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The Acute Physiological and Mood Effects of Tea and Coffee: The Role of Caffeine Level

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QUINLAN, P. T., J. LANE, K. L. MOORE, J. ASPEN, J. A. RYCROFT AND D. C. O'BRIEN. *The acute physiological and mood effects of tea and coffee: The role of caffeine level.* PHARMACOL BIOCHEM BEHAV **66**(1) 19–28, 2000.—The objective of this study was to determine the effect of caffeine level in tea and coffee on acute physiological responses and mood. Randomised full crossover design in subjects after overnight caffeine abstention was studied. In study 1 (n = 17) the caffeine level was manipulated naturalistically by preparing tea and coffee at different strengths (1 or 2 cups equivalent). Caffeine levels were 37.5 and 75 mg in tea, 75 and 150 mg in coffee, with water and no-drink controls. In study 2 (n = 15) caffeine level alone was manipulated (water, decaffeinated tea, plus 0, 25, 50, 100, and 200 mg caffeine). Beverage volume and temperature (55°C) were constant. SBP, DBP, heart rate, skin temperature, skin conductance, and mood were monitored over each 3-h study session. In study 1, tea and coffee produced mild autonomic stimulation and an elevation in mood. There were no effects of tea vs. coffee or caffeine dose, despite a fourfold variation in the latter. Increasing beverage strength was associated with greater increases in DBP and energetic arousal. In study 2, caffeinated beverages increased SBP, DBP, and skin conductance and lowered heart rate and skin temperature compared to water. Significant dose–response relationships to caffeine were seen only for SBP, heart rate, and skin temperature. There were significant effects of caffeine on energetic arousal but no consistent dose–response effects. Caffeinated beverages acutely stimulate the autonomic nervous system and increase alertness. Although caffeine can exert dose-dependent effects on a number of acute autonomic responses, caffeine level is not an important factor. Factors besides caffeine may contribute to these acute effects. © 2000 Elsevier Science Inc.

Tea Coffee Caffeine Mood Autonomic responses Blood pressure

BLACK tea and coffee are the main sources of caffeine in the Western diet. Caffeine has well documented physiological and behavioural effects, and it is therefore reasonable to assume that the effects of tea and coffee consumption will be principally due to caffeine. However, two recent studies in which the effects of tea, coffee, and hot water ingestion (±caffeine) were compared have shown that the acute effects of tea and coffee consumption are not identical to the same dose of caffeine (11,28). In both studies tea and coffee were normalised to the same caffeine content so that the factors "caffeine" and "beverage type" could be analysed independently. However, tea and coffee as normally consumed contain different levels of caffeine that could lead to differences in the acute effects of these beverages. A serving of tea typically contains ~40 mg caffeine, instant coffee 60 mg, and filter or percolated coffee 80–115 mg (1,23). In practice, caffeine levels can vary widely, primarily due to differences in preparation method. A recent study showed that the caffeine content of tea infusions as prepared by consumers varied between 32 and 56 mg, and for filter and percolated coffee was 60–125 mg caffeine per 200-ml serving (24). Two observations arise from this analysis.

First, because the amount of caffeine consumed in a single serving can vary over a wide range (~30 to 175 mg per serving), it is important to understand the dose–response effects of caffeine. Comparatively few studies have been conducted within this range. Dose–response effects have been observed for SBP over the range of 45–360 mg caffeine but not DBP (25). Similarly, caffeine levels between 40–160 mg (17) and 100–400 mg (9) did not increase DBP dose dependently. Furthermore, at low doses the behavioural effects of caffeine do not appear to be strongly dose dependent (9,20).

Second, in many clinical studies the caffeine dose administered is often ⩾200 mg, and can be as high as 600 mg, given as

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a single bolus—far greater than the amount in a typical cup of tea or coffee. The effects observed under such conditions may not reflect the responses produced by normal tea and coffee consumption. At high doses (~4–500 mg) the mood benefits of caffeine can be reversed leading to increases in tension and anxiety (22) and even performance decrements (15).

Relatively few studies have been conducted using low doses of caffeine. At doses ≤200 mg, caffeine has been shown to increase blood pressure after overnight withdrawal (9,25,28) and improve performance on simple reaction tasks, increase alertness, and decrease drowsiness and fatigue (4,9,11,17,20,28,30,31,35). The lowest dose tested in the above studies was 32 mg caffeine, which significantly improved auditory vigilance and visual reaction time (20), indicating that even caffeine levels typically found in a cup of tea can have behavioural effects.

The current studies were, therefore, designed to determine the acute physiological and mood effects of tea and coffee as normally consumed (study 1) and the dose–response effects of caffeine over the range of 0–200 mg using decaffeinated tea as the vehicle (study 2). In particular, we have examined further to what extent the acute effects of tea and coffee ingestion can be explained by the caffeine level in the beverage.

STUDY 1

Method

Subjects. All subjects were healthy nonsmokers. The main exclusion criteria were: <18 years old: smokers; caffeine abstainers; a significant past history of any medical disorders; chronic users of any form of medication (except the contraceptive pill); systemic drug usage in the previous 7 days; nursing mothers; and women who were planning or thought they might be pregnant. The study was conducted according to the guidelines issued by the British Psychological Society, and written informed consent was obtained from all subjects.

Eight male and nine female subjects (mean age 35, range 21–51 years) were recruited. All subjects were habitual caffeine consumers with a mean caffeine intake, estimated from a 7-day food diary (including caffeine from beverages, analgesics, and sweets), of 339 mg/day (range 110–534 mg/day).

Design. This was a within-subject complete crossover design with 6(beverage) × 2(caffeine abstention) conditions—a total of 12 treatments. Within the beverage treatments there were three levels of caffeine given as either tea or coffee, with the strength manipulated to deliver different doses and a "no-drink" and hot-water treatment included as controls. The six beverages were (caffeine levels in brackets): no drink; hot water; tea (37.5 mg); tea (75 mg); coffee (75 mg); coffee (150 mg).

Beverages were administered after either a 3- or 16-h (overnight) abstention from caffeine. In the 3-h abstention group subjects were instructed to consume their normal caffeinated drink at breakfast. Detailed instructions were given to subjects concerning which foods and beverages could be consumed during the abstention period, and subjects were required to complete a food and beverage diary during this period. This was checked for compliance to study restrictions. Subjects were told that they may be required to consume a beverage during the study session; no further details concerning the beverages were provided. No attempt was made to disguise the nature of the beverage (tea, coffee, or water), which was consumed immediately on presentation to the subject. The presentation of the 12 treatments to subjects was balanced for order and carryover effects.

Beverages. All beverages, including hot water were served at 55°C. These were given in plastic cups with holders, thus preventing direct skin contact with the hot surface.

Fresh brewed tea was prepared from a standard blend supplied by T. J. Lipton Inc., and the strength manipulated to deliver either 37.5 or 75 mg caffeine per 300-ml serving. Tea solids/serving were 0.5 and 1 g, respectively. Instant coffee (Nescafe Gold blend) was used at 2.46 and 4.91 g/300 ml to provide caffeine levels of 75 and 150 mg, respectively.

Measures. Blood pressure was measured at 3-min intervals via detection of Korotkoff sounds using a SD700A BP monitor (Industrial and Biomedical Sensors Corp., MA) placed around the nondominant upper arm with the microphone positioned over the brachial artery. Deflation rate was set at 3 mmHg/s.

A Psylab system (Contact Precision Instruments, London, UK) was used to continuously measure cardiac interbeat interval, skin conductance, and skin temperature, and the data processed via an analog-to-digital converter, Psylab version 3.0 data collection and processing software, and a 486 PC. Cardiac interbeat interval, defined as the time between successive peaks of an electrocardiogram R-wave, was obtained using 16 mm Ag/AgCl electrodes (Red Dot, 3M, St. Paul, MN) one placed on the musculature of the right side of the neck, and two on the left lateral abdomen. Skin conductance was measured using direct coupling with constant voltage electrode excitation. Electrodes (8 mm Ag/AgCl, Contact Precision Instruments) were placed on the medial phalanges on the middle fingers on the nondominant hand. Electrode paste was prepared as described previously (28). Skin temperature was measured using a TP active temperature probe attached to the palmar surface of the fourth finger.

Saliva was collected in Salivette tubes (Sarstedt, Numbrecht, FRD) 15 min prior to beverage administration and 15, 30, 60, and 90-min postconsumption. Subjects were asked to place the cotton wool plug in their mouth for 1 min, and return the plug to the collection tube. Samples were kept at 4°C until analysed using the EMIT assay as described previously (16).

Questionnaires were completed at the same time that saliva was collected. These included the University of Wales Institute of Science & Technology (UWIST) mood adjective questionnaire (24) comprising a series of 24 mood adjectives, which subjects scored as describing their current mood on a four-point scale (definitely, slightly, slightly not, definitely not). These scores were then aggregated to provide three measures of mood: energetic arousal, tense arousal, and hedonic tone. Significant correlations have been demonstrated between the arousal scales and psychophysiological measures of arousal (24). Line Analogue Ratings Scale (LARS) were administered at the same time points. Subjective ratings of treatment effects were obtained from a series of 100 mm LARS. The mean score of ratings of tiredness, drowsiness, and alertness (which were included among a series of distracter scales) was taken as a measure of subjective sedation (10).

Procedure. The study sessions were conducted in a room maintained at a constant temperature of 21–23°C and a relative humidity of 40%. On arrival (0930 h), subjects were connected to the various physiological measures and seated in a comfortable chair where they remained quietly with the minimum of interference for the duration of the session. When not completing questionnaires, subjects were allowed to browse general interest magazines. Beverages were administered at 1000 h, and subjects monitored until 1145 h.

Data handling and analysis. Physiological data were screened and values set as missing if they fell outside the following

ranges: SBP, 90–180 mmHg; DBP, 50–100 mmHg; SBP-DBP >10 mmHg; heart rate, 40–120 bpm; skin temperature, >19°C. Data points outside these ranges were rare, and generally associated with dislodged electrodes or, in the case of blood pressure, inconclusive readings due to subject movement during measurement. To check that subjects received the correct treatment, the beverages were sampled and a random 10% analysed for caffeine content. Caffeine levels in saliva were determined to ensure compliance to the prestudy caffeine restrictions and checked for consistency with the treatment administered on each study day. No discrepancies were found.

Skin conductance response, skin conductance level, skin temperature, and heart rate (interbeat interval) data were divided into 3-min bins and median values calculated. During preliminary analysis it was found that the assumption of homogeneity of variance was not upheld for skin conductance count and heart rate. These variables were, therefore, transformed to the natural logarithmic scale where the assumption of variance homogeneity was upheld. For all variables the adjusted means were calculated by ANCOVA, using baseline values as covariates. A mixed model (8) was fitted for all variables to estimate the required fixed effects, adjusted for the random subject effect and the session order fixed effects, and accounting for the repeated-measures structure within a study session. The latter was achieved by using a full unstructured variance-covariance matrix.

For all variables significance tests were conducted on the following contrasts: (a) no drink vs. hot water; hot water vs. caffeinated beverages; (c) tea vs. coffee; beverage strength (1 cup vs. 2 cups-equivalent); caffeine dose response.

All statistical analysis was performed using a standard software package (21).

Results

Saliva caffeine. There was a significant difference in baseline saliva caffeine levels for the 16- and 3-h caffeine abstention conditions, $F(1, 158) = 3.55$, $p = 0.0005$. However, this difference though highly significant was quantitatively small (2.97 vs, 4.45 μM, respectively). Subsequently we checked subjects' diet records in the "3-h caffeine abstention" group and found that on a significant number of occasions subjects did not consume a caffeinated beverage at breakfast, either because of an overzealous interpretation of the dietary instructions or because this was their normal custom. As this compromised interpretation of this aspect of the study, no results are reported for the "3-h caffeine abstention" group, although the data was analysed as dictated by the protocol.

The postdrink change in salivary caffeine was consistent with the level present in each beverage (Fig. 1). There was no significant difference in the salivary caffeine levels following tea and coffee ingestion at equivalent caffeine levels.

Blood pressure. Blood pressure remained stable for both no drink and hot water for most of the study session. Compared to no drink, however, consumption of hot water was associated with a transient increase in SBP (but not DBP) of 4 mmHg in the first 10-min postconsumption, $F(1, 140) = 2.45$, $p = 0.016$. All caffeinated beverages showed a similar small increase, and this was maintained compared to hot water during the 10–30-min, $F(1, 140) = 3.22$, $p = 0.002$, and 30–60-min, $F(1, 140) = 3.53$, p 0.0006 (Fig. 2) periods postconsumption, but was not significant beyond 60 min. Similarly, compared to hot water, caffeinated beverage ingestion was associated with a short-lived increase in DBP over the 10–30, $F(1, 140) = 1.95$, $p = 0.053$, and 30–60-min, $F(1, 140) = 3.28$, $p = 0.001$ (Fig. 2) postbeverage periods only.

There was no effect of caffeine dose on SBP or DBP for any of the time periods. Tea and coffee were not significantly different; however, for SBP only at 60–105 min, the difference between tea and coffee was of borderline significance, $F(1, 140) = 1.95$, $p = 0.053$, with coffee showing an increase over baseline of 7.5 (0.9) and tea an increase of 4.6 (0.9) mmHg [mean (SE)]. There was no effect of beverage strength on SBP; however, for DBP, beverage strength was significant at 10–30 min, $F(1, 140) = 2.13$, $p = 0.013$, and 30–60 min, $F(1, 141) = 2.32$, $p = 0.022$, with the "2-cup equivalent" beverages giving a greater response than the "1-cup equivalent" (Table 1).

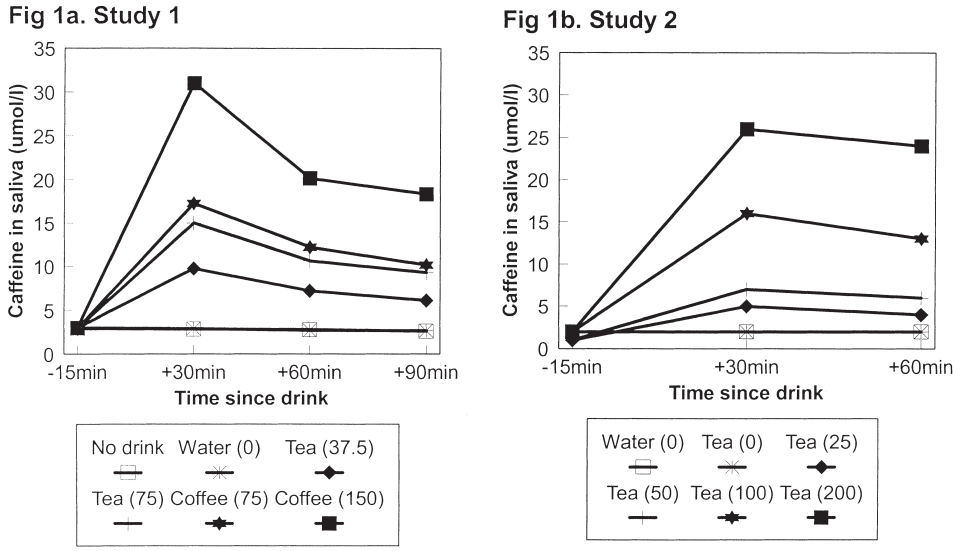

FIG. 1. Caffeine levels in saliva before and after beverage ingestion. Saliva samples were collected and analysed as described in the Method section. Caffeine levels (mg/serving) in beverages are shown in parentheses.

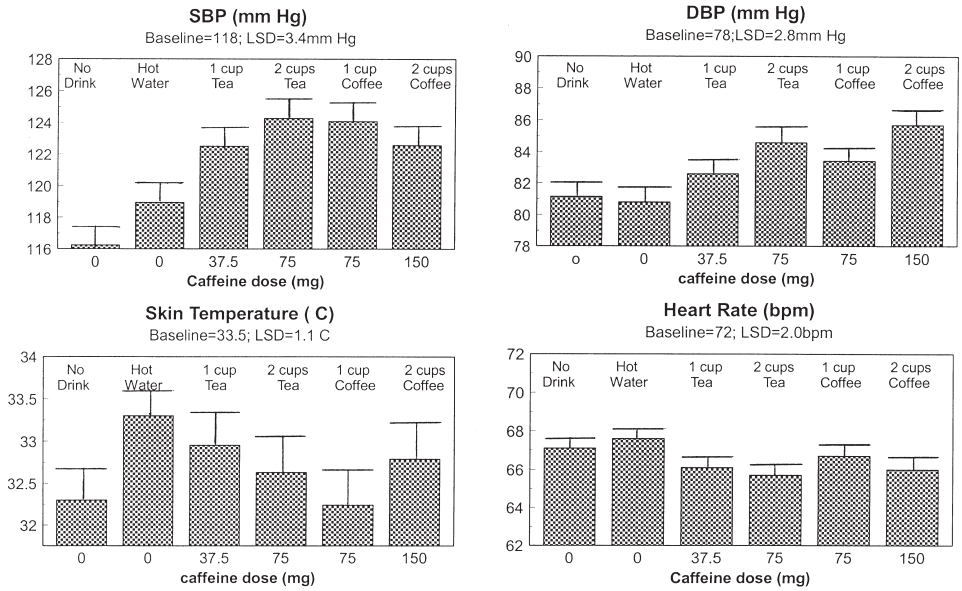

FIG. 2. Effect of caffeine dose on autonomic responses: response to tea and coffee of differing strength. Beverage volume was constant (300 ml) with strength manipulated to deliver 1 or 2 cups-equivalent of tea or coffee. Data are adjusted means using baseline (defined as the 10 min immediately prior to beverage ingestion) as covariate. All caffeinated treatments were significantly different from no drink and water, but there was no effect of caffeine dose. Heart rate data was backtransformed from the log scale.

Heart rate. Compared to no drink, consumption of hot water was associated with a transient increase in heart rate of ~5 bpm in the first 10-min postconsumption, $F(1, 141) = 7.93$, $p = 0.0001$. All caffeinated beverages showed a similar immediate increase, but was followed by a significant decline in heart rate compared to hot water of ~2 bpm during the 10–30-min, $F(1, 141) = 2.55$, $p = 0.012$, 30–60-min, $F(1, 141) = 2.19$, $p = 0.03$, and 60–105-min, $F(1, 141) = 2.1$, $p = 0.037$, periods postconsumption.

There was no effect of caffeine dose or tea vs. coffee for any of the time periods. The effect of beverage strength was of borderline significance at 10–30 min, $F(1, 141) = 1.95$, $p = 0.054$ (Table 1).

Skin conductance. Both skin conductance response (SCR, counts/min) and level declined throughout the study session in the no-drink group. Responses for both parameters were very similar, and therefore, only data for SCR is presented (Table 2). Beverage ingestion was associated with an immediate increase in SCR, which, in the case of hot water vs. no drink, was sustained only for the 0–10 min, $F(1, 141) = 2.59$, $p = 0.01$, and 10–30 min, $F(1, 141) = 3.03$, $p = 0.003$, period. Caffeinated beverages showed an additional increase in SCR over hot water during the 10–30-min period only, $F(1, 141) = 2.23$, $p = 0.03$.

Skin temperature. Skin temperature gradually declined in the no-drink group throughout the study from a predrink baseline of 33.5 to 30°C 60–105 min postconsumption. This was probably due to the lack of physical activity during the study session. Beverage ingestion was associated with a rapid rise in skin temperature of ~1°C in the first 10 min and ~1.8°C in the 10–30-min period. The no-drink vs. hot water contrast was significant at 0–10 min, $F(1, 139) = 2.57$, $p = 0.011$, and 10–30 min, $F(1, 139) = 4.55$, $p = 0.0001$, but not thereafter. There was no effect of caffeine dose, beverage strength, or tea vs. coffee for any of the time periods (Fig. 2).

Mood. There was no effect of time postconsumption on the mood data, which was, therefore, averaged across the time points. Consumption of a caffeinated beverage compared to hot water was associated with significant improvements in energetic arousal, $F(1, 62) = 2.03$, $p = 0.05$, and hedonic tone, $F(1, 62) = 2.77$, $p = 0.007$, and a reduction in sedation score, $F(1, 62) = 2.27$, $p = 0.03$ (Fig. 3). There were no effects of caffeine dose or tea vs. coffee. However, coffee consumption was associated with a lower sedation score than tea, $F(1, 62) = 2.06$, $p = 0.04$. Beverage strength affected energetic arousal, $F(1, 62) = 2.12$, $p = 0.03$, with "2 cups equivalent" giving a greater increase in arousal than 1 cup (Table 2).

STUDY 2

Method

Unless otherwise indicated these were identical to Study 1.

Subjects. Seven male and eight female subjects (mean age 33.9, range 22–52 years) were recruited. All subjects were habitual caffeine consumers, with a mean caffeine intake, estimated from a 7-day food diary, of 351 mg/day (range 185–635 mg/day).

Design. Within-subject, complete crossover design, with treatment days separated by at least 1 week. Decaffeinated tea was used as the vehicle for caffeine, and hot water as the control. Tea solids and beverage volume were kept constant, with only the caffeine level varied. The six treatments were: hot water, decaffeinated tea (5 mg caffeine), and decaffeinated tea plus 25, 50, 100, and 200 mg caffeine. Caffeine levels were, therefore, 0, 5, 30, 55, 105, and 205 mg, respectively.

Beverages. Black tea extract was prepared from a standard blend by T. J. Lipton Inc., Englewood Cliffs, NJ, and decaffeinated using supercritical carbon dioxide as solvent. This process reduced the caffeine content from 7.5 to 0.5%. The

TABLE 1
EFFECT OF BEVERAGE INGESTION ON AUTONOMIC PARAMETERS

	Postbeverage Period			
Mean (SE)	1–10 min	10–30 min	30–60 min	60–105 min
SBP (baseline: 118 mmHg)				
No drink	117.6 (1.2)	118.3 (1.1)	116.8 (1.1)	118.9 (1.2)
Water	121.8 (1.2)*	117.5 (1.1)	118.9 (1.1)	122.5 (1.2)*
Tea/coffee	121.7 (1.3)	121.6 (0.6)¶	123.4 (0.6)#	124.2 (0.6)
DBP (baseline: 78 mmHg)				
No drink	80.8 (1.1)	80.5 (1.0)	81.1 (0.9)	82.0 (1.0)
Water	82.0 (1.1)	80.0 (1.0)	80.8 (0.0)	82.7 (1.0)
Tea/coffee	82.0 (0.6)	82.2 (0.5)	84.1 (0.5)¶	84.0 (0.5)
Skin temperature (baseline 33.5ºC)				
No drink	33.8 (0.3)	33.3 (0.3)	32.3 (0.4)	30 (0.5)
Water	34.7 (0.3)*	35.1 (0.3)‡	33.3 (0.4)	30.2 (0.5)
Tea/coffee	34.5 (0.1)	35.2 (0.1)‡	32.7 (0.2)	29.6 (0.3)
Skin conductance (baseline: 1.52 counts/min)				
No drink	0.82 (0.4)	1.02 (0.3)	0.32 (7)	0.12 (0.2)
Water	2.22 (0.4)†	2.22 (0.3)†	0.82 (0.3)	0.22 (0.2)
Tea/coffee	1.1 (0.2)	1.6 (0.1)§	1.51 (0.1)	0.32 (0.1)
Heart rate (baseline: 72 bpm)				
No drink	69.8 (0.5)	69.4 (0.6)	67.1 (0.7)	65.7 (0.6)
Water	75.6 (0.5)‡	70.3 (0.6)	67.6 (0.7)	67.3 (0.6)
Tea/coffee	75.7 (0.3)	68.8 (0.3)¶	66.1 (0.4)§	65.9 (0.3)§

No drink vs. hot water: *$p < 0.05$; †$p < 0.01$; ‡$p < 0.001$.
Hot water vs. tea/coffee: §$p < 0.05$; ¶$p < 0.01$; #$p < 0.001$.
The table shows the time-dependent effect of beverage ingestion on autonomic parameters. Data are adjusted means using baseline as covariate. For ease of interpretation, the heart rate and skin conductance data are backtransformed from the log scale (together with an approximate SE) on which the statistical analysis was based. The caffeinated beverages (weak and strong tea and coffee) are combined, as for the most part, these were not significantly different.

tea solids were used at a constant level of 1 g/400 ml serving, with additional caffeine (Alfa Chemicals Ltd, Bracknell, UK) added to the required level. This level of tea solids was within the range of normal fresh brewed tea, and was kept constant to avoid confounding the effect of caffeine level and to prevent problems of palatability. The level of caffeine used did not significantly affect the taste of the tea as determined by a "blind" tasting session.

Procedure. Subjects abstained from all caffeine containing foods and beverages for 24 h prior to the study session.

Saliva samples were collected, and questionnaires administered 30 min before, and 15, 30, and 60 min after beverage consumption.

Data handling and analysis. Each study session was divided into three bins of approximately 30-min duration, comprising a baseline (predrink) and two postdrink periods (0–30 and 30–60 min postdrink). Adjusted means were calculated after ANCOVA, with baseline as covariate. In these analyses,

TABLE 2
EFFECT OF BEVERAGE STRENGTH ON AUTONOMIC PARAMETERS AND MOOD

Median (SE)	1 Cup Equivalent	2 Cups Equivalent	*p*-Value
Heart rate (baseline 72 bpm)			
10–30 min postbeverage	69.3 (0.5)	68.2 (0.5)	0.07
30–60 min postbeverage	66.4 (0.5)	65.9 (0.5)	NS
DBP (baseline 78mm Hg)			
10–30 min postbeverage	80.9 (1.1)	83.6 (1.1)	0.01
30–60 min postbeverage	83.0 (1.1)	85.26 (1.2)	0.02
Energetic arousal (baseline 2.73)			
Postbeverage*	2.78 (0.07)	2.98 (0.07)	0.04

*Average at 15, 30, 60, and 90 min postconsumption.
Results show the effect of 1 vs. 2 cups-equivalent of tea or coffee on DBP and energetic arousal. Data are adjusted means using baseline as covariate. Heart rate data was backtransformed from the log scale.

TABLE 3
MEAN SCR TO BEVERAGE INGESTION

Beverage	Caffeine Level (mg)	SCR (Counts/min)*
Baseline		1.99
Water	0	2.65 (0.15)
Tea	0	2.51 (0.16)
Tea	25	2.24 (0.16)
Tea	50	2.48 (0.14)
Tea	100	3.22 (0.15)
Tea	200	2.88 (0.15)

*10–15, 30–35, and 60–65 min postconsumption.
Results show the effect of beverage and caffeine ingestion on the change in skin conductance response (SCR). For presentation, the data was backtransformed from the log scale on which the statistical analysis was based.

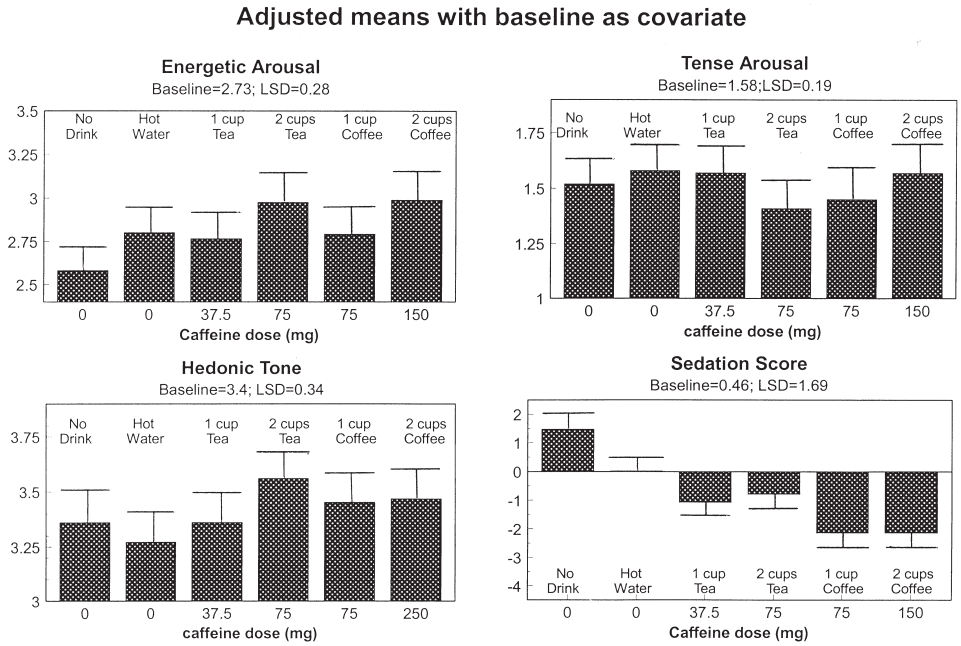

FIG. 3. Effect of caffeine dose on mood: response to tea and coffee of differing strength. The UWIST mood questionnaire was analysed (24) to provide the following dimensions of mood: energetic arousal, hedonic tone, and tense arousal. The LARS were analysed to provide a single measure—sedation score (10). Data are adjusted means using baseline as covariate.

the repeated-measures structure within a study session was accounted for by adjusting the appropriate degrees of freedom by the Greenhouse-Geisser epsilon (7).

The main statistical comparison was within the tea treatments to determine the effect of caffeine dose for 0–60 min postingestion. In addition, the effect of caffeinated (tea with 25, 50, 100, and 200 mg caffeine) vs. decaffeinated beverages (hot water and decaffeinated tea) was determined after first checking that the latter two treatments were not statistically different. The questionnaire data was analysed as for Study 1 for the comparisons outlined above.

Results

Salivary caffeine levels. Baseline saliva caffeine levels were typically 2 μM or less, indicating good compliance to the dietary restrictions. Saliva caffeine levels postbeverage ingestion showed a clear dose-dependent effect proportional to the beverage caffeine content (Fig 1b).

Blood pressure. A main effect of caffeine was seen on SBP, $F(1, 166) = 9.38$, $p = 0.003$, which was dose dependent, $F(3, 166) = 2.94$, $p = 0.035$ (Fig. 4). However, 100 mg or above was required to significantly increase SBP above predrink levels ($LSD_{0.05} = 2.32$). There was a main effect of caffeine on DBP, $F(1, 166) = 12.4$, $p < 0.001$, but this effect was not dose dependent (Fig. 4).

Heart rate. Caffeine ingestion was associated with a small but significant reduction in heart rate, $F(1, 67) = 16.4$, $p < 0.001$ (Fig. 4). Compared to predrink levels, heart rate decreased by 1.8 bpm following the decaffeinated beverages, and by 4.3 bpm with the caffeinated treatments. Heart rate progressively declined with increasing caffeine dose, $F(3, 67) = 3.0$, $p = 0.036$ (Fig. 4).

Skin conductance. Hot beverage ingestion was associated with a small increase in SCR from 2.76 to 3.22 counts/min. Over the whole time course caffeine ingestion had no effect on SCR, $F(1, 68) = 1.72$, $p = 0.194$. However, more detailed analysis showed that caffeine did augment the SCR response during the three periods (10–15, 30–35, and 60–65 min postconsumption) when questionnaires were being completed, $F(2, 1612) = 3.54$, $p = 0.03$. However, no effect of caffeine dose was observed (Table 2).

Skin temperature. Hot beverage ingestion was associated with a rapid increase in skin temperature of ~1.5°C after 10 min, before declining back to baseline or below around 40 min postconsumption. Caffeine ingestion was associated with a dampening of this response and an overall reduction in skin temperature, $F(1, 67) = 7.38$, $p = 0.008$, and this effect was dose dependent, $F(3, 67) = 2.9$, $p = 0.041$ (Fig. 4). Black decaffeinated tea maintained the highest skin temperature of all the treatments, including hot water, whereas the 200-mg caffeine dose decreased temperature by 1.39°C over the same period (Fig. 4). However, using an $LSD_{0.05}$ of 0.713 (SED = 0.360) decaffeinated tea, 25- and 50-mg treatments were not significantly different from baseline.

Questionnaires. Analysis of the mood questionnaire (UWIST) revealed an effect of caffeine, $F(1, 135) = 7.72$, $p = 0.006$, and caffeine dose, $F(3, 135) = 2.74$, $p = 0.046$, on energetic arousal (Fig. 5). The dose response was "U"-shaped, with the lowest and highest doses producing the largest increase. However, there was no effect of caffeine on tense arousal or hedonic tone.

An effect of caffeine, $F(1, 112) = 3.76$, $p = 0.0003$, and caffeine dose, $F(3, 113) = 6.88$, $p = 0.0003$, was seen on the LARS assessment of sedation score (Fig. 5). Sedation was decreased by all doses of caffeine except 50 mg.

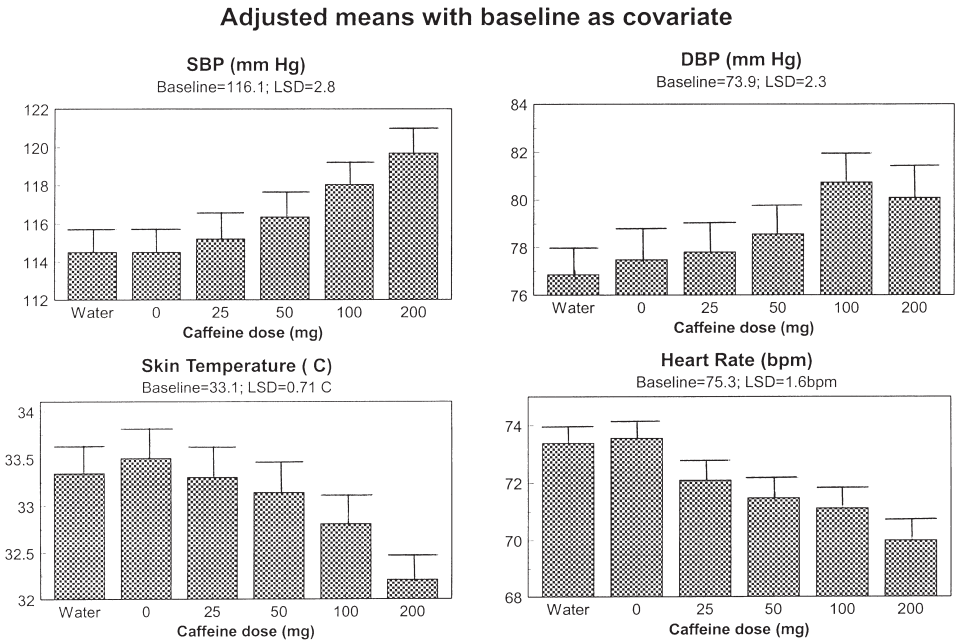

FIG. 4. Effect of caffeine dose on autonomic responses: caffeine dose response at constant tea solids. Caffeine dose level was manipulated between 0 and 200 mg/serving while maintaining constant tea solids. Hot water served as a control. The reponse to beverage ingestion was calculated as in Fig. 2. Caffeinated tea treatments were significantly different from caffeine free beverages (water and decaffeinated tea), and within the tea treatments there were significant effects of caffeine dose on SBP ($p = 0.035$), heart rate ($p = 0.03$), and skin temperature ($p = 0.04$). Data are adjusted means using baseline as covariate.

Discussion

Effect of caffeinated beverage ingestion. In keeping with many published studies, we found that caffeinated beverage ingestion was associated with mild stimulation of autonomic measures (Figs. 2 and 4), and improvements in some aspects of mood, particularly alertness (Figs. 3 and 5), which, in many cases, were independent of caffeine dose. The small physiological changes observed following beverage ingestion are clinically insignificant, but may contribute to the immediate effect of these beverages on mood.

Caffeinated beverage ingestion produced a small increase in blood pressure, typically in the range of 4–6 mmHg. Blood pressure has been shown to increase following caffeine administration in many studies [e.g., (9,25,26,28,32)]. Caffeine's pressor effects are thought to be mediated at least in part via adenosine receptor antagonism, leading to peripheral vasoconstriction and an increase in systemic vascular resistance (26,27,32).

Heart rate decreased slightly following caffeine ingestion by around 2 bpm, over and above the effect of hot water (Figs. 2 and 4). Similar decreases in heart rate following caffeine ingestion have been reported (25,27), although others found no change (6,19,28) or even an increase (26). Caffeine can affect heart rate via a number of mechanisms; at sympathetic nerve terminals adenosine antagonism by caffeine stimulates norepinephrine release leading to increases in heart rate and contractility (5). This may be augmented by increased sympathetic drive to the heart via increased activity at the locus coeruleus. However, caffeine can also stimulate the medullary vagal nuclei, directly or via baroreceptor reflex mechanisms, causing a decrease in heart rate (5). These opposing effects may explain why caffeine can have mixed effects on heart rate. In the present study, the decreased heart rate combined with increases in blood pressure suggests that baroreceptor-mediated stimulation of the vagal nuclei dominated.

Skin temperature, an index of blood flow to the skin (14), decreased over the course of the test sessions, probably as a result of physical inactivity. However, in the first 30 min postbeverage, skin temperature increased (data not shown) largely due to the effects of hot water, as shown previously (28). Caffeinated beverage ingestion was associated with a reduction in skin temperature, suggestive of peripheral vasoconstriction and an increase in vascular resistance. This finding is in line with the mechanism proposed above for the effect of caffeine on blood pressure.

Skin conductance is a sensitive measure of autonomic nervous system activation (12). In keeping with previous studies (2,3,28,34,36), we found that caffeinated beverage ingestion was associated with small increases in skin conductance (Table 2). In the first study, this effect was significant only during the 10–30-min period postbeverage consumption, when the increase in skin conductance was at its greatest. However, during the second study, there was no overall effect of caffeinated beverage ingestion during the same period. Closer examination of the pattern of response indicated skin conductance was particularly elevated during the three time periods when questionnaires were being completed by subjects. These periods were, therefore, examined in further detail (Table 2), and a significant effect ($p = 0.03$) of caffeine was found on SCR elicited during the completion of questionnaires. Others have reported that caffeine can increase both spontaneous and elicited SCRs (32,34).

Caffeinated beverage ingestion was also associated with increases in mood, particularly dimensions associated with

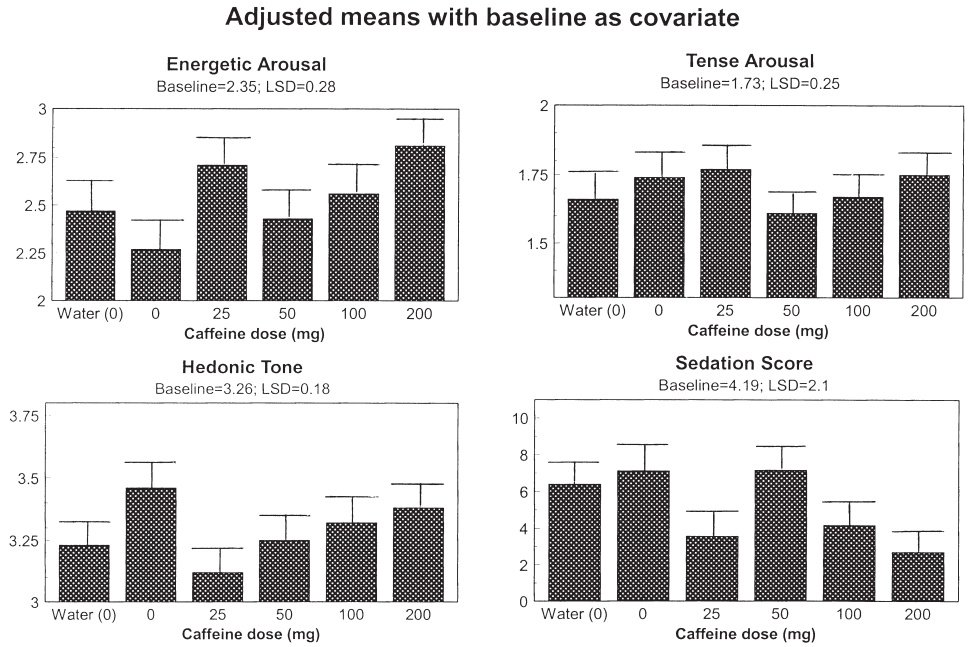

FIG. 5. Effect of caffeine dose on mood: caffeine dose response at constant tea solids. Questionnaires were analysed as described in Fig. 4.

alertness (increased energetic arousal and reduced sedation score; Figs 3 and 5). This is in keeping with previous studies, demonstrating that even low doses of caffeine are able to have positive mood effects (11,20,28,35). These low doses of caffeine were not associated with increases in anxiety ratings.

The effect of caffeine withdrawal on the behavioural responses to caffeine ingestion is disputed, with some investigators suggesting that caffeine may only restore performance degraded by abstinence [e.g., (13,19)]. Study 1 was designed to address this issue in that subjects were either withdrawn for 16 h (overnight) or 3 h (since breakfast) prior to the study session, in the event some subjects in the "3-h withdrawn" condition failed to consume a caffeinated beverage at breakfast thus compromising this arm of the study. Thus, while the 3-h withdrawn subjects had significantly higher baseline caffeine levels than the 16-h withdrawn, the differences were small (4.45 vs. 2.97 μM, respectively). Results from the 3-h withdrawn group are, therefore, not reported, though statistical analysis showed no difference in the physiological or behavioural effects of tea or coffee in the two conditions. The effect of withdrawal requires further investigation, particularly as investigators have found both improvements (11,31,35) or no effect of caffeine (13) on behavioural measures after short periods of deprivation. Nevertheless, overnight abstention from caffeine as used in the present studies is representative of normal consumer behaviour.

Effect of caffeine dose. Tea and coffee as consumed can vary widely in the amount of caffeine per serving (1,23) due to differences in preparation method (beverage strength) or the beverage itself (tea typically has half the caffeine of coffee). It is, therefore, important to determine to what extent differences in the caffeine content of beverages affect the acute responses following ingestion.

Differences in caffeine intake were achieved in Study 1 by preparing tea and coffee at two different strengths (typical of 1 or 2 cups of tea or coffee), and in Study 2 by varying only the caffeine content in a tea-based beverage. In Study 1, differences in caffeine level may have been "cued" by the perceived strength of the beverage, whereas in Study 2 the caffeine manipulation was blind to the subjects, and could not be discriminated during an independent taste test. The effects on autonomic variables are shown in Figs. 2 and 4. In Study 1, we found no evidence for a dose–response effect of caffeine for any measure, with all caffeinated treatments producing similar effects. Similarly, we could find no evidence for an effect of tea vs. coffee on these measures, despite a twofold difference in caffeine level between these drinks. By contrast, in Study 2 we were able to demonstrate dose-dependent effects on SBP, heart rate, and skin temperature (Fig 4). There was some evidence for dose-dependent effects on mood also, but the responses were atypical with the lowest and highest doses of caffeine producing the greatest improvement in mood (Fig. 5).

It is possible that individual differences in caffeine metabolism may have weakened any association between caffeine intake and dose–response effects on the dependent measures. An alternative approach in future studies may, therefore, be to relate circulating caffeine levels to the biological effects, but this would require a larger pool of subjects.

A few studies have examined the dose–response effects of low doses of caffeine. In one study where the effect of 45, 90, 180, and 360 mg caffeine was examined, a dose–response effect to heart rate and SBP, but not DBP was observed (25). For comparison, 90 mg caffeine produced a 4-mmHg rise in SBP, 8-mmHg rise in DBP, and a 2-bpm drop in heart rate, similar to the results we found for 100 mg caffeine (Fig. 4). In another study, no dose–response effects to caffeine were observed at 90, 180, and 360 mg caffeine for DBP, reaction time, and motor activity, but dose–response effects were observed for SBP, α- and β-EEG frequencies, anxiety, and wakefulness (9). In relation to mood, lower doses tend to produce more

favourable subjective effects than higher doses. For example, 200–250 mg caffeine can enhance mood and performance, whereas 400–500 mg had no effect on performance and negative effects on mood (15,22). Consistent with this, the low caffeine levels used in the present study were generally associated with small improvements in mood, although there was no consistent effect of caffeine dose.

Our results indicate that low levels of caffeine can produce dose-dependent effects on short-term autonomic responses, but that this dose dependency can be overridden by other factors associated with consumption of these beverages. Thus, the immediate physiological and mood effects of tea and coffee are similar, despite differences in caffeine level, and may form part of a general conditioned response to caffeinated beverage ingestion. Expectancy and/or sensory cues linked to beverage ingestion may be important moderators, which, in the period immediately postingestion, may be more critical than caffeine dose. In support of this, a recent study found that acute tea consumption produced greater improvements in mental alertness than the equivalent amount of caffeine in hot water (11).

Effect of beverage strength. Ingestion of strong vs. weak (2 cups vs. 1 cup-equivalent) tea/coffee was associated with a significantly higher DBP and self-report energetic arousal and a borderline significant effect on heart rate (Table 1). The physiological effects were more pronounced in the 10–30-min postbeverage period than the 30–60-min period, whereas the mood effects were independent of time postbeverage. It is important to emphasise that the same volume of beverage was consumed in each case; only the strength was manipulated to deliver different total tea/coffee solids. While caffeine level also increased in going from weak to strong tea/coffee, there was no independent effect of caffeine dose on the above measures. Thus, it is unlikely that the effects of beverage strength are simply a surrogate for caffeine level.

In a previous study we found that during the drinking phase tea or coffee ingestion was associated with a greater increase in skin conductance compared to hot water containing the same amount of caffeine (28). Furthermore, addition of milk to tea or coffee reduced heart rate and skin conductance responses during the drinking phase, and improved mood and reduced anxiety for up to 1 h postingestion (28). This and the current findings are suggestive of a role for sensory factors—for example, the perception of beverage strength as bitterness intensity—in modulating the immediate response to beverage ingestion.

CONCLUSIONS

In agreement with our previous results (28), the present studies demonstrate that consumption of tea and coffee rapidly produces mild stimulation of the autonomic nervous system and improvements in mood. Our particular concern in this study, however, was to examine the role of caffeine level on these responses. While we were able to demonstrate that manipulation of caffeine alone produced dose-dependent effects on many (but not all) physiological parameters, this was not the case when caffeine dose was manipulated indirectly by consumption of tea and coffee of differing strength. In the latter study, tea and coffee were significantly different from water or no drink, but we found no robust evidence for dose-dependent effects of caffeine, or differences between tea and coffee on these measures. In neither study did we find clear evidence for dose-dependent effects of caffeine on mood, although there was some evidence that increasing beverage strength can increase both physiological and mood responses.

We conclude that while low doses of caffeine as found in tea or coffee can be shown to dose dependently affect a number of autonomic responses, caffeine level per se does not affect the short-term response to tea or coffee ingestion. The results suggest that the immediate effects of caffeinated beverage ingestion may form part of a conditioned response. Indeed, the significant effect of beverage strength, and previous results on the effects of milk addition (28) suggests that sensory factors may cue some of the short-term effects of these beverages. The role of such factors and the processes by which these effects are learned are interesting areas for future research.

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