Psychopharmacology (1993) 110:45–52

Psychopharmacology

Does caffeine intake enhance absolute levels of cognitive performance?

Martin J. Jarvis

ICRF Health Behaviour Unit, Institute of Psychiatry, National Addiction Centre, 4 Windsor Walk, London SE5 8AF, UK

Received April 13, 1992 / Final version July 13, 1992

Abstract. The relationship between habitual coffee and tea consumption and cognitive performance was examined using data from a cross-sectional survey of a representative sample of 9003 British adults (the Health and Lifestyle Survey). 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 was observed for all four tests ($P<0.001$ in each case). Similar but weaker associations were found for tea consumption, which were significant for simple reaction time ($P=0.02$) and visuo-spatial reasoning ($P=0.013$). Estimated overall caffeine consumption showed a dose-response relationship to improved cognitive performance ($P<0.001$ for each cognitive test, after controlling for confounders). Older people appeared to be more susceptible to the performance-improving effects of caffeine than were younger. The results suggest that tolerance to the performance-enhancing effects of caffeine, if it occurs at all, is incomplete.

Key words: Caffeine – Cognitive performance – Coffee – Tea

Caffeine is generally accepted to be the most widely consumed drug in the world (Gilbert 1984). Drinking coffee is reported by users to produce feelings of increased alertness, to enhance the ability to work and concentrate, as well as to induce wakefulness (Goldstein and Kaizer 1969; Goldstein et al. 1969). These effects have been confirmed in numerous placebo-controlled laboratory studies. Caffeine has been shown to decrease reaction time (Clubley et al. 1979; Lieberman et al. 1987; Kerr et al. 1991), to enhance vigilance (Zwyghuizen-Doorenbos et al. 1990; Frewer and Lader 1991), to improve workshift performance (Walsh et al. 1990), and to delay sleep onset (Brezinova 1974; Karacan et al. 1977).

As with other widely used and socially sanctioned drugs, such as nicotine, interpretation of apparent performance-enhancing effects of caffeine is problematic. They could represent either absolute improvements in levels of performance, or, alternatively, alleviation of deficits induced by temporary caffeine abstinence. Rall, writing in the most recent edition of Goodman and Gilman comments as follows: "Since the long term ingestion of caffeine can produce tolerance and evidence of physical dependence (Griffiths and Woodson 1988), the history of exposure to methylxanthines will influence the effect of a given dose. Hence enhanced alertness, energy and ability to concentrate could reflect alleviation of withdrawal symptoms in some instances" (Rall 1990, p 621).

Further light could be thrown on this issue by comparing performance in groups of the population who habitually take different doses of caffeine. If users perform better than non-users, and there is evidence of dose-related improvements in performance with increased levels of intake, this would provide prima facie evidence that caffeine retains its effects on performance in long-term users. Tolerance to the performance enhancing effects of caffeine would be manifested by the absence of relation between level of performance and habitual level of intake.

A recent large population survey carried out in the United Kingdom, which incorporated a number of tests of cognitive performance in addition to enquiring about caffeine intake in the form of coffee and tea drinking, provided an opportunity to examine this issue. By comparison with laboratory studies, the data from this survey, which were gathered from a sample fully representative of the UK adult population, provide greater ecological validity. But this gain is at the cost of considerable loss of the experimental control and rigour that can be achieved in the laboratory. It also becomes imperative to control carefully for demographic and other variables which are related both to caffeine intake and to level of performance, and which may serve as potential confounders.

Subjects and methods

The Health and Lifestyle survey interviewed 9003 adults, a randomly selected sample of individuals aged 18 or over who were resident in England, Scotland, or Wales during 1984 and 1985. A general account of the methods of sample selection, data collection, and preliminary analyses have been published (Cox et al. 1987).

The survey involved three stages of data collection. An initial interview was carried out in respondents' homes and covered a wide range of topics, including health and health beliefs and lifestyle variables such as diet, exercise, alcohol consumption and smoking. At the end of the interview consent was sought for a visit from a research nurse. A total of 7414 respondents participated in this phase of the survey. The visit took place about a week after the interview. The nurse took objective measures of a number of physiological variables, and in addition administered simple tests of cognitive function. Finally, the nurse left a number of self-completion questionnaires for subsequent return by post.

Measures of caffeine intake. At the initial interview subjects were asked "How many cups of coffee do you *usually* drink in a day?" (none, 1 or 2, 3 or 4, 5 or 6, more than 6). A similar question enquired about tea drinking. Responses to these questions were taken as the measures of coffee and tea consumption. An estimate of overall caffeine intake was derived by combining coffee and tea consumption into a single measure, assigning weights of 1.0 to coffee and 0.5 to tea. For these purposes 1 or 2 cups was scored as 1.5, 3 or 4 as 3.5, 5 or 6 as 5.5, and more than 6 as 6.5. The resulting caffeine intake scale was treated as a continuous variable in multiple regression analyses, and rounded down to cups of coffee-equivalent for presentation of mean performance scores. The scale ranged from 0 to 8 (values of 8 or above all being assigned the value 8).

Cognitive tests. Four simple tests of cognitive function were administered at the nurse visit. Their order was as given below and was the same for all subjects.

Reaction time (RT) was measured using a purpose-built portable machine. Subjects were asked to press numbered response keys as quickly as possible when the corresponding digit appeared on a small screen at the top of the unit. In the case of *simple reaction time* only the digit "0" appeared and subjects were required to press the centre key labelled "0". The time between a response and the next appearance of the digit varied randomly between 1 and 3 seconds. There were 8 practice trials and 20 test trials. The mean RT and standard deviation was recorded for the 20 test trials.

For *choice RT,* the digits 1, 2, 3 or 4 could appear and subjects had to press the corresponding key. There were 8 practice trials and 40 test trials (10 each of the 4 digits in random order). Inter-stimulus intervals were as for simple RT. Mean and standard deviation RT was recorded separately for correct and incorrect responses. The number of errors was also recorded.

Incidental verbal memory. A list of ten common foods was read out, and respondents were asked whether each contained dietary fibre. There was no indication that memory for the list would subsequently be tested. A few minutes later, following a distracting task, subjects were asked to name as many as possible of the foods on the list. The measure taken was the total number of foods recalled.

Visuo-spatial reasoning. Subjects were shown drawings representing three-dimensional piles of square blocks, and asked to say how many blocks each pile contained. To obtain the correct answer subjects needed to count the blocks hidden from view as well as those visible, and were therefore required to make inferences about the three-dimensional structure of simple shapes. Six drawings were used. Subjects were asked to write down their responses, taking as much time as they needed.

Control variables. A number of potential confounding variables were identified from the initial interview. These included *social class* (coded according to the Registrar General's classification of occupations); *housing tenure* (owner occupied/rented); and *educational level* (coded to five levels ranging from no educational qualification through to university degree). Use of other drugs included *alcohol* (number of units in past week; ex-alcohol drinker; never drinker); *cigarette smoking* (current, never, ex-smoker); and current use of *tranquillisers* (yes/no). Respondents provided an estimate of their *overall health* on a four-point scale ranging from "excellent" to "poor"; and in addition answered eight questions relating to current psychological well-being from which a *malaise* score (low/medium/high) was derived. Scores on the Neuroticism, Extraversion and Social Desirability scales of the Eysenck Personality Inventory were examined as potential control variables, but were not included in the results presented. They did not influence the relationships between coffee and tea consumption and test performance, and their inclusion would have reduced the subject base by over 1000.

Statistical analysis. The effects of coffee, tea and overall caffeine consumption on cognitive performance were examined by linear multiple regression analyses in which these variables were added to models which included the demographic, drug use and health variables. The resulting t statistic represents a test of the linear dose-response trend in performance across increasing levels of caffeine intake. The appropriateness of linear regression modelling was confirmed by inspecting the form of the relationships between control variables and the measures of cognitive test performance, and by examination of the distribution of residuals from the regression analysis.

Mean performance scores adjusting for control variables were derived from analyses of covariance.

Results

Patterns of coffee and tea consumption

Coffee and tea consumption were inversely related ($r = -0.44$, $n = 7200$). Each in turn showed strong associations with a number of demographic, drug use, and health variables. These relationships are detailed in Tables 1 and 2. Higher coffee consumption was associated with younger age, higher social class and educational level, owner-occupation, higher cigarette smoking prevalence and alcohol consumption, lower tranquilliser use, and better self-rated health. In most cases the association with tea consumption was of similar strength, but opposite in direction. Figure 1 illustrates the contrasting patterns of tea and coffee consumption by social class.

Scores on the four cognitive tests also varied according the level of the variables listed in Tables 1 and 2. The relationship between cognitive test performance and scores on the main demographic control variables is shown in Table 3. In particular, performance declined steeply with increasing age (e.g. correlation of age with choice reaction time $r = 0.57$), and was lower among those living in rented accommodation, with fewer educational qualifications, in lower occupational groups, and those with poorer health. Men scored better on the spa-

Table 1. Coffee consumption by demographic variables and of other drugs

	Usual number of cups of coffee per day					Univariate P value
	0 (n=2149)	1–2 (n=2645)	3–4 (n=1412)	5–6 (n=609)	7+ (n=588)	
Sex (% male)	47	44	43	44	44	NS
Age (years)	47	48	42	39	39	<0.000
Class (% non manual)	30	43	52	54	49	<0.000
Housing tenure (% owner occupied)	54	67	74	73	69	<0.000
Educatiomal level (% A-level or higher qualification)	16	26	33	35	34	<0.0001
% Retired	25	28	12	6	5	<0.000
% Not working through disability	3	2	1	2	1	0.001
Cigarette smokers %	37	27	32	43	56	<0.000
Alcohol units in past week	8.2	7.7	8.5	10.9	10.1	<0.000
% Never alcohol drinker	29	36	19	8	8	<0.000
Tranquilliser % current use	4.2	3.6	2.2	2.0	2.5	0.003
Tea (cups per day)	3.28	3.04	2.31	1.66	1.54	0.000
Health good or excellent %	67	73	76	76	73	0.000
Malaise score	1.98	1.90	1.91	1.94	1.95	0.01

Note: P values are from analysis of variance or chi-square test as appropriate

Table 2. Tea consumption by demographic variables and use of other drugs

	Usual number of cups of tea per day					Univariate P value
	0 (n=927)	1–2 (n=1308)	3–4 (n=2001)	5–6 (n=1387)	7+ (n=1784)	
Sex (% male)	43	43	42	46	49	=0.0001
Age (years)	36	41	47	50	47	<0.000
Class (% non manual)	47	53	44	41	32	<0.000
Housing tenure (% owner occupied)	66	71	67	66	58	<0.000
Education level (% A-level or higher qualification)	31	34	26	23	18	<0.0001
% Retired	6	14	26	29	19	<0.000
% Not working through disability	1	2	2	2	4	0.001
Cigarette smokers %	40	31	27	28	49	<0.000
Alcohol units in past week	9.1	10.0	8.0	7.4	8.3	<0.000
% Never alcohol drinker	19	20	25	26	24	=0.0001
Tranquilliser % current use	2.8	2.1	2.8	3.6	4.6	0.001
Coffee (cups per day)	3.03	2.29	1.66	1.36	1.33	0.000
Health good or excellent %	74	76	72	73	67	0.000
Malaise score	1.92	1.89	1.93	1.91	1.99	0.004

Note: P values are from analysis of variance or chi-square test as appropriate

tial reasoning task and had slightly faster reaction times, but women did better on the incidental verbal memory task (Cox et al. 1987).

Relationship of coffee intake to cognitive performance

On a univariate analysis, increasing levels of coffee consumption were associated with substantial improvements in performance levels on all four tasks, not surprisingly in view of the association of both coffee consumption and performance with age, social class, educational levels etc. (Table 4*A*). After controlling for tea consumption, demographic variables (age, sex, class, educational level, housing tenure, retired, not working through disability), health (self-rated overall health and current psychological malaise score), and use of alcohol, tobacco and tranquillisers, a significant trend to improved performance with increased coffee consumption was observed for each of the four tasks (simple reaction time $t=-3.36$, $P<0.001$; choice reaction time $t=-4.69$, $P<0.0001$; incidental verbal memory $t=3.41$, $P<0.001$; visuo-spatial reasoning $t=4.15$, $P<0.0001$). These relationships are illustrated in Fig. 2. Comparing those who drank more than six cups of coffee per day with those who drank none, and after adjustment for confounders,

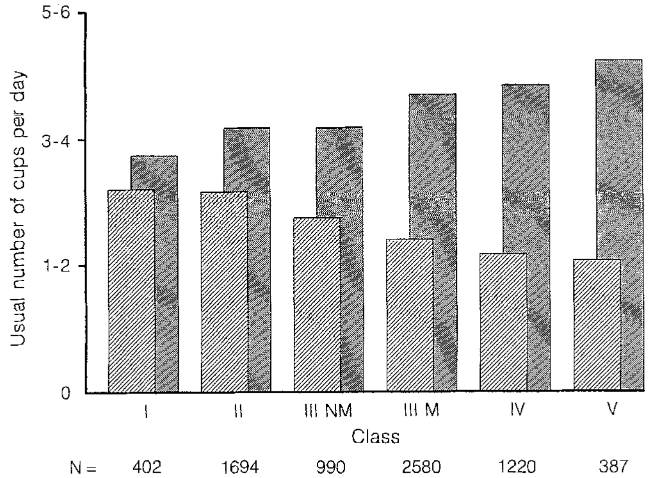

Fig. 1. Relationship between coffee (▨) and tea (▤) consumption and social class. Coffee consumption was greatest in higher social class groups, while the converse was true for tea

simple reaction time was faster by some 6% and choice reaction time by 4%, and scores on incidental verbal memory and visuo-spatial reasoning were likewise higher by 4–5%. There was no relationship between coffee consumption and the number of errors on the choice reaction time test.

Examination of interaction terms showed no differences in coffee's effects by sex, but there was a significant coffee × age interaction for the reaction time and memory (but not the visuo-spatial reasoning) tasks. This interaction was manifested as a greater performance-enhancing effect of coffee consumption in older than in younger subjects.

Relationship of tea consumption to cognitive performance

Higher tea consumption considered univariately was associated with poorer performance on all tasks (Table 4*B*). In a model which included other variables as above, but not coffee, performance did not differ significantly by tea consumption on any of the tests. However, after additionally controlling for coffee consumption, significant trends to improved performance with higher consumption were observed for simple reaction time ($t = -2.42$, $P = 0.02$) and for visuo-spatial reasoning ($t = 2.47$, $P = 0.013$). The trends towards improved per-

Table 3. Mean cognitive test scores by main demographic, social and health control variables

	n	Simple RT (ms)	Choice RT (ms)	Incidental verbal memory (no. recalled)	Visuo-spatial reasoning (no. correct)
Sex					
Male	3311	329	657	6.34	5.12
Female	4103	350	670	6.81	4.55
Age					
16–24	922	303	582	6.93	4.86
25–34	1454	312	599	6.97	4.99
35–49	2140	313	632	6.85	4.94
50–59	1108	342	686	6.52	4.83
60+	1790	416	790	5.90	4.44
Social class					
I	402	308	630	7.11	5.22
II	1695	316	638	6.98	5.15
III NM	992	325	640	6.73	4.90
III M	2582	348	676	6.50	4.68
IV	1220	369	695	6.18	4.52
V	387	379	727	6.08	4.39
Housing tenure					
Owner occupied	4825	326	646	6.77	5.00
Rented	2574	368	700	6.30	4.43
Educational qualifications					
None	3902	374	715	6.23	4.51
CSE, "O" level	1583	306	605	6.87	5.04
"A" level	938	303	606	7.08	5.15
Semi-professional	591	306	628	7.12	5.24
Degree	367	293	597	7.37	5.40
Self-reported health					
Excellent	1547	327	651	6.72	4.95
Good	3765	332	652	6.74	4.86
Fair	1680	355	686	6.36	4.69
Poor	398	409	749	5.89	4.29

Table 4. Raw and adjusted performance scores by coffee and tea consumption

	0 (n=2021)	1–2 (2504)	3–4 (1347)	5–6 (579)	7+ (563)
A. By coffee consumption, (number of cups) adjusted for standard variables and tea					
Simple RT					
Raw	357.9	349.1	323.6	307.4	307.1
Adjusted	346.9	342.6	335.9	328.6	324.4
Choice RT					
Raw	692.3	678.6	638.4	616.2	618.4
Adjusted	675.4	666.4	658.5	652.4	648.0
Incidental verbal memory					
Raw	6.29	6.58	6.81	7.00	6.92
Adjusted	6.46	6.64	6.66	6.77	6.75
Visuo-spatial reasoning					
Raw	4.60	4.78	5.00	5.06	4.98
Adjusted	4.70	4.79	4.90	4.96	4.93
B. By tea consumption (number of cups) adjusting for standard variables and coffee					
	(n=866)	(1233)	(1891)	(1326)	(1693)
Simple RT					
Raw	313.8	322.9	352.3	350.8	343.3
Adjusted	345.8	341.5	345.6	336.7	332.2
Choice RT					
Raw	617.0	636.5	678.6	686.4	677.7
Adjusted	668.5	665.3	668.4	663.3	659.9
Incidental verbal memory					
Raw	6.90	6.78	6.57	6.51	6.44
Adjusted	6.53	6.55	6.62	6.65	6.63
Visuo-spatial reasoning					
Raw	4.88	4.92	4.79	4.80	4.73
Adjusted	4.67	4.76	4.82	4.88	4.85

formance on the other tasks were weaker and failed to reach significance (choice reaction time $t=-1.27$, $P=0.20$; incidental verbal memory $t=1.26$, $P=0.21$) (see Fig. 2). No interactions between tea consumption and either age or sex in effects on test performance were present. As with coffee, errors on the choice reaction time test were unrelated to tea consumption.

Overall caffeine intake and performance

Unvariate and adjusted mean test scores by estimated overall caffeine consumption are given in Table 5. Adjustment for the same set of control variables used in the

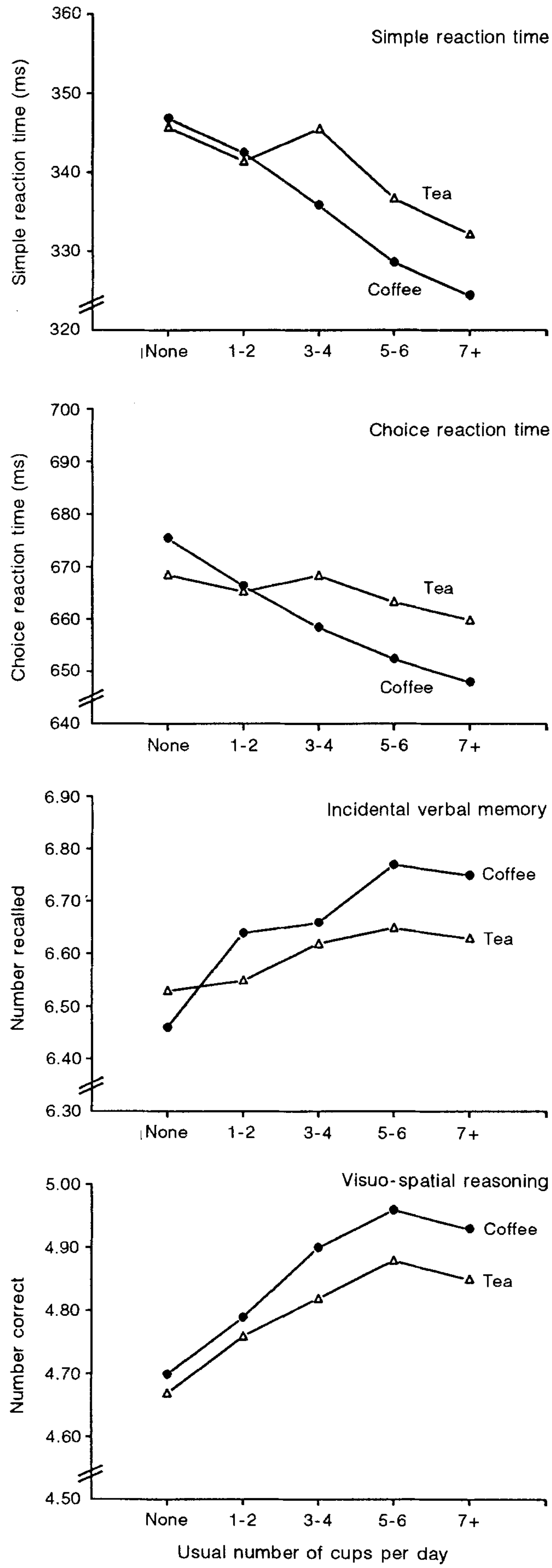

Fig. 2. Adjusted mean cognitive test scores by coffee and tea consumption. Control variables were as specified in text

Table 5. Unadjusted and adjusted mean performance scores by overall caffeine consumption (coffee and tea combined)

	Daily caffeine consumption expressed as cups of coffee equivalent									t statistic
	0– (n=284)	1– (574)	2– (839)	3– (1794)	4– (1024)	5– (1262)	6– (345)	7– (578)	8+ (363)	
Simple reaction time										
Raw	341.2	371.1	349.6	349.4	339.8	334.4	313.5	314.4	306.1	
Adjusted	350.8	358.6	345.2	340.5	337.1	337.9	329.6	330.8	327.0	$t=-3.51$ $P<0.001$
Choice reaction time	(281)	(571)	(832)	(1777)	(1017)	(1249)	(343)	(577)	(362)	
Raw	649.7	701.8	682.4	678.8	663.9	657.7	630.4	633.2	619.5	
Adjusted	673.4	686.2	676.5	664.5	658.1	662.1	653.3	658.1	649.2	$t=-4.46$ $P<0.0001$
Incidental verbal memory	(291)	(591)	(853)	(1838)	(1038)	(1285)	(351)	(585)	(368)	
Raw	6.36	6.32	6.46	6.47	6.74	6.73	6.88	6.74	6.98	
Adjusted	6.31	6.49	6.52	6.57	6.71	6.70	6.69	6.59	6.80	$t=3.26$ $P=0.001$
Visuo-spatial reasoning	(285)	(585)	(842)	(1816)	(1031)	(1280)	(348)	(582)	(368)	
Raw	4.46	4.45	4.77	4.77	4.91	4.90	5.00	4.87	5.09	
Adjusted	4.47	4.56	4.77	4.84	4.89	4.87	4.85	4.81	4.94	$t=4.07$ $P<0.0001$

Table 6. Relationship between estimated overall caffeine consumption and cognitive performance by age group

	Age Groups						All ages		
	16–34 (n=2243)		35–54 (n=2637)		55+ (n=2207)		(n=7087)		Coffee × age interaction P value
	B	t	B	t	B	t	B	t	
Simple RT	−0.53	−0.60	−1.33	−1.56	−2.82	−1.22	−2.59	−3.51**	<0.001
Choice RT	−0.84	−1.03	−1.73	−1.96*	−4.00	−2.0*	−3.02	−4.46**	<0.001
Incidental verbal memory	0.005	0.32	0.020	1.31	0.065	2.73**	0.033	3.26**	<0.001
Visuo-spatial reasoning	0.022	1.54	0.031	2.32*	0.047	2.15*	0.036	4.07**	NS

Note: B and t values are from forced-entry multiple regression analyses which controlled for the following variables: Age, sex, class, housing tenure, educational level, working status (retired/not retired); smoking status (current, ex, never); alcohol drinking (never, ex, number of units in past week); and current use of tranquillisers

B gives the change in scores on the dependent variable for a single category change in the measure of caffeine consumption

The t statistic tests the linear trend in performance across levels of caffeine consumption

Ns vary to a minor extent by cognitive task. Those presented are for choice reaction time, which had the smallest n of the four tasks

* $P<0.05$

** $P<0.01$

separate analyses of tea and coffee consumption attenuated but did not eliminate the trend to higher levels of performance with increasing caffeine intake. In each case the significance level was 0.001 or better. Figure 3 shows the adjusted trends in test performance by estimated caffeine intake.

As was the case with coffee consumption, there were significant caffeine intake × age interactions in performance on three of the four tests (the exception being the visuo-spatial reasoning test). To explore the nature of these interactions, the sample was broken into three approximately equally sized groups (16–34, 35–54, and 55 years and older), and separate multiple regression analyses were carried out on each group. Within each of these groups the age × caffeine interaction no longer reached statistical significance. The results are presented in Table 6, from where it can be seen that larger improvements in performance with increasing caffeine intake were found in older than in younger subjects. For example, comparing the highest with the lowest caffeine intake category, the regression model predicted choice reaction times faster by 32 ms in the oldest age group but by only 7 ms in the youngest. Likewise, on the memory test, among the oldest group the modelled improvement in recall was 0.52 of an item in those with the highest caffeine intake versus 0.04 of an item among the youngest group.

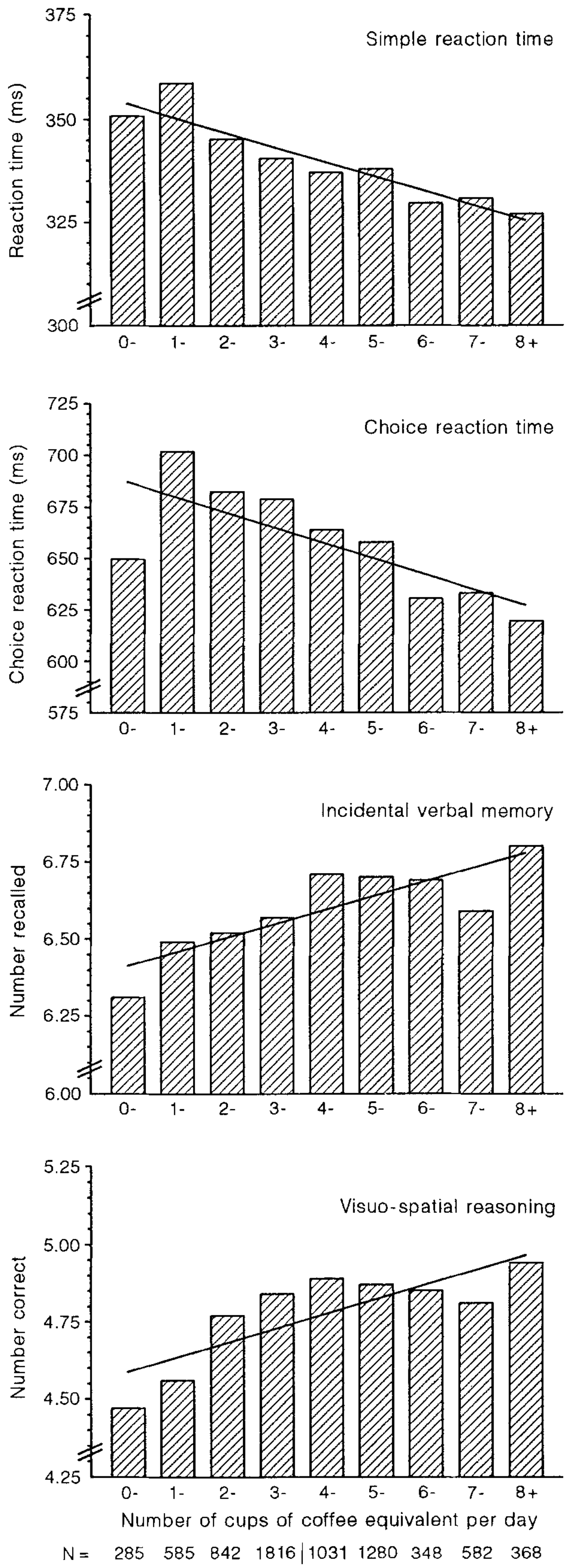

Fig. 3. Adjusted mean cognitive test scores by estimated overall caffeine consumption. Control variables as for Fig. 2

Discussion

In this large population sample, increased levels of coffee and tea consumption were associated with improved performance on a range of cognitive tests. The effects were strongest in relation to coffee, but were also found with tea, and when coffee and tea consumption were combined into an overall caffeine intake scale. The performance improvements showed a dose response relationship to increasing levels of consumption, and were independent of a wide range of potential confounding variables. The results are thus consistent with the possibility that habitual coffee and tea drinkers may not develop tolerance to the performance-enhancing effects of caffeine, but rather continue to experience absolute improvements in performance levels from use of the drug. However, there are a number of factors which might potentially militate against this conclusion.

In a cross-sectional survey of this kind subjects have self-selected their particular consumption level, and individuals in different consumption categories differ widely in age, health and socio-economic profile. Despite controlling extensively for these confounding variables, it is in principle impossible to rule out the possibility that some unidentified variable rather than caffeine might be responsible for the observed pattern of results. Only randomized allocation could answer this objection definitively. However, bias due to uncontrolled confounding seems unlikely to be of great significance. While coffee consumption was positively associated with performance when considered univariately, the association with tea consumption was negative, and coffee and tea had opposite associations with major demographic and health variables. It was only after controlling for confounders that tea consumption predicted improved performance. That there was a positive association of performance with both coffee and tea consumption, but stronger with coffee than tea is precisely what would be expected from the relative caffeine concentrations in the two beverages (Barone and Roberts 1984; Scott et al. 1989).

The level of measurement of coffee and tea consumption was only approximate. No distinction could be drawn between instant and ground coffee, or even decaffeinated. Nor was there any indication of whether individuals preferred their drinks weak or strong. Consumption on the day of testing might not be representative of usual consumption, and there was no information available on length of time since drinking the last cup. The effect of all these factors would be to introduce substantial measurement error and to reduce the power of the study to detect true effects. In view of these considerations the present analysis should be viewed more as testing the null hypothesis of no relationship between chronic caffeine intake and performance than as capable of providing reliable evidence on the size of any effects. Because of measurement error, the relation between coffee and tea intake and cognitive performance is probably stronger than appears in these data.

The estimated overall caffeine intake scale suffers from the individual weakness of tea and coffee measurement, and in addition assumes a particular caffeine equivalence between the two drinks (a cup of tea assumed to have half the caffeine content of a cup of coffee). While this seems not unreasonable in view of published data (Barone and Roberts 1984; Gilbert 1984), it may not be the true equivalence. To explore the extent to which the findings might depend on the relative weights assigned to the two drinks, weights for tea ranging from 0.3 to 0.9 of coffee were examined (data not presented). The performance improvement with increasing intake proved to be robust, and was essentially unchanged across this range.

The similarity in performance enhancement across tasks differing widely in their requirements could indicate either that caffeine affects processes specific to each test, or, more plausibly, that it influences general aspects of functioning which would influence performance on the various tests in a similar way. The most obvious candidate is level of arousal or vigilance, which many studies have shown to be raised by caffeine (e.g. Zwyghuizen-Doorenbos et al. 1990; Frewer and Lader 1991). Effects on attentional processes are another possibility. While effects on reaction time have been clearly established (Clubley et al. 1979; Lieberman et al. 1987), there are conflicting results on memory (Erikson et al. 1985; Loke 1988; Kerr et al. 1991). No previous studies appear to have investigated caffeine's effects on visuo-spatial reasoning.

A greater sensitivity to caffeine's effects in older than in younger people has been reported previously (Swift and Tiplady 1988), and would not appear to reflect age-related changes in caffeine disposition (Blanchard and Sawers 1983). One hypothesis to account for the effect might be that older people tend to operate further below their ceiling than do the young, so that there is greater scope for increases in their level of functioning. It is also possible that the weaker relationships in the young are due to less accurate measurement of their caffeine intake. Soft drinks such as colas are an important source of caffeine for teenagers and young adults, but much less so for older people. This source of caffeine intake could not be reliably ascertained in the present data.

The findings from this survey suggest that tolerance to the performance-enhancing effects of caffeine, it it occurs at all, is incomplete, with the result that higher daily caffeine consumers tend to perform somewhat better than do low consumers. This conclusion could be strengthened by further study incorporating more precise measures of caffeine dose, preferably circulating levels in blood.

Acknowledgements. Financial support was provided by the Medical Research Council and the Imperial Cancer Research Fund. The Health and Lifestyle Survey data file was supplied by the ESRC National Data Archive, Essex University.

References

Barone JJ, Roberts H (1984) Human consumption of caffeine. In: Dews PB (ed) Caffeine. Springer, Berlin, pp 59–73

Blanchard J, Sawers SJA (1983) Comparative pharmacokinetics of caffeine in young and elderly men. J Pharmacokinet Biopharm 11:109–126

Brezinova V (1974) Effect of caffeine on sleep: EEG study in late middle age people. Br J Clin Pharmacol 1:203–208

Clubley M, Bye CE, Henson TA, Peck AW, Riddington CJ (1979) Effects of caffeine and cyclizine alone and in combination on human performance, subjective effects and EEG activity. Br J Clin Pharmacol 7:157–163

Cox BD, Blaxter M, Buckle ALJ, Fenner NP, Golding JF, Gore M et al. (1987) 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 9003 British adults. Health Promotion Research Trust, London

Erikson GC, Hager LB, Houseworth C, Dungan J, Petros T, Beckwith BE (1985) The effects of caffeine on memory for word lists. Physiol Behav 35:47–51

Frewer LJ, Lader M (1991) The effects of caffeine on two computerised tests of attention and vigilance. Hum Psychopharmacol 6:119–128

Gilbert RM (1984) Caffeine consumption In: Spiller GA (ed) The Methylxanthine beverages and foods: chemistry, consumption and health effects. Liss, New York, pp 189–213

Goldstein A, Kaizer S (1969) Psychotropic effects of caffeine in man. III. A questionnaire survey of coffee drinking and its effects in a group of housewives. Clin Pharmacol Ther 10:477–488

Goldstein A, Kaizer S, Whitby O (1969) Psychotropic effects of caffeine in man. IV. Quantitative and qualitative differences associated with habituation to coffee. Clin Pharmacol Ther 10:489–497

Griffiths RR, Woodson PP (1988) Caffeine physical dependence: a review of human and laboratory animal studies. Psychopharmacology 94:437–451

Karacan I, Thornby JI, Anch M et al. (1977) Dose-related sleep disturbances induced by coffee and caffeine. Clin Pharmacol Ther 20:682–689

Kerr JS, Sherwood N, Hindmarch I (1991) Separate and combined effects of the social drugs on psychomotor performance. Psychopharmacology 104:113–119

Lieberman HR, Wartman RJ, Emde GG, Roberts C, Coviella ILG (1987) Effects of low doses of caffeine on human performance and mood. Psychopharmacology 92:308–312

Loke WH (1988) Effects of caffeine on mood and memory. Physiol Behav 44:367–372

Rall TW (1990) (In) Gilman AG, Rall TW, Nies AS, Taylor P (eds) The pharmacological basis of therapeutics, 8th ed. Pergamon Press, New York, pp 618–637

Scott NR, Chakraborty J, Marks V (1989) Caffeine consumption in the United Kingdom: a retrospective survey. Food Sciences and Nutrition 42F:183–191

Swift CG, Tiplady B (1988) The effects of age on the response to caffeine. Psychopharmacology 94:29–31

Walsh JK, Muelbach MJ, Humm TM, Dickins QS, Sugerman JL, Schweitzer PK (1990) Effect of caffeine on physiological sleep tendency and ability to sustain wakefulness at night. Psychopharmacology 101:271–273

Zwyghuizen-Doorenbos A, Roehrs TA, Lipschutz L, Timms V, Roth T (1990) Effects of caffeine on alertness. Psychopharmacology 100:36–39