NUTRITION RESEARCH XX (2013) XXX–XXX

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Acute and chronic caffeine administration increases physical activity in sedentary adults

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ARTICLE INFO

Article history:
Received 18 October 2012
Revised 5 April 2013
Accepted 5 April 2013

Keywords:
Caffeine
Ergogenic aid
Exercise
Ratings of perceived exertion
Humans

ABSTRACT

Caffeine is a commonly used stimulant thought to have ergogenic properties. Most studies on the ergogenic effects of caffeine have been conducted in athletes. The purpose of this study was to test the hypothesis that caffeine reduces ratings of perceived exertion and increases liking of physical activity in sedentary adults. Participants completed treadmill walking at 60% to 70% of their maximal heart rate at baseline and for 6 subsequent visits, during which half of the participants were given caffeine (3 mg/kg) and half given placebo in a sports drink vehicle. To investigate the potential synergistic effects of acute and chronic caffeine on self-determined exercise duration, participants were rerandomized to either the same or different condition for the last visit, creating 4 chronic/acute treatment groups (placebo/placebo, placebo/caffeine, caffeine/placebo, caffeine/caffeine). Participants rated how much they liked the activity and perceived exertion at each visit. There was a main effect of time on liking of physical activity, with liking increasing over time and an interaction of sex and caffeine treatment on liking, with liking of activity increasing in female participants treated with caffeine, but not with placebo. There was no effect of caffeine on ratings of perceived exertion. Individuals who received caffeine on the final test day exercised for significantly longer than those who received placebo. These data suggest that repeated exposure to physical activity significantly increases liking of exercise and reduces ratings of perceived exertion and that caffeine does little to further modify these effects.

1. Introduction

Caffeine is considered the most widely used psychoactive substance in the world [1] and is often used by athletes as an ergogenic aid. Caffeine delays the onset of fatigue and ultimately results in enhanced endurance [2]. Caffeine supplementation has been shown to improve both endurance [3] and athletic performance [4]. Caffeine administration 60 minutes before exercise resulted in improved performance during 15-minute bouts on a cycle ergometer at 60% of maximal oxygen consumption (VO_2max). [4]. Similar results were found in trained cyclists at extended bouts of exercise (120 minutes) at intensities ranging between 60% and 75% VO_2max [5,6]. The effects of caffeine on athletic performance have been demonstrated with a variety of aerobic activities, including 1-km time trials on a track [7], rowing [8,9], and swimming [10,11].

The ergogenic effects of caffeine may be a result of decreased ratings of perceived exertion (RPEs). A meta-analysis of the relationship between caffeine and RPE concluded that caffeine is associated with a 5.6% decrease in RPE during constant rate exercise [12]. These findings were supported in a recent study in trained cyclists who were given caffeine before exercise and experienced attenuated RPE [13].

Abbreviations: ANOVA, analysis of variance; BMI, body mass index; ratings of perceived exertion, RPEs.

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0271-5317/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.nutres.2013.04.003

A number of studies investigating RPE in resistance exercise produced equivocal results. Low-to-moderate caffeine doses decreased RPE and pain perception in resistance-trained individuals [14], decreased pain perception only in recreationally trained individuals [15], and resulted in no changes in RPE or pain perception in active men [16]. Reduction of perceived exertion has the potential to increase exercise participation in sedentary individuals. For example, RPE is inversely related to exercise duration [17]; thus, if RPE is reduced by caffeine, exercise duration may increase.

Research on the relationship between caffeine and physical activity has been conducted almost exclusively in trained individuals. Therefore, little is known about the effects of caffeine on physical activity in sedentary or lightly active individuals. It is possible that caffeine administration before exercise may increase the enjoyment of physical activity in sedentary individuals because of reductions in RPE. This is important because making exercise more enjoyable could increase the frequency and duration of physical activity in sedentary adults. The purpose of this study was to test the hypothesis that caffeine administration increases liking of physical activity and decreases RPE in sedentary and lightly active adults. This study also tested a second hypothesis that chronic caffeine administration would have synergistic effects with acute caffeine administration to maximize self-determined exercise duration in the same population. To test these hypotheses, we examined subjective liking of physical activity and RPE in sedentary adults for 2 weeks of treadmill walking in the laboratory paired with either caffeine or placebo. In addition, we examined potential interactions between acute and chronic caffeine administration by randomizing individuals into 4 acute vs chronic caffeine administration groups for the final laboratory visit and measuring self-determined exercise duration. We chose to conduct this study in sedentary adults to determine if caffeine paired with physical activity would facilitate exercise in this population.

2. Methods

2.1. *Participants and recruitment*

Participants were men and women between the ages of 18 and 50 years (n = 35). Eligibility criteria included previous exposure to caffeine with no adverse reactions, no medical conditions or medications that would restrict participating in physical activity, nonsmokers, not pregnant, and lead sedentary or lightly active lifestyles (moderate-to-vigorous activity limited to <30 minutes per day 2 days or fewer per week). Potential participants underwent screening via telephone or through an online survey administered through Survey Monkey (surveymonkey.com) to collect demographic information, preliminary anthropometric data, average daily caffeine use and consumption patterns, physical activity level, and brief medical history information, including any potential contraindications to exercise. We made an attempt to recruit participants across a broad range of caffeine use with an equal distribution of low to high users in each treatment group. We had more than 50 individuals complete the screening questionnaires, but many were not eligible or chose not to enroll in the study once they were given detailed information on the procedures. We did not record the exact number of participants who were interested but chose not to enroll. From the pool of interested, eligible participants, 37 completed consent forms and 35 completed the study. The 2 people who withdrew from the study had scheduling conflicts and could not attend all of the visits. All procedures were approved by the University at Buffalo Social and Behavioral Sciences Institutional Review Board.

2.2. *Experimental procedures*

Eligible participants were scheduled for 8 laboratory sessions, approximately 60 to 75 minutes in duration, during a 2-week period. Before their first visit, participants were randomized to caffeine (3 mg/kg) or placebo (0 mg/kg) conditions. Participants were instructed to abstain from caffeine for 24 hours before all sessions. In addition, participants were asked to refrain from engaging in physical activities on the day of their laboratory visits.

Upon arrival to the laboratory for the first session, participants read and signed a consent form. Next, participants were given their choice of sports drink flavors (orange, lemon-lime, or berry) and instructed to consume the entire beverage within 5 minutes. During the first visit, all drinks contained the placebo solution. A 30-minute period of relaxation followed to allow for digestion and absorption. Caffeine levels peak in the blood after 30 to 60 minutes after oral consumption, so this 30-minute rest period was instituted so that physical activity would correspond to maximal caffeine effects [18]. During this time, participants completed demographic and caffeine consumption questionnaires. In addition, participant height and weight were measured.

During the last 5 minutes of the relaxation period, participants were equipped with a heart rate monitor (Polar F4, Polar Electro Inc., Lake Success, NY, USA) in preparation for the treadmill exercise. A target heart rate range of 60% to 70% of age-predicted maximal heart rate (maximal heart rate = 220 − age) was used as the experimental exercise intensity. For the first and last visits only, participants engaged in treadmill walking for a minimum duration of 10 minutes but were allowed to continue exercising for as long as they desired to establish a self-determined exercise duration. Participants were granted up to 5 minutes to achieve their target heart rate by self-adjusting the speed and grade settings and were told to exercise for a minimum of 5 additional minutes. After the exercise session, participants completed postactivity liking and RPE.

Sessions 2 through 7 were conditioning sessions. Upon arrival to the laboratory, participants consumed their sports drink with treatment (placebo or caffeine). After 30 minutes, participants were equipped with the heart rate monitor and engaged in 30 minutes (5-minute warm-up, 20 minutes at target heart rate, 5-minute cool down) of treadmill walking. These sessions concluded with postactivity liking and RPE ratings. We chose a 2-week period because we have observed changes in liking of food paired with caffeine over this period [19,20], and the goal of this study was to observe changes in the liking of physical activity in the absence of significant changes in fitness.

For the final session, participants were rerandomized to receive either caffeine or placebo such that 4 conditions created (chronic treatment [visit 2-7]/acute treatment [visit 8]):

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placebo/placebo, placebo/caffeine, caffeine/placebo, or caffeine/caffeine. This allowed us to examine the chronic and acute effects of caffeine on physical activity liking, RPE, and duration. The final exercise session was similar to the first session. Participants were then debriefed and compensated for their completion of the study ($100 Wegman's gift card).

2.2.1. *Caffeine preparation*

The caffeine and placebo additives were prepared and coded by an individual who was not involved in data collection to ensure double-blind experimental design. A flattened Sprite (Coca Cola Inc., Atlanta, GA, USA) stock solution was created by heating Sprite to 140°F and stirring it at 50 rpm for 25 minutes. This served as the placebo, and the caffeine solution was created by adding 20 mg of anhydrous caffeine/mL (Sigma, St Louis, MO, USA). The placebo and caffeine solutions were coded, aliquoted, and frozen at −20°C. On the testing days, aliquots were thawed and solutions were prepared for each subject, based on body weight (0.15 mL/kg body weight).

2.2.2. *Sports drink preparation*

Stock solutions were prepared in 3 flavors (orange, lemon-lime, and frost glacier freeze) of Gatorade (Gatorade Co., Chicago, IL, USA) by combining 120 g of drink powder mix with 1890 mL of water. The stock solutions were refrigerated until use and then poured into 300-mL portions for use during study sessions.

2.3. *Measurements*

2.3.1. *Anthropometrics*

Participant weight was assessed in light clothing without shoes by the use of a digital scale (SECA, Hanover, MD, USA), and height was assessed using a digital stadiometer (SECA).

2.3.2. *Heart rate*

Participant maximal heart rate was estimated using the following formula: 220 − age recommended by the American College of Sports Medicine. The 60% to 70% of heart rate maximal target was then calculated using the following formula: [0.6 × (220 − age) to 0.7 × (220 − age)].

2.4. *Questionnaires*

2.4.1. *Demographic questionnaire*

A general demographic questionnaire was used to assess education, annual household income, employment status, and race and ethnicity.

2.4.2. *Caffeine use questionnaire*

Average daily caffeine consumption was calculated based on the participants' self-report on a caffeine use questionnaire adapted from Miller [21] that was designed to assess sources, amounts, and frequency of caffeinated food and beverage intake as well as reasons why adolescents use and/or do not use caffeine. Participants were asked "Do you drink ______" and "How often do you drink _________ (soda with caffeine, hot tea or iced tea, coffee, energy drinks)?" "How often do you eat chocolate?" and "How often do you take ________ (Excedrin or No-Doze)?" The possible answers for each of these questions were as follows: once a month, 2 to 3 times a month, 1 time per week, 2 to 3 times per week, 4 to 5 times per week, and every day. Then, participants were asked "When you are drinking _______, how many cups (or cans) do you drink?" The possible answers ranged from 1 to more than 7 cups. Amounts of caffeine consumed were estimated based on information from the US Department of Nutritional Services and include the following: tea (40 mg/5 oz), soda (40 mg/12 oz), coffee (100 mg/5 oz), energy drinks (150 mg/12 oz), chocolate (10 mg/oz), and caffeine-containing pills (Excedrin or No-Doze—130–200 mg/pill, Novartis, New York, NY, USA).

2.4.3. *Subjective ratings*

Liking of physical activity was assessed on a 5-point Likert-type scale anchored by "not at all" (1) and "extremely" (5). Likert-type scales are commonly used to assess subjective responses [22,23]. Rating of perceived exertion was assessed using the Borg Category, ratio 10 scale anchored by "no exertion at all" (0) and "maximal exertion" (10). This scale is frequently used to assess perception of difficulty of physical activity and has been validated against other measures of perceived exertion as well as physiological measures such as heart rate and blood lactate [2].

2.5. *Statistical analyses*

Potential difference in participant characteristics between the placebo (n = 19) and caffeine (n = 16) groups were analyzed using a 1-way analysis of covariance with treatment as the between-subject variable and sex, age, and average daily caffeine consumption as covariates. We used χ^2 analyses for categorical variables (sex, education, and ethnicity). Differences in mean exercise liking and RPE between the placebo and caffeine groups were compared using a mixed analysis of variance (ANOVA) with treatment (placebo vs caffeine) and sex as between-subject factors and time as the repeated measure. Changes in Mean self-determined exercise duration were analyzed using a mixed ANOVA with chronic and acute treatment and sex as between-subject factors and pre/post as the within-subject factor. Significance was set at $P < .05$ level for all results. All analyses were conducted using SYSTAT 11.0 (Chicago, IL, USA).

3. Results

3.1. *Participant characteristics*

The sample population comprised evenly among men (48.6%) and women (51.4%), was well educated (57.1 % completed college or graduate school), had an average age (mean ± SEM) of 24.4 ± 4.9 years, had an average body mass index (BMI) of 24.1 ± 3.9 kg/m^2, and had an average daily caffeine use of 81.9 ± 18.5 mg/d (Table 1). There were no statistically significant differences in any characteristics between the participants in the placebo and caffeine groups.

3.2. *Effects of caffeine on self-reported liking of physical activity*

We hypothesized that caffeine would increase self-reported liking of physical activity, but we did not find data to support

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Table 1 – Demographic data

	Caffeine	Placebo
BMI (kg/m^2), mean ± SEM	24.4 ± 4.04	23.8 ± 3.95
Age (y), mean ± SEM	23.4 ± 3.88	25.2 ± 5.71
Caffeine use (mg/d), mean ± SEM	63.2 ± 15.4	99.6 ± 32.8
Sex, n (%)		
Male	8 (50.0)	9 (47.4)
Female	8 (50.0)	10 (52.6)
Education, n (%)		
Completed high school	4 (25.0)	2 (10.5)
Some college	5 (31.3)	4 (21.0)
Completed college	2 (12.5)	6 (31.5)
Completed graduate degree	5 (31.3)	7 (36.8)
Ethnicity, n (%)		
Asian	5 (31.3)	13 (68.4)
African American	1 (6.3)	0 (0.0)
White	7 (43.8)	5 (26.3)
Other	3 (18.8)	1 (5.3)

Descriptive characteristics for participants who received caffeine (n = 16) or placebo (n = 19) on visits 2 to 7. Potential difference in participant characteristics between the placebo (n = 19) and caffeine (n = 16) groups were analyzed using a 1-way ANOVA, with treatment as the between-subject variable for BMI and age and χ^2 analyses for categorical variables (sex, education, and ethnicity). There were no statistically significant differences in any characteristics between the participants in the placebo and caffeine groups.

that hypothesis. When liking of physical activity was examined over time, we found a main effect of time ($F_{7,189}$ = 3.0, P = .006), with participants increasing liking over time, regardless of treatment. We also found a significant treatment by sex interaction ($F_{1,7}$ = 3.379, P = .002). Post hoc data analysis revealed that there was no effect of caffeine on exercise liking in men (Fig. 1A), but caffeine increased exercise liking in women (Fig. 1B).

3.3. *Effects of caffeine on RPEs*

We hypothesized that caffeine would decrease RPE, but we did not find data to support that hypothesis. When RPE was examined over time, we found a main effect of time ($F_{7,217}$ = 7.98, *P* < .0001). We also found a significant interaction between time and BMI ($F_{1,5}$ = 2.716, P = .005), with individuals with a BMI less than 25 kg/m^2 having no change in RPE, but those with a BMI greater than 25 kg/m^2 showing a significant decrease in RPE over time (data not shown).

3.4. *Effects of acute vs chronic caffeine on self-determined exercise duration*

We hypothesized that caffeine would increase self-determined exercise duration. Our data support this hypothesis. We found a main effect of pre/post ($F_{1,27}$ = 12.3, P = .002) and an interaction between pre/post and caffeine condition ($F_{1,27}$ = 8.6, *P* = .007). Most participants increased time engaged in exercise during visit 8 compared with visit 1, but this effect was significantly greater in participants who had caffeine on visit 8, regardless of their caffeine treatment throughout the rest of the study (Fig. 2).

4. Discussion

The purpose of this study was to test the hypothesis that caffeine administration increases liking and decreases perceived exertion of physical activity in sedentary and lightly active adults. A secondary hypothesis was that caffeine supplementation increases the duration of self-determined exercise in the same target population. We found that, in general, participants increased liking of physical activity over time, regardless of caffeine treatment. Female participants given caffeine showed significant increases in their liking of exercise over the 2-week period relative to placebo; however, there was no difference between placebo and caffeine in male participants. When we examined RPE, we found that RPE decreased over time, regardless of caffeine treatment. Given these findings, we must reject our original hypothesis that

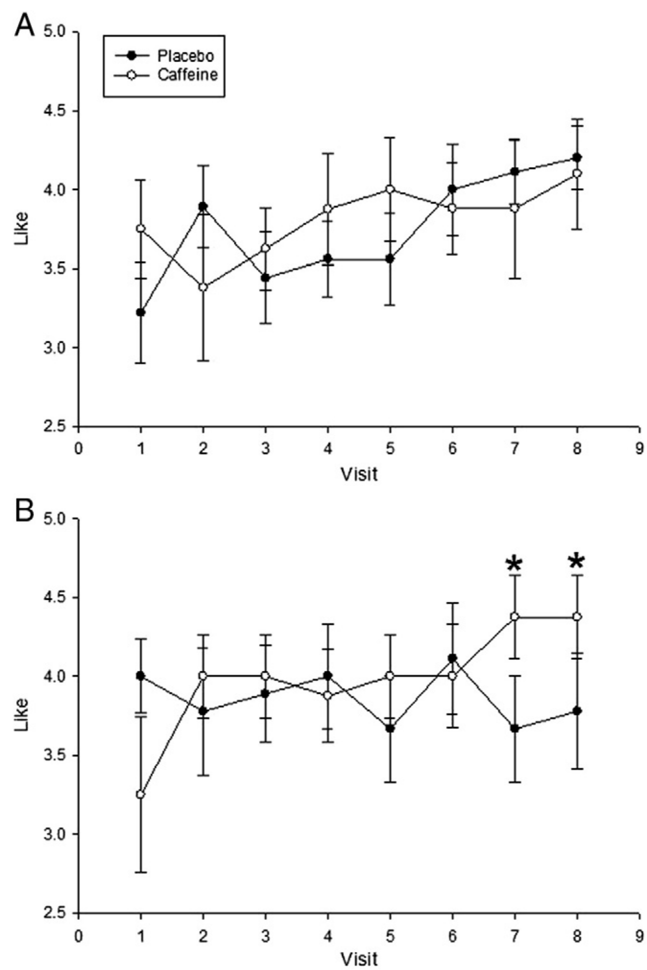

Fig. 1 – Means ± SEM liking ratings of physical activity in men (n = 17; A) and women (n = 18; B) across placebo (n = 19) and caffeine (n = 16) treatment conditions over time. Statistical analyses revealed a main effect of time ($F_{7,189}$ = 3.0, P = .006) with participants increasing liking over time, regardless of treatment and a significant treatment by sex interaction ($F_{1,7}$ = 3.379, P = .002). Post hoc analysis revealed that there was no effect of caffeine on exercise liking in men (A), but caffeine increased exercise liking in women (B). *Significantly different (*P* < .05).

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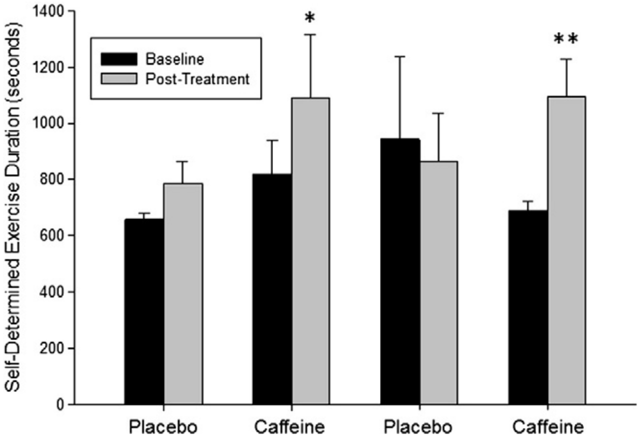

Fig. 2 – Means ± SEM self-determined exercise duration at baseline (black bars) and after 2 weeks of treatment (gray bars) in participants treated with placebo (n = 19; left set of bars) or caffeine (n = 16; right set of bars) throughout the training period, and treated with either placebo (n = 18) or caffeine (n = 17) on the last exercise visit (*x*-axis labels). This produced 4 groups (chronic treatment: acute treatment) shown from left to right: placebo/placebo (n = 11), placebo/caffeine (n = 7), caffeine/placebo (n = 8), and caffeine/caffeine (n = 9). Statistical analyses revealed a main effect of pre/post (visit 1 vs visit 8; $F_{1,27} = 12.3$, $P = .002$) and an interaction between pre/post and caffeine condition ($F_{1,27} = 8.6$, $P = .007$). Post hoc analyses revealed that the participants who received placebo on visit 8 did not increase exercise duration from baseline (placebo: $F_{1,10} = 4.24$ and caffeine: $F_{1,6} = 0.32$; $P = .59$), but those who had caffeine on visit 8 did increase exercise duration from baseline (placebo: $F_{1,7} = 5.58$ [$P = .048$] and caffeine: $F_{1,8} = 11.8$ [$P = .009$]). There were no interactions with chronic caffeine treatment. *Significantly difference from placebo ($P < .05$). **Significantly different from placebo ($P < .01$).

caffeine increases liking of physical activity and reduces RPE. Finally, when we examined changes in self-determined exercise duration between the first and the last visit, we found that individuals who had caffeine on the last visit chose to exercise for significantly longer than those who had placebo, regardless of the treatment during the conditioning phase of the study. This result supports our hypothesis that caffeine treatment will increase the duration of self-determined exercise. When taken together, these data suggest that repeated exposure to moderate physical activity in sedentary individuals increases liking and reduces RPE. Chronic caffeine exposure may facilitate liking of physical activity in women, but not in men. Acute caffeine intake may be more important than chronic for increasing physical activity duration.

This study had several strengths. First, we used a double-blind, placebo-controlled design. Second, we used a sedentary and lightly active population. Finally, we investigated caffeine consumption that is typical of adult caffeine intake and not supraphysiological doses. This study was not without limitations. First, our population was predominantly well educated. Although we made attempts to recruit a more diverse population, our advertisements and word-of-mouth referrals attracted such a population. Second, we used a treadmill for our exercise condition. Because the treadmill is a weight-bearing activity, this may have impacted overweight and obese participants differently from lean participants. Future studies may benefit from using a cycle ergometer, a non–weight-bearing mode of exercise. Third, we did not keep track of caffeine use immediately before the beginning of the study, so it is possible that participants began the study in different states of caffeine withdrawal. This may have affected the initial exercise bout. Fourth, we only examined RPE at the end of the exercise bout. We may have observed a difference if RPE had been assessed throughout the duration of the exercise bout. Finally, we did not include measures of caffeine tolerance or withdrawal; thus, it is possible that some of the participants were experiencing withdrawal or were tolerant to the effects of caffeine. We feel that, if anything, this makes our findings more conservative. If anything, screening out individuals who are tolerant to the effects of caffeine would have likely increased responses to caffeine, which would have made us more likely to find an effect of caffeine.

One of the strengths of this study was the use of a sedentary or lightly active population. Most studies on caffeine and perceived exertion have been conducted in trained athletes and have shown that caffeine reduces RPE [12]. Of the studies that have been conducted on sedentary or lightly active adults, the results have been mixed. One study in sedentary men with an average age of 25 years (similar to our study population) reported no difference in RPE during cycle ergometer performance trials in sedentary men when comparing caffeine to placebo conditions [12]. However, in 2 studies conducted in elderly men and women, one showed that caffeine administration reduced RPE and the other showed no effect of caffeine on RPE [24,25]. In the study conducted in the younger men, the participants were light caffeine users (<120 mg/d), but in the studies in the elderly populations, most participants were heavy caffeine users, with an average daily intake of 486 mg. Our study population was similar in age and caffeine consumption to the one conducted by Laurence and colleagues [26], who also saw no effect of caffeine on RPE. It may be that in younger populations with lower average caffeine use, that caffeine has less of an effect. In addition, in our study we found that RPE decreased over time in all participants. Thus, it may be that the repeated exposure to moderate physical activity maximally reduced RPE on its own that caffeine could not reduce it further. It is important to note that our RPE values were fairly low. Perhaps if we had participants exercise at a higher intensity, we would have seen more of an influence of caffeine. Another possible reason why we did not see greater effects of caffeine on RPE is that the intensity of the exercise was based on the participants' heart rate. Acute caffeine administration lowers heart rate [27–29], so participants in the caffeine group may have had to work harder to achieve their target heart rate, thus increasing the RPE. Future studies can address this by using another measure to standardize intensity, such as VO_2max.

Although we did not find a main effect of caffeine on liking of physical activity, there was a sex by treatment interaction, with sex increasing liking of physical activity in women but not in men. One possible mechanism for the sex difference in caffeine-induced liking of physical activity is alterations in caffeine metabolism. Caffeine metabolism is dependent on

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cytochrome P450 activity, specifically the CYP1A2 isoform [30]. Women express reduced CYP1A2 activity as compared with men [31]. As a result, the half-life of caffeine is greater in women, which would allow for prolonged stimulatory action caused by elevated plasma caffeine concentration over a longer period. This sex difference appears to be mediated by steroid hormones because men and women show similar responses to caffeine during the follicular phase, but women are less responsive than men during the luteal phase [32]. In our study, we did not control for menstrual cycle phase or measure steroid hormones, so we can only speculate about why caffeine influenced women's perception of exercise but not men's.

In addition to examining the influence of caffeine on subjective responses to caffeine, we also examined the separate and combined effects of acute and chronic caffeine administration on self-determined exercise duration. We found that chronic caffeine exposure had no effect, but acute caffeine increased duration relative to placebo. This increase in duration, considered as an increase in performance, is consistent with reports of improved performance within the literature. For example, cycling performance was shown to improve after caffeine supplementation for total work output [4,6,33,34]. Contrary to our study, sedentary women who engaged in a self-paced exercise bout that followed a fixed-paced exercise bout showed no improvement in performance after moderate caffeine supplementation [35]. It is difficult to directly compare our study to the research cited above because cycling and treadmill walking are not equivalent, and we were using a low-to-moderate intensity exercise condition. Future studies need to examine the influence of caffeine in sedentary adults using different types, intensities, and durations of exercise.

One weakness of this study is that we did not measure caffeine use immediately before the beginning of the study, so it is possible that participants began the study in different states of caffeine withdrawal. This may have affected the initial exercise bout. In addition, we did not collect any measures of caffeine withdrawal or tolerance, so we have no way of knowing how this may have affected our findings. Although withdrawal reversal has been hypothesized to account for many of the effects of acute caffeine administration, including mood and cognitive functioning [36], psychomotor performance [37], and attention [38], studies on the contribution of withdrawal reversal to ergogenic properties of caffeine are equivocal. For example, a study in trained cyclists showed that caffeine administration improved exercise performance, regardless of the caffeine withdrawal state [39]. Similarly, caffeine was shown to improve exercise endurance in recreational athletes regardless of withdrawal state [40]. By contrast, a study in habitual female caffeine consumers found that caffeine administration after a 4-day withdrawal period resulted in the greatest enhancement of exercise performance [41]. Given the relatively low level of caffeine consumption in our study population (81.9 ± 18.5 mg/d) relative to the studies cited above, we think that caffeine withdrawal is not likely to have affected our findings. If withdrawal was having a significant impact, we would expect that withdrawn participants in the placebo group would have liked exercise less or perceived the exertion is greater than those who received caffeine on the test day, but this was not the case.

Although this study was relatively small, we hope to continue this line of research in the future. One question that we have is whether there are dose-dependent effects of caffeine on exercise liking and RPE in sedentary adults. Future studies will use a dose-response design with higher doses included to be more consistent with the literature. Another question that we have is whether a longer training period might have been necessary to see significant effects of caffeine on liking of exercise and RPE. Future studies will extend the duration of the training period. Finally, once we have good data on the most effective dose and period of caffeine and exercise pairing, we would like to determine if caffeine paired with exercise can be used outside the laboratory to make sedentary individuals more likely to be physically active.

In sum, this study shows that caffeine administration can increase liking of physical activity and exercise duration in some individuals. Acute caffeine administration had the most significant effect on exercise duration. This suggests that pairing caffeine with exercise may be a way to make individuals exercise for longer and, thus, increase the likelihood of achieving the American College of Sports Medicine recommendations for physical activity.

Acknowledgments

The authors thank David Williamson and Todd Rideout for feedback on an earlier version of this manuscript. They also thank Amanda Ziegler for help with scheduling and training for this study. This study was supported using funds from the University at Buffalo and the School of Public Health and Health Professions. None of the authors have any conflicts of interest.

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Please cite this article as: Schrader P, et al, Acute and chronic caffeine administration increases physical activity in sedentary adults, Nutr Res (2013), http://dx.doi.org/10.1016/j.nutres.2013.04.003