Effects of Caffeine on Repetitions to Failure and Ratings of Perceived Exertion During Resistance Training

J. Matt Green, P. Jason Wickwire, John R. McLester, Shawn Gendle, Geoffrey Hudson, Robert C. Pritchett, and C. Matt Laurent

Context: Ergogenic effects of caffeine on aerobic or endurance exercise are well documented. Conversely, the ergogenic value of caffeine on high-intensity, primarily anaerobic performance is not well understood even though the proposed mechanisms of action for caffeine permit a strong theoretical basis for application to this type of exercise. Purpose: This study examined effects of caffeine (Ca) on number repetitions (reps), ratings of perceived exertion (RPE), and peak heart rate (PHR) during resistance-training exercise with reps performed to volitional failure. Methods: Subjects (N = 17) were tested for 10-rep maximum in bench press (BP) and leg press (LP). In sessions 2 and 3, Ca (~6 mg/kg) or placebo (Pl) was ingested 1 hr beforehand in a double-blind manner and counterbalanced order. Subjects performed 3 sets to failure (BP and LP) with reps, PHR, and RPE recorded each set. Repeated-measures ANOVAs, 2 (trial) × 3 (set), were used to analyze dependent measures with the Tukey honestly significant difference used when necessary as the post hoc test. Results: In BP, no significant differences (Ca vs Pl) were observed (reps, RPE, PHR). During set 3 of LP training, Ca was associated with significantly higher reps (12.5 ± 4.2 vs 9.9 ± 2.6) and PHR (158.5 ± 11.9 vs 151.8 ± 13.2). No significant RPE differences were found during LP. Conclusions: The findings of similar RPE concurrent with higher reps suggest that caffeine can blunt pain responses, possibly delaying fatigue in high-intensity resistance training. Ergogenic effects might be limited to the later sets in a resistance-training session. Further research is warranted regarding ergogenic effects of caffeine during resistance training and potential mechanisms of action.

Key Words: ergogenic aid, heart rate, strength training

Caffeine can enhance endurance-based exercise performance with ergogenic properties attributed to mechanisms such as enhanced free-fatty-acid mobilization.1,2

---

Green, Gendle, Pritchett, and Laurent are with the Dept of Kinesiology, University of Alabama, Tuscaloosa, AL 35487-0312. Wickwire and McLester are with the Dept of Health, Physical Education and Sport Science, Kennesaw State University, Kennesaw, GA 30144. Hudson is with the Dept of Health, Human Performance and Recreation, Baylor University, Waco, TX 76798.
and glycogen sparing,\textsuperscript{3-5} although other studies have challenged these findings.\textsuperscript{6,7} Studies examining the ergogenic effect of caffeine on high-intensity anaerobic-exercise bouts (ie, ones relying principally on oxygen-independent metabolism) are sparse. Although it is plausible that enhanced free-fatty-acid mobilization and glycogen sparing would improve endurance performance, these responses do not provide a strong rationale for caffeine to influence anaerobic exercise. This is particularly the case when free fatty acid plays a minimal role as a substrate and exercise duration does not threaten glycogen availability. Other mechanisms of action, however, that might permit a positive impact of caffeine on anaerobic performance have been proposed. Magnified plasma epinephrine could promote peripheral- or central-nervous-system responses.\textsuperscript{4,8,9} Caffeine can also blunt ratings of perceived exertion (RPE).\textsuperscript{1,10} Although studies have generally been limited to endurance exercise, attenuating subjective pain and fatigue (reflected in RPE) could potentially augment anaerobic exercise by extending time to volitional fatigue.

Doherty et al\textsuperscript{10} reported that caffeine ingestion (vs placebo) increased mean power and blood lactate while concurrently lowering RPE during 3-minute high-intensity cycling with the final minute at maximal exertion. Conversely, Greer et al\textsuperscript{5} and Collomp et al\textsuperscript{8} found no effect on 30-second maximal Wingate performance even with increased ammonia\textsuperscript{5} and epinephrine\textsuperscript{8} indicating enhanced anaerobic metabolism. Recently Stuart et al\textsuperscript{11} concluded that caffeine provided substantial benefits in simulated high-intensity team-sport performance in which tasks were predominantly anaerobic in nature. Paton et al,\textsuperscript{12} however, contradicted those results, concluding that caffeine had no effect on 20-m sprint (10 repeats) performance. Given these conflicting findings, the efficacy of caffeine as an ergogenic aid during exercise dominated by anaerobic ATP production remains uncertain.

Although results on anaerobic performance are equivocal, there is a theoretical basis for caffeine’s enhancing short-duration high-intensity exercise. No published research to date, however, has investigated the effects of caffeine on performance during resistance training, a popular mode of exercise for fitness enthusiasts and athletes. The purpose of the current study was to determine the effects of caffeine consumption on 3 sets of 2 resistance-training exercises performed to failure. A double-blind crossover design was used to compare performance and RPE during repeated sets of selected resistance-training exercises.

### Methods

#### Participants

Physically active men (n = 13) and women (n = 4) who had been strength training for a minimum of 8 weeks served as participants. Before data collection, they signed a written informed consent outlining study requirements. All procedures were approved by the local institutional review board for protection of human subjects. Each participant arrived at the testing site with instructions to be well hydrated and at minimum 3 hours postprandial. Participants were also instructed to avoid alcohol and caffeine (excluding treatment) for at least 24 hours before testing. Age, height, and mass were measured and recorded. Body-fat percentage was estimated using Lange skinfold calipers (Cambridge, Md) and a 3-site method (men: chest, abdomen, thigh; women: triceps, iliac, thigh).\textsuperscript{13}
Determination of 10-Repetition Maximum (10-RM)

After collection of descriptive data, participants estimated the resistance they thought they could bench press (BP) successfully 10 times without assistance. Participants performed 2 warm-up sets (12 repetitions each) at 50% to 80% of this resistance. Based on perceived difficulty of this bout, resistance was increased to 100% or near 100% of the estimated 10-RM. In the following bouts resistance was increased by varying amounts based on feedback from participants regarding their perceived ability to lift a given resistance. When participants reached failure at approximately 10 repetitions and verbally indicated that they thought they could not achieve 10 repetitions at a greater resistance, this weight was recorded as their 10-RM. Generally, the 10-RM was identified by the third bout. If excessive fatigue was evident because of the multiple attempts, however, subjects returned on a different day to complete the 10-RM assessment. The 10-RM was determined in the same manner for leg press (LP). Although resistance for the 10-RM lifts was based on subjective estimations, participants with a history of strength training were employed, and these individuals were acutely aware of their ability and able to avoid excessive attempts and premature fatigue.

Performance Trials

After exercise-specific 10-RM had been determined, subjects were supplied with capsules containing either treatment (caffeine) or placebo in amounts equaling 6 mg/kg body weight. Participants consumed the substance 1 hour before reporting for testing. Caffeine (Ca) and placebo (Pl) trials were counterbalanced and administered in a double-blind manner. On reporting, subjects donned a Polar heart-rate monitor at the level of the sternum and then completed a short stretching routine. They then completed a warm-up set of BP or LP at what they considered a “light” intensity for no more than 12 repetitions. After warm-up subjects completed 3 sets of either BP or LP followed by 3 sets of the alternate exercise (order of exercises counterbalanced). Sets were separated by 3 minutes passive recovery, with 5 minutes between the 2 exercises. Successful repetitions and peak heart rate (PHR) were recorded for each set. Subjects also provided an RPE (specific to active musculature) according to the omni RPE scale within the 10 to 15 seconds immediately after each set. Verbal encouragement was provided during testing. On completion of the first performance-testing session, participants were provided with capsules containing the alternate treatment. Performance session 2 was completed with a minimum of 2 days rest after the first session but within 7 days.

After each performance-testing session participants completed a questionnaire regarding subjective feelings of fatigue, mood, nervousness, restlessness, presence of muscle tremors, and stomach distress. The response to each question was recorded by subjects on a continuous scale of 0 to 10 that included verbal descriptors associated with numerical-rating values.

Statistics

Ca and Pl treatments were compared using a 2 (trial) × 3 (set) repeated-measures ANOVA for each variable (repetitions, RPE, and PHR), with the Tukey honestly significant difference used for post hoc analysis when needed. Coefficients of
variation were used as measures of reliability. Estimates of effect size (partial eta squared; $\eta$) were computed to illustrate the strength of association between the treatment (Ca) and the observed changes. Questionnaire responses were compared between Ca and Pl using a paired $t$-test for each variable. Results were considered significant at a predetermined alpha of $\leq .05$.

**Results**

Means and standard deviations for descriptive data were, for men, age 21.0 ± 1.5 years, height 177.0 ± 11.7 cm, mass 81.5 ± 16.6 kg, body fat 12.0% ± 4.0%, and mean 10-RM BP 90 ± 41 and LP 223 ± 95 kg, and women, age 22.0 ± 1.5 years, height 160.0 ± 6.7 cm, mass 59.1 ± 6.8 kg, body fat 19.5% ± 3.2%, and mean 10-RM BP 35 ± 5.9 and LP 163 ± 49 kg. Figure 1 shows there were no significant differences (Ca vs Pl) for repetitions on BP or LP for set 1. There was, however, a main effect for Ca versus Pl for LP ($P < .05$, $\eta = .46$), with the Tukey honestly significant difference showing that LP repetitions were significantly higher for Ca (vs Pl) in set 3 ($P < .05$, $\eta = .41$). Similarly, the difference between Ca and Pl for set 2 was significant at $P = .13$, $\eta = .08$. There were no significant differences between Ca and Pl for RPE for BP or LP (Figure 2). Figure 3 shows values between trials for PHR. There were no significant differences for PHR for BP for any set. During LP, however, the PHR during set 3 was significantly higher for Ca treatment. Coefficients of variation were BP Pl 23.9, Ca 24.6, and LP Pl 10.0, Ca 11.7. Figure 4 shows values for responses to the subjective questionnaire. Responses for

![Figure 1](image-url) — Repetitions per set for bench press and leg press, means and standard deviations. Pl indicates placebo, and Ca, caffeine. *$P < .05$, **$P = .13$, Ca vs Pl.
Figure 2 — Ratings of perceived exertion per set for bench press and leg press, means and standard deviations. Pl indicates placebo, and Ca, caffeine. No significant differences Ca vs Pl.

Figure 3 — Peak-heart-rate response per set for bench press and leg press, means and standard deviations. Pl indicates placebo, and Ca, caffeine. *P < .05, Ca vs Pl.
mood and general feelings of fatigue were not significantly different. Nervousness, tremors, and stomach distress were significantly different between trials, with the differences in ratings significant at $P = .06$.

**Discussion**

Caffeine ingestion provided ergogenic benefits during strength-training exercise with repetitions completed to failure. There were no significant effects of caffeine on performance for BP throughout the 3 sets or for initial sets of LP. We observed, however, a greater number of repetitions for LP set 3, with a trend for a greater number ($P = .13$) after set 2. In previous studies on endurance performance, glycogen sparing and free-fatty-acid mobilization were identified as principle mechanisms of the ergogenic effects of caffeine.\textsuperscript{1-5} Anaerobic exercise depends on ATP production from sources other than free fatty acid, and because of its relatively short duration, adequate intramuscular glycogen (for repeated short-duration, intense muscle contraction) should be available in individuals consuming a normal diet. However, an ergogenic effect of caffeine on anaerobic exercise might be anticipated based on other mechanisms. Previous research on the influence of caffeine on anaerobic exercise is limited, with results of studies being equivocal.\textsuperscript{5,8,10-12} In this study we
examined effects of caffeine on performance and perceived exertion during acute bouts of 2 strength-training exercises.

The current results provide evidence of an acute effect of caffeine on strength-training performance, with certain limitations. Although BP performance was unaffected, subjects completed significantly more repetitions for LP during set 3, with the difference for set 2 significant at $P = .13$ (Figure 1). It is unlikely that elevated fatty-acid oxidation (or consequent glycogen sparing) was responsible for the greater repetitions observed in this resistance-training setting. Caffeine might act via the central nervous system\(^\text{15}\) to blunt pain and by way of augmented catecholamines.\(^\text{4,9}\) Recently, Stuart et al\(^\text{11}\) showed that caffeine improved various anaerobic and sprint, as well as skill-based, tasks; the improved performances were attributed to attenuation of fatigue. In their study, the benefits of caffeine were observed throughout testing but were more pronounced (with respect to sprints) during the later stages of testing. Similarly, in the current study, benefits of caffeine were limited to set 3 on LP (with significance at $P = .13$ for set 2 on leg press), with no discernible differences in set 1 (LP) or for any set for BP (Figure 1). Participants in the current study were required to exercise to failure, with verbal encouragement provided. Using this model, failure was an inevitable endpoint in each set, and we think that the greater number of repetitions for selected sets during LP reflects an attenuation of fatigue. Precise mechanisms responsible for the diminished fatigue associated with caffeine are speculative. Fatigue is thought to be either central or peripheral in nature, with support existing for both concepts. If we subscribe to the central-governor theory of Noakes et al,\(^\text{16}\) caffeine, which does have analgesic properties,\(^\text{17}\) could have altered pain perception, extending the time until each subject reached a self-imposed termination point. According to this hypothesis, fatigue operates somewhat independently of the physiological capacity of the muscles. Alternatively, fatigue might result from failure of one or more peripheral mechanisms sustaining cross-bridge cycling or ATP turnover. Caffeine can influence myosin-actin interaction\(^\text{18,19}\) and the potassium gradient.\(^\text{9,20}\) It is therefore plausible that caffeine acted peripherally in the current study. Improved performance could also have resulted from a combination of central and peripheral actions. More in-depth investigations are required to determine the mechanisms by which caffeine might enhance anaerobic performance.

There were no substantial differences in RPE responses between treatments. This outcome would be expected when similar repetitions were completed (BP all sets, LP set 1). RPE is affected by a variety of variables in aerobic exercise (for reviews see references 21 and 22). In resistance exercise to failure, between high- and low-intensity (resistance) bouts, RPE was more strongly associated with total work than with acute fatigue (Pritchett RC et al, unpublished findings). In the current study, however, RPE across sets increased while total repetitions decreased (Figures 1 and 2), indicating that RPE in multiset resistance exercise at an established resistance hinges on factors other than just total work. Because total work increases concurrently with repetitions, and cumulative fatigue is magnified in sequential sets, a greater RPE would be anticipated for set 3 (and possibly set 2) for LP in Ca trials. This was not the case. RPE values were similar within sets between Ca and Pl sets for both exercises even when significantly more repetitions were completed and when PHR was significantly elevated. A similar blunted RPE response has been observed with caffeine and aerobic exercise\(^\text{1}\) and high-intensity
Caffeine and Resistance Training

Because perceived exertion is subjective, a dampened RPE might support the notion that caffeine exerts a central rather than a peripheral effect. This conclusion is tentative, however, because the central and peripheral explanations of fatigue are not mutually exclusive. For example, with the central-governor theory, various physiological variables are monitored via afferent feedback and regulated through subsequent efferent input to appropriate control systems. Although the current study did not allow in-depth elucidation of mechanistic factors, it provided evidence that caffeine improves performance (repetitions) in absence of changes that would be anticipated for RPE.

The isolation of caffeine’s effects to latter sets of LP and the absence of effects for BP should be considered. Failure of caffeine to enhance performance in set 1 and a possible ergogenic effect in set 2 suggest that these responses might be limited to a semifatigued state rather than a well-rested state. That is, caffeine exerts an effect only when previous bouts or sets have created a partially fatigued environment, whether involving peripheral (ie, pH or electrolyte imbalance, altered phosphate concentrations, etc) or central mechanisms. In the current study, fatigue was amplified in sequential sets with lower repetitions and elevated RPE across time, but a potential ergogenic effect was limited to the later sets. This is consistent with the work of Stuart et al, who reported a greater impact of caffeine during the second half of testing in simulated rugby play.

The absence of an effect for BP is difficult to explain. For a given subject a greater volume of total muscle would be involved in LP than in BP. It is possible that caffeine’s effects were limited to larger-muscle-group activity. It is established for aerobic exercise that as the volume of muscle mass is decreased (ie, cycling vs running) RPE is dominated by local feelings of muscle strain and exertion. Assuming that caffeine acted centrally instead of peripherally and that fatigue is a central issue, it is plausible that caffeine would potentially operate more effectively as the volume of muscle increases and feelings of fatigue become more global rather than isolated at the level of the muscle. We must emphasize that the current design does not permit a definitive conclusion in this regard. Further work is warranted to identify a threshold of muscle volume beyond which caffeine becomes more effective. Another potential explanation centers on the observation that the number of repetitions completed during LP exceeded the repetitions completed during BP. The protocol for identifying the 10-RM was less precise for LP. It was not uncommon for subjects to exceed 10 repetitions during LP sets (Figure 1). Although this raises questions regarding the efficacy of determining 10-RM in this manner, it offered the added advantage of evaluating caffeine in a higher-repetition paradigm. Ergogenic properties might occur principally in this situation. Higher repetitions would presumably elicit greater disturbances in acid-base balance, phosphagen concentration, and electrolyte balance. It is tempting to conclude that caffeine might have operated peripherally when the intramuscular compartment was at higher levels of disturbance. The central-governor theory proposes, however, that these disturbances are monitored by the brain, and thus caffeine action through a central mechanism could not be confidently excluded.

Survey responses indicate that caffeine consumption altered various subjective feelings. Subjects reported feeling more nervous, more restless, more feelings of tremors, and greater stomach distress (Figure 4). Although much less conclusive than plasma measures of caffeine, altered psychophysiological responses provide
indirect support that subjects complied with the treatment requirements and that caffeine was absorbed. Although subjective responses regarding overall fatigue were not different between Ca and Pl, it is interesting that this was the only variable in which the mean response was lower (by 5%) for Ca (Figure 4). With more repetitions completed during Ca trials, greater subjective fatigue might be expected. Similar to the absence of higher RPE responses under these conditions, however, the lack of amplified feelings of fatigue is noteworthy.

Practical Applications

Considerable attention has been given to the use of various doping agents in sports, including pharmacological agents such as caffeine. Results of this study indicate that caffeine might provide benefits in some circumstances during acute bouts of resistance training. More specifically, more repetitions were achieved for LP only, with improvements further limited to the later sets. Enhancing performance during acute resistance training might help athletes achieve greater physiological overload during acute bouts. Although this is speculative, greater adaptation might consequently be expected longitudinally if acute caffeine use permits the completion of a greater volume (ie, enhanced training overload) across time.

Conclusions

Results of this study provide evidence that, within certain limitations, caffeine has an ergogenic effect during short-duration high-intensity (anaerobic) exercise. More specifically, subjects were able to complete more repetitions without altering subjective feelings of acute fatigue (RPE) or overall fatigue after the completion of the entire exercise bout. It appears that the ergogenic effect of caffeine might be limited to larger-muscle activity and a semifatigued state. The current study does not permit elucidation of the specific mechanisms by which caffeine might exert its ergogenic effects. Future studies should be considered focusing on the limitations of caffeine’s effects in an anaerobic paradigm with specific attention to mechanistic factors.

References