RESEARCH
Original Research

Caffeine Transiently Affects Food Intake at Breakfast

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ABSTRACT

Background Caffeine is frequently added to dietary supplements with claims it facilitates weight loss.

Objective The purpose of this study was to test the hypothesis that caffeine administration reduces laboratory and free-living food intake by reducing appetite and that these effects vary by body mass index (BMI).

Participants/setting Fifty adults aged 18 to 50 years completed the study (42% male). Exclusion criteria included no previous experience with caffeine, previous adverse event following caffeine consumption, taking any medications or having a medical condition contraindicating caffeine or stimulant consumption or affecting appetite or eating, and reported tobacco use within the past 6 months.

Design and intervention Participants visited the laboratory on four separate occasions to complete a double-blind, placebo-controlled, randomized, crossover study. On the first three visits, participants consumed a beverage containing 0, 1, or 3 mg/kg caffeine (order randomized). Thirty minutes later, participants consumed a buffet breakfast, ad libitum. After leaving the laboratory, participants completed hourly appetite assessments and dietary habit books until midnight or bedtime. The fourth session consisted of questionnaires, debriefing, and compensation.

Main outcome measures Total and macronutrient intake and appetite sensations in and out of the laboratory were measured.

Statistical analyses performed Intake data were analyzed using mixed analysis of covariance (ANCOVA). Appetite sensations were analyzed using repeated measures mixed ANCOVA.

Results Total laboratory energy intake was lower (~10%) after 1 mg/kg caffeine (650.4±52.2 kcal at 1 mg/kg; 721.2±63.2 at 0 mg/kg; 714.7±79.0 at 3 mg/kg) (P=0.046). In the laboratory, appetite sensations were not significantly different by caffeine treatment. Out of the laboratory, neither total intake nor appetite was significantly different by caffeine treatment. There were no significant interactions between caffeine treatment and BMI on intake and appetite sensations in or out of the laboratory.

Conclusions These results suggest caffeine has weak, transient effects on energy intake and do not support caffeine as an effective appetite suppressant.

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AS OBESITY PREVALENCE CONTINUES TO CLIMB IN developed countries, it becomes imperative to determine ways to reduce energy intake and increase energy expenditure. One common way to induce hypophagia (reduced intake and eating behavior) and increase expenditure is through dietary supplements such as caffeine. Epidemiological evidence suggests regular caffeine consumers have lower body mass index (BMI; calculated as kg/m^2) than nonconsumers, and coffee consumption may attenuate long-term weight gain or improve weight loss.[1-5] Some research has speculated these effects are achieved through caffeine's thermogenic properties.[6] Caffeine has been shown to increase thermogenesis and fat oxidation in humans, with increases in energy expenditure ranging from 5% to 22% (kilojoules [kJ]) in lean participants and blunted responses (5% to 10% kJ) in overweight and obese participants.[7,8]

Another potential explanation for the relationship between caffeine and body weight is that caffeine suppresses appetite. For example, together caffeine's effects on leptin, glucose, epinephrine, and dopamine may lead to an overall suppression of appetite and intake.[9-19] However, empirical support for appetite suppression due to caffeine is equivocal. Acute caffeine administration has been shown to reduce hunger in some studies, but not others.[19-21] Similarly, in studies that have directly examined the impact of preloads (premeal foods and beverages) containing caffeine on energy intake, results have been mixed, with some studies showing caffeine decreases energy intake, some showing no effect of caffeine on energy intake, and others showing caffeine increases energy intake.[7,12,20,22] One possible explanation for these differences may be that peak caffeine concentrations occurred after leaving the laboratory. For example, the average half-life

of caffeine is 4.5 hours among normal and underweight individuals, but average half-life is longer among overweight and obese individuals.[23,24] Many other factors could account for these differences, including different doses of caffeine used, expectancy of caffeine created when using coffee and tea beverages, other ingredients in the caffeinated preloads such as fiber or green tea catechins, different amounts of time between caffeine administration and eating, and different levels of usual caffeine intake, withdrawal, and withdrawal reversal.[7,19-22,25] Further research is needed describing the effects of acute caffeine administration on energy intake considering the factors described previously.

The purpose of this study was to examine the impact of acute caffeine administration on energy intake at breakfast and throughout the remainder of the day in adults. This study tested the following hypotheses: (1) caffeine dose-dependently reduces ad libitum laboratory and free-living energy intake; (2) caffeine exerts its effects on energy intake by reducing hunger and desire to eat; and (3) the effects of caffeine on appetite and energy intake vary as a function of BMI.

RESEARCH SNAPSHOT

Research Question: Does acute caffeine administration decrease laboratory and free-living energy intake and reduce appetite, and do these effects vary by BMI?

Key Findings: This double-blind, placebo-controlled, randomized, crossover study showed total laboratory energy intake was 10% lower after 1 mg/kg caffeine and this small, transient effect did not persist throughout the day. There were no significant effects or interactions with caffeine or BMI on appetite in the laboratory or throughout the day. The findings of this study do not support the use of caffeine as an appetite suppressant.

MATERIALS AND METHODS

Participants

Potential participants were recruited from flyers posted around the University at Buffalo campus and surrounding community. In addition, potential participants were identified from the Nutrition and Health Research Laboratory database and recruitment e-mails. Fifty-three adults aged 18 to 50 years began this study. Two females did not complete the study due to scheduling conflicts, and one female was removed due to a change in health status that contraindicated caffeine consumption, leaving 50 adults (42% male) completing the study (Table 1). Potential participants were excluded from the study if they had no previous experience or a previous adverse event with caffeine, were taking any medication or had a medical condition contraindicating caffeine or stimulant consumption, were taking any medications or had a medical condition affecting appetite or eating, or reported using tobacco products within the past 6 months. The State University of New York University at Buffalo Institutional Review Board approved the study protocol, and all participants provided written informed consent. All sessions took place at University at Buffalo, Department of Exercise and Nutrition Sciences, Nutrition and Health Research Laboratory.

Study Design

This study was a randomized, double-blind, placebo-controlled, crossover design with order of caffeine treatment presentation counterbalanced (0, 1, 3; 1, 3, 0; or 3, 0, 1) by random number generator (https://www.randomizer.org). To minimize variability, each participant visited the laboratory for three breakfast sessions at the same time of day, the same day of the week, over 3 consecutive weeks. Participants returned to the laboratory 2 to 7 days after the final breakfast session to collect follow-up data, be debriefed about the purpose of the study, and receive compensation. To minimize expectancy effects, upon obtaining written informed consent, participants were told that the beverage may have different levels of one or more of the following substances normally found in foods and beverages: sugar, caffeine, artificial sweetener, or flavoring or coloring.

Baseline Characteristics. To describe and assess baseline characteristics of the sample, participants were asked to complete a demographic questionnaire. To describe eating habits and screen for potential eating disorders (n=0), participants completed three eating behavior questionnaires: (1) Three Factor Eating Questionnaire, (2) Questionnaire on Eating and Weight Patterns, and (3) Binge Eating Scale.[26-28] To assess anthropometrics, waist and hip circumferences were measured using a soft tape measure, and height and weight were taken using a digital wall-mounted stadiometer (SECA) and a digital scale (SECA). Body mass index (BMI) was calculated using the Centers for Disease Control website for adult BMI calculations (metric). Body weight was used to calculate relative dose (0, 1, and 3 mg caffeine per kilogram body weight) for the caffeine treatments.

Caffeine and Physical Activity Abstinence. The day prior to breakfast sessions, participants were instructed to abstain from beverages and foods containing caffeine, to consume only plain water as a beverage, and not to engage in any vigorous exercise, which was defined and explained according to the talk test.[7,19,20,29] In addition, participants were required to abstain from all foods and beverages except plain water overnight for a minimum 8 hours. Participants were told they would be asked to provide a 2.5 mL saliva sample; they provided a 2.5 mL saliva sample at the beginning of each breakfast session to encourage compliance with study protocols, but these samples were not analyzed. All participants completed a Caffeine Use Questionnaire to quantify their usual daily caffeine intake (milligrams per day) by source as well as occasions and reasons for caffeine consumption.[30,31]

Caffeine Preparation and Administration. At all breakfast sessions, the beverage vehicle was 350 mL of the same chilled juice beverage of their choice (orange [165 kcal], lemonade [165 kcal], or cranberry-grape [225 kcal]). Participants were given a body weight (relative) dose of caffeine treatment (0, 1, 3 mg caffeine per kilogram body weight) added to the beverage. Caffeine doses were selected based on the known range (~150 to 250 mg/d) of usual caffeine intake in a population 18 to 50 years old and previous caffeine

Table 1. Baseline characteristics of 18- to 50-year old men and women (n=51) participating in a clinical trial of dose response to acute caffeine administration on ad libitum laboratory and free-living energy intake and appetite

	BMI[a]<25		BMI 25-35		
Characteristic	**Mean±SD[b]**	**N (%)**	**Mean±SD**	**N (%)**	***P* value[c]**
Gender (% male)		32 (34)		19 (53)	
Age (y)	24.9±1.2		25.7±1.9		0.60
BMI	21.8±1.9		29.1±3.7		<0.001
Weight (kg)	63.8±11.8		84.8±15.7		<0.001
Waist (cm)	75.1±8.5		88.8±12.6		<0.001
Waist-to-hip ratio	0.79±0.06		0.84±0.06		0.01
Daily caffeine (mg/day)	200.4±205.2		163.2±134.8		0.48
Caffeine dose range (mg/kg)					
0	N/A[d]		N/A		
1	47-104		62-129		
3	140-311		185-388		
Three Factor Eating Questionnaire					
Restraint	8.8±5.7		12.2±4.9		0.04
Disinhibition	4.9±3.4		6.0±2.9		0.24
Hunger	4.4±3.2		5.7±3.2		0.17
Binge Eating Scale	7.2±5.4		9.6±6.1		0.16
Menstrual cycle phase[e]					
Placebo (0 mg/kg)					0.39
Follicular		9 (43)		2 (25)	
Luteal		12 (57)		6 (75)	
Low dose (1 mg/kg)					0.11
Follicular		11 (52)		2 (25)	
Luteal		10 (48)		6 (75)	
Moderate dose (3 mg/kg)					0.67
Follicular		9 (43)		4 (50)	
Luteal		12 (57)		4 (50)	
Education					0.51
High school		5 (15)		3 (16)	
Some college or vocational		8 (24)		7 (37)	
Completed college or university		10 (30)		3 (16)	
Completed graduate degree		9 (27)		5 (26)	
Annual income amount ($)					0.13
0-19,999		15 (45)		6 (32)	
20,000-49,999		8 (24		2 (11)	
50,000-99,999		4 (12)		5 (26)	
>100,000		1 (3)		2 (11)	
Ethnicity					0.30
Asian		13 (39)		6 (32)	

(*continued on next page*)

Table 1. Baseline characteristics of 18- to 50-year old men and women (n=51) participating in a clinical trial of dose response to acute caffeine administration on ad libitum laboratory and free-living energy intake and appetite (*continued*)

	BMI[a]<25		BMI 25-35		
Characteristic	Mean±SD[b]	N (%)	Mean±SD	N (%)	*P* value[c]
White		17 (52)		12 (63)	
Other		2 (6)		1 (5)	

[a]BMI=body mass index (calculated as kg/m^2).
[b]SD=standard deviation.
[c]*P* values assessed with analysis of variance methods for continuous variables and Pearson's χ^2 for categorical variables with BMI group (normal weight<25 kg/m^2 and overweight or obese 25 to 35) as the independent variable.
[d]N/A=not applicable.
[e]Females only.

preload studies in the Nutrition and Health Research laboratory.[32-34] Caffeine treatment was prepared and coded by an investigator not otherwise involved with the study. The principal investigator, all research assistants, and participants were blind to the treatment. For placebo aliquot preparations, a bitter tastant, powder quinine hydrochloride dihydrate (Sigma Aldrich), was added in the ratio 0.1 mg/mL caffeine-free lemon-lime-flavored soda (Sprite, The Coca Cola Company). For caffeine aliquot preparations, powder anhydrous caffeine (Fisher Scientific) was added in the ratios 10 mg/mL caffeine-free lemon-lime-flavored soda (for 1 mg/kg body weight) and 30 mg/mL caffeine-free lemon-lime-flavored soda (for 3 mg/kg body weight). Participants were given 5 minutes to consume the entire beverage and treatment, then asked to sit quietly for 30 minutes. During the 30-minute wait, questionnaires and dietary recalls were completed and dietary habit book completion and ecological, real-life setting, momentary assessment online appetite screening were reviewed and explained.

Laboratory—Buffet Breakfast, Appetite, and Mood. Thirty minutes after consuming the beverage and caffeine treatment (0, 1, 3 mg/kg), participants were presented with an ample, ~7,878 kcal total, North American–style buffet breakfast (Table 2). Participants were told they had 30 minutes to eat as much or as little as they wanted; they were instructed to ask if they wanted more of any items and to tell the researcher when they were finished. All foods and beverages were preweighed and intake was assessed by measuring plate waste. Appetite sensations (hunger, fullness, thirst, desire to eat) were assessed prior to caffeine (0, l, 3 mg/kg) treatment (pre), 30 minutes post–caffeine treatment and immediately prior to breakfast (mid), and post–breakfast consumption (post) on a 1 to 5 Likert scale anchored from "Not at all" (1) to "Extremely" (5). Immediately post, participants were asked to rate how much they liked their breakfast on a 100-mm visual analogue scale anchored from "Did not like at all" to "Liked extremely" and asked to provide any additional comments about the breakfast and why they did or did not eat all the food chosen. At pre, mid, and post time points, mood and psychological symptoms were also assessed. The Behavioral Checklist questionnaire asked participants to rate 31 adjectives for how they felt "right now" on a 9-point Likert-type scale anchored by "Not at all" (1) and "Extremely" (9). The Behavioral Checklist questionnaire is adapted from the Profile of Mood States—Bipolar Form, the Activation-Deactivation Adjective Checklist, and *Diagnostic and Statistical Manual of Mental Disorders, 4th Edition* symptoms of caffeine withdrawal.[35-40]

Free-Living Intake, Appetite, and Satiety. After leaving the laboratory, participants were required to complete a dietary habit book at every eating and drinking occasion for the remainder of the day until bed or midnight, whichever came first. The principal investigator instructed and trained research assistants on habit book explanation, completion, and review. At each breakfast session, research assistants instructed participants on completion of their habit book. Instructions included describing how to record items, references for portion sizes, a written example of a record, and images for portion size references within the habit book for later referral. In brief, each record was recorded by noting the time prior to each eating occasion, rating appetite (hunger, fullness, thirst, desire to eat), then completing details of consumed items. After each occasion, participants noted the time and again rated their appetite. Habit books were returned at the next laboratory session and reviewed with the participant for completion and accuracy.

Ecological Momentary Assessment. Ecological momentary assessment (EMA) techniques were used to better assess appetite sensations close in time to the experience and provide more sensitive, detailed, wide-ranging assessment.[41,42] Hourly, after leaving the laboratory, participants were e-mailed or texted (participant preference) a link to a short online survey about their appetite (hunger, fullness, thirst, desire to eat, consumption since last response) at that moment. To maintain consistency across laboratory and free-living (outside the laboratory) assessments, appetite sensations (hunger, fullness, thirst, desire to eat) were rated on the same 1 to 5 Likert scale anchored from "Not at all" (1) to "Extremely" (5). The survey also included a comment box to convey relevant information (eg, "Going to bed in 15 minutes").

Dietary Analysis. To determine compliance with the caffeine and dietary abstinence protocol, at each visit the experimenter guided participants through a five-step, multipass interview style recall of dietary intake for the previous day.[43] If caffeine or a caffeinated product was consumed, the session was rescheduled for the following week (n=2).

Table 2. Breakfast buffet items presented to 18- to 50-year-old adults 30 minutes after caffeine treatment (0, 1, and 3 mg/kg)

Item	Serving	Weight (g)	Energy (kcal)
Cinnamon french toast sticks	4 sticks	106	330
Homestyle waffles	2 waffles	70	170
Turkey sausage breakfast bowl	1 bowl	198	240
Sausage breakfast bowl	1 bowl	198	420
Vegetable egg white English muffin	1 sandwich	106	190
Veggie scramble with cheese sandwich	1 sandwich	95	140
Sausage, egg, and cheese sandwich	1 sandwich	105	220
Sausage, egg, and cheese muffin sandwich	1 sandwich	130	350
Double sausage, egg, and cheese muffin sandwich	1 sandwich	162	480
Nonfat strawberry yogurt	6 oz	170	80
Low-fat strawberry yogurt	6 oz	170	170
Fat-free milk	1 cup	200	75
Whole milk	1 cup	200	125
Silk plain soy milk	1 cup	200	92
100% whole wheat bread	2 slices	57	160
White bread	2 slices	52	140
Whole-wheat mini bagel	1 bagel	43	110
Plain mini bagel	1 bagel	43	110
Mixed fruit in pear juice	1 bowl	113	50
Red seedless grapes	1 cup	150	103
Streusel cake	2 cakes	92	360
Mini blueberry muffins	1 pouch	47	180
Croissant	1 croissant	62	210
Banana	1 medium	118	105
Clementine	1 fruit	74	35
Strawberry cereal bar	1 bar	37	140
Strawberry frosted toaster pastry	2 pastries	104	400
Raisin bran cereal	1 cup	120	386
Fruit-flavored sweetened toasted rice cereal	3/4 cup	54	220
Maple and brown sugar oatmeal, instant	1 packet	43	160
Plain oatmeal, instant	1 packet	28	100
Creamy natural peanut butter	4 Tbsp	60	263
Sweetened hazelnut cocoa spread	4 Tbsp	60	324
Concord grape jelly	2 Tbsp	40	100
Triple berry jam	2 Tbsp	36	60
Honey	2 Tbsp	42	120
2% Maple syrup	1/4 cup	60	210
Light syrup	1/4 cup	60	100
Low-fat cream cheese	1 3/4 Tbsp	50	125
Cream cheese	1 3/4 Tbsp	50	161
Salted butter	2 Tbsp	30	214
Buttery spread	2 Tbsp	30	150
Total			7,878

Measuring cups and spoons and rulers were provided to help participants estimate portion sizes. For intake in the laboratory, unique dietary entries based on brand data were created specific to the study foods. For intake outside the laboratory, US Department of Agriculture Standard Reference Database, Food and Nutrient Database or brand (when known) was used. To calculate total and macronutrient intake, upper division dietetics students, not otherwise affiliated with the study, reviewed and entered dietary intake data using Nutritionist Pro version 6.3.0. The Principal Investigator quality-checked entered values to recorded values and to industry standards.[44]

Power and Statistical Analysis

Previous studies in the Nutrition and Health Research Laboratory have not investigated the impact of acute caffeine on energy intake. To determine the appropriate sample size for a 20% change in energy intake after an acute treatment, means and standard deviations (SDs) were used from a previous study in this laboratory assessing the association of change in energy intake with different nutrition labels.[45] The mean (SD) energy consumed under a no label condition was 822.8±409.0 and under the label condition was 620.4±203.6. Assessing a 3×3 balanced design and using an effect size of 0.33, a power of 0.81, and a $P<0.05$, the current study would need at least 33 participants for a between-subjects effect. Because the current study used a within-subjects design, where all participants received all treatments, 52 participants were recruited.

Participant characteristics were analyzed using analysis of variance methods for continuous variables and Pearson's χ^2 for categorical variables with BMI group (normal weight <25 and overweight or obese 25 to 35) as the independent variable. Participant characteristic data were considered significant if $P<0.05$.

The effects of caffeine on dietary intake were analyzed using analysis of covariance (ANCOVA). The outcome variable(s) were total and macronutrient intake. Independent variables were BMI group (normal weight vs overweight and obese), caffeine treatment (0, 1, and 3 mg/kg), and usual caffeine intake. Interactions were assessed for BMI by caffeine treatment in all models. Results of dietary intake data analyses were considered significant if $P<0.05$.

Repeated measures mixed ANCOVA was used to assess appetite sensations, EMA data, and Behavioral Checklist data. In these models, the outcome variables were hungry, full, thirsty, desire to eat in and out of the laboratory and mood. Caffeine treatment was a fixed effect and time (pre, mid, post) was a random effect. All models included usual caffeine intake and statistically significant different baseline variables as fixed effects. A time by group interaction was tested for all models. When significant differences were identified at baseline (pre), the baseline (pre) values were included in the model as an independent variable. Interactions were assessed for BMI by caffeine treatment in all models. Results of appetite sensations, EMA data, and Behavioral Checklist data analyses were considered significant if $P<0.05$.

In models where caffeine dose was observed to be statistically significant, doses were compared to determine which doses were different from each other. Bonferroni correction was used for these comparisons, and data were considered significant if $P<0.017$. To estimate clinical significance, effect size was calculated using mean and SDs with $\alpha=.05$ and $\beta=.80$. Effect sizes 0.1 to 0.29 were considered small, 0.3 to 0.5 moderate, and >0.5 large. Systat 11.0 (released 2004) was used for analyses.[46]

RESULTS

Participant Characteristics

Mean waist circumference was 75.1±8.5 cm (mean±SD) for normal-weight and 88.8±12.6 for overweight and obese subjects. In addition, mean waist-to-hip ratio was 0.79±0.06 (mean±SD) for normal-weight and 0.84±0.06 for overweight and obese subjects (Table 1). Overweight and obese subjects had greater dietary restraint than normal-weight subjects ($P=0.044$). There were no other significant differences or interactions in participant characteristics ($P>0.05$).

Effects of Caffeine on Ad Libitum Laboratory and Free-Living Intake

Laboratory Intake. Caffeine treatment had a moderate effect on mean energy intake at breakfast with 1 mg/kg (650.4±52.2 kcal) lower than 0 mg/kg (721.2±63.2) and 3 mg/kg (714.7±79.0) [$F(2,91)=3.18$; $P=0.046$, $\eta_p^2=0.49$]. There was no interaction of caffeine treatment and BMI group on mean energy intake. There was also no interaction of caffeine treatment and BMI group on mean intake of macronutrients (Table 3). Mean "like" scores for the buffet breakfast were not significantly different between caffeine treatments ($P>0.05$).

Free-Living Intake. Caffeine treatment had no effects or interactions with BMI on mean energy or mean macronutrient intake throughout the day (Table 3).

Effects of Caffeine on Appetite Sensations

Laboratory Appetite Sensations. As expected, hunger, fullness, and desire to eat significantly decreased and fullness increased mid to post ($P<0.0001$) (Table 4). No differences in hunger, fullness, thirst, or desire to eat were observed by caffeine treatment. Caffeine treatment did not interact with BMI to affect appetite sensations in the laboratory.

Free-Living Appetite Sensations and EMA. Compliance with completing hourly appetite screenings was high, 93.8%, with a broad range of compliance, 66% to 100%, and no significant effects of caffeine treatment or significant interactions of BMI and caffeine treatment on compliance ($P>0.05$). No effects of caffeine treatment or significant interactions of caffeine treatment and BMI were found in free-living appetite over time ($P>0.05$) (data not shown).

Effects of Caffeine on Behavioral Checklist

Baseline (pre) Behavioral Checklist ratings of impatience, mood swings, and sadness did not differ by caffeine treatment or BMI group (Table 5). For impatience, 0 mg/kg was different from 1 and 3 mg/kg ($P=0.022$). For mood swings, 0 mg/kg was different from 3 mg/kg ($P=0.003$). Caffeine treatment and BMI significantly interacted on ratings of sadness. Treatment with 1 mg/kg caffeine only had a small effect on the change in sadness in normal-weight compared with overweight and obese subjects with both decreasing sadness but normal-weight subjects' rating sadness higher than overweight and obese subjects at all time points

Table 3. Mean and total energy and macronutrient intake at ad libitum buffet breakfast 30 minutes after caffeine treatment (0, 1, and 3 mg/kg) in the laboratory and for the entire day among 18- to 50-year-old adults (n=51)[a]

	BMI[b]<25 (n=32)			BMI 25-35 (n=19)					
Intake	0 mg/kg	1 mg/kg	3 mg/kg	0 mg/kg	1 mg/kg	3 mg/kg	*P* value[c]	Effect size[d]	Effect size[e]
Mean intake at buffet									
Total (kcal)	675.6±438.3	538.2±270.1	715.0±629.5	832.3±461.8	846.3±446.9	739.5±448.4	0.05	0.23	0.49
Carbohydrates (g)	100.0±61.2	83.8±41.4	106.3±79.8	110.7±55.0	111.4±57.7	100.1±51.7	0.42	0.16	0.07
Fats (g)	20.9±20.7	14.4±12.7	20.2±20.5	31.5±24.9	31.4±21.8	26.3±23.1	0.09	0.30	0.08
Proteins (g)	25.7±18.0	21.9±11.4	26.6±25.5	29.7±17.7	32.7±22.8	28.4±22.2	0.46	0.17	0.03
Total intake for entire day									
Total (kcal)	2,161.8±935.1	1,921.5±869.7	2,067.7±1092.5	2,438.2±900.0	2,546.4±1050.0	2,225.9±910.1	0.237	0.21	0.05
Carbohydrates (g)	287.0±120.1	256.3±136.0	278.3±133.7	300.3±103.7	292.8±105.3	264.4±112.2	0.457	0.13	0.07
Fats (g)	75.1±44.6	63.0±47.5	71.0±65.0	96.0±49.2	99.9±49.9	85.1±39.3	0.074	0.27	0.05
Proteins (g)	85.2±46.9	84.7±33.1	80.5±34.0	91.3±35.1	111.5±46.4	93.6±43.1	0.075	0.25	0.11

[a]Data are unadjusted mean±standard deviation for total calories and macronutrients (grams) consumed.
[b]BMI=body mass index (calculated as kg/m^2).
[c]*P* values from analysis of covariance with BMI group, caffeine treatment, and usual caffeine intake as the independent variables.
[d]Effect size calculated from unadjusted mean and standard deviation of total calories and macronutrients by BMI and caffeine treatment.
[e]Effect size calculated from unadjusted mean and standard deviation of total calories and macronutrient by caffeine treatment only.

Table 4. Appetite sensation ratings pre, mid, and post caffeine (0, 1, and 3 mg/kg) treatment in the laboratory among 18- to 50-year-old normal and overweight or obese adults (n=51)[a]

	BMI[b]<25 (n=32)			BMI 25-35 (n=19)		
Appetite sensation	**0 mg/kg**	**1 mg/kg**	**3 mg/kg**	**0 mg/kg**	**1 mg/kg**	**3 mg/kg**
Hungry[cd]						
Pre	3.72±1.1	3.87±0.9	3.58±1.0	4.00±0.8	3.95±1.1	3.88±0.9
Mid	3.63±1.0	3.65±0.8	3.44±1.0	3.83±0.9	3.74±1.1	3.41±1.2
Post	1.09±0.3	1.13±0.3	1.06±0.2	1.00±0.0	1.00±0.0	1.12±0.3
Full[cd]						
Pre	1.41±0.7	1.32±0.6	1.30±0.5	1.28±0.5	1.47±0.7	1.35±0.6
Mid	1.68±0.6	1.61±0.7	1.50±0.6	1.67±0.9	1.58±1.0	1.71±0.8
Post	4.19±0.7	4.10±0.7	4.18±1.0	4.28±0.6	4.37±0.8	4.35±0.6
Thirsty[cd]						
Pre	3.47±1.2	3.52±1.1	3.39±1.0	3.78±0.8	3.79±1.0	3.77±0.8
Mid	2.47±1.1	2.26±1.1	2.06±1.0	2.94±1.2	2.37±1.0	2.88±1.2
Post	1.88±0.9	1.90±1.1	1.67±0.8	1.89±0.8	1.63±1.1	1.65±0.8
Desire to eat[cd]						
Pre	3.84±1.1	3.68±1.0	3.91±0.9	4.28±0.8	4.00±1.2	3.94±1.0
Mid	3.78±1.0	3.65±1.0	3.47±1.1	3.89±0.9	3.68±1.3	3.71±1.2
Post	1.13±0.3	1.16±0.4	1.03±0.2	1.06±0.2	1.05±0.2	1.00±0.0

[a]Data are adjusted mean±standard deviation for hungry, full, thirsty, desire to eat on a 1 ("Not at all") to 5 ("Extremely") Likert scale.
[b]BMI=body mass index (calculated as kg/m^2).
[c]*P* value>0.05 was assessed with repeated measures mixed analysis of covariance with caffeine treatment as a fixed effect and time (pre, mid, post) as a random effect. Model included usual caffeine intake and statistically significant differences in baseline variables as fixed effects.
[d]*P* value<0.001 was assessed with repeated measures mixed analysis of covariance with caffeine treatment as a fixed effect and time (pre, mid, post) as a random effect. Model included usual caffeine intake and statistically significant differences in baseline variables as fixed effects. A time by group interaction was tested for the model.

(pre, mid, post) [F(2,94)=8.1, P=0.001, η_p^2=0.33]. As expected, and supporting results from laboratory appetite sensations, hunger significantly decreased with breakfast consumption (mid to post) (P=0.011) (data not shown).

DISCUSSION

The purpose of this study was to evaluate the dose-response effect of acute caffeine administration on ad libitum, individual discretion, laboratory and free-living intake and appetite and variability in these effects as a function of BMI. Although a dose response was not observed, this study demonstrated that following 1 mg/kg of caffeine, participants had a small (~10%) to moderate effect of reduction in laboratory intake in total calories. This result of reduced mean energy intake did not remain when looking at intake over the course of the entire day, suggesting participants compensated for breakfast intake after leaving the laboratory. The observed results of reduced mean laboratory intake at 1 mg/kg cannot be attributed to altered perceptions of hunger, fullness, desire to eat, or liking of the food, because none of these ratings varied as a function of caffeine dose. Results do not support an effect of caffeine treatment on intake or appetite throughout the day. This study suggests acute caffeine ingestion can have small, transient effects on subsequent meal mean energy intake, but these effects are not likely to result in meaningful reductions in energy intake over the long term.

Few studies have examined the impact of acute caffeine intake on laboratory intake, and in the ones that have, the findings are equivocal. Carter and Drewnowski found 100 mg and 167 mg caffeinated beverages in combination with soluble fiber and green tea catechins administered three times over the course of the morning decreased lunch intake in a laboratory setting in overweight and obese participants.[12] By contrast, Gavrieli and colleagues found, compared with water preload, a caffeine dose of 3 mg/kg increased and 6 mg/kg decreased ad libitum laboratory intake in overweight and obese participants, with no impact of caffeine dose on energy intake in normal-weight participants.[10] The results from the current study found a significant effect across all three caffeine treatments with 1 mg/kg caffeine dose reducing ad libitum laboratory energy intake by approximately 10% compared with 0 and 3 mg/kg. There were several differences among these studies, which may account for the discrepancies. First, the beverage (tea, coffee, or juice) vehicles for caffeine delivery were all different. By using tea and coffee, participants may have had expectancies about caffeine that could influence the outcomes. Second, the current study used a bitter placebo and the other two studies' control conditions were either no beverage or water without placebo. These differences could have created perceptions or expectancy

Table 5. Behavioral checklist ratings pre, mid, and post caffeine (0, 1, and 3 mg/kg) treatment in the laboratory among 18- to 50-year-old normal and overweight or obese adults (n=51)[a]

	BMI[b]<25 (n=32)			BMI 25-35 (n=19)			
Behavioral checklist	**0 mg/kg**	**1 mg/kg**	**3 mg/kg**	**0 mg/kg**	**1 mg/kg**	**3 mg/kg**	***P* value[c]**
Impatience							0.01[d]
Pre	1.7±1.4	1.8±1.2	1.8±1.5	2.4±1.7	2.0±1.4	1.8±1.2	0.11
Mid	2.1±1.5	1.9±1.5	1.8±1.4	2.4±1.9	2.1±1.3	1.8±1.3	
Post[e]	1.9±1.5	1.7±1.3	1.6±1.2	1.5±0.9	1.4±0.9	1.4±1.2	
Mood swings							0.003[d]
Pre	1.9±1.4	1.7±1.2	1.6±1.0	1.6±1.1	1.6±1.2	1.1±0.2	0.05
Mid	1.6±1.0	1.6±1.1	1.3±0.6	1.6±1.7	1.1±0.2	1.1±0.2	
Post[f]	1.4±0.9	1.5±0.9	1.4±0.8	1.2±0.4	1.0±0.0	1.0±0.0	
Sadness							0.03[g]
Pre	1.5±1.0	2.0±1.4[h]	1.8±1.6	1.8±1.9	1.5±0.7[h]	1.6±1.0	0.50
Mid	1.5±1.1	1.7±1.2[h]	1.2±0.4	1.6±1.9	1.2±0.4[h]	1.3±0.8	
Post	1.3±0.6	1.7±1.1[h]	1.3±0.8	1.4±1.7	1.2±0.5[h]	1.2±0.7	

[a]Data are adjusted mean±standard deviation for impatience, mood swings, sadness on a 1 ("Not at all") to 9 ("Extremely") Likert scale.
[b]BMI=body mass index (calculated as kg/m^2).
[c]*P* values from repeated measures mixed analysis of covariance (ANCOVA) with caffeine treatment as a fixed effect and time as a random effect. All models included usual caffeine intake and statistically different baseline variables as fixed effects.
[d]*P* value indicates effect of caffeine with data analyzed from repeated measures mixed ANCOVA with caffeine treatment as a fixed effect and time as a random effect.
[e]*P*-value of 0.02 for 0 mg/kg compared with 1 and 3 mg/kg with data from repeated measures mixed ANCOVA with caffeine treatment as a fixed effect and time as a random effect.
[f]*P* value of 0.002 for 0 mg/kg compared with 3 mg/kg with data analyzed from repeated measures mixed ANCOVA with caffeine treatment as a fixed effect and time as a random effect.
[g]*P* value indicates interaction of caffeine and BMI group with data analyzed from repeated measures mixed ANCOVA with caffeine treatment as a fixed effect and time as a random effect. Interactions were assessed for BMI by caffeine treatment.
[h]*P* value of 0.05 for 1 mg/kg BMI <25 compared with BMI 25-35 with data analyzed from repeated measures mixed ANCOVA with caffeine treatment as a fixed effect and time as a random effect. Interactions were assessed for BMI by caffeine treatment.

effects for the caffeine in the beverages, because caffeine is bitter. Finally, the timing of caffeine administration relative to meal consumption differed in each study, ranging from 30 minutes in the current study to 2 or 3 hours in the other studies. In the current study, the small (~10%) reduction and lack of other significant effects and interactions do not support the use of acute caffeine administration to reduce intake.

This study hypothesized that caffeine dose dependently reduces ad libitum free-living energy intake. However, no significant caffeine treatment effects or interactions with BMI on total energy intake or macronutrient intake (individually or as a percentage of total) were observed. The half-life of caffeine is approximately 4 hours, with peak effects observed 30 to 60 minutes after consumption.[47] The effects of caffeine may have peaked after the leaving the laboratory.[23,24] The difference in timing of meal consumption after leaving the laboratory relative to caffeine administration may have impacted the outcome as well. This is in contrast to a study by Gavrieli and colleagues, who observed reductions in energy intake at lunch remained when intake for the entire day was examined.[10] One explanation for this difference is that the impact of caffeine on energy intake was smaller in this study, thus it was easier to compensate once more energy was consumed later in the day. Finally, it is possible that because the laboratory meal, breakfast, was consumed earlier in the day, compared with lunch in the Gavrieli study, participants had more eating occasions in which to compensate.[10] The lack of a significant effect of caffeine on intake for the entire day in this study suggests there was not a delayed response due to caffeine treatment, beverage vehicle, meal timing, or BMI.

Another hypothesis of this study was that the effect of caffeine on energy intake would occur in accord with reduced hunger and desire to eat. The 10% reduction in breakfast energy intake in this study was not related to differences in appetite sensations because there were no effects of caffeine treatment on ratings of hunger, fullness, thirst, or desire to eat. Results do not support a delayed response due to caffeine treatment, beverage vehicle, or meal timing on appetite for the entire day. The study by Gavrieli and colleagues described above also found reductions in intake without reductions in self-reported hunger.[10] Similarly, a study by Josic and colleagues reported no effect of caffeine on self-reported hunger, although caffeine did reduce desire to eat and promote satiety.[48] Taken together, intake and appetite may be affected by acute caffeine administration, but results do not support significant changes in appetite as predictors of intake.

The final objective of this study was to evaluate variations by BMI in response to acute caffeine administration on ad libitum laboratory and free-living intake and appetite. Results do not support interactions between BMI and caffeine treatment on ad libitum laboratory or free-living intake or appetite. Further research is needed to identify and describe

any expected differences in ad libitum energy intake with different caffeine doses and adiposity.

Results do not support caffeine withdrawal symptoms as a factor in the lack of a dose response in mean energy intake at breakfast and throughout the day. For example, intake after 0 mg/kg was not significantly different from intake after 1 mg/kg or 3 mg/kg. Caffeine withdrawal symptoms may include negative affect such as tiredness, headache, and fatigue.[35] Negative affect, mood, is associated with increased responding to food cues and increased eating.[49-51] In addition, withdrawal reversal due to caffeine consumption had expected reversal effects on affect with 1 mg/kg and 3 mg/kg showing stabilization in mood swings and impatience and reduced sadness compared with maintenance of these negative affective states without caffeine consumption (0 mg/kg). The mean caffeine doses among normal weight were ~64 mg (1 mg/kg) and ~191 mg (3 mg/kg), respectively, and among overweight and obese ~84 mg (1 mg/kg) and ~254 mg (3 mg/kg). The participants in this study reported daily caffeine intake (Table 1) (158 to 218 mg/d) more than the average American consumes (139 mg/d).[33] In perspective, an 8-ounce cup of medium roast home-brewed coffee is 95 to 165 mg, indicating participants were administered a wide range of caffeine, the equivalent of about 4 to 24 ounces coffee.[52] Although overweight and obese subjects were exposed to a larger caffeine dose, results do not support interactions between BMI and caffeine on mean energy intake or eating behavior. Although the study by Gavrieli and colleagues found a significant reduction in energy intake among overweight and obese after caffeine exposure, this effect was seen at a higher dose (6 mg/kg) than was used in this study with similar effects observed at similar doses (3 mg/kg).[10] The caffeine doses used in this study may be insufficiently different from usual caffeine intake to significantly alter mean energy intake.

The results of this study indicate caffeine treatment reduces mean energy intake (1 mg/kg only) and improves mood but does not alter appetite. It should also be noted the effect on energy intake was transient because there were no subsequent alterations on appetite or energy intake when considering the entire day.

This study had several strengths and limitations. Strengths of the study include the randomized double-blind crossover dose response design, an ample well-liked buffet to encourage ad libitum consumption, and EMA techniques to assess appetite under free-living conditions. Furthermore, the experimental design for this study attempted to address some of the inconsistencies described herein. For example, caffeine was added to juice to remove expectancy effects. A low (1 mg/kg) and moderate dose (3 mg/kg) of caffeine was administered relative to body weight. This study was a within-subjects design, so all participants had each dose of caffeine and placebo. Finally, energy intake was measured between 30 to 60 minutes after caffeine consumption, which captures the time in which caffeine exerts its maximum effects.[47]

However, this study was not without limitations. This study did not have an objective measure to verify caffeine abstinence and relied on participant self-report. Although laboratory intake measures were well controlled, free-living intake relied on self-report and researcher probing did not occur until 1 week after intake. This 1-week delay in food diary review for correctness and completeness may be too long for an accurate recall of missing information and limits the usefulness of these results. In addition, administration of a caffeine dose relative to body weight along with the known positive correlation between increased adiposity and total caffeine concentration may have altered eating behavior or the effects may have occurred after leaving the laboratory.[23,24,47] Furthermore, men and women exhibit similar responses to caffeine during the follicular phase (day 0 to day 14) and dissimilar responses during the luteal phase (day 14 and on).[53] Based on estimates of menstrual cycle phase by self-reported use of hormonal contraception and menstrual cycle duration, no significant differences were identified in menstrual cycle phase and caffeine treatment; however, hormone levels were not tested, so any potential differences in intake and appetite due to hormones could not be tested. Post laboratory appetite sensations data (EMA) could only be analyzed up to the earliest time point of self-reported free-living intake due to appetite alterations associated with energy intake and differences in intake at the first free-living eating occasion. Another potential limitation of the study relates to characteristics of the sample. Despite BMI indicating overweight and obesity for males, waist-to-hip ratio indicates acceptable central adiposity. In this young, healthy population, it may be that males had greater lean body mass increasing weight and BMI, but body composition data were not collected. Finally, ecological momentary assessment techniques have been shown to induce attentional bias, which may have drawn participants' attention to their appetite and altered eating behaviors, potentially reducing the ability to observe changes.[41,42]

The results of this study add to the literature on the efficacy of caffeine for inducing hypophagia in adults.

CONCLUSIONS

As overweight and obesity rates continue to climb, people are searching for strategies to curb appetite and reduce energy intake. Several weight loss products contain caffeine and purport that caffeine acts as an appetite suppressant. The results presented here suggest acute caffeine administration has only a small, transient effect on meal energy intake, but there is no evidence that the effect persists throughout the day. The findings of this study provide no evidence to support the use of caffeine as an appetite suppressant.

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STATEMENT OF POTENTIAL CONFLICT OF INTEREST

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