

COFFEE, ATTENTION, MEMORY AND MOOD: FROM THE BRAIN TO THE WORKPLACE

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ABSTRACT

Coffee is a major source of caffeine, which has been shown to have a number of behavioural effects. For example, caffeine increases alertness, improves sustained attention and psychomotor performance. These beneficial effects often increase with dose (within the limits consumed by the majority of the population). Caffeine has less effect on memory but has recently been shown to improve retrieval from general knowledge and the ability to think logically. Improvements following ingestion of caffeinated coffee are most easily observed when alertness is low (e.g. after sleep deprivation; in the early morning; after lunch; when performing at night; after prolonged work; when the person has a minor illness such as the common cold). Caffeine influences many neurotransmitter systems and the beneficial effects seen in low arousal contexts probably reflect its effects on central noradrenaline. Other effects, such as the increased speed of encoding new information after caffeine, reflect changes in other neurotransmitter systems (e.g. the cholinergic system).

It has been suggested that the positive effects of caffeine merely reflect removal of negative effects of withdrawal. This is unlikely as effects can be demonstrated in non-consumers and also consumers who have not had caffeine withdrawn.

The beneficial effects of caffeine can be demonstrated using realistic consumption patterns. Similarly, simulations of real-life activities (e.g. driving) show improved performance after caffeine. Furthermore, recent epidemiological analyses suggest that those with above average intake of caffeine report fewer errors at work and are involved in fewer accidents. Overall, these findings suggest that the levels of caffeine in coffee consumed by most people have largely beneficial effects on behaviour.

CAFFEINE IN COFFEE

Coffee is one of the major sources of caffeine. Instant coffee typically contains about 60 mg per cup whereas coffee prepared by the drip method can have nearly twice that amount of caffeine per cup. While it is quite plausible that other compounds in coffee may produce behavioural change previous research has largely focused on caffeine. The present article is, therefore, largely concerned with the

behavioural changes that might be associated with consumption of caffeinated coffee.

Caffeine (1,3,7-trimethylxanthine) is one member of a class of naturally occurring substances termed methylxanthines. Absorption from the gastrointestinal tract is rapid and reaches 99% in humans in about 45 minutes after ingestion. The hydrophobic properties of caffeine allow its passage through all biological membranes and there is no blood-brain barrier to caffeine. The time for peak plasma concentration is variable (15-120 minutes) and caffeine half-lives range from 2.5 to 4.5 hours.

CNS MECHANISMS

The effects of caffeine on the CNS have been reviewed in detail by Fredholm *et al.* (1999). Most of the data suggest that caffeine, in the doses that are commonly consumed, acts primarily by blocking adenosine A1 and A2a receptors. Even though the primary action of caffeine may be to block adenosine receptors this leads to very important secondary effects on many classes of neurotransmitters, including noradrenaline, acetylcholine, dopamine, serotonin, glutamate and GABA (Daly, 1993). Such effects show that caffeine has the ability to increase alertness, a possible reason underlying why people consume caffeine-containing beverages.

CAFFEINE AND PERFORMANCE

Early research on this topic has been reviewed by Lieberman (1992). This research has suggested that caffeine improves sustained attention and psychomotor speed but has little effect on memory. More recent studies of effects of caffeine on performance have confirmed many of the earlier results. For example, the beneficial effects of caffeine on psychomotor speed and vigilance have been replicated (e.g. Fine *et al.*, 1994; Frewer and Lader, 1991). Similarly, the absence of effects in episodic memory tasks has also been confirmed (e.g. Loke, 1990; Smith *et al.*, 1997a).

Consideration of other aspects of memory

The effects of caffeine on other aspects of memory have also been investigated. For example, components of Baddeley's working memory model have been examined and the results show no effects of caffeine on the articulatory loop (Smith, Clark and Gallagher, 1999) or the visuo-spatial sketchpad (Warburton, 1995) but improved central executive function as shown by improved speed and accuracy of performing a logical reasoning task (Smith *et al.*, 1992; Smith, Maben and Brockman, 1994).

Semantic memory has also been studied and results show that caffeine improves the speed of retrieval of semantic information. Indeed, this effect appears to be very consistent with the majority of studies showing improved performance after caffeine (Smith, Kendrick and Maben, 1992; Smith *et al.*, 1994; Smith, Sturgess and Gallagher, 1999).

CAFFEINE AND LOW ALERTNESS SITUATIONS

Caffeine often has its biggest effect when alertness is low (e.g. in the early morning or when working at night). Research has shown that the decreased alertness produced by consumption of lunch can be eliminated by consumption of caffeinated coffee (see Figure 3.1 - Smith *et al.*, 1991; Smith and Phillips, 1993).

Furthermore, alertness is often reduced by minor illnesses such as the common cold, and caffeine can remove the impaired performance and negative mood associated with these illnesses (Smith *et al.*, 1997a). The ability of caffeine to counteract the effects of fatigue has been confirmed using simulations of driving (Horne and Reyner, 1996;

Reyner and Horne, 1997). A study of simulated assembly line work (Muehlbach and Walsh, 1995) also demonstrated significant improvements after caffeine on five consecutive nights and showed no decrements when caffeine was withdrawn.

Some of the above studies allow one to assess the magnitude of the effects of caffeine. For example, Smith *et al.*, (1993) found that consumption of caffeine at night maintained individuals at the levels seen in the day. Another approach has been to compare the effects of caffeine with other methods aimed at counteracting sleepiness. Bonnet and

Arand (1994a,b) report that the combination of a prophylactic nap and caffeine was more effective in maintaining nocturnal alertness than was the nap alone. Other studies have continued to demonstrate that caffeine can remove impairments produced by sedative drugs (e.g. alcohol -

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Hasenfratz *et al.*, 1993; scopolamine - Riedel *et al.*, 1995; lorazepam – Rush *et al.*, 1994a; triazolam - Rush *et al.*, 1994b).

One issue is whether positive effects of caffeine are largely restricted to low alertness situations. Battig and Buzzi (1986) argued that caffeine can improve performance beyond a mere restoration of fatigue. Other studies have shown that fatigued subjects show larger performance changes after caffeine than do well-rested volunteers (Lorist, Snel and Kok, 1994; Lorist *et al.*, 1994). Another issue is whether caffeine exacerbates negative effects produced by stressful conditions (e.g., electrical shocks - Hasenfratz and Battig, 1992; noise - Smith *et al.*, 1997b) and results suggest that it does not.

DIFFERENT DOSES OF CAFFEINE

A number of studies (e.g. Lieberman *et al.*, 1987; Smith, Sturgess and Gallagher, 1999) have shown that beneficial effects of doses of caffeine typically found in commercial products can now be demonstrated in both measures of mood and performance. A linear dose response curve has also been shown in a number of studies (Amendola, Gabrieli and Lieberman, 1998; Smith, 1999) although, like the animal literature, beneficial effects often disappear at very high doses. The strongest evidence for beneficial effects of regular caffeine consumption comes from a study by Jarvis (1993). He examined the relationship between habitual coffee and tea consumption and cognitive performance using data from a cross-sectional survey of a representative sample of over 9,000 British adults. Subjects completed tests of simple reaction time, choice reaction time, incidental verbal memory and visuo-spatial reasoning, in addition to providing self-reports of usual coffee and tea intake. After controlling extensively for potential confounding variables, a dose-response trend to improved performance with higher levels of coffee consumption (best performance associated with about 400mg caffeine per day) was found for all tests. Estimated overall caffeine consumption showed a dose-response relationship to improved cognitive performance that was strongest in those who had consumed high levels for the longest time period (the 55 years plus age group).

BENEFICIAL EFFECTS OF CAFFEINE OR REMOVAL OF NEGATIVE EFFECTS OF WITHDRAWAL?

Overall, the previous sections confirm that the effects of caffeine on performance are largely beneficial. However, this view has been questioned by James (1994) who argues that the beneficial effects of caffeine are really only removal of negative effects produced by caffeine withdrawal. Smith (1995) has argued against this general view of caffeine effects on a number of grounds. First, it cannot account for the behavioral effects seen in animals or nonconsumers, where withdrawal cannot occur. Secondly, caffeine withdrawal cannot account for behavioral changes following caffeine consumption after a short period of abstinence (Warburton, 1995; Smith, Maben and Brockman, 1994) or the greater effects of caffeine when arousal is low. Finally, claims about the negative effects of caffeine withdrawal require closer examination as they can often be interpreted in ways other than caffeine dependence (e.g. expectancy - Smith, 1996; Rubin and Smith, 1999). Indeed, in most of the studies that have demonstrated increases in negative affect following caffeine withdrawal, the volunteers have not been blind but have been told or even instructed to abstain from caffeine. This is clearly very different from the double-blind methodology typically used to study effects of caffeine challenge. The view that beneficial effects of caffeine reflect degraded performance in the caffeine-free conditions (James, 1994) crucially depends on the strength of the evidence for withdrawal effects. James states that there is an extensive literature showing that caffeine withdrawal has significant adverse effects on human performance. If one examines the details of the studies cited to support this view one finds that some of them do not even examine performance, and that where

they do, any effects are selective, not very pronounced, and largely unrelated to the beneficial effects of caffeine reported in the literature.

Rogers, Richardson and Derroncourt (1995) have reviewed a number of studies of caffeine withdrawal and performance. They conclude that "...in a review of recent studies we find no unequivocal evidence of impaired psychomotor performance associated with caffeine withdrawal.. Indeed, they found that caffeine improved performance in both deprived volunteers and non-consumers (Richardson *et al.*, 1994). Furthermore, other studies which suggest, that withdrawal may impair performance (e.g. Bruce, *et al.*, 1991; Rizzo, Stamps and Lawrence, 1988) can be interpreted in other ways than deprivation (e.g. changes in state).

The effects of caffeine withdrawal are still controversial. James (1998) showed that caffeine withdrawal impaired short-term memory performance but caffeine ingestion had no effect. In contrast, Smith (1999) reported that caffeine improved attention in both those who had been deprived of caffeine for a short period and those who had no caffeine for 7 days (see Figure 3.2). Other studies (e.g. Comer *et al.*, 1997) suggest that effects of withdrawal are restricted to mood and that performance is unaltered. Like many areas of caffeine research, some of the effects that have been attributed to withdrawal are open to other interpretations. For example, Lane (1997), Phillips-Bute and Lane (1997) and Lane and Phillips-Bute (1998) compared days when mid-morning coffee was either caffeinated or de-caffeinated. Caffeine consumption was associated with better performance and mood. The authors interpret this as a negative effect of caffeine withdrawal whereas one could interpret it as a positive effect of caffeine.

Other studies of caffeine withdrawal effects have methodological problems such as the lack of pre-drink baselines (e.g. James, 1998; Robelin and Rogers, 1998) or failure to consider possible asymmetric transfer when using within subject designs (e.g. James, 1998). This topic will be returned to when very recent research is considered.

Caffeine withdrawal

Recent research in this area has been concerned with two main topics, namely what underlies the increase in symptoms following caffeine withdrawal, and, secondly, whether the effects of caffeine reflect removal of negative effects of withdrawal. Dews, O'Brien and Bergman (2002) have considered factors underlying caffeine withdrawal and conclude that "non pharmacological factors related to knowledge and expectation are the prime determinants of symptoms and their reported prevalence on withdrawal of caffeine after regular consumption ..

In contrast, some researchers still suggest that caffeine only has beneficial effects on performance when the person has had caffeine withdrawn.

Yeomans *et al.* (2002) report that caffeine improved performance on a sustained attention task and increased rated alertness when volunteers had been caffeine deprived but had no such effects when they were no longer deprived. However, the results showed an effect of order of treatments with those who received caffeine first continuing to show better performance even when subsequently given placebo.

Smith, Christopher and Sutherland (submitted) examined effects of caffeine in the evening after a day of normal caffeine consumption. Caffeine improved performance (see Figure 3.3) which casts doubt on the view that reversal of caffeine withdrawal is a major component underlying effects on performance.

Further evidence against the caffeine withdrawal explanation comes from recent studies of nonconsumers (Smith, Brice and Nguyen van Tam, 2001).

These studies not only detected few negative effects of withdrawal but showed that caffeine improved the performance of both withdrawn consumers and non-consumers, a finding that argues strongly against the withdrawal reversal explanation.

REAL LIFE PERFORMANCE

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Recent research has shown that caffeine can have beneficial effects on performance when it is consumed in a realistic way (Brice and Smith, 2001b) and in real life situations. Lieberman *et al.* (2002) investigated whether caffeine would reduce the adverse effects of sleep deprivation and exposure to severe environmental and operational stress. They studied U.S. Navy Sea-Air-Land trainees and found that even in the most adverse circumstances moderate doses of caffeine improved vigilance, learning, memory and mood state. A dose of 200 mg appeared to be optimal under such conditions. Lieberman *et al.* (2002) conclude that .When cognitive performance is critical and must be maintained during exposure to severe stress, administration of caffeine may provide a significant advantage .. Such beneficial effects of caffeine have been reported in many real life activities (Weinberg and Beale, 2002) and a recent study suggests that performance at work may be improved (Brice and Smith, 2001a). Smith (submitted) examined associations between caffeine consumption and accidents at work in a sample of 1555 blue-collar workers. The results showed that those who consumed higher levels of caffeine than average had half the risk of having an accident. Similarly, white collar workers (N=1253) who consumed more than 150 mg/caffeine a day were less likely to make errors of memory, attention and action at work.

UNDERLYING CNS MECHANISM: HUMAN STUDIES

Animal studies of the CNS effects of caffeine show that it can potentially influence behaviour through a number of mechanisms. In contrast to this, research with human volunteers is often based on the assumption that all the observed changes can be accounted for by a single mechanism. Evidence for distinct effects of caffeine comes from pharmacological challenge studies. Low states of alertness can be induced by reducing the turn over of central noradrenaline by giving clonidine. In a recent study (Smith *et al.*, 2003) we have shown hat caffeine can reverse the effect of clonidine However, certain types of task (e.g. a cognitive vigilance task) were not impaired by clonidine yet showed significant improvements following ingestion of caffeine. These tasks are known to be sensitive to cholinergic challenges and prior research has shown that caffeine can reverse these (Riedel *et al.*, 1995). These cholinergic effects reflect an increase in the speed of encoding of information and a reduction in variability in performance (Warburton, Bersellini and Sweeney, 2001) and are not restricted to low alertness situations. This dual mechanism model is clearly an over simplification of the effects of caffeine but it represents a move towards mapping the behavioural effects with the underlying neurotransmitter changes.

CONCLUSIONS

The present article has reviewed the effects of caffeine on mood and mental performance. Most of the research has examined acute effects of single doses, and further studies are needed to produce a more detailed profile of effects of regular levels of consumption. However, the general picture to emerge is that when caffeine is consumed in moderation by the majority of the population there are unlikely to be many negative effects. Indeed, the positive effects may be important in maintaining efficiency and safety in both the workplace and other environments. Excessive consumption of caffeine will produce problems, and appropriate information should be given to minimise effects in psychiatric patients and other sensitive groups. It is important to balance this with information on the benefits of caffeine, for most consumers can usually control their intake to maximise the beneficial effects and reduce or prevent adverse effects due to over-consumption or consumption at inappropriate times. The behavioural effects of caffeine may reflect a variety of different neurotransmitter changes and further research is needed to identify the mechanisms

underlying specific effects. The beneficial effects of caffeine can be demonstrated using realistic consumption patterns. Similarly, simulations of real-life activities (e.g. driving) show improved performance after caffeine. Furthermore, recent epidemiological analyses suggest that those with above average intake of caffeine report fewer errors at work and are involved in fewer accidents. Overall, these findings suggest that the levels of caffeine in coffee consumed by most people have largely beneficial effects on behaviour.

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