing (e.g., see Fig. 1).

Some of the strongest evidence for an effect on psychomotor performance related to caffeine deprivation comes from a study that compared the performance of heavy caffeine users and nonusers on a choice reaction time task (37). There was no difference in performance on the first occasion that the subjects were tested (caffeine users 4 h caffeine deprived), but the users were markedly slower than the nonusers when they were retested later, this time after 2 full days of caffeine deprivation. This is consistent with the data on the subjective effects of caffeine withdrawal (above) and the time course of elimination of caffeine from the body (25), which predict that any deleterious effects on psychological functioning will be much greater 48 h after the onset of caffeine deprivation than 4 h after. In another study (11), 200 mg of caffeine given after overnight caffeine deprivation was found to improve performance on a 3-h long visual vigilance task. Again, in support of a withdrawal-reversal effect, this was due mainly to poorer performance of "high" habitual consumers of caffeine (>100 mg/day), with these subjects making significantly slower reaction times and detecting significantly fewer targets after placebo than low habitual caffeine consumers (<100 mg/day). Using a similar experimental design, Mitchell and Redman (33) found less clearly interpretable results, possibly because they used only short duration tasks (see above).

From a different standpoint, it has been suggested that the demonstration that caffeine administration can improve psychomotor performance in noncaffeine-deprived individuals (i.e., caffeine given after only a few hours of caffeine deprivation) would provide evidence for net beneficial effects of caffeine (44,50). The argument is that if subjects are not restricted in their consumption of caffeine prior to testing, then improvement of performance after caffeine vs. placebo administration cannot be due to alleviation of deficits induced by caffeine abstinence. Some studies have, indeed, reported significant performance-enhancing effects of caffeine under such conditions [e.g., (12,46,50)].

In Frewer and Lader's study (12), subjects were tested in the morning after being allowed to consume their caffeine-containing drinks as usual before 0900 h (L. J. Frewer, personal communication), but the doses of caffeine subsequently administered in the experiment were rather high (250 and 500 mg), as was that given by Smith et al. (46) (~200 mg). Warburton (50) pretreated subjects with 75 mg of caffeine 1 h before giving them a further dose of either 0, 75, or 150 mg of caffeine. This is similar to our group of 1.5-h–deprived caffeine users (36). Although no data (e.g., mean ± SE performance scores) are presented, Warburton (50) reports that caffeine vs. placebo significantly improved performance on attentional, logical reasoning, and delayed recall tasks, and argues that these "effects cannot be seen as representing the alleviation of deficits induced by caffeine abstinence" (p. 66). As James (25) points out, however, it remains possible that

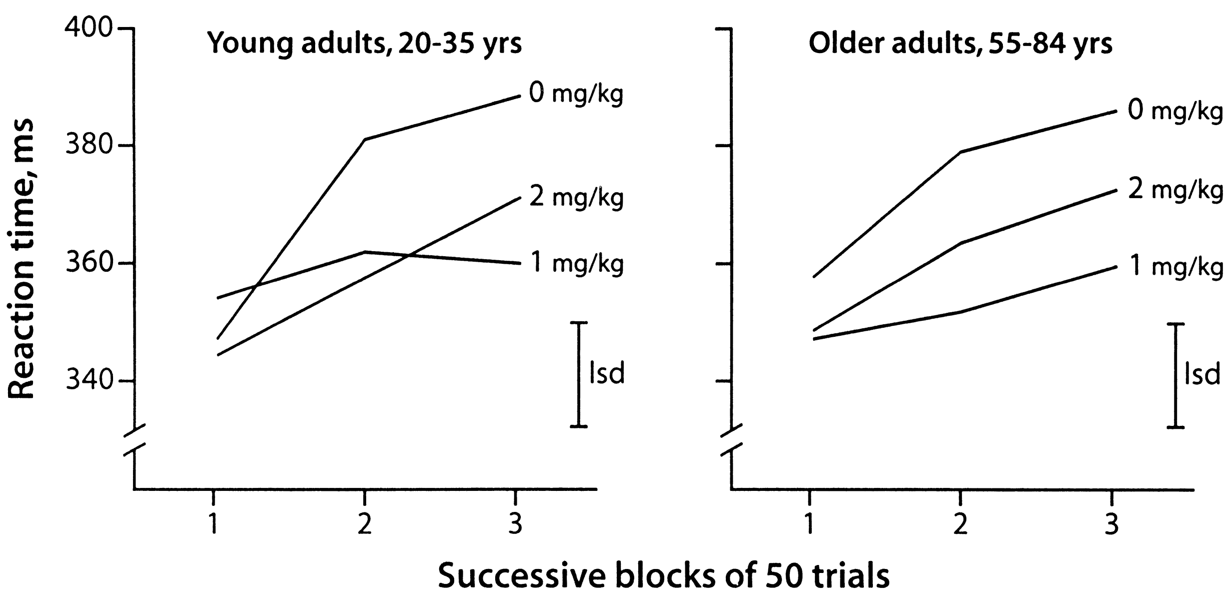

FIG. 1. Effects of caffeine (0, 1, and 2 mg/kg) on simple reaction time performance of young and older adults as a function time on task (block). The subjects, who were habitually moderate to high caffeine consumers, were deprived of caffeine overnight before being tested on the task in the morning. The vertical bar is the least significant difference (lsd) at the 5% level of significance.

the pretreatment only partially eliminated caffeine withdrawal effects.

A related issue concerns findings that suggest that caffeine is possibly most beneficial when baseline performance is degraded (by factors other than caffeine deprivation). An example is provided by a study (10) of the interaction between the performance effects of the benzodiazepine, lorazepam, and caffeine (125 and 500 mg). Lorazepam significantly impaired performance on several tasks, and caffeine tended to improve performance compared with placebo. For a symbol copying task, however, caffeine alleviated the lorazepam-induced impairment, but had no effect alone (i.e., without lorazepam, there was no difference between the level of performance after caffeine compared with placebo). Similarly, cyclizine, an antiemetic agent, was found to significantly impair performance on an arithmetical test, and this was counteracted by 100 mg of caffeine, which had only a relatively small effect on baseline performance (5). Interactive effects such as these suggest a net benefit of caffeine irrespective of possible superimposed effects of caffeine withdrawal (38).

Such results are, however, relatively rare. Thus, the effects of alcohol plus caffeine on performance can generally be predicted by the sum of their effects when given alone (1,20,40), as can the combined effects of caffeine and sleep deprivation [(45), but see (30)]. Nevertheless, another example of an interactive effect, which is perhaps particulary revealing, is provided by the results of an epidemiological (i.e., correlational) study showing a highly significant positive dose–response relationship between habitual caffeine intake and psychomotor performance (26). This association remained even "after controlling extensively for potential confounding variables" (p. 45), and was present even though tea and coffee consumption tended to have opposite relationships with other predictors of performance such as socio-economic class. Furthermore, the effect was much stronger in older subjects (aged 35–54 and 55+ years) whose overall level of performance was poorer than that of subjects in the youngest age group (aged 16–34 years).

Unfortunately, despite Jarvis's (26) careful analysis and interpretation of this large data set (a survey of 9003 British adults), certain aspects of the results remain ambiguous. For example, because time of testing was apparently uncontrolled (6), estimated caffeine intake may simply have been a proxy measure for the duration of caffeine withdrawal. This, in particular, would be consistent with the findings for one of the four tasks, a choice reaction time task, on which caffeine nonusers performed markedly better than low to moderate users, only being slower than individuals consuming six or more cups-of-coffee equivalent of caffeine per day [Fig. 3 in (26)].

The main purpose of the study described below was to investigate further the performance effects of caffeine as a function of age. It, therefore, addresses the issue of whether caffeine use provides a net benefit when performance is relatively impaired (in this case, poorer performance is expected in the older participants). A second purpose was to examine the dose–response relationship for caffeine at levels of acute administration that are relevant to the amounts of caffeine consumed when tea or coffee is drunk. As noted above, surprisingly few previously published studies provide this information.

EFFECTS OF CAFFEINE ON THE COGNITIVE PERFORMANCE OF YOUNG AND OLDER ADULTS

Following up this correlational evidence on age-related effects of caffeine, we designed a placebo-controlled study to investigate further the impact of caffeine on cognitive performance in adults aged between 20 and 84 years. These subjects were moderate to high caffeine consumers. They were tested in the morning, after overnight caffeine deprivation, on a long duration simple reaction time task, a memory task, and a tapping task. Caffeine (0, 1, and 2 mg/kg) was administered 45 min before the start of testing.

Method

Subjects. Volunteers were recruited through an advertisement placed in a local newspaper. A total of 36 subjects was selected for the study. Eighteen (12 women and 6 men) were aged between 20 and 35 years (mean ± SE, 26.7 ± 0.7 years), and 18 (11 women and 7 men) were aged between 55 and 84 years (62.6 ± 1.1 years). Body weights of these two groups were, 64.4 ± 2.0 and 68.9 ± 2.1 kg, respectively. All subjects were moderate to high caffeine consumers (see below), but none were smokers. The study was described to the subjects as research investigating the effects of constituents of nonalcoholic drinks on mood and performance, and they were told that it had been approved by the Institute of Food Research Human Research Ethics Committee. After completing the three test sessions they were paid £12, reimbursed their travelling expenses, and fully debriefed as to the purpose of the study.

Habitual caffeine intakes. For 3 days preceding the start of the study proper and on the day preceding each test session the subjects completed drink intake diaries from which their habitual caffeine intake was assessed [see (36) for details of this method].

Caffeine administration. Caffeine BP (Courtin and Warner, Sussex) at 1 and 2 mg/kg and placebo were administered in white gelatine capsules according to a within subjects design. The placebo was cornflour (2 mg/kg, and 1 mg/kg cornflour was mixed with the 1 mg/kg dose of caffeine). The order of administration of these treatments was, as far as possible, counterbalanced across gender and age.

Cognitive performance tasks. These were completed under uniform conditions, with the subjects sitting 0.5 m from a VDU monitor. The tasks were presented to participants via a 100 MHz Pentium PC, running MEL 1.0 (Psychology Software Tools, Pittsburgh, PA) in the following order.

Simple reaction time (SRT) task: in this task the subjects were presented with 150 trials in which a star appeared in the center of the screen. They were instructed to press the space bar as quickly as possible upon detection of the star. There was a variable stimulus onset of 1, 3, 5, or 7 s.

Memory task: lists of 20 words were presented on the VDU, one at the rate of one word per second and another at the rate of one word per 2 s. The subjects were instructed to memorize the lists. After the presentation of each list they were given 4 min to write down as many of the words as possible.

Two-finger tapping task: the subjects were instructed to alternately tap, as quickly as possible, the one and two keys on the numeric keyboard using the first and second fingers of their preferred hand. The task lasted 1 min.

Procedure. The subjects were told that they should not consume any foods and drinks containing caffeine or artificial sweeteners (the latter was to help conceal the true nature of the study), or any alcoholic drinks from 2100 h on the night before each testing session until after they had completed the session the next day (about 1130 h). They were asked to eat their normal breakfast but to drink only water on the morning of each test session. When they arrived at the Institute for testing at 0930 h the subjects provided a saliva sample, which they had previously been told could be used to check for compliance with these dietary restrictions. Caffeine or placebo was then administered with 50 ml warm water, and 45 min later subjects began the SRT task.

Results

Habitual caffeine intakes. None of the young subjects consumed < 4.5 mg/kg/day of caffeine, and none of the older subjects consumed <5.8 mg/kg/day of caffeine. Average daily caffeine intakes (mean $\pm$ SE) of these two groups of subjects were respectively 6.4 ± 0.5 and 8.9 ± 0.6 mg/kg/d, $t(34) = 2.40$, $p < 0.05$.

Cognitive performance. Analysis of variance was used to analyze for the main and interactive effects of caffeine (0, 1, and 2 mg/kg) and age (young and older subjects) on performance. Block was included as an additional factor in the analyses of the SRT (three blocks of 50 trials) and tapping task data (six blocks of 10 s).

There were no between-session practice effects for any of the tasks ($p > 0.1$).

The young subjects performed better on the memory task than the older subjects; with 7.8 vs. 5.9 words recalled for the one word per second lists, $F(1, 34) = 23.40$, $p < 0.001$; and 10.0 vs. 7.7 words recalled for the one word per 2 s lists, $F(1, 34) = 19.95$, $p < 0.001$. There were no significant effects involving caffeine for this task ($p > 0.1$).

There were significant age, $F(1, 32) = 12.81$, $p < 0.005$, and age $\times$ block, $F(5, 160) = 7.83$, $p < 0.001$, effects for the tapping task. The young subjects displayed a substantially faster tapping rate throughout the task than the older subjects, although this difference decreased as the task progressed due to a steady slowing of tapping by the young subjects. There were no significant effects involving caffeine for the tapping task ($p > 0.1$).

In contrast, there were no significant age-related effects for the SRT task ($p > 0.1$), but caffeine significantly improved SRT performance. There were significant main effects of caffeine, $F(2, 68) = 19.09$, $p < 0.001$, and block, $F(2, 68) = 33.90$, $p < 0.001$, and a significant caffeine $\times$ block interaction effect, $F(4, 136) = 4.25$, $p < 0.005$. From Fig. 1 it can be seen that these results were due mainly to a relative quickening of reaction time by caffeine during the second and third blocks of the task. Both caffeine doses had similar effects. Indeed, if anything, the higher dose had a smaller beneficial effect on reaction times of the older subjects than did the lower dose.

Discussion

This study found significant effects of caffeine on a long-duration SRT task, but no effects on an immediate memory task or a short-duration tapping task. These results, however, do not confirm the existence of a greater beneficial effect of caffeine in older vs. young subjects as reported by Jarvis (26). The older adults displayed much poorer immediate memory and tapping performance than the young adults, but neither group's performance on these tasks was improved by caffeine. In contrast, Jarvis (26) found a significant correlation between incidental memory performance and caffeine consumption in older (55+ years) but not younger subjects.

In the present study there were also no age-related effects of caffeine on SRT performance. This is unlikely to be due to the somewhat higher habitual caffeine intakes of the older subjects, because the higher dose of caffeine administered before testing to these subjects quickened reaction time to no greater extent than did the lower dose given to the young subjects (Fig. 1). Notably, though, the finding that the two doses of caffeine did not differ significantly in their performance-enhancing effects, either for the young or older adults, is consistent with other results showing a relatively flat dose–response relationship for caffeine [e.g., (29)]. These two doses are about equivalent to the amount of caffeine obtained from 1 and 2 cups of instant coffee (2).

In fact, for the SRT task a more appropriate comparison with the results described by Jarvis (26) is to consider only the first block of trials, because the data in that study were based on a mean reaction time for 20 trials, which followed eight practice trials (6). During the first block of trials in the present study caffeine did indeed speed up the (slightly slower) reaction time of the older subjects more than that of the young subjects (Fig. 1), but these differences were not significant ($p > 0.1$). This perhaps suggests that the study lacked sufficient power to test our hypothesis, although, as discussed above, it did detect significant effects of age on memory and tapping performance. In any case, by far the most substantial effect of caffeine occurred during the second and third blocks of the SRT task. Therefore, age appears to be a much less important factor than task duration in determining sensitivity to caffeine administration.

Arguably, this latter finding itself supports the suggestion that caffeine is particularly effective in improving degraded performance. Thus, absolute reaction time was not improved by caffeine. Instead, caffeine very clearly offset the slowing of reaction time across blocks, which presumably was due to fatigue and/or boredom induced by the task. Although it is cognitively undemanding, optimal performance on this "vigilance" task requires a high level of sustained attention.

In other words, the present study appears to provide a further example of an interactive effect of caffeine on psychomotor performance [(38), see above]. Unfortunately, even this does not show unequivocally that there are net benefits to be gained from caffeine use. This is because it remains possible that the degraded performance is, in fact, due to an interactive effect of the caffeine withdrawal and, for the present example, task-related fatigue. The existence of psychostimulant effects of caffeine in the absence of caffeine withdrawal can only be proved by demonstrating that caffeine can improve mood and/or cognitive performance in caffeine nonusers or fully withdrawn caffeine users [cf. (36)]. As far as we are aware, very little of such evidence has been published.

CONCLUSIONS

Although many studies have found that caffeine compared with placebo can increase alertness and improve mood and cognitive performance, the evidence reviewed here also demonstrates adverse consequences of caffeine withdrawal. These include lowered alertness and decreased clearheadedness, which are clearly detectable after overnight caffeine withdrawal, and are, therefore, a feature of everyday life for regular caffeine users. Because this has not been widely recognized, the research carried out to date has generally failed to ascertain the extent to which the measured psychostimulant effects of caffeine are, in fact, due to "withdrawal relief." The critical importance of withdrawal relief is supported by evidence of relatively strong negative reinforcing effects of caffeine [e.g., (39,41), and perhaps also the flat dose–response relationship for the psychostimulant action of caffeine. For example, the data in Fig. 1 and those of Lieberman et al. (29) might be best explained in terms of reversal of withdrawal-related deficits in performance by a low dose of caffeine and a failure of higher doses to produce absolute improvements in performance. The latter might be due to the development of tolerance to larger doses or cumulative doses of caffeine in regular caffeine users. In turn, these higher intakes might be motivated primarily by a negatively reinforced liking (39) for the vehicles (coffee, tea, etc.) in which caffeine is consumed, rather than their perceived beneficial psychostimulant effects. The tolerance would also play a role in reducing any aversive effects, which might otherwise limit the higher intakes.

In addition to the negative effects of overnight caffeine withdrawal and perhaps the lack of any substantial net benefit for cognitive or psychomotor performance, longer periods of caffeine withdrawal, such as may occur at weekends, are likely to be associated with more severe symptoms of fatigue and headache (19). Related to this, caffeine withdrawal has also been recognized as a significant factor contributing to postoperative pain [e.g., (9)]. Taken together with aversive effects of caffeine consumption, such as the exacerbation of anxiety and panic attacks, decreased hand steadiness, reduced quality of sleep, and increased blood pressure [e.g., (23,25,27,36)], it might be concluded that the overall net benefit of caffeine use is negative. The qualification to this conclusion is that this will very much depend on the individual's pattern of consumption of caffeine. Moderate caffeine intake may perhaps improve performance, especially under conditions leading to fatigue; however, even this has yet to be demonstrated definitively.

Despite occasional arguments to the contrary (31), there is indeed a strong case for more research on the behavioral effects of caffeine. Even if its use is associated with only a small net benefit or harm, because caffeine is the "most popular drug in the world," its total impact on the mental and physical well-being of the human population will be relatively very large. In particular, as well as assessing the immediate consequences of caffeine consumption and withdrawal, future studies should attempt to improve current understanding of the factors that motivate the patterns of the everyday use of caffeine.

ACKNOWLEDGEMENTS

This research was supported by the Biotechnology and Biological Sciences Research Council.

REFERENCES

1. Azcona, O.; Barbanoj, M. J.; Torrent, J.; Jané, F.: Evaluation of the central effects of alcohol and caffeine interaction. Br. J. Clin. Pharmacol. 40:393–400; 1990.
2. Barone, J. J.; Roberts, H. R.: Caffeine consumption. Food Chem. Toxicol. 34:119–129; 1996.
3. Bruce, M.; Scott, N.; Lader, M.; Marks, V.: The psychopharmacological and electrophysiological effects of single doses of caffeine in healthy human subjects. Br. J. Clin. Pharmacol. 22:81–87; 1986.
4. Bruce, M.; Scott, N.; Shine, P.; Lader, M.: Caffeine withdrawal: A contrast of withdrawal symptoms in normal subjects who have abstained from caffeine for 24 hours and for 7 days. J. Psychopharmacol. 5:129–134; 1991.
5. Clubley, M.; Bye, C. E.; Henson, T. A.; Peck, A. W.; Riddington, C. J.: Effects of caffeine and cyclizine alone and in combination on human performance, subjective effects and EEG activity. Br. J. Clin. Pharmacol. 7:157–163; 1979.
6. Cox, B. D.; Blaxter, M.; Buckle, A. L. J.; Fenner, N. P.; Golding, J. F.; Gore, M.; Huppert, F. A.; Nickson, J.; Roth, M.; Stark, J.; Wadsworth, M. E. J.; Whichelow, M.: The Health and Lifestyle Survey. Preliminary report of a nationwide survey of the physical and mental health, attitudes and lifestyle of a random sample of 9,003 British adults. London: Health Promotion Trust; 1987.
7. Dreisbach, R. H.; Pfeiffer, C.: Caffeine-withdrawal headache. J. Lab. Clin. Med. 28:1212–1219; 1943.
8. Fagan, D.; Swift, C. G.; Tiplady, B.: Effects of caffeine on vigilance and other performance tests in normal subjects. J. Psychopharmacol. 2:19–25; 1988.
9. Fennelly, M.; Galletly, D. C.; Purdie, G. I.: Is caffeine withdrawal the mechanism of postoperative headache? Anesth. Analg. 72: 449–453; 1991.
10. File, S. E.; Bond, A. J.; Lister, R. G.: Interaction between effects of caffeine and lorazepam in performance tests and self-ratings. J. Clin. Psychopharmacol. 2:102–106; 1982.
11. Fine, B. J.; Kobrick, J. L.; Lieberman, H. R.; Marlowe, B.; Riley, R. H.; Tharion, W. J.: Effects of caffeine or diphenhydramine on visual vigilance. Psychopharmacology (Berlin) 114:233–238; 1994.
12. Frewer, L. J.; Lader, M.: The effects of caffeine on two computerized tests of attention and vigilance. Hum. Psychopharmacol. 6:119–128; 1991.
13. Garattini, S.: Caffeine, coffee, and health. New York: Raven Press; 1993.
14. Gilbert, R. M.: Caffeine consumption. In: Spiller, G. A., ed. The methylxanthine beverages and foods: Chemistry, consumption and health. New York: Alan R. Liss; 1984:185–214.
15. Goldstein, A.; Kaizer, S.; Warren, R.: Psychotropic effects of caffeine in man II. Alertness, psychomotor coordination, and mood. J. Pharmacol. Exp. Ther. 150:146–151; 1965.
16. Goldstein, A.; Kaizer, S.; Whitby, O.: Psychotropic effects of caffeine in man IV. Quantitative and qualitative differences associated with habituation to coffee. Clin. Pharmacol. Ther. 10:489–497; 1969.
17. Griffiths, R. R.; Bigelow, G. E.; Liebson, I. A.: Human coffee drinking: Reinforcing and physical dependence producing effects. J. Pharmacol. Exp. Ther. 239:416–425; 1986.
18. Griffiths, R. R.; Mumford, G. K.: Caffeine—A drug of abuse? In: Bloom, F. E.; Kupfer, D. J., eds. Psychopharmacology: The fourth generation of progress. New York: Raven Press; 1995: 1699–1713.
19. Griffiths, R. R.; Woodson, P. P.: Caffeine physical dependence: A review of human and laboratory animal studies. Psychopharmacology (Berlin) 94:437–451; 1988.
20. Hasenfratz, M.; Binge, A.; Dal Prá, G.; Bättig, K.: Antagonistic effects of caffeine and alcohol on mental performance parameters. Pharmacol. Biochem. Behav. 46:463–465; 1993.
21. Höfer, I.; Bättig, K.: Cardiovascular, behavioral, and subjective effects of caffeine under field conditions. Pharmacol. Biochem. Behav. 48:899–908; 1994.
22. Hughes, J. R.; Oliveto, A. H.; Helzer, J. E.; Higgins, S. T.; Bickel, W. K.: Should caffeine abuse, dependence, or withdrawal be added to DSM-IV and ICD-10? Am. J. Psychiatry 149:33–40; 1992.
23. Hughes, R. N.: Drugs which induce anxiety: Caffeine. N. Z. J. Psychol. 25:36–42; 1996.
24. James, J. E.: Does caffeine enhance or merely restore degraded psychomotor performance? Neuropsychobiology 30:124–125; 1994.
25. James, J. E.: Understanding caffeine: A biobehavioural analysis. Thousand Oaks, CA: Sage; 1997.
26. Jarvis, M. J.: Does caffeine intake enhance absolute levels of cognitive performance? Psychopharmacology (Berlin) 110:45–52; 1993.
27. Landolt, H.-P.; Werth, E.; Borbély, A. A.; Dijk, D.-J.: Caffeine (200 mg) in the morning affects human sleep and EEG power spectra at night. Brain Res. 675:67–74; 1995.
28. Leathwood, P. D.; Pollet, P.: Diet-induced mood changes in normal populations. J. Psychiatr. Res. 17:147–154; 1982/83.
29. Lieberman, H. R.; Wurtman, R. J.; Emde, G. G.; Roberts, C.; Coviella, I. L. G.: The effects of low doses of caffeine on human performance and mood. Psychopharmacology (Berlin) 92:308–312; 1987.
30. Lorist, M. M.; Snel, J.; Kok, A.: Influence of caffeine on informa-

tion processing stages in well rested and fatigued subjects. Psychopharmacology (Berlin) 113:411–421; 1994.
31. Medical Research Council.: The basis of drug dependence: MRC field review. London: MRC; 1994.
32. Miller, L. S.; Lombardo, T. W.; Fowler, S. C.: Caffeine and time of day effects on a force discrimination task in humans. Physiol. Behav. 57:1117–1125; 1995.
33. Mitchell, P. J.; Redman, J. R.: Effects of caffeine, time of day and user history on study-related performance. Psychopharmacology (Berlin) 109:121–126; 1992.
34. Penetar, D.; McCann, U.; Thorne, D.; Kamimori, G.; Galinski, C.; Sing, H.; Thomas, M.; Belenky, G.: Caffeine reversal of sleep deprivation effects on alertness and mood. Psychopharmacology (Berlin) 112:359–365; 1993.
35. Regina, E. G.; Smith, G. M.; Keiper, C. G.; McKelvey, R. K.: Effects of caffeine on alertness in simulated automobile driving. J. Appl. Psychol. 59:483–489; 1974.
36. Richardson, N. J.; Rogers, P. J.; Elliman, N. A.; O'Dell, R. J.: Mood and performance effects of caffeine in relation to acute and chronic caffeine deprivation. Pharmacol. Biochem. Behav. 52: 313–320; 1995.
37. Rizzo, A. A.; Stamps, L. E.; Feht, L. A.: Effects of caffeine withdrawal on motor performance and heart rate changes. Int. J. Psychophysiol. 6:9–14; 1988.
38. Rogers, P. J.; Richardson, N. J.; Dernoncourt, C.: Caffeine use: Is there a net benefit for mood and psychomotor performance? Neuropsychobiology 31:195–199; 1995.
39. Rogers, P. J.; Richardson, N. J.; Elliman, N. A.: Overnight caffeine abstinence and negative reinforcement of preference for caffeine-containing drinks. Psychopharmacology (Berlin) 120: 457–462; 1995.
40. Rush, C. R.; Higgins, S. T.; Hughes, J. R.; Bickel, W. K.; Wiegner, M. S.: Acute behavioural and cardiac effects of alcohol and caffeine, alone and in combination, in humans. Behav. Pharmacol. 4:562–572; 1993.
41. Schuh, K. J.; Griffiths, R. R.: Caffeine reinforcement: The role of withdrawal. Psychopharmacology (Berlin) 130:320–326; 1997.
42. Silverman, K.; Evans, S. M.; Strain, E. C.; Griffiths, R. R.: Withdrawal syndrome after the double-blind cessation of caffeine consumption. N. Engl. J. Med. 327:1109–1114; 1992.
43. Smith, A.; Kendrick, A.; Maben, A.; Salmon, J.: Effects of breakfast and caffeine on cognitive performance, mood and cardiovascular functioning. Appetite 22:39–55; 1994.
44. Smith, A. P.: Caffeine, caffeine withdrawal and psychomotor performance: A reply to James. Neuropsychobiology 31:200–201; 1995.
45. Smith, A. P.; Brockman, P.; Flynn, R.; Maben, A.; Thomas, M.: Investigation of the effects of coffee on alertness and performance during the day and night. Neuropsychobiology 27:217–223; 1993.
46. Smith, A. P.; Maben, A. Brockman, P.: Effects of evening meals and caffeine on cognitive performance, mood and cardiovascular functioning. Appetite 22:57–65; 1994.
47. Smith, A. P.; Rusted, J. M.; Savory, M.; Eaton-Williams, P.; Hall, S. R.: The effects of caffeine, impulsivity and time of day on performance, mood and cardiovascular function. J. Psychopharmacol. 5:120–128; 1991.
48. Streufert, S.; Pogash, R.; Miller, J.; Gingrich, D.; Landis, R.; Lonardi, L.; Severs, W.; Roache, J. D.: Effects of caffeine deprivation on complex human functioning. Psychopharmacology (Berlin) 118:377–384; 1995.
49. van Dusseldorp, M.; Katan, M. B.: Headache caused by caffeine withdrawal among moderate coffee drinkers switched from ordinary to decaffeinated coffee: A 12-week double-blind trial. Br. Med. J. 300:1558–1559; 1990.
50. Warburton, D. M.: Effects of caffeine on cognition and mood without caffeine abstinence. Psychopharmacology (Berlin) 119: 66–70; 1995.
51. Wright, K. P.; Badia, P.; Myers, B. L.; Plenzler, S. C.: Combination of bright light and caffeine as a countermeasure for impaired alertness and performance during extended sleep deprivation. J. Sleep Res. 6:26–35; 1997.
52. Zwyghuizen-Doorenbos, A.; Roehrs, T. A.; Lipschutz, L.; Timms, V.; Roth, T.: Effects of caffeine on alertness. Psychopharmacology (Berlin) 100:36–39; 1990.