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 crosssectional 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 Dernoncourt (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 o 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 predrink 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

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 reallife 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.

References

Amendola, C. A., Gabrieli, J. D. E and Lieberman, H. R. (1998) Caffeine.s effects on performance and mood are independent of age and gender. Nutritional Neuroscience 1, 269-280.
Battig, K. and Buzzi, R. (1986) Effect of coffee on the speed of subject-paced information processing. Neuropsychobiology 16, 126-130.
Bonnet M. H. and Arand D. L. (1994b) Impact of naps and caffeine on extended nocturnal performance. Physiology and Behavior 56, 103-109.

Brice, C.F. and Smith, A.P. (2001a) The effects of caffeine on simulated driving, subjective alertness and sustained attention. Human Psychopharmacology 16, 523-531.

Brice, C. F. and Smith, A. P. (2002b) Effects of caffeine on mood and performance: A study of realistic consumption. Psychopharmacology 164, 188-192.

Bruce, M., Scott, N., Shine, P. and Lader ,M. (1991) Caffeine withdrawal: A contrast of withdrawal symptoms in normal subjects who have abstained from caffeine for 24 hours and for 7 days. Journal of Psychopharmacology 5, 129- 134.

Comer, S. D., Haney, M., Foltin, R. W. and Fischman, M. W. (1997) Effects of caffeine withdrawal in humans living in a residential laboratory. Experimental and Clinical Psychopharmacology 5, 399-403.

Daly, J. W. (1993) Mechanism of action of caffeine. In: Caffeine, Coffee and Health (Garattini S., ed). New York: Raven Press. Pp 97-150.

Dews P. B., O.Brien, C. P. and Bergman J. (2002) Caffeine: behavioural effects of withdrawal and related issues. Food and Chemical Toxicology 40, 1257-1261.

Fine, B. J., Kobrick, J. L., Lieberman, H. R., Marlowe, B., Riley, R. H. and Tharion, W. J. (1994) Effects of caffeine or diphenhydramine on visual vigilance. Psychopharmacology 114, 233-238.

Fredholm, B. B., Battig, K., Holmen, J., Nehlig, A.and Zvartau, E. E. (1999) Actions of caffeine in the brain with special reference to factors that contribute to its widespread use. Pharmacological Reviews 91, 83-133.

Frewer, L. J. and Lader, M. (1991) The effects of caffeine on two computerized tests of attention and vigilance. Human Psychopharmacology Clinical and Experimental 6, 119-128.

Hasenfratz, M. and Battig, K. (1992) No psychophysiological interactions between caffeine and stress? Psychopharmacology 109, 283-290.

Horne, J. A. and Reyner, L. A. (1996) Counteracting driver sleepiness: Effects of napping, caffeine, and placebo. Psychophysiology 33, 306-309.

James, J. E. (1994) Does caffeine enhance or merely restore degraded psychomotor performance? Neuropsychobiology 30, 124-125.

James, J.E. (1998) Acute and chronic effects of caffeine on performance, mood, headache and sleep. Neuropsychobiology 38, 32-41.

Jarvis, M. J. (1993) Does caffeine intake enhance absolute levels of cognitive performance? Psychopharmacology 110, 45-52.

Lane, J. D. (1997) Effects of brief caffeinatedbeverage deprivation on mood, symptoms and psychomotor performance. Pharmacology, Biochemistry and Behavior 58, 203-208.

Lane, J. D. and Phillips-Bute, B. G. (1998) Caffeine deprivation affects vigilance performance and mood. Physiology and Behavior 65, 171-175.

Lieberman, H. R. (1992) Caffeine. In Handbook of Human Performance. Edited by A. P. Smith and D. M. Jones. Vol. 2, pp. 49-72. Academic Press, London.

Lieberman, H. R., Tharion ,W. J., Shukitt-Hale, B., Speckman, K. L. and Tulley, R. (2002) Effects of caffeine, sleep loss, and stress on cognitive performance and mood during U.S. Navy SEAL training.

Psychopharmacology 164, 250- 261.
Lieberman, H. R., Wurtman, R. J., Emde, G. G., Roberts, C. and Covielle, I. L. G. (1987) The effects of low doses of caffeine on human performance and mood. Psychopharmacology 92, 308-312.
Loke, W. H. (1990) Effects of repeated caffeine administration on cognition and mood. Human Psychopharmacology Clinical and Experimental 5, 339-348.
Lorist, M. M., Snel, J. and Kok, A. (1994) Influence of caffeine on information processing stages in well rested and fatigued subjects. Psychopharmacology 113, 411-421.
Lorist, M. M., Snel, J., Kok, A. and Mulder, G. (1994) Influence of caffeine on selective attention in well-rested and fatigued subjects. Psychophysiology 31, 525-534.
Muehlbach, M. J. and Walsh, J. K. (1995) The effects of caffeine on simulated night-shift work and subsequent daytime sleep. Sleep 18, 22-29.
Phillips-Bute, B.G. and Lane, J. D. (1997) Caffeine withdrawal symptoms following brief caffeine deprivation. Physiology and Behavior 63, 35- 39.
Reyner, L. A. and Horne, J. A. (1997) Suppression of sleepiness in drivers: Combination of caffeine with a short nap. Psychophysiology 34, 721- 725.
Richardson, N. J., Rogers, P. J., Elliman, N. A. andO.Dell, R. J. (1994) Mood and performance effects of caffeine in relation to acute and chronic caffeine deprivation. Pharmacology, Biochemistry and Behavior 52, 313-320.
Riedel, W., Hogervorst, E., Leboux, R. and Verhey, F. (1995) Caffeine attenuates scopolamineinduced memory impairment in humans. Psychopharmacology 122, 158-168.
Rizzo, A. A., Stamps, L. E. and Lawrence, A. F. (1988) Effects of caffeine withdrawal on motor performance and heart rate changes. International Journal Psychophysiology 6, 9-14.
Robelin, M. and Rogers, P. J. (1998) Mood and psychomotor performance effects of the first but not subsequent, cup .of-coffee equivalent doses of caffeine consumed after overnight caffeine abstinence. Behavioral Pharmacology 9, 611-618.
Rogers, P. J., Richardson, N. J. and Dernoncourt, C. (1995a) Caffeine use: Is there a net benefit for mood and psychomotor performance? Neuropsychobiology 31, 195-199.
Rogers, P. J., Richardson, N. J. and Elliman, N.A. (1995b) Overnight caffeine abstinence and negative reinforcement of preference for caffeine containing drinks. Psychopharmacology 120, 457-462.
Rubin, G. J. and Smith, A. P. (1999) Caffeine withdrawal and headaches. Nutritional Neuroscience 2, 123-126.
Smith, A. P. (1995) Caffeine, caffeine withdrawal and psychomotor performance: A reply to James. Neuropsychobiology 31, 200-201.
Smith, A. P. (1996) Caffeine dependence: An alternative view. Nature Medicine 2, 494.
Smith, A. P. (1999) Caffeine,caffeine withdrawal and performance efficiency. In: Caffeine and Behavior: Current views and research trends. B.S.Gupta & Uma Gupta (eds). CRC Press. Pp.161-178.
Smith, A.P. (submitted) Caffeine at work. Psychopharmacology.
Smith, A. P., Brice, C. F. and Nguyen-van-Tam, D. (2001) Beneficial effects of caffeinated coffee and

effects of withdrawal . 19th International Scientific Colloquium on Coffee. Trieste. Association Scientifique Internationale du Café. P500.

Smith, A. P., Brice, C. F., Nash ,J., Rich,N. and Nutt, D. J (2003) Caffeine and central noradrenaline: effects on mood and cognitive performance. Journal of Psychopharmacology 17, 283-292.

Smith, A. P., Brockman B., Flynn R., Maben A. and Thomas M. (1993) Investigation of the effects of coffee on alertness and performance during the day and night. Neuropsychobiology 27, 217- 223.

Smith, A. P., Christopher,G. and Sutherland, D. (submitted) Effects of caffeine on mood and performance following a day of normal consumption. Psychopharmacology.

Smith, A. P, Clark, R. and Gallagher, J. (1999) Breakfast cereal and caffeinated coffee: Effects on working memory, attention, mood and cardiovascular function. Physiology and Behavior 67, 9-17.

Smith, A.P., Kendrick, A.M. and Maben, A.L. (1992) Effects of breakfast and caffeine on performance and mood in the late morning and after lunch. Neuropsychobiology 26, 198- 204.

Smith, A. P., Maben, A. and Brockman, P. (1993) The effects of caffeine and evening meals on sleep and performance, mood and cardiovascular functioning the following day. Journal of Psychopharmacology 7, 203-206.

Smith, A. P., Maben, A., and Brockman, P. (1994) Effects of evening meals and caffeine on cognitive performance, mood and cardiovascular functioning. Appetite 22, 57-65.

Smith, A. P. and Phillips, W. (1993) .Effects of low doses of caffeine in coffee on human performance and mood. In 15th International Scientific Colloquim on Coffee Vol 2. Association Scientifique Internationale de Cafe, Paris, pp 461-469.

Smith, A. P., Rusted, J. M., Eaton-Williams, P., Savory, M. and Leathwood, P. (1991) Effects of caffeine given before and after lunch on sustained attention. Neuropsychobiology 23, 160-163.

Smith, A.P., Sturgess, W. and Gallagher, J. (1999) Effects of a low dose of caffeine given in different drinks on mood and performance. Human Psychopharmacology 14, 473-482.

Smith, A. P., Thomas, M., Perry, K. and Whitney, H. (1997a) Caffeine and the common cold. Journal of Psychopharmacology 11, 319-324

Smith, A. P., Whitney, H., Thomas, M., Perry, K. and Brockman, P. (1997b) Effects of caffeine and noise on mood, performance and cardiovascular functioning. Human Psychopharmacology 12, 27-33

Warburton, D. M. (1995) Effects of caffeine on cognition and mood without caffeine abstinence. Psychopharmacology 119, 66- 70.

Warburton, D. M., Bersellini, E. and Sweeney, E. (2001) An evaluation of a caffeinated taurine drink on mood, memory and information processing in healthy volunteers without caffeine abstinence. Psychopharmacology 158, 322-328.

Weinberg, B. A. and Bealer, B. K. (2002) The Caffeine Advantage. New York: The Free Press

Yeomans, M. R., Ripley, T., Davies, L. H., Rusted, J. M., and Rogers, P. J. (2002) Effects of caffeine on performance and mood depend on the level of caffeine abstinence. Psychopharmacology 164, 241-249.