Oolong Tea Increases Metabolic Rate and Fat Oxidation in Men

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ABSTRACT According to traditional Chinese belief, oolong tea is effective in the control of body weight. Few controlled studies, however, have been conducted to measure the impact of tea on energy expenditure (EE) of humans. A randomized cross-over design was used to compare 24-h EE of 12 men consuming each of four treatments: *1*) water, *2*) full-strength tea (daily allotment brewed from 15 g of tea), *3*) half-strength tea (brewed from 7.5 g tea) and *4*) water containing 270 mg caffeine, equivalent to the concentration in the full-strength tea treatment. Subjects refrained from consuming caffeine or flavonoids for 4 d prior to the study. Tea was brewed each morning; beverages were consumed at room temperature as five 300 mL servings. Subjects received each treatment for 3 d; on the third day, EE was measured by indirect calorimetry in a room calorimeter. For the 3 d, subjects consumed a typical American diet. Energy content of the diet was tailored to each subject's needs as determined from a preliminary measure of 24-h EE by calorimetry. Relative to the water treatment, EE was significantly increased 2.9 and 3.4% for the full-strength tea and caffeinated water treatments, respectively. This increase over water alone represented an additional expenditure of 281 and 331 kJ/d for subjects treated with full-strength tea and caffeinated water, respectively. In addition, fat oxidation was significantly higher (12%) when subjects consumed the full-strength tea rather than water. J. Nutr. 131: 2848–2852, 2001.

KEY WORDS: • *Tea* • *metabolic rate* • *fat oxidation* • *caffeine* • *catechins*

The Chinese belief that drinking tea promotes good health and longevity is gaining scientific merit (1). Oolong tea is one of the three types of tea that is manufactured from tea leaves; the others are black and green teas. Green tea, which is consumed largely in Asia, is processed to minimize fermentation, whereas black tea, which is popular in western countries, is fermented to produce the characteristic flavor components. Oolong tea is less fermented than black tea. It is sold commercially in the United States and is often served in Chinese restaurants.

Oolong tea has been studied for its antioxidant properties (2) and its effects on cardiovascular disease (3), cancer (4) and obesity (5). In a recent study, 102 Chinese women who drank four cups of oolong tea per day (the brew from four 2 g tea bags) lost over a kilogram of body weight during a 6-wk period (6). These data suggest that oolong tea may promote weight loss by increasing energy expenditure (EE)[2] 10–20%. Caffeine has been shown to increase EE for several hours following ingestion depending on the level of intake. Oolong tea contains caffeine and the 102 Chinese women received ~125 mg/d. Studies show that consuming this amount of caffeine causes a 16% increase in resting EE (7). Whether the increase in EE that accompanies the consumption of oolong tea is due solely to caffeine or to other constituents such as polyphenolic compounds is unclear (8). This study was designed to assess under controlled conditions whether consumption of oolong tea increases EE or modulates substrate oxidation relative to control beverages.

METHODS

Subjects. Twelve men ages 25–60 y were recruited from the general population with an average age, weight and height of 44 ± 9 y, 83 ± 10 kg and 179 ± 6 cm, respectively. Body composition, as determined by dual-energy X-ray absorptometry (DEXA) averaged 60 ± 8 kg lean body mass and 23 ± 7 g/100 g fat. To minimize within-subject variation, the study was designed to complete all measurements on a single subject within a month. Males were studied to avoid masking the expected response by the variation in EE known to occur in premenopausal women across their menstrual cycle.

All volunteers participated in an initial screening that involved completion of questionnaires related to diet, physical activity, family and personal health history and availability for participation in the study. A cooperating physician performed a simple medical evaluation. A 20 mL blood sample was collected from fasting subjects, and height and weight were recorded. The blood sample was analyzed for routine blood chemistry. All men selected were in basic good health, had a BMI between 18 and 30 kg/m^2 and had no history of cancer, heart disease, hypertension, diabetes, liver or kidney disease, endocrine disorders or food allergies. Multiple selection criteria (height, weight, age, body composition, medical evaluation, blood chemistry and normal level of physical activity) were used to select a homogeneous group of participants. Self-reported daily caffeine consumption was recorded and used as a selection criterion. The target population

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[2] Abbreviations used: BHNRC, Beltsville Human Nutrition Research Center; BMR, basal metabolic rate; DEXA, dual-energy X-ray absorptometry; EE, energy expenditure; EGCG, epigallocatechin gallate; RQ, respiratory quotient.

Manuscript received 8 February 2001. Initial review completed 30 March 2001. Revision accepted 16 August 2001.

was men who, on a daily basis, consume caffeinated beverages with caffeine content equal to 2–4 cups of coffee (100–400 mg/d caffeine). Additional exclusion criteria included self-reported smoking, consumption of vitamin/mineral supplements above 2 times RDA, consumption of herbal supplements or use of recreational or performance enhancing drugs. Subjects approved for the study were required to read and sign the written informed consent form prior to their entry into the study. The Committee on Human Research, Johns Hopkins University, approved all procedures.

Before the start of the experiment, each subject participated in a preliminary 24-h calorimeter measurement without oolong tea or caffeine. This measurement was intended to familiarize subjects with the room calorimeter environment and to establish 24-h energy requirements. A DEXA scan was performed on each subject once during the study. This procedure is used to estimate body composition by mathematical decomposition of the DEXA signal into fat, muscle and bone components.

Experimental design. Subjects were randomly assigned to one of three cohorts of four subjects. The four treatments were represented in each of four blocks according to a 4×4 Latin square design. A treatment consisted of a beverage consumed five times daily (0830, 1000, 1130, 1300 and 1430) containing one of four test beverages. The test beverages were water, water plus caffeine (270 mg caffeine/d) and two levels of oolong tea. Each block consisted of 3 d of controlled feeding in which participants consumed the same food each day. A single day's menu was used for the entire study. The diet was formulated to meet the RDA for essential nutrients and energy and to have little or no caffeine. The energy level for the 2 d prior to entering the calorimeter was set at 115% of the EE determined during the preliminary calorimeter measurement and 100% during the day in the calorimeter. These energy intake levels were used to maintain energy balance during the 3 d of controlled feeding. All participants were asked to avoid food and beverages containing caffeine, except those provided by the Beltsville Human Nutrition Research Center (BHNRC), for 4 d prior to the beginning and during the entire study. Participants were free-living during the first 2 d of each period and consumed only the food provided by the BHNRC. During this period, daily beverage records were kept and checked for caffeinated beverages. Subjects were reminded daily to refrain from consumption of caffeinated beverages. During the third day of each period, participants stayed in the BHNRC calorimeter for a continuous 23-h measurement starting at 0800 h. Participants were free to resume their normal activities when not in the calorimeter, with the exception that they were not to engage in any strenuous exercise for 24 h before entering the calorimeter.

Tea and preparation. A single source of tea leaves, enough for the entire study, was obtained from Suntory Ltd (Osaka, Japan) prepared in bags containing 3 g of tea leaves per bag. Tea for all subjects was prepared each morning in a single batch. The tea was brewed at full strength by adding boiling distilled deionized water to a glass container containing the tea bags. The tea was steeped for 20 min, and the bags were then removed and the tea was cooled to room temperature and sealed in single-serve Nalgene bottles. The half-strength tea was prepared by adding equal amounts of brewed tea and distilled deionized water. Each serving of tea was equal to 300 mL of water prepared with either 1.5 or 3 g tea. The total amount of tea consumed by each individual was 1500 mL prepared with either 7.5 or 15 g tea/d. Before the study, we assessed the stability of tea compounds in brewed tea using the same lot of oolong tea and the same brewing method that was used in the human study. All components analyzed, including caffeine, individual catechins and other polyphenols, as listed in **Table 1**, were stable for at least 12 h after the tea was brewed (data not shown).

Catechin and caffeine analysis. Concentration of caffeine, gallic acid, flavanols and other polyphenols (fraction including polymerized flavanols and other flavonoids) in the oolong tea were analyzed by HPLC with UV detection at 280 nm (9). Analysis was performed with a Cosmosil 5PE-MS column (4.6 mm i.d. × 150 mm; Nacalai Tesque, Kyoto, Japan) at 40°C. Compounds were eluted (eluent A: 0.05% trifluoroacetic acid in water; eluent B: 0.05% trifluoroacetic acid in acetonitrile) at a flow rate of 2 mL/min using a gradient program (eluent B content: 10% for 5 min, from 10 to 21% in 8 min, from 21 to 90% in 1 min and 90% for 6 min). The quantification of caffeine, gallic acid and flavanols was determined using standard calibration curves for known compounds marketed commercially. Other polyphenols were quantified using a calibration curve that was derived from polyphenols that had been isolated from tea by HPLC. Caffeine and flavanol content of a single serving of tea is presented in Table 1. Total caffeine consumption for subjects consuming five servings of the full-strength tea was 270 mg caffeine; epigallocatechin gallate (EGCG) content was 244 mg/day. Thus, caffeine intake was 270, 270 and 135 g/d on the caffeinated water, full-strength tea and half-strength tea treatments, respectively.

TABLE 1

Analysed composition of oolong tea consumed by subjects[1]

	mg/300 ml
Catechins	
Epigallocatechin (EGC)	49.7
Epigallocatechin Gallate (EGCG)	48.7
Epicatechin (EC)	14.2
Epicatechin Gallate (ECG)	12.1
Catechin (C)	3.93
Catechin Gallate (CG)	2.28
Gallocatechin Gallate (GCG)	1.56
Other polyphenols including polymerized polyphenols	52.8
Gallic acid	5.25
Caffeine	53.9

[1] 3 g oolong tea were steeped in 300 mL hot water for 20 min.

Plasma and urine samples were diluted 1:10 with 20% acetonitrile in water and subsequently analyzed for caffeine and the metabolites theobromine and theophylline by HPLC (10). Analytes were separated on a RP-C18 column (250 × 4.6 mm Microsorb-MV, 100 Å; Varian, Walnut Creek, CA) with a 30 × 4.6 mm RP-C18 Brownlee guard cartridge by isocratic elution with 20% acetonitrile in reverse osmosis water at a flow rate of 0.8 mL/min. Absorbance was measured by diode array detection at 280 nm, and the concentration of analytes was determined by calibration curves of the pure standards.

Energy expenditure. A BHNRC room calorimeter (11) was used to determine EE of each individual. Participants entered the calorimeter at 0800 h, followed a fixed activity schedule and exited at 0700 h, 23 h later. Values reported here as 24-h EE were extrapolated from 23-h measurements. Volunteers consumed the same food during each of the 24-h periods. EE, oxygen consumption and carbon dioxide production were continuously recorded and all urine was collected during the calorimeter measurements. Protein, carbohydrate and fat oxidation were calculated using measured values of oxygen consumption, carbon dioxide production and urinary nitrogen excretion based on the equations of Livesey et al. (12). A basal metabolic rate (BMR) determination was conducted each morning immediately following each of the 23-h calorimeter measurements. During the BMR measurement, the subject was asked to lie quietly on a bed for 30–50 min with his head in a clear plastic canopy. Oxygen consumption and carbon dioxide production were measured while fresh outside air was circulated through the canopy. During each of the calorimeter measurements, blood and urine samples were collected for caffeine analysis through ports in the calorimeter wall. Blood was collected prior to entering the calorimeter and 2 h after the final intake of tea for the day (~1630 h). Subjects fasted for at least 12 h for the blood sample collected prior to entering the calorimeter.

Statistical analysis. Data were analyzed using a mixed model procedure from SAS/STAT software, version 8, of the SAS System for personal computers (SAS Institute, Cary, NC). The means reported are least squares means; standard errors represent the standard error of the estimate of main effect means, and a binomial probability test (*P*-value) was used to test differences between means.

RESULTS

Energy expenditure. There were no significant differences in basal (resting) EE among the four treatments (**Table 2**).

TABLE 2

24 h energy expenditure (EE), basal metabolic rate, respiratory quotient (RQ) and substrate oxidation of men consuming oolong tea or control beverages

Treatment	Resting		24 hour		
	EE	RQ	EE	Carbohydrate oxidation	Fat oxidation
	kJ/d	*LCO_2/LO_2*	*kJ/d*	*g/d*	
Water	7032	0.786	9602[a]	307	61[a]
Water + caffeine	7158	0.783	9933[b]	312	66[ab]
Half-strength tea	7320	0.783	9649[a]	308	62[ab]
Full-strength tea	7227	0.781	9883[b]	305	69[b]
SEM	180	0.01	198	13	5

[1] Values are means, $n = 12$. Means in columns without a common letter differ, $P < 0.05$.

Twenty-four hour EE was higher when subjects consumed full-strength tea and water plus caffeine than when consuming either water alone or half-strength tea. The consumption of the full-strength tea elevated 24 h EE 2.9% above the water alone. The highest EE was observed when subjects consumed the water plus caffeine, resulting in an elevation of EE 3.4% above water alone. The half-strength tea did not significantly increase EE above the water alone. **Figure 1** presents 24-h EE divided into 4-h blocks. EE tended to be greater throughout the 24 h for each of the caffeinated beverages when compared to water. However, the greatest and only significant differences occurred during the 12- to 16-h period when the EE associated with consumption of caffeinated water and the full-strength tea were greater than that for water. Ten of the 12 subjects had an increase in EE >100 kJ/d, relative to water alone, when consuming the caffeinated water, and seven had an increase when consuming the full-strength tea. There were no correlations between the individual responses and other variables (i.e., weight, age and body fatness) measured in the study.

Although we did not observe any difference in activity as measured by the motion detectors in the calorimeter, the system is incapable of detecting small differences in activity or determining whether the subject is awake or asleep. It has been observed that both EE and respiratory quotient (RQ) decrease once subjects fall asleep (13). The persistent high plasma caffeine levels could have maintained wakefulness in the subjects longer when they consumed the high-caffeine beverages. This would have increased RQ and could account for this observation. However, there was no consistent report of wakefulness by subjects upon questioning after exit from the calorimeter. In addition, EE during the 16- to 20-h and 20- to 24-h periods were not significantly higher than water for any of the treatments (Fig. 1).

RQ and substrate utilization. RQ during the basal (resting) EE measure was not significantly different among the treatments (Table 2). Substrate utilization during the 24-h EE was significantly affected by treatment. Fat oxidation was elevated 12% and 8% for the full-strength tea and the caffeinated water, respectively ($P < 0.05$). There were no significant effects on carbohydrate oxidation for any of the beverages when compared to water.

Figure 2 presents 24-h fat oxidation divided into 4-h blocks. Carbohydrate oxidation is not presented for 4-h blocks because no significant treatment effects were observed for the 24-h data. Fat oxidation tended to be greater for each of the caffeinated beverages than for water alone during each of the periods except the 12- to 16-h period. Fat oxidation tended to be less for each of the beverages during this period when compared to water alone. However, only the difference between the half-strength tea and water approached ($P < 0.08$) significance. Six of the 12 subjects had an increase in fat oxidation >4 g/d, relative to water alone, when consuming the caffeinated water and >8 g/d when consuming the full-strength tea. There were no correlations between the individual responses and other parameters (i.e., weight, age and body fatness) measured in the study.

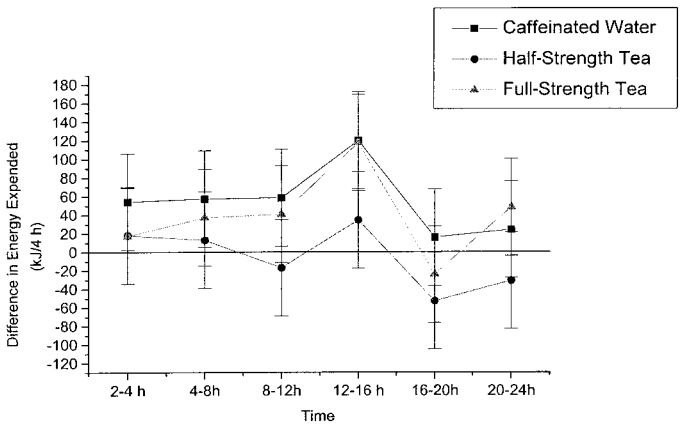

FIGURE 1 Difference, over 4 h, in energy expended between consumption of water and caffeinated beverages

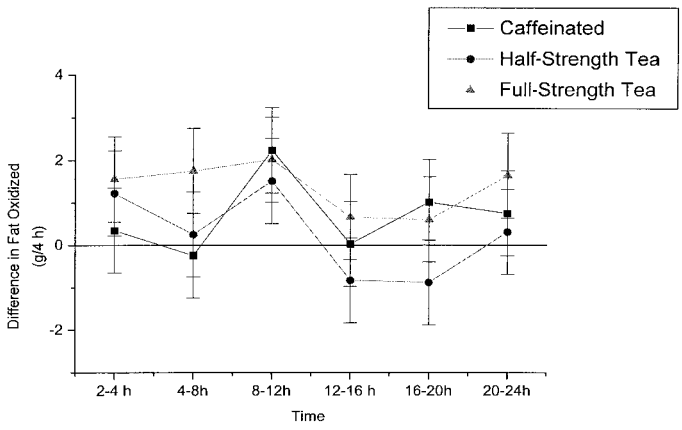

FIGURE 2 Difference, over 4 h, in fat oxidized between consumption of water and caffeinated beverages .

TABLE 3

Plasma caffeine level of men 2 h after consuming the day's final oolong tea or control beverage (8 h) or at the end of the 24 h calorimeter measurement

Treatment	8 h	End of 24 h
	g/L	
Water	0.3[d]	0.2[d]
Water + caffeine	2.7[a]	0.8[c]
Half-strength tea	1.6[b]	1.0[c]
Full-strength tea	2.7[a]	0.9[c]
SEM	0.3	

[1] Values are means, $n = 12$, Means without a common letter differ, $P < 0.05$.

Plasma caffeine. Plasma caffeine (**Table 3**) levels did not differ when the men consumed the caffeinated water and the full-strength tea and were ~40% lower on the half-strength tea. The plasma caffeine levels were higher both at the midday (8-h) measurement and at the end (24 h) of the calorimeter measurements for the caffeinated beverages than with water alone. However, there were no differences in plasma caffeine concentration among the caffeinated beverages at the end of the calorimeter measurement.

DISCUSSION

Tea is one of the most frequently consumed beverages worldwide, yet very little is known about its metabolic effects in humans. Caffeine is generally regarded as the major metabolically active compound in tea. No consistent scientific evidence links moderate caffeine consumption to any health risks, including cancer, cardiovascular disease, fibrocystic breast disease or birth defects. Some individuals are sensitive to caffeine and find that it induces jitters, sleeplessness or irritation to the gastrointestinal tract but others consume it specifically because it is a mild stimulant and increases alertness and metabolic rate.

Dulloo et al. (8) recently reported that the consumption of green tea extract elevates both the metabolic rate and the rate of fat oxidation by individuals. Green tea, as well as the oolong tea consumed in this study, contains substantial amounts of caffeine, which has been demonstrated to affect metabolic rate and substrate metabolism (14–19).

The effect of caffeine on metabolic rate has been well documented. A number of studies have reported an elevation in metabolic rate following consumption of caffeine in amounts of 200 mg or higher. Significant increases of 2–12% in metabolic rate are observed with caffeine doses of 200–300 mg (14–19). Hollands et al. (7), among few others, demonstrated a significant effect with doses <200 mg. One interesting aspect of these short duration studies with caffeine is that EE does not return to a baseline value within a few hours. Astrup et al. (15) conducted a comprehensive study of the metabolic effects of caffeine. They measured both plasma caffeine and EE for 3 h after a single dose, either 100, 200 or 400 mg of caffeine. They observed that regardless of dose, caffeine levels and EE peaked around 30-min post dose. In addition, plasma caffeine and EE remained near this peak level for the entire 3 h of observation and had not returned to pretreatment levels by the end of the measurement period. In the current study, the greatest effect of the caffeinated beverages was observed 4–8 h following the last dose (Fig. 1). From these data, it is clear that the effect of caffeine is sustained for many hours following consumption. To fully determine the impact of caffeine on EE, it is necessary to measure for more than the 3 h generally monitored during these short-duration studies.

Including the current study, four studies (8,18,19) have examined the response to caffeine over a 24-h period in which caffeine was consumed during the first 12 h but not during the second 12 h. Caffeine intake ranged from 150 to 600 mg/d and was consumed either in capsule form or as a beverage (tea or coffee). Only the Dulloo et al. (8) study, which used 150 mg/d of caffeine, did not observe a significant increase in EE for 24 h or for the 12-h period in which the caffeine was consumed. In the remaining three studies, EE was elevated by 3–7.6% in response to the consumption of caffeine. However, the greatest increase in 24-h EE was not in response to the highest dose of caffeine. Dulloo et al. (18) reported a 5.5% increase in 24-h EE in response to a dose of 600 mg caffeine/d. This response is similar in magnitude to that observed in the current study with a much lower dose of caffeine. In their later study Dulloo et al. (8) point out that the lack of response to the 150 mg/d dose may have resulted from administering the caffeine as 50-mg doses three times per day. They suggest that a 50-mg dose may be below the threshold level necessary to elicit a response. However, in the current study we administered ~50-mg doses five times per day and report a significant response. This suggests that the effect of each successive dose of caffeine is cumulative and persists for several hours. The lack of response observed by Dulloo et al. (8) may have been due to an insufficient number of doses to achieve a total dose level sufficient to elicit a measurable response.

The impact of caffeinated beverages on substrate oxidation was significant in both the current study and that of Dulloo et al. (8). We observed a 12% increase in fat oxidation over 24 h when subjects consumed the full-strength tea. Dulloo et al. (8) observed a smaller increase in fat oxidation with consumption of 150 mg of caffeine but a much greater increase with the consumption of green tea (33%). They suggest that the catechin content of the tea must have stimulated the fat oxidation rate. In support of this observation, they cite the lack of difference in fat oxidation due to the 250-mg/d caffeine dose in the study by Bracco et al. (19). However, there is some evidence that caffeine alone increases fat oxidation rates. Studies with short-duration measurements (14,16) report lower RQ, indicating a possible higher fat oxidation rate in response to caffeine consumption.

Fat oxidation was not significantly different from water alone during any of the 4-h periods after test beverage consumption when considered separately. However, fat oxidation was consistently higher during each of the 4-h periods (Fig. 2) and approached significance ($P < 0.12$) during the 8- to 12-h period, with the full-strength tea accounting for the significant difference over 24 h. It is interesting to note that the smallest difference in fat oxidation occurred during the period with the greatest difference in EE.

It has been widely assumed that the metabolic effects of beverages containing caffeine have been due to their caffeine content. It is clear from the results of this study and others that the consumption of tea both elevates metabolic rate and increases fat oxidation. However, it is not entirely clear whether these effects can be attributed to caffeine alone. In the current study, the full-strength tea and the caffeinated water resulted in comparable increases in EE. However, in their most recent study, Dulloo et al. (8) observed no effect of caffeine alone but a significant increase in metabolic rate when green tea extract was the source of caffeine.

Recently much attention has been focused on the flavanol

content of foods. Dulloo et al. (8) ascribed much of the elevation in metabolic rate observed to an interaction between caffeine and the EGCG content of the green tea. This polyphenol has been demonstrated to be present in both green and black tea (20) and detectable levels have been observed in plasma and urine of human subjects consuming tea (21–23). In this study we report substantial levels of EGCG in the oolong tea served to our subjects. Catechins have a wide variety of metabolic actions (24,25). They have been related to a decrease in the turnover of norepinephrine (25), suggesting an impact on metabolic rate and fat oxidation.

The current study and the Dulloo et al. (8) study are similar in approach with the basic difference being the type of tea and the method of delivery. We prepared the tea as it would be normally consumed and Dulloo et al. (8) provided it as an extract in capsule form. The question that arises is "are the results from the two studies consistent?" The Dulloo et al. (8) study made two important observations regarding the effect of tea on metabolic rate and fat oxidation. The first represented an attempt to explain the lack of response from their caffeine alone treatment. They suggest that there appears to be a threshold level of caffeine necessary to increase metabolic rate significantly. We did observe that there were no significant effects on 24-h EE when the tea was consumed at the half-strength level (Table 2). However, when compared to the water alone, the metabolic rate was elevated when men consumed the half-strength tea, during the period in which the tea was consumed but was lower than the water-alone treatment value during the last 8 h of the 24-h period (Fig. 1). It is also interesting to note that the fat oxidation rate was much lower on the half-strength tea treatment than water alone during the last 8–12 h of the 24-h period (Fig. 2) but was not different over the whole 24-h period. It is clear that the response to the half-strength tea was much less than either of the treatments with higher caffeine. There does not appear to be a dose-response relationship since consumption of the half-strength tea resulted in EE not different from water alone.

The central conclusion of Dulloo et al. (8) was that EGCG and caffeine from the tea act synergistically to produce the thermogenic response and an increase in fat oxidation. The data from the current study support the observation that the consumption of tea results in a greater impact on fat oxidation than does caffeine alone. The EGCG intake in this study was similar to that in the green tea extract used by Dulloo et al. (8), but our caffeine levels were nearly twice as high. Yet, the increase in 24-h EE induced by tea consumption in our study was very similar to the response reported in their study, and the caffeine alone resulted in an elevation in metabolic rate similar to the full-strength tea. If there had been some synergistic effect of caffeine and EGCG as suggested by Dulloo et al. (8), we should have observed a much higher thermic effect of the tea. Given that the response observed in this study is similar in magnitude to the other studies that reported increases in 24-h EE (8,18,19), it seems possible that maximal response is reached with caffeine doses of 200–300 mg/d. The addition of more stimuli may not result in a greater response beyond an elevation in metabolic rate of 3–7.2% over 24 h.

The observed effect of tea on fat oxidation may reflect the synergistic effect of the caffeine and the catechins as suggested by Dulloo et al. (8). Both studies demonstrated a significant effect of tea on 24-h fat oxidation but not with caffeinated beverages alone. However, without data on the impact of the noncaffeine components of tea independent of the caffeine, there is no clear answer as to whether the caffeine is necessary to stimulate fat oxidation.

It is clear that consumption of oolong tea stimulates both EE and fat oxidation in normal weight men. This raises the possibility that tea consumption could have some beneficial effect on an individual's ability to maintain a lower body fat content. However, any beneficial effect would only be realized if the effect was sustained upon chronic consumption of tea and the individual did not compensate with greater food intake in response to tea consumption.

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