Effect of Caffeine Intake on Pain Perception During High-Intensity Exercise

Todd A. Astorino, Michael N. Terzi, Daniel W. Roberson, and Timothy R. Burnett

Caffeine has been shown to reduce leg-muscle pain during submaximal cycle ergometry, as well as in response to eccentric exercise. However, less is known about its analgesic properties during non-steady-state, high-intensity exercise. The primary aim of this study was to examine the effect of 2 doses of caffeine on leg pain and rating of perceived exertion (RPE) during repeated bouts of high-intensity exercise. Fifteen active men (age 26.4 ± 3.9 yr) completed 2 bouts of 40 repetitions of “all-out” knee extension and flexion of the dominant leg at a contraction velocity equal to 180°/s. Before each trial, subjects abstained from caffeine intake and intense exercise for 48 hr. Over 3 days separated by 48 hr, subjects ingested 1 of 3 treatments (5 mg/kg or 2 mg/kg of anhydrous caffeine or placebo) in a randomized, single-blind, counterbalanced, crossover design. Leg-muscle pain and RPE were assessed during and after exercise using established categorical scales. Across all treatments, pain perception was significantly increased (p < .05) during exercise, as well as from Bout 1 to 2, yet there was no effect (p > .05) of caffeine on pain perception or RPE. Various measures of muscle function were improved (p < .05) with a 5-mg/kg caffeine dose vs. the other treatments. In the 5-mg/kg trial, it is plausible that subjects were able to perform better with similar levels of pain perception and exertion.

Keywords: muscle endurance, perceived exertion, hypoalgesia, ergogenic aid, adenosine

Previous studies (e.g., Cook, O’Connor, Oliver, & Lee, 1998) revealed that exercise can be used to elicit leg-muscle pain. In their study, Cook et al. devised a 0–10 category ratio scale from revisions of the Borg (1982) scale and the Pain Perception Inventory (Tursky, Jamer, & Friedman, 1982) to measure pain perception during exercise. Results demonstrated linear increases in pain intensity during incremental cycle ergometry to exhaustion in active men and women. This is important, because excess pain sensation may reduce individuals’ performance, adherence, and eventual participation in physical activity.

Subsequent studies investigated the efficacy of caffeine to reduce muscle pain during and after exercise. Findings from an initial study (Motl, O’Connor, & Dishman, 2003) revealed significant reductions in leg-muscle pain when 10 mg/kg caffeine was ingested before 30 min of submaximal cycling. Follow-up studies by those investigators corroborated early data, showing reduced pain perception (a) when lower doses (5 mg/kg) were ingested by men (O’Connor, Motl, Brogio, & Ely, 2004), (b) when higher work rates equal to 80%VO2max were performed by women (Gliottoni & Motl, 2008), (c) in those who consumed low and high amounts of caffeine and exercised at 75% VO2max (Gliottoni, Meyers, Arngrimsson, Brogio, & Motl, 2009), and (d) in response to eccentric exercise (Maridakis, O’Connor, Dudley, & McCully, 2007). Collectively, these data demonstrate caffeine-induced attenuations in leg pain during aerobic exercise with relatively high caffeine doses (5 or 10 mg/kg of caffeine, equivalent to 3 and 6 cups of coffee, respectively). Whether lower doses of caffeine, which can be easily ingested as part of a typical dietary intake or preexercise meal, similarly reduce pain perception remains to be determined. It is also unknown whether caffeine expresses similar hypoalgesic effects at higher pain intensities than observed in previous studies (Gliottoni & Motl, 2008; Motl et al., 2003), in which pain intensity ranged from 1.0 to 4.0 in response to submaximal cycle ergometry. This is important for common training modalities such as resistance training and interval exercise, characterized by repeated, near-maximal to maximal efforts, which likely create greater pain than steady-state exercise.

Caffeine seems to reduce pain sensation through its effects as an adenosine antagonist (Sawynok, 1998). Adenosine, a cellular component that is increased with muscle contraction, inhibits neuron excitability and synaptic transmission via binding to its receptors (Latini & Pedata, 2001), leading to decreased arousal and increased sleep (Rogers & Dinges, 2005). Caffeine seems to exert a direct effect via blocking of peripheral A2A receptors on sensory afferents or central blocking of adenosine A2B receptors that influence pain signaling (Sawynok, 1998). However, further research
is merited to explain the attenuated pain perception with caffeine.

The primary aim of the current study was to determine the effects of two doses of caffeine on leg-muscle pain and perceived exertion during repeated bouts of maximal knee-extension and -flexion exercise that are likely to induce greater pain intensity than previous studies. This mode also better simulates the demands of intense athletic performance compared with steady-state cycling used in previous studies. We hypothesized that the higher dose of caffeine equal to 5 mg/kg body weight, but not a lower dose equal to 2 mg/kg, would reduce pain perception compared with placebo.

Methods

Subjects

Fifteen active men participated in the study; their demographic data are shown in Table 1. They met the following inclusion criteria: participation in at least 4 hr/week of exercise for at least 1 year, including recreational sports and aerobic or resistance training; nonsmoker; current caffeine intake >100 mg/day; absence of knee ailments or existing knee pain; not taking any supplements or medications that alter pain perception; and nonobese with BMI <30 kg/m². They had prior experience completing testing employed in the current study. Written informed consent was obtained from all subjects, and the study procedures were approved by the university institutional review board.

Familiarization Trial

Subjects initially arrived at the human performance laboratory in shorts and T-shirts, having refrained from lower body exercise for 48 hr before the visit. Height and weight were measured, and after a 5-min warm-up on a cycle ergometer (Monark 808e, Finland), each participant was seated in the isokinetic dynamometer (Biodex System 4, Shirley, NY) for a practice trial consisting of one “all-out” bout of 40 repetitions of knee extension and flexion of the dominant leg at a velocity of 180°/s. Exercise began with the knee in the fully flexed position, and flexion of the dominant leg at a velocity 180°/s, during which one effort of knee extension and flexion signified one repetition. Bouts were separated by 3 min of passive recovery, during which the subject remained in the dynamometer and the strap placed on the exercising leg was loosened. Subjects were provided strong verbal encouragement during exercise but had no feedback regarding their progress or performance during the protocol. Peak and average torque (ft/lb), power (W), and total work (ft/lb) were recorded for both knee extension and flexion across both bouts. Pilot testing revealed coefficients of variation for peak extension torque, peak flexion torque, and extension total work of 5.3%, 6.5%, and 7.8%, respectively.

Table 1  Demographic Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>M ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>26.4 ± 3.9</td>
<td>21.0–36.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.6 ± 7.1</td>
<td>165.0–190.0</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>82.7 ± 11.5</td>
<td>68.0–107.6</td>
</tr>
<tr>
<td>Physical activity (hr/week)</td>
<td>6.8 ± 2.7</td>
<td>4.0–15.0</td>
</tr>
<tr>
<td>Caffeine intake (mg/day)</td>
<td>243.3 ± 136.3</td>
<td>120.0–600.0</td>
</tr>
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</table>

Assessment of Muscle Pain

A previously validated categorical scale with ratio properties (Cook et al., 1998) was used to assess muscle-pain perception. During the familiarization trial, participants were read specific instructions established by Cook et al. regarding the pain scale. They were refamiliarized with

Treatment Ingestion

Solutions ingested included anhydrous caffeine (Gallop, St. Paul, MN; 5 and 2 mg/kg body weight) and placebo, which were housed in identical containers containing one package of a commercially available, noncaloric lemon-flavored beverage (Crystal Light, Northfield, IL). Treatment order was assigned to subjects using a single-blind, randomized, counterbalanced, crossover design. Subjects were unaware of the order of their treatments; one coinvestigator who participated in most of the trials prepared all drinks and provided them to subjects before testing. For example, subjects were provided their solution for the first day of testing during their familiarization trial, and this process was repeated during remaining trials. They were provided specific instructions with each drink to mix it with 8 oz of cold water and drink it 1 hr before their exercise trial, because this duration has been shown to maximize plasma levels of caffeine (Graham, 2001).

Pretest Guidelines

Subjects were instructed to refrain from intense exercise and caffeine intake for 48 hr before each trial and to fast for 3 hr pretrial. This was confirmed through completion of formal questionnaires. Over 3 separate days separated by at least 48 hr, they ingested one of three beverages 1 hr before each trial, which was confirmed by requiring them to return the empty container to the investigators at each visit.

Exercise Protocol

After a 5-min warm-up on the cycle ergometer, subjects completed two all-out bouts of 40 repetitions of knee extension and flexion of the dominant leg at a velocity of 180°/s, during which one effort of knee extension and flexion signified one repetition. Bouts were separated by 3 min of passive recovery, during which the subject remained in the dynamometer and the strap placed on the exercising leg was loosened. Subjects were provided strong verbal encouragement during exercise but had no feedback regarding their progress or performance during the protocol. Peak and average torque (ft/lb), power (W), and total work (ft/lb) were recorded for both knee extension and flexion across both bouts. Pilot testing revealed coefficients of variation for peak extension torque, peak flexion torque, and extension total work of 5.3%, 6.5%, and 7.8%, respectively.
the scale before each subsequent exercise bout. During exercise, subjects reported their pain perception at 15 and 35 repetitions; this measurement was repeated 2.5 min into recovery.

Rating of Perceived Exertion

The Borg (1982) 0–10 category ratio scale was initially explained to subjects during their familiarization trial, and instructions were repeated before subsequent trials. During exercise, subjects reported their rating of perceived exertion (RPE) 25 repetitions into each exercise bout.

Data Analysis

Data are reported as $M \pm SD$ and were analyzed using SPSS version 16.0 (Chicago, IL). A 3 (treatment) × 2 (sets) analysis of variance with repeated measures was used to examine differences in muscle performance, pain perception, and RPE between the caffeine and placebo treatments. In specific analyses, group membership was used as a between-subjects variable. The Greenhouse–Geisser correction was used to account for the sphericity assumption of unequal variances across groups. Tukey’s post hoc test was used to locate differences between means when a significant $F$ ratio was obtained. Effect size for the $F$ ratio was expressed as eta-squared ($\eta^2$). Statistical significance was established at $p < .05$.

Results

Pain Perception

Changes in leg-muscle pain with treatment ingestion are revealed in Figure 1. There were significant increases ($p < .05, \eta^2 = .79$) in leg-muscle pain from 15 to 35 repetitions and from Bout 1 to Bout 2 across all treatments. Pain was unaltered ($p > .05, \eta^2 = .04$) by caffeine ingestion versus placebo. Postexercise leg pain increased ($p < .05$) from Bout 1 to Bout 2 but was unaffected ($p > .05$) by treatment ingestion. After Bout 1, leg pain was equal to 1.67 ± 0.81, 1.80 ± 0.86, and 1.67 ± 0.90, and after Bout 2, 2.93 ± 1.53, 2.80 ± 2.14, and 2.40 ± 1.12, in the 5-mg/kg, 2-mg/kg, and placebo trials, respectively.

Table 2 Alterations in Ratings of Perceived Exertion (RPE) During Fatiguing Contractions of the Knee

<table>
<thead>
<tr>
<th>Treatment</th>
<th>RPE, $M \pm SD$</th>
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<tr>
<td>Bout 1</td>
<td></td>
</tr>
<tr>
<td>5 mg/kg caffeine</td>
<td>5.47 ± 1.50</td>
</tr>
<tr>
<td>2 mg/kg caffeine</td>
<td>5.47 ± 1.50</td>
</tr>
<tr>
<td>placebo</td>
<td>5.27 ± 1.53</td>
</tr>
<tr>
<td>Bout 2</td>
<td></td>
</tr>
<tr>
<td>5 mg/kg caffeine</td>
<td>6.47 ± 1.25*</td>
</tr>
<tr>
<td>2 mg/kg caffeine</td>
<td>6.47 ± 1.25*</td>
</tr>
<tr>
<td>placebo</td>
<td>6.27 ± 1.58*</td>
</tr>
</tbody>
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* $p < .05$ from Bout 1.

RPE

RPE significantly increased ($p < .05, \eta^2 = .70$) from Bout 1 to Bout 2, $F(1, 14) = 32.59$, yet there was no main effect ($p > .05, \eta^2 = .06$) of caffeine on RPE (Table 2).

Peak Torque

Figure 2 reveals the effects of caffeine on peak knee-extension and -flexion torque during isokinetic exercise. Knee-extension and -flexion torque were significantly

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* $p < .05$ from Bout 1.

Figure 2 — Effect of two doses of caffeine on peak (a) extension and (b) flexion torque during isokinetic dynamometry. * $p < .05$ from Bout 1 to Bout 2. # $p < .05$ between 5 mg/kg and placebo.
different \((p < .05, \eta^2 = .81)\) between Bouts 1 and 2. For peak knee-extension torque, there was no main effect or interaction \((p > .05, \eta^2 = .04)\), yet for peak knee-flexion torque, there was a significant main effect of treatment, \(F(2, 28) = 4.24, p < .05, \eta^2 = .28\), with the 5-mg/kg trial showing higher torque than placebo in Bout 1.

**Average Torque**

Figure 3 reveals the effects of caffeine on average knee-extension and -flexion torque during isokinetic exercise. Knee-extension and -flexion torque were significantly different \((p < .05, \eta^2 = .74-.84)\) between Bouts 1 and 2. There was a significant interaction for average knee-extension torque, \(F(2, 28) = 5.47, p < .05, \eta^2 = .28\), although no main effect \((p > .05, \eta^2 = .04)\) was revealed for either flexion or extension.

**Total Work**

Figure 4 demonstrates the effects of caffeine on knee-extension and -flexion total work during isokinetic exercise. Total work declined \((p < .05, \eta^2 = .53)\) from Bout 1 to Bout 2. There was a main treatment effect \((p < .05, \eta^2 = .21-.32)\) for both knee-extension (5-mg/kg dose vs. placebo and 2 mg/kg in Bout 1) and -flexion total work (5 mg/kg vs. placebo in Bout 1).

**Power Output**

Figure 5 reveals the effects of caffeine on knee-extension and -flexion power during isokinetic exercise. For knee-extension power, there was a significant difference \((p < .05, \eta^2 = .83)\) across Bouts 1 and 2, as well as a significant main effect, \(F(2, 28) = 4.61, p < .05, \eta^2 = .34\), and interaction, \(F(2, 28) = 5.87, p < .05, \eta^2 = .30\). Knee-extension power in the 5-mg/kg trial was significantly higher than with placebo. For knee-flexion power, there was a significant decrement \((p < .05, \eta^2 = .80)\) in power between Bouts 1 and 2. Data revealed a main effect for treatment, \(F(2, 28) = 3.80, p < .05, \eta^2 = .22\), with power higher \((p < .05)\) with 5 mg/kg caffeine than with placebo in Bout 1.

**Discussion**

The primary aim of this novel study was to examine the effects of two doses of caffeine on leg-pain perception and perceived exertion during high-intensity exercise dependent on nonoxidative metabolism in which muscle performance was measured. Data revealed no effect of caffeine on leg pain or perceived exertion, although caffeine intake improved multiple measures of performance of the knee extensors and flexors. The magnitude of leg pain induced by repeated fatiguing contractions of the
knee was greater than that caused by submaximal cycling, which merits further inquiry into the efficacy of caffeine to reduce pain during non-steady-state exercise such as resistance training or interval exercise or in field-based studies simulating the demands of athletic competition, in which severe muscle pain occurs.

The current findings corroborate data from a previous study in resistance-trained men (Hudson, Green, Bishop, & Richardson, 2008) who completed four sets of knee extension and biceps curl at an intensity equal to 12-repetition maximum. In this study, RPE and pain perception assessed 10 s postexercise were unaltered with caffeine (6.0–6.4 mg/kg) ingestion, yet there was a small but significant increase in performance. Similar to the current study (Figure 1), peak pain scores were higher than those previously observed for submaximal cycle ergometry (Gliottoni & Motl, 2008; Motl et al., 2003), when significant attenuations in muscle pain were exhibited. Our data contradict those of recent investigations revealing caffeine-mediated attenuations in leg pain during cycle ergometry (Gliottoni & Motl, 2008; Gliottoni et al., 2009; Motl et al., 2003; O’Connor et al., 2004) and lower pain intensity after eccentric exercise (Maridakis et al., 2007). It is plausible that the pain scale developed by Cook et al. (1998) lacks the sensitivity to capture small alterations in leg pain induced by intense, fatiguing exercise after intake of drugs such as caffeine or aspirin (Hudson et al., 2008). Nevertheless, this scale was able to detect the increase in pain perception from Bout 1 to Bout 2 (Figure 1). It is also plausible that subjects cannot accurately report pain perception during or immediately after fatiguing exercise, because their primary focus is on fully contracting the muscle rather than identifying their exact level of leg pain. This is an area that merits future investigation, especially in studies simulating the demands of competition.

Intraindividual variation concerning the effects of caffeine across subjects is evident. Examination of differences in pain perception between “responders” (men who revealed a dose-response effect of caffeine on performance) and “nonresponders” revealed that leg pain was consistently lower across all treatments and bouts in responders than nonresponders, although this difference was not significant ($p = .32$). During Bout 1 at 15 repetitions, the discrepancy in pain perception ($M \pm SD$) between groups tended to be greater in the 5-mg/kg trial ($2.75 \pm 1.67$ vs. $4.57 \pm 1.90$) than with the 2-mg/kg dose ($3.25 \pm 1.67$ vs. $3.43 \pm 1.27$) and placebo ($3.13 \pm 1.46$ vs. $3.86 \pm 1.77$). Further investigation using a larger sample size to augment statistical power is needed to confirm these findings.

RPE obtained during exercise was unaltered ($p > .05$) with caffeine intake. There is a growing body of literature revealing reductions in RPE during aerobic exercise after caffeine ingestion. In a meta-analysis of 21 studies (Doherty & Smith, 2005), data revealed significant reductions in RPE during submaximal aerobic exercise versus placebo. However, the authors emphasized that perceptions of effort are unaltered by caffeine when exercise is of a maximal, fatiguing nature, as was completed in the current study.

The improved muscle performance observed in the current study is not a universal finding in the caffeine literature. Using a similar isokinetic protocol, improved muscle performance with a high caffeine dose (7 mg/kg) was demonstrated in football players (Jacobson, Weber, Claypool, & Hunt, 1992); however, performance was unaltered in other studies (Bond, Gresham, McRae, & Tearney, 1986; Jacobson & Edwards, 1991) using this mode of exercise. A recent systematic review (Astorino & Roberson, 2010) showed that about 60% of studies reveal an ergogenic effect of caffeine for short-term, high-intensity exercise. These equivocal data suggest that there is variation in subjects’ ability to improve performance with caffeine, which is probably mediated by discrepancies in caffeine metabolism (Gu, Gonzalez, Kalow, & Tang, 1992).

The current study has a few limitations. First, the data can only be generalized to young, active men. A previous study (Cook et al., 1998) revealed lower leg pain in women than men during maximal cycle ergometry. Second, the findings can only be applied to pain induced by intense lower body exercise characterized by dynamic contractions of the knee extensors and flexors, not to upper body resistance training or total-body exercise.

**Figure 5** — Effect of two doses of caffeine on (a) extension and (b) flexion power. *$p < .05$ from Bout 1 to Bout 2. #$p < .05$ between 5 mg/kg and placebo.
such as jogging or competitive sport. Third, it is unknown whether similar results would be observed in caffeine-naïve populations, who may have different responses than caffeine-habituated individuals, although a recent study (Gliottoni et al., 2009) revealed similar reductions in pain perception during aerobic exercise. Future studies would also benefit from measuring creatine kinase as a marker of muscle damage in response to caffeine ingestion before intense exercise.

Overall, this study provides novel findings that neither low nor high doses of caffeine reduce leg pain or perceived exertion during fatiguing, non-steady-state contractions of the knee that induce marked leg pain. These findings contradict recent data showing attenuated pain perception during submaximal exercise after caffeine intake. Despite no change in leg pain or RPE, performance was significantly improved with the 5-mg/kg dose of caffeine compared with placebo.

Acknowledgments

The authors thank the participants for their outstanding effort in meeting the demands of the study. This project was funded by a Research and Scholarly Activity Grant at CSU–San Marcos. An abstract of this study was presented at the annual meeting of the American College of Sports Medicine in May 2009.

References


