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The Acute Effects of a Caffeine-Containing Supplement on Strength, Muscular Endurance, and Anaerobic Capabilities

Travis W. Beck,[1] Terry J. Housh,[1] Richard J. Schmidt,[1] Glen O. Johnson,[1] Dona J. Housh,[2] Jared W. Coburn,[1] and Moh H. Malek[1]

[1]*Department of Nutrition and Health Sciences, Human Performance Laboratory, University of Nebraska–Lincoln, Lincoln, Nebraska 68588;* [2]*University of Nebraska Medical Center, College of Dentistry, Department of Oral Biology, Lincoln, Nebraska 68583.*

Abstract. Beck, T.W., T.J. Housh, R.J. Schmidt, G.O. Johnson, D.J. Housh, J.W. Coburn, and M.H. Malek. The acute effects of a caffeine-containing supplement on strength, muscular endurance, and anaerobic capabilities. *J. Strength Cond. Res. 20(3): 506–510. 2006.*—The purpose of this study was to examine the acute effects of a caffeine-containing supplement on upper- and lower-body strength and muscular endurance as well as anaerobic capabilities. Thirty-seven resistance-trained men (mean ± *SD*, age: 21 ± 2 years) volunteered to participate in this study. On the first laboratory visit, the subjects performed 2 Wingate Anaerobic Tests (WAnTs) to determine peak power (PP) and mean power (MP), as well as tests for 1 repetition maximum (1RM), dynamic constant external resistance strength, and muscular endurance (TOTV; total volume of weight lifted during an endurance test with 80% of the 1RM) on the bilateral leg extension (LE) and free-weight bench press (BP) exercises. Following a minimum of 48 hours of rest, the subjects returned to the laboratory for the second testing session and were randomly assigned to 1 of 2 groups: a supplement group (SUPP; $n = 17$), which ingested a caffeine-containing supplement, or a placebo group (PLAC; $n = 20$), which ingested a cellulose placebo. One hour after ingesting either the caffeine-containing supplement or the placebo, the subjects performed 2 WAnTs and were tested for 1RM strength and muscular endurance on the LE and BP exercises. The results indicated that there was a significant ($p < 0.05$) increase in BP 1RM for the SUPP group, but not for the PLAC group. The caffeine-containing supplement had no effect, however, on LE 1RM, LE TOTV, BP TOTV, PP, and MP. Thus, the caffeine-containing supplement may be an effective supplement for increasing upper-body strength and, therefore, could be useful for competitive and recreational athletes who perform resistance training.

Key Words. ergogenic aid, performance, sports nutrition

Introduction

Caffeine is one of the most widely consumed drugs in the world and has become a popular ergogenic aid for many athletes (2). Some of the proposed exercise-related effects of caffeine include increased secretion of catecholamines (11, 12, 17), enhanced calcium release from the sarcoplasmic reticulum (20), and an improvement in skeletal muscle contractility (23). Furthermore, although the exact mechanisms have not been identified (24), it has been suggested that caffeine may increase force production by enhancing neuromuscular transmission (23) and improving the ability to achieve maximal muscle activation (19). Most previous investigations, however, have examined the acute effects of caffeine on endurance performance during aerobic exercise, such as submaximal treadmill running and cycle ergometry (7, 14). The findings from these studies (7, 14) indicated that caffeine may be an effective ergogenic aid for increasing endurance exercise performance.

The effects of caffeine on maximal anaerobic performance and muscle strength, however, are less well understood. For example, Bell et al. (6) reported that caffeine supplementation (5 mg·kg^{-1} of body weight) 1.5 hours prior to testing had no effect on peak power (PP) during a Wingate Anaerobic Test (WAnT). Anselme et al. (1), however, found that during 6-second maximal cycle ergometer sprints performed against various loads, a 250-mg dose of caffeine, ingested 30 minutes prior to testing, increased peak power output at all loads. In addition, Collomp et al. (10) examined the acute effects of a 250-mg dose of caffeine on maximal swimming velocity for both trained swimmers and untrained subjects during 100-m sprints and reported that caffeine supplementation 1 hour prior to testing resulted in an increase in maximal swimming velocity for the trained swimmers, but had no effect on the untrained subjects. Thus, the acute effects of caffeine on anaerobic capabilities may depend on the type of activity performed, the dosage of caffeine used, and the characteristics of the subjects who are being tested.

Kalmar and Cafarelli (19) recently reported that caffeine (6 mg·kg^{-1} of body weight ingested 1 hour before testing) significantly increased isometric leg extension strength and the time that a submaximal (50% of the isometric maximum velocity contraction [MVC]) isometric leg extension could be maintained. No studies, however, have examined the acute effects of caffeine on strength and muscular endurance during dynamic constant external resistance (DCER) muscle actions.

Although caffeine was recently removed from its banned substance list, the International Olympic Committee continues to monitor caffeine consumption in competitive athletes (25), and the National Collegiate Athletic Association requires that athletes have a urinary caffeine concentration below 15 μg·ml^{-1} prior to competition (21). Graham and Spriet (13), however, suggested that caffeine may improve performance when the urinary caffeine concentration is as low as 10 μg·ml^{-1}. Thus, if caffeine has an ergogenic effect on anaerobic capabilities, strength, and muscular endurance, it could be used by competitive and recreational athletes prior to training and competition. Therefore, the purpose of this investigation was to examine the acute effects of a caffeine-containing supplement on upper- and lower-body strength and muscular endurance as well as anaerobic capabilities. We hypothesize that the caffeine-containing supplement will result in acute increases in upper- and lower-body strength and muscular endurance and enhance anaerobic capabilities.

METHODS

Experimental Approach to the Problem

This study used a randomized, double-blinded, placebo-controlled, parallel design. For the first laboratory visit (VISIT1), the subjects performed 2 WAnTs to determine PP and mean power (MP). The WAnT is the most popular anaerobic cycling test, and previous studies have reported that it is a reliable (5) and valid (18) method for measuring anaerobic capabilities. A minimum of 24 hours following the WAnTs, the subjects returned to the laboratory and were tested for 1 repetition maximum (1RM) DCER strength and muscular endurance on the bilateral leg extension (LE) and free-weight bench press (BP) exercises. The 1RM and muscular endurance tests are commonly used in the field of strength and conditioning to measure low-speed strength and local muscular endurance, respectively, and the results from these tests are related to the dynamic performance characteristics of many sports (16). For the second laboratory visit (VISIT2; ≥48 hours following the strength and muscular endurance tests), the subjects were randomly assigned to 1 of 2 groups: a supplement group (SUPP; n = 17) or a placebo group (PLAC; n = 20). The subjects in the SUPP group ingested 1 dose (3 tablets = 1 dose) of a caffeine-containing supplement, while the subjects in the PLAC group ingested 1 dose (3 tablets = 1 dose) of microcrystalline cellulose. Table 1 contains the ingredients for the caffeine-containing supplement. The placebo was designed by the manufacturer (General Nutrition Corporation, Pittsburgh, PA) to have the same volume, taste, and color as the caffeine-containing supplement. One hour after ingesting the caffeine-containing supplement or the placebo, the subjects performed 2 WAnTs to determine PP and MP. A minimum of 24 hours after the WAnTs, the subjects returned to the laboratory and ingested another dose of the caffeine-containing supplement or the placebo and sat quietly for 1 hour. The subjects then performed the strength and muscular endurance tests on the LE and BP exercises.

Subjects

Thirty-seven men volunteered to participate in the investigation. All subjects reported that they had at least 1 year of resistance-training experience and were currently performing 3–4 training sessions per week. The randomization procedure resulted in similar characteristics for the subjects in the SUPP (mean ± *SD*, age: 20.8 ± 2.0 years; body weight: 83.6 ± 8.5 kg; height: 181.4 ± 6.8 cm) and PLAC (mean ± *SD*; age: 21.0 ± 1.9 years; body weight: 85.0 ± 19.9 kg; height: 181.7 ± 7.2 cm) groups. In addition, each subject did not report or exhibit (a) a history of medical or surgical events that might have significantly affected the study outcome, including cardiovascular disease or metabolic, renal, hepatic, or musculoskeletal disorders; (b) use of any medication that might have significantly affected the study outcome; (c) use of nutritional supplements (such as creatine, protein drinks, amino acids, and vitamins) in the 6 weeks prior to the

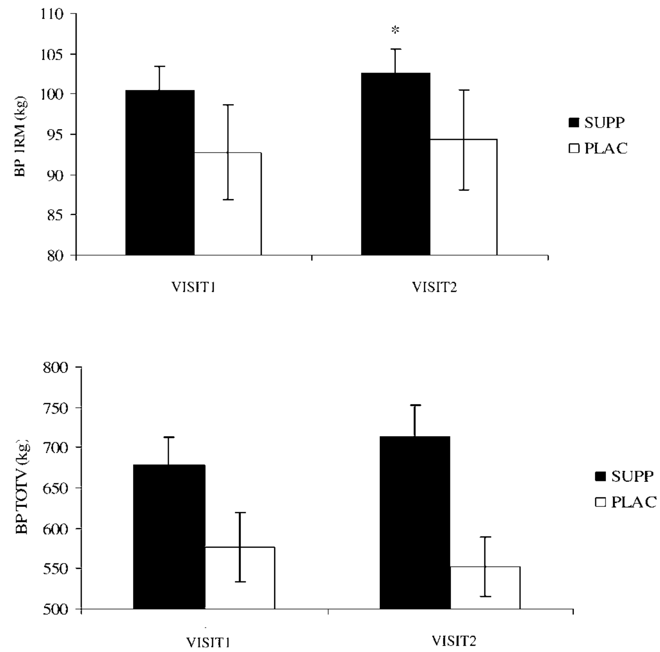

FIGURE 1. The top graph shows the means ± *SEM* for bench press (BP) 1 repetition maximum (1RM; in kg) for the supplement (SUPP) and placebo (PLAC) groups for the first (VISIT1) and second (VISIT2) laboratory visits. The bottom graph shows the means ± *SEM* for BP volume (TOTV; in kg) for the SUPP and PLAC groups for VISIT1 and VISIT2. There was a significant (2.1 kg = 2.1%) increase in BP 1RM from VISIT1 to VISIT2 for the SUPP group, but not for the PLAC group, and the increase (34.0 kg = 5.0%) in BP TOTV for the SUPP group approached statistical significance (p = 0.074), while ingestion of the placebo resulted in a nonsignificant mean decrease of 24.0 kg (4.2%). * VISIT2 > VISIT1.

TABLE 1. The ingredients contained in 1 dose of the caffeine-containing supplement.*

Ingredient	Caffeine-containing supplement Amount per serving (mg)
Yerba Maté (*Ilex paraguariensis*) (8% caffeine = 40 mg)	500.0
Guarana seed extract (*Paullinia cupana*) (36% caffeine = 152 mg)	422.0
Black tea extract (*Camellia sinensis*) (9% caffeine = 9 mg)	100.0
Ginger extract (*Zingiber officinale*) (5% gingerols)	500.0
Schisandra chinensis fruit extract	100.0
Dill weed extract (*Anethum graveolens*)	5.0
Grape seed extract (*Vitis vinifera*)	1.0
Vitamin C (as ascorbic acid)	120.0
Niacin	20.0
Vitamin B6 (as pyridoxine hydrochloride)	2.0
Pantothenic acid (as calcium D-pantothenate)	10.0
Vitablue (*Vaccininium angustifolium*)	50.0
Cinnamon	25.0

* Total caffeine content for 1 dose of the caffeine-containing supplement was approximately 201.0 mg. The placebo was microcrystalline cellulose.

start of the study; and (d) participation in another clinical trial or ingestion of another investigational product within 30 days prior to screening and enrollment. The study was approved by the University Institutional Review Board for Human Subjects, and all subjects were briefed regarding the risks of the study. In addition, each subject completed a health history questionnaire and signed a written informed consent document before testing.

Procedures

The WAnTs were performed on a bicycle ergometer (Monarch 818 E; Quinton Instruments, Seattle, WA). Prior to the tests, the seat height was adjusted to allow for near full extension of the legs while pedaling, and toe clips with straps were used to prevent the feet from slipping off the pedals. The subjects warmed up by cycling for 4 minutes against a light load of 0.5 kg. Prior to the start of the first test, the subjects were instructed to pedal as fast as possible from the beginning and to attempt to maintain maximum pedal speed throughout the 30-second test. At the command "go," the subjects began pedaling as fast as possible against a low resistance that was increased to 7.5% of the subject's body weight (4) within 2–3 seconds. When this load was reached, an optical sensor (OptoSensor 2000; Linear System Design, Delray Beach, FL) interfaced with a personal computer (Gateway 2000; Gateway, Irvine, CA) counted the number of flywheel revolutions every 1.0 seconds. Computer software (SMI Power, Linear System Design) calculated PP (the highest power output during any 5-second period) and MP (the average power output during the 30-second test) (4). Immediately after the test, the subjects continued to pedal at zero load for 3 minutes, followed by 3 minutes of passive rest. The subjects then pedaled against 0.5 kg of resistance for 1 minute prior to performing another WAnT. Following the second test, the subjects pedaled against zero load for 4 minutes as a cool down. For each subject, the average (from the 2 WAnTs) PP and MP values were used for the statistical analyses.

The LE exercises were performed on a plate-loaded leg extension resistance training machine (Body-Solid, Forest Park, IL). Each subject sat with his back flat against the backrest and was instructed to hold tightly to the handles of the device. The backrest was adjusted to align the anatomical axes of the knees with the mechanical axis of the machine. The subject's legs were placed against shin pads that were attached to the lever arm of the machine. The distance between the shin pads and the axis of rotation of the lever arm was fixed and not adjustable. The positioning of each subject, however, was consistent across all tests. The BP exercises were performed on a standard free-weight bench (Body Power, Williamsburg, VA) with an Olympic bar. After receiving a lift-off from a spotter, the subject lowered the bar to his chest, paused briefly, and then pressed the bar to full extension of the forearms. For both the LE and BP exercises, the 1RM was determined by applying progressively heavier loads until the subject could not complete a repetition through the full range of motion (approximately 1.57 rad for the LE and to full extension of the forearms for the BP). Additional trials were performed with lighter loads until the 1RM was determined within 2.27 kg, and this was usually achieved within 5 trials. Two minutes of rest were allowed between all trials (3). Following determination of the 1RM on the LE and BP, the subjects rested for 2 minutes and then performed as many repetitions as possible with 80% of their 1RM to test muscular endurance. The total volume of weight lifted during the endurance test (TOTV) was then calculated by multiplying the weight (kg) by the number of repetitions that were performed.

Statistical Analyses

Six separate 2-way mixed factorial analyses of variance (time [VISIT1 and VISIT2] × group [SUPP and PLAC]) were used to analyze the LE 1RM, LE TOTV, BP 1RM, BP TOTV, PP, and MP data. When appropriate, follow-up analyses included paired samples *t*-tests. An alpha of $p \leq 0.05$ was considered statistically significant for all comparisons. Previous strength and WAnT data from our laboratory for young men ($n = 51$) indicated that the mean (± *SD*) values for LE 1RM, BP 1RM, PP, and MP were 81.5 ± 15.4 kg, 74.8 ± 12.5 kg, 744.8 ± 118.0 W, and 565.44 ± 81.88 W, respectively. A statistical power analysis was performed based on these data (assuming a meaningful effect size of one-half of the *SD* value) to determine the sample sizes that yielded power values of 0.80 or greater. The intraclass correlation coefficients for LE 1RM, LE TOTV, BP 1RM, BP TOTV, PP, and MP were $R = 0.97$, $R = 0.84$, $R = 0.99$, $R = 0.94$, $R = 0.96$, and $R = 0.97$, respectively, with no significant ($p > 0.05$) mean differences between test and retest values for any of the measurements.

RESULTS

The results of this study indicated that ingestion of the caffeine-containing supplement resulted in a significant (2.1 kg = 2.1%) increase in BP 1RM, but ingestion of the placebo did not. When compared to the placebo, the caffeine-containing supplement had no effect on LE 1RM, LE TOTV, BP TOTV, PP, or MP. The increase (34.0 kg = 5.0%) in BP TOTV with ingestion of the caffeine-containing supplement, however, approached statistical significance ($p = 0.074$), while ingestion of the placebo resulted in a nonsignificant mean decrease of 24.0 kg (4.2%).

DISCUSSION

The results of this study indicated that there was an increase in BP 1RM for the SUPP group, but not for the PLAC group (Figure 1). The caffeine-containing supplement had no effect, however, on LE 1RM, LE TOTV, and BP TOTV when compared to the cellulose placebo. Although no previous studies have examined the acute effects of caffeine on strength and muscular endurance during DCER muscle actions, Kalmar and Cafarelli (19) recently reported that when compared to a placebo of all-purpose wheat flour, caffeine dosages of 6 $mg\cdot kg^{-1}$ of body weight significantly increased isometric leg extension torque and the time that a submaximal (50% MVC) isometric leg extension could be maintained. These findings were not consistent with the LE 1RM and LE TOTV results from the present study. It is possible, however, that the discrepancy between the results from the present investigation and those of Kalmar and Cafarelli (19) were due to differences between studies in the caffeine dosages that were used, the type of muscle actions that were performed, and the characteristics of the subjects being tested. Specifically, Kalmar and Cafarelli (19) used caffeine dosages of 6 $mg\cdot kg^{-1}$ of body weight and tested unilateral isometric leg extension strength in untrained male subjects. The present study, however, examined the effects of lower dosages of caffeine (approximately 201.0 mg; 2.4 mg·kg^{-1} of body weight; range = 2.1–3.0 mg·kg^{-1} of body weight), and the resistance-trained men performed bilateral DCER leg extensions.

In addition, the SUPP group in the present study demonstrated increases in strength for the BP, but not for the LE. Although the mechanism(s) underlying these findings are unclear, the results from recent investigations (6, 8) indicated that caffeine may have different effects for upper- vs. lower-body exercise. For example, Bruce et al. (8) reported that a caffeine dosage of 6 mg·kg^{-1} of body weight increased average power output by approximately 3% during a 2,000-m rowing test. Bell et al. (6), however, found that a slightly lower dose of caffeine (5 mg·kg^{-1} of body weight) had no effect on MP during a WAnT. Therefore, the findings of Bruce et al. (8) and Bell et al. (6) indicate that the ergogenic effects of caffeine may be specific to the muscle groups that are being tested. Additional research is needed, however, to examine the effects of caffeine on performance during various types of upper- and lower-body anaerobic activities.

The results from the present study indicated that the caffeine-containing supplement had no effect on PP and MP, compared to the cellulose placebo. These findings were consistent with those from previous investigations that have examined the acute effects of caffeine on PP and MP in untrained subjects (9, 15). For example, Collomp et al. (9) reported that when compared to a gelatin placebo, caffeine supplementation had no effect on PP or MP during a single WAnT. In addition, Greer et al. (15) found that during 4 consecutive WAnTs separated by 4 minutes of rest, caffeine ingestion had no effect on PP or MP when compared to a dextrose placebo. Collomp et al. (9) and Greer et al. (15) suggested that although caffeine supplementation did not have an ergogenic effect for untrained subjects, it may increase performance for individuals that regularly perform anaerobic training. The results from the resistance-trained men in the present study, however, did not support this hypothesis. One potential explanation for these findings is that there may be differences between subjects in terms of the responses to caffeine supplementation. For example, individuals that do not regularly consume caffeine may be more likely to experience the ergogenic effects of a given dosage than are habitual caffeine users (19). It is also possible, however, that higher dosages of caffeine are required to stimulate improvements in anaerobic capabilities. Collomp et al. (9) used dosages of 5 mg·kg^{-1} of body weight, while Greer et al. (15) used 6 mg·kg^{-1} of body weight. In the present study, each dose of the caffeine-containing supplement contained about 201.0 mg of caffeine (approximately 2.4 mg·kg^{-1} of body weight). Thus, the dosage used in the present study was lower than those used in previous investigations (9, 15), and a higher dosage (>6 mg·kg^{-1} of body weight) of caffeine may be necessary to improve anaerobic capabilities, particularly for habitual caffeine users.

In summary, the results of the present study indicated that there was a significant increase in BP 1RM for the SUPP group, but not for the PLAC group. The caffeine-containing supplement had no effect, however, on LE 1RM, LE TOTV, BP TOTV, PP, and MP when compared to the cellulose placebo. Therefore, these findings, in conjunction with those from previous studies (9, 15, 19), indicated that although the caffeine dosage used in the present investigation may not enhance anaerobic capabilities or strength and muscular endurance during certain exercises, it could have an ergogenic effect for maximal upper-body strength. Future studies should examine the acute effects of various dosages of caffeine on strength, muscular endurance, and anaerobic capabilities in both trained and untrained subjects.

PRACTICAL APPLICATIONS

The present results indicated that ingestion of the caffeine-containing supplement resulted in an acute increase in upper-body strength in resistance-trained men. It did not, however, have an effect on lower-body strength, muscular endurance, anaerobic capabilities, or upper-body muscular endurance. These findings may be useful for competitive and recreational athletes who perform high-intensity anaerobic activities, such as resistance training. Specifically, ingesting a supplement that contains a moderate dose of caffeine approximately 1 hour prior to activity may be beneficial for increasing upper-body strength.

REFERENCES

1. ANSELME, F., K. COLLOMP, B. MERCIER, S. AHMAÏDI, AND CH. PREFAUT. Caffeine increases maximal anaerobic power and blood lactate concentration. *Eur. J. Appl. Physiol.* 65:188–191. 1992.
2. ANTONIO, J. Caffeine: The forgotten ergogenic aid. *Strength Cond. J.* 26:50–51. 2004.
3. BAECHLE, T.R., R.W. EARLE, AND D. WATHEN. Resistance training. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. p. 395–425.
4. BAR-OR, O. The Wingate anaerobic test: An update on methodology, reliability, and validity. *Sports Med.* 4:381–394. 1987.
5. BAR-OR, O. *Testing of Anaerobic Performance by the Wingate Anaerobic Test.* Bloomington, IL: ERS Tech, Inc., 1994.
6. BELL, D.G., I. JACOBS, AND K. ELLERINGTON. Effect of caffeine and ephedrine ingestion on anaerobic exercise performance. *Med. Sci. Sports Exerc.* 33:1399–1403. 2001.
7. BELL, D.G., AND T.M. MCLELLAN. Effect of repeated caffeine ingestion on repeated exhaustive exercise endurance. *Med. Sci. Sports Exerc.* 35:1348–1354. 2003.
8. BRUCE, C.R., M.E. ANDERSON, S.F. FRASER, N.K. STEPTO, R. KLEIN, W.G. HOPKINS, AND J.A. HAWLEY. Enhancement of 2000-m rowing performance after caffeine ingestion. *Med. Sci. Sports Exerc.* 32:1958–1963. 2000.
9. COLLOMP, K., S. AHMAIDI, M. AUDRAN, J.-L. CHANAL, AND CH. PRÉFAUT. Effects of caffeine ingestion on performance and anaerobic metabolism during the Wingate Test. *Int. J. Sports Med.* 12:439–443. 1991.
10. COLLOMP, K., S. AHMAIDI, J.C. CHATARD, M. AUDRAN, AND CH. PRÉFAUT. Benefits of caffeine ingestion on sprint performance in trained and untrained swimmers. *Eur. J. Appl. Physiol.* 64: 377–380. 1992.
11. COSTILL, D.L., G.P. DALSKY, AND W.J. FINK. Effects of caffeine ingestion on metabolism and exercise performance. *Med. Sci. Sports Exerc.* 10:155–158. 1978.
12. GRAHAM, T.E. Caffeine and exercise: Metabolism, endurance and performance. *Sports Med.* 31:786–807. 2001.
13. GRAHAM, T.E., AND L.L. SPRIET. Performance and metabolic responses to a high caffeine dose during prolonged exercise. *J. Appl. Physiol.* 71:2292–2298. 1991.
14. GRAHAM, T.E., AND L.L. SPRIET. Metabolic, catecholamine, and exercise performance responses to various doses of caffeine. *J. Appl. Physiol.* 78:867–874. 1995.
15. GREER, F., C. MCLEAN, AND T.E. GRAHAM. Caffeine, performance, and metabolism during repeated Wingate exercise tests. *J. Appl. Physiol.* 85:1502–1508. 1998.

16. HARMAN, E., J. GARHAMMER, AND C. PANDORF. Administration, scoring, and interpretation of selected tests. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 287–317.
17. IVY, J.L., D.L. COSTILL, W.J. FINK, AND R.W. LOWER. Influence of caffeine and carbohydrate feedings on endurance performance. *Med. Sci. Sports Exerc.* 11:6–11. 1979.
18. KACZKOWSKI, W., D.L. MONTGOMERY, A.W. TAYLOR, AND V. KLISSOUROUS. The relationship between muscle fiber composition and maximal anaerobic power and capacity. *J. Sports Med. Phys. Fitness* 22:407–413. 1982.
19. KALMAR, J.M., AND E. CAFARELLI. Effects of caffeine on neuromuscular function. *J. Appl. Physiol.* 87:801–808. 1999.
20. LOPES, J.M., M. AUBIER, J. JARDIM, J.V. ARANDA, AND P.T. MACKLEM. Effect of caffeine on skeletal muscle function before and after fatigue. *J. Appl. Physiol.* 54:1303–1305. 1983.
21. NATIONAL COLLEGIATE ATHLETIC ASSOCIATION. *NCAA Banned-Drug Classes 2004–2005.* Available at: http://www1.ncaa.org/membership/ed_outreach/health-safety/drug_testing/banned_drug_classes.pdf. Accessed June 15, 2005.
22. SPRIET, L.L. Caffeine and performance. *Int. J. Sport Nutr.* 5: S84–S99. 1995.
23. WILLIAMS, J.H. Caffeine, neuromuscular function and high-intensity exercise performance. *J. Sports Med. Phys. Fitness* 31: 481–489. 1991.
24. WILLIAMS, J.H., W.S. BARNES, AND W.L. GADBERRY. Influence of caffeine on force and EMG in rested and fatigued muscle. *Am. J. Phys. Med.* 66:169–183. 1987.
25. WORLD ANTI-DOPING AGENCY. *The 2005 Monitoring Program.* Available at: http://www.wada-ama.org/rtecontent/document/Monitoring_Program_2005.pdf. Accessed June 15, 2005.

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Address correspondence to Travis W. Beck, tbeck@unlserve.unl.edu