The Effects of Caffeine in Women During Aerobic-Dance Bench Stepping


People of all ages and fitness levels participate regularly in aerobic-dance bench stepping (ADBS) to increase fitness and control body weight. Any reasonable method for enhancing the experience or effectiveness of ADBS would be beneficial. This study examined the acute effects of a single dose of caffeine on physiological responses during ADBS in women. When compared with a placebo, neither a 3- nor a 6-mg/kg dose of caffeine altered physiological responses or rating of perceived exertion (RPE) in 20 women (age 19–28 y) of average fitness level, not habituated to caffeine, while they performed an ADBS routine. Since neither dose of caffeine had any effect on VO₂, VCO₂, minute ventilation, respiratory-exchange ratio, rate of energy expenditure, heart rate, or RPE during ADBS exercise, it would not be prudent for a group exercise leader to recommend caffeine to increase energy cost or decrease perception of effort in an ADBS session. Furthermore, caffeine ingestion should not interfere with monitoring intensity using heart rate or RPE during ADBS.

**Key Words:** energy expenditure, heart rate, rating of perceived exertion

Aerobic-dance bench stepping (ADBS) is a popular activity that, when monitored properly, can help people meet the ACSM guidelines for proper aerobic conditioning (23). For example, ADBS performed at approximately 60–71% of maximal oxygen-uptake reserve (VO₂R) results in an estimated rate of energy expenditure (REE) of 29–33 kJ/min (=7–8 kcal/min), or 1160–1320 kJ (=280–320 kcal) for a 40-min session (18). Lloyd et al. (20) reported that when performed at the same workload (i.e., same oxygen consumption, VO₂), the average rating of perceived exertion (RPE) for ADBS was significantly lower than walking on a treadmill or cycling on a leg ergometer. In short, ADBS might be appealing to some because it feels easier than other conventional modes of activity yet has a high energy cost.

Enhancing the exercising experience by increasing REE while lowering RPE might make structured physical activity, including ADBS, even more attractive. Caffeine is a popular ergogenic aid that has been shown to increase VO₂ (4, 8,
and decrease RPE (4, 5) during common modes of exercise such as cycling and treadmill running. Most of the research on caffeine ingestion during aerobic exercise has examined highly trained subjects exercising at high intensities, often to exhaustion (4, 5, 15, 24, 25). To date, no studies have investigated the effects of caffeine ingestion on ADBS performance. Consequently, it is not clear whether caffeine intake should be recommended before engaging in ADBS in order to increase REE or decrease RPE.

The purpose of this study was to determine the effects of caffeine ingestion on physiological responses and RPE during ADBS in recreationally active women. Based on the results of previous studies (4, 5, 8, 25), we hypothesized that caffeine supplementation would have modest effects, elevating VO₂ and reducing RPE, during ADBS in recreationally active women.

**Methods**

**Subjects**

Twenty women, 19–28 years of age, enrolled in a personal fitness and wellness aerobic class at a university participated in this study. To ensure that the subjects were able to follow a videotaped routine and also to reduce the risk of injury, the criteria for subject participation included a minimum of 1 mo of regular attendance (at least 3 d/wk) in formal ADBS classes.

Table 1 reports the subjects’ descriptive statistics. The aerobic-fitness levels of the participants ranged from poor to good, according to measurements of their maximal oxygen consumption (VO₂ max) (2). Based on analysis of their 3-day dietary recalls, 7 consumed no caffeine and 13 consumed no more than 80 mg of caffeine per day; thus, none of the subjects were considered regular caffeine users (4, 14, 15). Therefore, this sample can be generalized to women of varying fitness levels who are not regular caffeine users and are familiar with the techniques required for ADBS.

This investigation was approved by the university’s Institutional Review Board.

**Table 1 Subject Characteristics (N = 20)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>22.4 ± 2.3</td>
<td>19.0–28.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.6 ± 8.0</td>
<td>152.4–177.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>71.7 ± 10.0</td>
<td>58.6–96.8</td>
</tr>
<tr>
<td>Peak VO₂ (mL·kg⁻¹·min⁻¹)²</td>
<td>32.9 ± 6.2</td>
<td>22.9–46.0</td>
</tr>
<tr>
<td>Average caffeine intake (mg/d)</td>
<td>16.2 ± 21.6</td>
<td>0–75.9</td>
</tr>
</tbody>
</table>

²Peak VO₂ indicates peak oxygen consumption.
Testing Procedures

Subjects visited the laboratory on 4 separate occasions, 2–7 d apart. Before their first visit, they were provided pretest instructions based on ACSM guidelines (2). During visit 1, they signed an informed consent, completed a health appraisal, were measured for height and weight (in exercise clothes, without shoes) using a calibrated physician’s scale (Detecto Scale Co., Jericho, NY), and performed a Bruce graded maximal exercise test (2) on a Trackmaster treadmill (FullVision, Newton, KS). Peak VO₂ was considered VO₂max if 3 of the following criteria were met: leveling off of VO₂ despite an increase in workload, achieving age-predicted maximal heart rate (HR; 220 – age), a respiratory-exchange ratio (RER) greater than 1.15, or failure to maintain pace despite strong verbal encouragement (2). During maximal and submaximal exercise tests, each subject’s HR was measured with a Polar Vantage XL telemetric HR monitor (Stanford, CT). HR was recorded at the end of each minute. Expired air was analyzed throughout all tests with a PARVO Medics metabolic analyzer (Salt Lake City, UT). VO₂, carbon-dioxide production (VCO₂), minute ventilation (VE), RER, and REE were determined from 60-s averages. Calibration was performed before each test using a certified gas mixture (O₂ = 16% and CO₂ = 4%, Scott Medical Products, Plumsteadville, PA). RPE was recorded at the end of each minute on a 6- to 20-point Borg scale (6).

During visit 1, subjects were instructed to record their usual dietary intake for 3 d. Instructions regarding accuracy in recording consumption of foods and beverages were given both individually and in the form of a detailed handout. Before visit 2, their records were submitted and analyzed for nutrient content (4). Analysis using the Food Processor SQL (ESHA Research, Salem, OR) revealed that on average, subjects consumed 53%, 14%, and 33% of calories from carbohydrate, protein, and fat, respectively. Subjects were given copies of their diet records and instructed to replicate their usual intake on the day before each remaining trial (24). In addition, they were instructed to prepare for each trial by abstaining from caffeine for 12 h (14) and eating as they normally would before a bout of exercise (25), including a light snack 1–2 h before each trial. The light snack was recommended to offset any gastrointestinal discomfort that might follow caffeine supplementation (4).

Before visits 2–4, capsules were prepared and placed in coded envelopes by a person who was not involved in the data analysis. Capsules contained anhydrous caffeine powder (Spectrum Chemicals, New Brunswick, NJ) or a similar volume of dextrose (Spectrum Chemicals, New Brunswick, NJ), which had the same color and texture as the caffeine. During visits 2–4, subjects were randomly administered caffeine (3 or 6 mg/kg) or placebo in a double-blind manner. Capsules were consumed with an 8-oz serving of water. After 60 min, subjects followed a previously videotaped, 8-min, submaximal ADBS routine, stepping up and off an 8-in bench at a cadence of 128 beats/min. Trials were separated by a minimum of 48 h, which is adequate to eliminate caffeine from the circulation (10).

The primary investigator, a group exercise leader (Aerobics and Fitness Association of America-certified) with 2 y of ADBS teaching experience, had previously developed and videotaped the choreographed bench-stepping routine of moderate to hard intensity consisting of movements commonly used in ADBS (16). The routine consisted of basic stepping, alternating kicks, knee lifts, leg curls, back leg lifts,
Ahrens et al.

Turn stepping, and traveling back and forth over the top of the bench. Various arm movements, including opening and closing the arms overhead and across the chest and lateral and forward raises to shoulder height, were performed simultaneously with the stepping. The cadence was verified by a metronome. Within 2 wk of the actual trials, participants were oriented to the laboratory and familiarized with the protocol, which included practicing the step-aerobics routine. For the trials, subjects were fitted with heart-rate monitors and headgear that housed the breathing apparatus. They then rested for 15 min, and, as instructed, followed the exact movements of the ADBS routine. Before the beginning of each trial, the bench was positioned so that the subject could perform the routine. The gas-collection tubing was suspended overhead and to the side of the subject, extending from the metabolic cart through a plastic loop support. With the continuous aid of a technician to control the slack in the tubing, the exercise trials were completed with minimal interference in movement from the metabolic apparatus.

**Statistical Analysis**

The physiological measurements (i.e., VO$_2$, VCO$_2$, VE, RER, REE, %VO$_2$R, and HR) and RPE recorded at the end of minutes 6, 7, and 8 were averaged and used for data analysis. Analyses of variance (ANOVA) with repeated measures were conducted to determine the effect of different doses of caffeine (placebo vs. 3 mg/kg vs. 6 mg/kg) on the measurements.

**Results**

Table 2 reports the subjects’ cardiovascular and metabolic responses (mean ± SD), including means for relative VO$_2$ (ml·kg$^{-1}$·min$^{-1}$), VCO$_2$ (L/min), VE (L/min), RER, REE (kcal/min), % VO$_2$R, HR (beats/min), and RPE, rating of perceived exertion.

### Table 2  Physiological Responses (Mean ± SD) and Rate of Perceived Exertion During Aerobic-Dance Bench Stepping 1 h After Ingestion of Placebo or Caffeine

<table>
<thead>
<tr>
<th>Variable</th>
<th>Placebo</th>
<th>3 mg/kg caffeine</th>
<th>6 mg/kg caffeine</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_2$ (mL·kg$^{-1}$·min$^{-1}$)</td>
<td>25.0 ± 3.6</td>
<td>26.1 ± 3.3</td>
<td>26.4 ± 2.8</td>
</tr>
<tr>
<td>VCO$_2$ (L/min)</td>
<td>1.9 ± 0.3</td>
<td>1.9 ± 0.3</td>
<td>1.9 ± 0.3</td>
</tr>
<tr>
<td>VE (L/min)</td>
<td>45.3 ± 6.8</td>
<td>48.5 ± 7.9</td>
<td>48.7 ± 8.0</td>
</tr>
<tr>
<td>RER</td>
<td>0.99 ± 0.07</td>
<td>0.99 ± 0.08</td>
<td>1.00 ± 0.07</td>
</tr>
<tr>
<td>REE (kcal/min)</td>
<td>9.0 ± 1.5</td>
<td>9.4 ± 1.5</td>
<td>9.6 ± 1.3</td>
</tr>
<tr>
<td>% VO$_2$R</td>
<td>75.4 ± 15.9</td>
<td>80.0 ± 18.1</td>
<td>81.0 ± 15.4</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>168.5 ± 16.8</td>
<td>168.8 ± 17.6</td>
<td>171.7 ± 17.5</td>
</tr>
<tr>
<td>RPE</td>
<td>10.3 ± 2.3</td>
<td>10.2 ± 2.7</td>
<td>9.9 ± 2.4</td>
</tr>
</tbody>
</table>

VO$_2$ indicates oxygen uptake; VCO$_2$, carbon-dioxide production; VE, minute ventilation; RER, respiratory-exchange ratio; REE, rate of energy expenditure; % VO$_2$R, % of maximal oxygen-uptake reserve; HR, heart rate; and RPE, rating of perceived exertion.
Effects of Caffeine

REE (kcal/min), %VO₂ R, HR (beats/min), and RPE measured during the last 3 min of each steady-state ADBS trial after placebo or caffeine ingestion.

Repeated-measures ANOVA comparing placebo and caffeine trials revealed no significant differences in the subjects’ VO₂, VCO₂, VE, RER, REE, % VO₂ R, HR, or RPE (P > 0.05) among any of the placebo or caffeine trials.

Discussion

The effects of an acute dose of caffeine on RPE and on the physiological responses to ADBS in women of average fitness levels have not been previously reported. This study determined that caffeine intake 60 min before exercise had no significant effect on VO₂, VCO₂, VE, RER, REE, %VO₂ R, HR, or RPE in adult women of average fitness, not habituated to caffeine, during ADBS.

There is evidence that during high-intensity cycling in highly fit men and women and during moderate-intensity treadmill walking, caffeine ingestion increases the metabolic cost of exercise (i.e., VO₂ and REE) (4, 8, 25). Based on results of these studies, we predicted that caffeine supplementation 1 h before exercise would elevate the metabolic cost of ADBS in recreationally active women. Although there are many purported mechanisms of caffeine action, the effect of caffeine on metabolic cost is most likely explained by its role as an agonist of the ryanodine receptor in skeletal-muscle cells (7). On stimulation of ryanodine receptors, there is a consequent increase in intracellular calcium flux, muscle contraction, heat production, and ATP turnover (1, 12).

Unlike in previous studies, the results of this study showed that caffeine intake did not significantly increase VO₂ or REE. ADBS is quite different from exercises traditionally used to assess the effects of caffeine. Specifically, although treadmill walking or running, rowing, and cycling involve the repetitive use of the same set of muscles, the ADBS choreography requires that a variety of movements involving both upper and lower body muscle groups are used during the routine. Thus, this study shows that caffeine might be less efficacious in an aerobic activity that involves less repetitive, more random types of movement.

Substrate utilization shifts during exercise. Specifically, during prolonged, continuous exercise, the rate of carbohydrate metabolism gradually decreases while that of fat gradually increases (19). RER is the ratio of VCO₂ to VO₂ and is often used to characterize substrate use during exercise. Studies regarding caffeine’s effect on RER are discordant (4, 8, 14, 24, 25). Although the conclusion is controversial, caffeine purportedly functions, at least in part, by facilitating free-fatty-acid mobilization (9). A decrease in RER as a result of caffeine intake would support this role of caffeine, but this study, like many others (4, 14, 24), showed that caffeine had no significant effect on RER during exercise. This lack of effect might be explained by the experimental protocol that allowed for snack consumption 1–2 h before exercise. Although researchers often require a 3-h fast before exercise, the snack was recommended to decrease the potential for gastrointestinal distress after ingestion of the supplement (4), which we have observed in women consuming higher caffeine doses in our laboratory. Furthermore, our intent was to determine whether caffeine affected the usual ADBS experience of recreationally active women. Because the women had reported that they sometimes ate snacks
within 1–2 h of exercise, we opted to instruct them to replicate their usual intake. It is possible, however, that conducting this experiment on subjects in a fasted state could affect substrate utilization differently.

The use of RER to characterize substrate utilization during exercise in caffeine studies has been questioned (25). Specifically, some studies have shown that caffeine increases VE and have attributed this response, at least in part, to caffeine’s stimulant effect on the central nervous system (10, 25). An increase in VE would result in a concurrent increase in CO₂ output, thus interfering with the utility of the RER measurement. In this study, however, caffeine intake had no effect on VE, VCO₂, or RER and, accordingly, had no effect on substrate utilization. Similar results regarding the effect of caffeine on VE, VCO₂, and RER have been reported (5, 14, 15, 24).

There has been no consensus on the effect of caffeine intake on HR during exercise. For example, Birnbaum and Herbst (5) reported that a 5-mg/kg dose of caffeine in trained individuals running at 70% VO₂max had no effect on HR. Similarly, a 6-mg/kg dose of caffeine administered to trained athletes 75 min before cycling at 65% VO₂max also failed to affect HR (24). In contrast, Bell and McClellan (4) demonstrated that a 5-mg/kg dose of caffeine increased HR during cycling at approximately 80% VO₂max. Although several mechanisms have been proposed to explain the physiological effects of caffeine, it is likely that any increase in HR during exercise includes caffeine’s stimulatory effect on the central nervous system (21). The results of the present study, however, showed no change in HR during ADBS as a result of caffeine ingestion. The results of this study contradict the findings of Bell and McClellan (4) but do support those of several other studies (3, 5, 15, 24). This is the first study to examine the effects of caffeine on HR during ADBS. It is possible that any potential for caffeine to raise HR might be masked by the nature of this exercise, which incorporates various overhead arm movements. The addition of arm movement during ADBS elicits a higher HR response relative to VO₂ (11).

In a recent meta-analysis of 21 studies, caffeine was shown to reduce RPE scores during treadmill and cycling exercise by almost 6% (13). Previous research employing protocols similar to the one used in this study (i.e., caffeine dose and exercise intensity) support the effect of caffeine in lowering RPE (4, 5, 9). If caffeine ingestion were to reduce RPE during ADBS, it might theoretically have the desirable effect of increasing the duration of exercise, simply because it seems easier. Our findings indicate, however, that caffeine did not lower RPE during ADBS. This might be a result of the nature of ADBS compared with cycle ergometry or treadmill exercise. It has been reported that the RPE for ADBS is lower than for other activities performed at a similar workload (20). Perhaps the distraction of following a complex choreography or listening to music while exercising contributes to a lowered RPE during ADBS. Thus, the subjects’ RPE during ADBS might already be too low for any effect of caffeine ingestion to be detectable.

On another note, exercise instructors often recommend using HR and RPE in order to self-monitor exercise intensity and stay within recommended ACSM intensity guidelines. Any effect of caffeine ingestion on either HR or RPE independent of effort (VO₂) could potentially decrease the reliability of using HR and RPE as self-monitoring processes. Neither a 3- nor a 6-mg/kg dose of caffeine affected HR or RPE during ADBS in this study. Consequently, caffeine intake...
Effects of Caffeine

before ADBS exercise does not appear to interfere with one’s ability to monitor exercise intensity.

Several strengths of this study, not usually included in previous research on caffeine ingestion, include the use of recreationally active women who were not habituated to caffeine, a comparatively large sample size ($N = 20$), the comparison of 2 doses of caffeine, and the use of a common but often untested form of activity, ADBS. Thus, results of this study offer information of pragmatic importance to recreationally active women. Because the study protocol demanded a considerable time commitment from volunteers (4 visits at $\approx 1.5$ h each), the duration of each ADBS test was restricted to 8 min to reduce the likelihood of attrition and therefore maximize the sample size. Because measurable effects of caffeine ingestion have been observed within 5 min of initiating steady-state aerobic exercise (4), this time frame was adequate to detect physiological effects of caffeine.

In summary, the intent of this study was to determine whether caffeine intake would affect casual exercise practiced by recreationally active individuals who exercise for general fitness and weight management. Although a popular ergogenic aid, caffeine use is not limited to athletes but is widely consumed in large quantities by people of all ages. In fact, in a representative sample of the U.S. population, 93% of adult men and nonpregnant women surveyed consumed more than 240 mg of caffeine per day (17). This study has shown that neither 3 nor 6 mg/kg of caffeine, amounts that can be obtained in a large cup of specialty coffee (22), had any measurable effect on RPE or the physiological responses to ADBS. Because these women were not habitual users of caffeine, any effect of caffeine should have been evident in this study. In conclusion, caffeine intake before ADBS will not make ADBS feel easier, interfere with monitoring exercise intensity, or increase energy expenditure.

Acknowledgment

This research was completed in partial fulfillment of the requirements for the primary author’s master of education degree in exercise science at Texas State University-San Marcos.

References