Examination of a Multi-ingredient Preworkout Supplement on Total Volume of Resistance Exercise and Subsequent Strength and Power Performance

Haley C. Bergstrom,[1] M. Travis Byrd,[1] Brian J. Wallace,[2] and Jody L. Clasey[1]

[1]*Department of Kinesiology and Health Promotion, University of Kentucky, Lexington, Kentucky; and* [2]*Kinesiology and Athletic Training Department, University of Wisconsin Oshkosh, Oshkosh, Wisconsin*

Abstract

Bergstrom, HC, Byrd, MT, Wallace, BJ, and Clasey, JL. Examination of a multi-ingredient preworkout supplement on total volume of resistance exercise and subsequent strength and power performance. *J Strength Cond Res* 32(6): 1479–1490, 2018—This study examined the acute effects of a multi-ingredient preworkout supplement on (a) total-, lower-, and upper-body volume of resistance exercise and (b) the subsequent lower-body strength (isokinetic leg extension and flexion), lower-body power (vertical jump [VJ] height), upper-body power (bench throw velocity [BT_v]), and cycle ergometry performance (critical power and anaerobic work capacity). Twelve men completed baseline strength and power measures before 2 experimental visits, supplement (SUP) and placebo (PL). The experimental visits involved a fatiguing cycling protocol 30 minutes after ingestion of the SUP or PL and 15 minutes before the beginning of the resistance exercise protocol, which consisted of 4 upper-body and 4 lower-body resistance exercises performed for 4 sets to failure at 75% 1 repetition maximum. The exercise volume for the total, lower, and upper body was assessed. The VJ height and BT_v were measured immediately after the resistance exercise. Postexercise isokinetic leg extension and flexion strength was measured 15 minutes after the completion of a second cycling protocol. There was a 9% increase in the total-body volume of exercise and a 14% increase in lower-body volume of exercise for the SUP compared with the PL, with no effect on exercise volume for the upper body between the SUP and PL. The increased lower-body volume for the SUP did not result in greater lower-body strength and power performance decrements after exhaustive exercise, compared with the PL. These findings suggested the potential for the SUP to increase resistance exercise volume, primarily related to an increased lower-body volume of exercise.

Key Words ergogenic aid, training volume, caffeine

Introduction

The use of preworkout supplements has become increasingly popular. These supplements are used to enhance both aerobic and anaerobic performance parameters and are generally considered safe when consumed at the recommended dosages (29). There are a number of preworkout supplements available, with various combinations of active ingredients but most contain caffeine. Caffeine has been shown to have an ergogenic effect on strength, power, and endurance at dosages of 3–6 $mg \cdot kg^{-1}$ (18). The effects of caffeine have been attributed to 3 primary mechanisms, which include (a) alteration of fat metabolism (4), (b) direct effect on calcium release from the sarcoplasmic reticulum (ryanodine receptors) (1), and (c) adenosine receptor antagonism (15,16). Currently, there is conflicting evidence regarding the potential for caffeine to influence fat oxidation (19), and it is unlikely that caffeine could exert its effects on calcium release at the typical dosage contained in preworkout beverages (~3–6 $mg \cdot kg^{-1}$) (16). It has been suggested that for high-intensity exercise, caffeine's effects are most likely related to its role as an adenosine receptor antagonist, which may serve to decrease the perception of fatigue (43) and increase the release of neurotransmitters (16) and motor neuron excitability (32,40). Caffeine supplementation has been shown to increase muscular strength (46), muscular endurance (5,36), and peak and mean power output during anaerobic cycling (5). There are limited data, however, regarding the effects of caffeine in combination with citrulline-malate, amino acids (beta-alanine, leucine, tyrosine), creatine, and vitamins (B-3, B-6, B-12, C, and D) on exercise performance.

Ingredients, such as citrulline-malate, leucine, and aspartic acid, contained in preworkout supplements may augment the effects of caffeine. For example, citrulline-malate has been shown to increase the number of repetitions to failure

Address correspondence to Dr. Haley C. Bergstrom, hbergstrom@uky.edu.

32(6)/1479–1490

Journal of Strength and Conditioning Research

during repeated sets at 60% 1 repetition maximum (RM) for lower-body exercise (50). In addition, citrulline may have vasodilatory properties as a precursor to arginine and nitric oxide production (45), increase muscle efficiency and delay fatigue (17), and increase utilization of amino acids during exercise (44). Bioperine is considered a thermogenic ingredient, extracted from black pepper, and may increase the metabolic rate (33), whereas huperzine A has been shown to have cognitive enhancing properties (51). Branched-chain amino acids, such as leucine, have potential acute and chronic effects related to enhanced cognitive function (48), decreased muscle soreness (26), and increased muscle protein synthesis (2,37). In addition, aspartic acid may reduce the accumulation of ammonia in the blood and improve muscular endurance performance (3), whereas tyrosine, the precursor to dopamine and norepinephrine, may improve cognitive function under environmental and physical stressors (28).

The acute affects of preworkout supplementation may be augmented by longer-term (>4 weeks) dosing strategies of other ingredients, such as beta-alanine, creatine, and amino acids, contained in multi-ingredient preworkout supplements (30). Research has shown increases in total exercise volume and a reduction in the subjective feelings of fatigue after 3 weeks of supplementation with beta-alanine (23). Both beta-alanine and creatine may augment the effects of caffeine by delaying neuromuscular fatigue (12,42). The branched-chain amino acid leucine has been shown to be an important signal to stimulate maximal muscle protein synthesis (37), and a preworkout supplement containing branched-chain amino acids and creatine has been shown to result in greater increases in muscle thickness, lean mass, and strength, when compared with a placebo (35). Thus, it is possible that a combination of caffeine, citrulline-malate, amino acids (beta-alanine, leucine, tyrosine), creatine, and vitamins (B-3, B-6, B-12, C, and D) may work synergistically to enhance performance in acute and longer-term dosing strategies, beyond supplementation with each ingredient alone. No previous studies, however, have examined the potential ergogenic effects of this combination of ingredients contained in a preworkout supplement. Thus, further research is needed on the combined effects of these ingredients on total exercise volume and subsequent strength, power, and anaerobic performance. Therefore, the primary purposes of this study were to examine the acute effects of multi-ingredient preworkout supplementation in resistance-trained men on (a) total-, lower-, and upper-body volume of resistance exercise; (b) the subsequent lower-body strength (isokinetic leg extension and flexion), lower-body power (vertical jump [VJ] height), upper-body power (bench throw velocity) and cycle ergometry performance (critical power [CP] and anaerobic work capacity [AWC]).

Methods

Experimental Approach to the Problem

This was a randomized, double-blind, placebo-controlled, crossover design with 2 treatments, supplement (SUP) and placebo (PL). This study involved 5 visits to the exercise physiology and human performance laboratories. All testing procedures were performed at the same time of day for each subject. During visit 1, the subjects demographic information was recorded, and subjects completed a familiarization of the isokinetic leg flexor and extensor strength testing, VJ test, bench press throw test, and CP 3-minute all-out test cycling protocol (CP_{3min}). After 24 hours, the subjects returned to the laboratory to complete visit 2, which included total-body dual-energy x-ray absorptiometry (DXA) scans for body composition assessment and baseline 1RM testing for the barbell back squat, barbell flat bench press, barbell deadlift, and barbell reverse lunge. Forty-eight to 72 hours after completing visit 2, the subjects returned to the laboratory for visit 3 to complete baseline testing for the VJ and bench press throw, followed by 1RM testing for the incline press, front squat, barbell bent-over row, and standing barbell overhead press. In addition, following the 1RM testing, the baseline values were measured for isokinetic leg flexion and extension strength. The experimental visits were completed during visits 4 and 5. Visit 4 was conducted 48–72 hours after completion of the baseline testing (visit 3), and visit 5 was completed 7–10 days after visit 4. For visit 4, the subjects were randomly assigned to ingest either the SUP or PL and ingested the crossover treatment for visit 5. Blood pressure (systolic and diastolic) and heart rate (HR) were taken at 2 time points (15 minutes after arrival and 25 minutes after ingestion). Thirty minutes after ingestion, the subjects completed the experimental protocol outlined in Figures 1 and 2. Briefly, the subjects completed a fatiguing cycling protocol 15 minutes before the beginning of the resistance exercise protocol (Figure 2). The exercise volume for the total body, lower body, and upper body was assessed. Five minutes after completion of the resistance exercise protocol, subjects completed VJ test and the bench throw test, to assess lower- and upper-body power, respectively. After the bench throw test, the subjects completed a second fatiguing cycling protocol. Isokinetic leg extension and flexion strength was measured 15 minutes after the completion of the second cycling protocol. The subjects were asked to refrain from strenuous exercise for at least 24 hours and avoid the consumption of alcohol or caffeine for at least 48 hours before each testing session. Furthermore, the subjects recorded any food and drink consumed 24 hours before, and the day of, the first experimental visit (visit 4). The subjects were asked to consume the same diet 24 hours before, and the day of, the last experimental visit (visit 5), to ensure the same total caloric (kilocalories), protein, carbohydrate, and fat intake.

Subjects

Twelve men, with resistance training experience (mean $\pm$ *SD*: age = 22 $\pm$ 3 years [range = 19–26 years]; height = 179 $\pm$ 7 cm; body mass = 86 $\pm$ 13 kg) were recruited for this

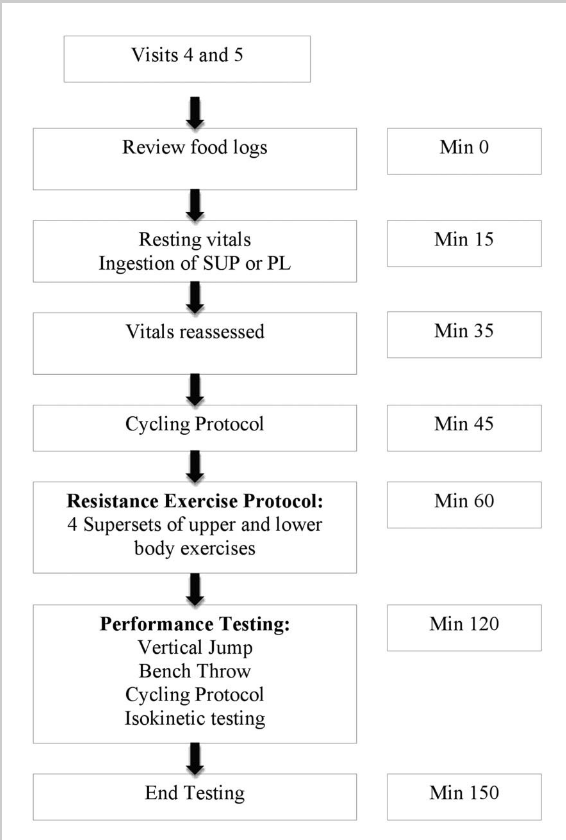

Figure 1. Schematic representation of the experimental sessions.

study. The subjects were involved in a whole-body resistance training program, at least 3 times per week continuously for at least 1 year. Potential subjects who were unable to maximally back squat a weight of ≥1.5 times their body mass were excluded from participation. The mean ± *SD* 1RM back squat for the subjects in this study was 142 ± 34 kg (1.7 ± 0.3 × body mass). All subjects were free from musculoskeletal injuries or neuromuscular diseases and did not report any medical disorders or medicinal or supplement usage that could have affected the outcome of this study. This study was approved by the University of Kentucky's Institutional Review Board for the protection of human subjects, and all subjects completed a written health history questionnaire and informed consent document before any testing.

Procedures

Body Composition Assessments. A total-body DXA scan (GE Lunar Prodigy; GE Lunar, Inc., Madison, WI, USA) scan was performed to assess total-body fat percentage (%BF) and mineral-free lean model mass (in kilograms). The subjects were instructed to remove all objects, such as jewelry or eyeglasses, and wore T-shirt and shorts containing no metal during the scanning procedure. All scans were analyzed by a single trained investigator using the Lunar software version 13.10 (GE Lunar, Inc., Madison, WI, USA).

1-Repetition Maximum Testing. All of the resistance exercises were dynamic constant external resistance (DCER) barbell movements, including 4 upper-body (flat bench press, bent-over row, incline bench press, and standing shoulder press) and 4 lower-body (back squat, deadlift, front squat, and reverse lunge) lifts. A standardized warm-up was completed before each of the 1RM tests. The warm-up began with 10 repetitions at 50%, 5 repetitions at 70%, 3 repetitions at 80%, and 1 repetition at 90% of each subject's predicted 1RM body mass. One minute of rest was provided between warm-up sets, and 2 minutes of rest was provided between the final warm-up set and the first 1RM attempt. The subjects completed up to 3 attempts to determine the 1RM (13). For all 1RM DCER strength testing, progressive loads were added until the subject could not complete a repetition through the full range of motion. Additional trials were performed with lighter loads until the 1RM was determined within 2.27 kg, which was typically achieved within 3 trials. Three minutes of rest was given between 1RM attempts.

The barbell back squat was performed on a standard free-weight rack using an Olympic barbell. The barbell was positioned above the posterior deltoids at the base of the neck. The subjects' feet were positioned shoulder-width apart, with the toes pointed slightly outward. The subjects were instructed to keep their feet on the floor and maintain a flat back, keeping the torso-to-floor angle relatively constant through the range of motion. A complete repetition was considered when the subject moved from an erect position into flexion at the knee and hip until the thighs were parallel to the floor and then returned to the original position (49). The front squat was performed in a similar manner as the back squat, with the exception that the barbell was positioned across the front of the body over the anterior deltoids near the clavicle. A clean grip or cross-armed grip was used at the subject's discretion.

The barbell deadlift was performed using free weights and a standard Olympic barbell. The subjects performed a conventional style deadlift (vs. sumo), in which their feet were approximately hip width, with toes pointed slightly outward. The subjects started the lift with flexion at the knees and hips so that the back was flat and at an approximately 60° angle to the floor. The subjects were instructed to use an alternating grip. A complete repetition was considered when the subject reached full extension at the knees and hips with the barbell and returned the barbell back to the floor in a controlled manner. "Hitching" and "back lifting" (where the lifter extends their knees before, not at the same time as, their hips) was not permitted.

The barbell reverse lunge was performed in a standard squat rack with an Olympic barbell. The subjects grasped the barbell with a closed, pronated grip. The bar was positioned above the posterior deltoids at the base of the neck. The

Resistance Exercise Protocol

Superset 1	Superset 2
Back Squat	Deadlift
Flat Bench Press	Bent Over Row

Superset 3	Superset 4
Front Squat	Reverse Lunge
Incline Bench Press	Shoulder Press

A

Superset 1

1. Back squat	0 seconds	2. Back squat	180 seconds
1. Bench press	60 seconds	2. Bench press	240 seconds
3. Back squat	360 seconds	4. Back squat	540 seconds
3. Bench press	420 seconds	4. Bench press	600 seconds

B

Figure 2. A) The resistance exercise protocol. All of the resistance exercises were performed with a barbell at 75% of the 1 repetition maximum. Four supersets of an upper- and lower-body exercise were completed. B) An example of one of the superset exercise procedures. Four sets each exercise were completed, and each set was performed for 10 repetitions or to volitional exhaustion. Three minutes of rest was provided between 1 set of an exercise and the start of the next set of that same exercise. One minute was provided between the lower- and upper-body exercise.

subjects stepped backward with one, keeping the torso erect and the trailing foot planted on the floor. The subject allowed the thigh and lower leg to slowly flex until the knee was 1–2 inches above the floor and the thigh was parallel with the floor (~2 seconds). The subjects pushed off the floor with the back leg, extending the leg and thighs, brining the back foot to the starting position. After a brief pause (~1 second), the subject completed the same movement with the opposite leg. The 1RM was considered to be achieved only if the weight could be moved through the range of motion twice (using right and left legs as the back leg 1 time).

The flat barbell bench press was performed on a standard free-weight bench with an Olympic barbell. After receiving a liftoff from the spotter, the subjects lowered the barbell to their chest just above the nipple line, paused briefly, and then pressed the bar to full extension of the forearms. This was defined as one complete repetition. The incline bench press was performed in the same manner as the flat barbell bench press, with the exception that the bench was inclined to approximately 45°. The barbell touched the chest slightly higher than during the flat barbell bench press.

The shoulder press was performed in a standard squat rack with an Olympic barbell. The subjects used a 3-handed pronated grip to secure the barbell in their hands and lifted it from the rack. The barbell was positioned across the front of the body over the anterior deltoids near the clavicle. The subjects were instructed to take one step backward with each foot, gain their balance, and push the barbell overhead to full elbow extension. One repetition was defined as raising and lowering the bar under control. Safety pins were set within the rack, so the subject could release the weight from their grip onto the pins if needed. Additionally, one spotter was placed on each side of the barbell for safety.

The barbell bent-over row was performed from the floor with an Olympic barbell, using a closed, pronated grip. The subjects positioned their feet shoulder-width apart, with slight flexion at the knees. The torso was flexed so that it is just slightly above parallel to the floor. The movement began with the forearms fully extended and the barbell 1–2 inches from the floor. The subject pulled the bar toward the torso, keeping the back flat and slight flexion at the knees. The barbell touched the lower chest or upper abdomen and was lowered back to the starting position.

Vertical Jump Test. Vertical jump height was measured using the Vertec vertical jump device (Gill Athletics, Champaign, IL, USA). Each subject was positioned directly underneath the Vertec and instructed to jump as high as possible from a standing 2-foot position, use a countermovement, and move the highest horizontal vane with a single hand (39). Each subject performed 3 VJs with 2 minutes of rest between each trial. Vertical jump height was calculated as the difference between the highest vane of the Vertec reached and the standing reach height and expressed in centimeters. The test-retest data from our laboratory for the VJ test ($n = 15$) has been shown to be highly reliable (intraclass correlation [ICC] = 0.99) with no significant mean differences (mean difference = −2.36 cm; 95% confidence interval [CI] = −6.92 to 2.19 cm; $p > 0.05$) between test-retest values.

Isokinetic Testing. Isokinetic strength was assessed using a Biodex System 4 (Biodex Medical, Shirley, NY, USA). The subjects were positioned on the isokinetic dynamometer in a seated position. After several submaximal repetitions, the subjects completed 3 maximum effort concentric leg flexion and extension contractions on the dynamometer at $30°\cdot sec^{-1}$. The peak torque (N·m) was defined as the highest of the 3 trials. The isokinetic strength testing has been shown to be highly reliable (ICC = 0.98), with no significant mean differences between test-retest values (9).

Bench Throw Test. The 1RM barbell flat bench press was determined before the bench throw test. The bench throw test was performed on a Smith machine (OSSM; Life Fitness, Chicago, IL, USA), with the subject supine on a flat bench. A weight equal to 30% of the subjects' bench press 1RM was used. The subjects were instructed to begin the movement with the arms fully extended and then lower the barbell in a rapid but controlled (without pulling or allowing the barbell to bounce off the chest) manner and then immediately move the barbell as fast as possible from the chest. The bar was released and caught by the subject, with a test administrator as the spotter. Three throws were performed, and the bench throw peak velocity was recorded by a HUMAC360 potentiometer and software (CSMi, Stoughton, MA, USA). The throw that resulted in the highest velocity

TABLE 1. Ingredients contained in 1 dose of the multi-ingredient preworkout supplement (SUP) in absolute serving size and relative dose (per kg body mass [BM]).

Ingredient	Amount per serving	Relative dose ($dose \cdot kg \cdot BM^{-1}$), mean ± *SD*
L-Citrulline DL-Malate	6 g	0.07 ± 0.01
L-Leucine	4 g	0.05 ± 0.01
D-Aspartic acid	3 g	0.04 ± 0.01
Creatine hydrochloride (HCl)	2 g	0.02 ± 0.003
CarnoSyn beta-alanine	1.6 g	0.02 ± 0.003
L-Tyrosine	1.2 g	0.02 ± 0.002
Agmatine sulfate	500 mg	5.94 ± 0.84
Caffeine anhydrous	350 mg	4.16 ± 0.59
Phosphatidylserine	125 mg	1.48 ± 0.21
BioPerine black pepper (*Piper nigrum*) fruit extract	5 mg	0.06 ± 0.01
Huperzine A (*Huperzia serrata*) (whole herb) powder	100 mcg	1.19 ± 0.17
Vitamin C (as ascorbic acid)	250 mg	2.97 ± 0.42
Vitamin D (as cholecalciferol)	400 IU	4.75 ± 0.67
Vitamin B3 (as niacin)	25 mg	0.30 ± 0.04
Vitamin B6 (as pyridoxine hydrochloride)	20 mg	0.24 ± 0.03
Vitamin B12 (as methylcobalamin)	90 mcg	1.07 ± 0.15
Calcium (as calcium silicate)	85 mg	1.01 ± 0.14
Magnesium (as magnesium D-aspartic acid)	260 mg	3.09 ± 0.44

($centimeter \cdot sec^{-1}$) was used for analysis. The bench throw test from our laboratory ($n = 10$) has been shown to be highly reliable (ICC = 0.924) with no significant mean differences (mean difference = $-4.0\ cm \cdot sec^{-1}$; 95% CI = -10.1 to $2.14\ cm \cdot sec^{-1}$; $p > 0.05$) between test-retest values.

Cycling Protocol. The subjects performed a CP_{3min} maximal effort protocol on mechanically braked cycle ergometer (model 894E; Monark HealthCare International, Langly, WA, USA) with the resistance set at 4.5% of body mass (0.045 × body mass in kilograms) (6,10). Before the test, the seat height was adjusted so that the subject's legs were near full extension at the bottom of the pedal revolution. Toe cages were used to maintain pedal contact throughout the test. The subjects completed a 5-minute warm-up at 50 W at their preferred cadence (70–80 $rev \cdot min^{-1}$) followed by a 5-minute rest. The test began with unloaded cycling at the preferred cadence followed by 3 minutes of an all-out effort. The subjects were instructed to increase the pedaling cadence to 110 $rev \cdot min^{-1}$ in the last 5 seconds of the unloaded phase and then maintain the cadence as high as possible for 3 minutes. The cycle ergometer protocol was performed twice during each experimental visit, 30 minutes after ingestion of the SUP or PL (prefatigue) and 15 minutes after the bench throw test (postfatigue) (Figure 1). The CP (expressed in Watts [W]) was defined as the mean power output over the final 30 seconds of the test, and the AWC (expressed in kilojoules [kJ]) was calculated using the equation, AWC = 150 seconds (P_{150}–CP), where P_{150} equals the mean power output for the first 150 seconds (10). The power outputs were recorded using the Monark Anaerobic Test software (Monark Exercise AB, Vansbro, Sweden). The test-retest reliability for the CP and AWC parameters from our laboratory ($n = 13$) indicated the ICC values were $R = 0.91$ and $R = 0.79$, respectively, with no significant mean differences between test and retest (CP mean difference = -0.23 W;

TABLE 2. Descriptive characteristics of the subjects ($n = 12$).*

	Age (y)	Height (cm)	Body mass (kg)	%BF (%)	LBM (kg)
Mean ± *SD*	22 ± 3	179 ± 7	86 ± 13	16 ± 4	68 ± 10
Range	19–26	170–189	66–113	11–24	54–85

*%BF = body fat percentage, LBM = mineral free lean body mass.

Table 3. Mean ± *SD* for the heart rate (HR) and blood pressure (BP, systolic and diastolic) measured 15 minutes after arrival and 25 minutes after ingestion of the placebo (PL) or supplement (SUP).*

	Time	
Condition	15 min after arrival	25 min post ingestion
HR ($b \cdot min^{-1}$)		
PL	72 ± 9	76 ± 10
SUP	70 ± 9	71 ± 13
Systolic BP (mm Hg)		
PL	122 ± 12	128 ± 77
SUP	126 ± 8	129 ± 8
Diastolic BP (mm Hg)		
PL	70 ± 11	77 ± 6
SUP	75 ± 8	80 ± 6
Marginal Means	72 ± 8	79 ± 4†

*There were no interactions and no main effects for HR and systolic BP and no interaction or main effect for condition for diastolic. There was a main effect for time for diastolic. See Results section for a description of overall and follow-up analyses.
†Significantly greater ($p \leq 0.05$) than the value measured 15 minutes after arrival.

95% CI = −13.0 to 12.6 W; $p > 0.05$; AWC mean difference = 0.65 J; 95% CI = −0.74 to 2.03 J).

Resistance Exercise Protocol. After the rest period, the subjects completed a resistance exercise protocol consisting of 4 lower-body exercises (barbell back squat, deadlift, front squat, and reverse lunge) superset with 4 upper-body exercises (flat barbell bench press, bent-over row, incline press, and shoulder press). A description of the supersets and protocol are presented in Figure 2. Four sets at 75% of 1RM of each exercise were completed. Each set was performed for 10 repetitions or to volitional exhaustion. Volitional exhaustion was defined as the inability of the subject to complete a repetition through the full range of motion. Completing a repetition through 50% of the range of motion was counted as a half repetition. Three minutes of rest was provided between 1 set of an exercise and the start of the next set of that same exercise. One minute was provided between the lower-body and upper-body exercise. Water was provided ad libitum during visit 4, and the total volume consumed was recorded. The subject was asked to consume the same volume of water during visit 5. The volume of exercise was calculated for the total body (all 8 exercises listed in Figure 2A), lower body (barbell back squat, deadlift, front squat, and reverse lunge), and upper body (flat barbell bench press, bent-over row, incline press, and shoulder press), as the product of the total number of repetitions completed and the weight lifted.

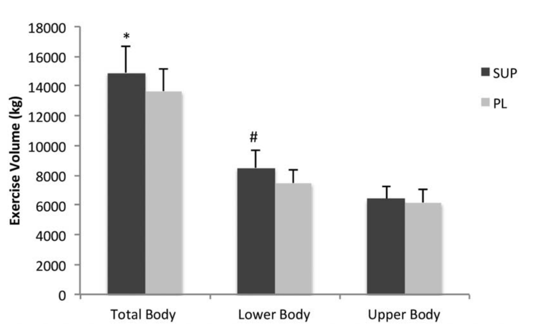

Figure 3. Total-, lower-, and upper-body resistance exercise volume expressed as mean ± 95% confidence interval. The resistance exercise protocol involved 8 exercise (4 lower body and 4 upper body) performed in 4 supersets. Each superset consisted of 1 lower- and 1 upper-body exercise performed at 75% of the 1 repetition maximum for 4 sets of 10 repetitions or to failure. The exercise volume was calculated as the product of the total number of repetitions and the weight lifted. See Figures 1 and 2 for a description of the resistance exercise protocol. *Significantly greater ($p \leq 0.05$) than the PL for total-body volume. #Significantly greater ($p \leq 0.05$) than the placebo for lower-body volume.

Supplementation. The subjects were randomly assigned to ingest either the SUP or PL during visit 4 and ingested the crossover treatment for visit 5. The subjects consumed 1 scoop (1 serving = 20.9 g) of either the SUP or PL powder mixed with approximately 12 oz. of water. The SUP (MusclePharm, Inc., Denver, CO, USA) contained citrulline-malate (6 g), leucine (4 g), aspartic acid (3 g), creatine hydrochloride (2 g), beta-alanine (1.6 g), tyrosine (1.2 g), and caffeine anhydrous (350 mg). A complete list of the ingredients and the relative dose of each ingredient is provided in Table 1. The PL was flavored maltodextrin, similar in color and flavor to the SUP formulation. An investigator,

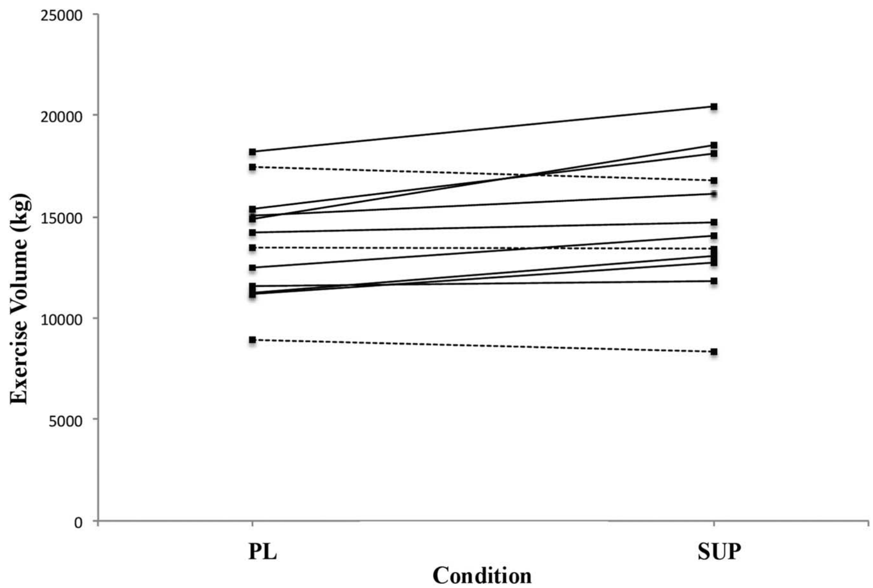

Figure 4. Individual total volume of exercise (in kilograms) for the resistance exercise protocol between the placebo (PL) and supplement (SUP) condition ($n = 12$). The total volume was calculated as the product of the total number of repetitions and the weight lifted. The solid lines indicate the subjects who had a greater volume of exercise in the SUP condition ($n = 9$), and the dotted lines indicate the subjects who had a lower volume of exercise in the SUP condition ($n = 3$). See Figures 1 and 2 for a description of the resistance exercise protocol.

who was not involved in the data collection, prepared and administered both the SUP and PL beverages for all subjects, providing double blinding of both the subjects and data collection personnel.

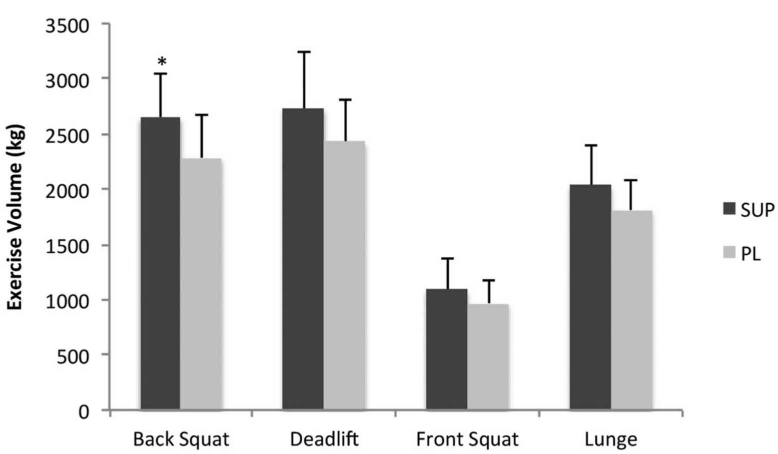

Figure 5. Lower-body resistance exercise volume for the back squat, deadlift, front squat, and reverse lunge expressed as mean ± 95% confidence interval. The resistance exercise protocol involved 8 exercise (4 lower body and 4 upper body) performed in 4 supersets. Each superset consisted of 1 lower-body and 1 upper-body exercise performed at 75% of the 1 repetition maximum for 4 sets of 10 repetitions or to failure. The exercise volume was calculated as the product of the total number of repetitions and the weight lifted. See Figures 1 and 2 for a description of the resistance exercise protocol. *Significantly greater ($p \leq 0.05$) than the placebo for back squat exercise volume.

Dietary Analyses. The subjects recorded all food and beverages consumed the day before, and the day of, the first experimental trial (visit 4). The subjects were provided a copy of the 2-day food logs and asked to consume a similar diet the day before, and the day of, the second experimental visit (visit 5). The total energy and macronutrient intake were analyzed (www.supertracker.usda.gov).

Statistical Analyses

Mean differences in total-, lower-, and upper-body volume of resistance exercise for the SUP and PL were examined with separate, paired samples *t*-tests. In addition, mean differences in total volume between the SUP and PL were examined for each exercise (back squat, deadlift, front squat, reverse lunge, flat bench press, incline press, bent-over row, and standing overhead press) using separate, paired samples *t*-tests. The VJ height, bench throw velocity, and

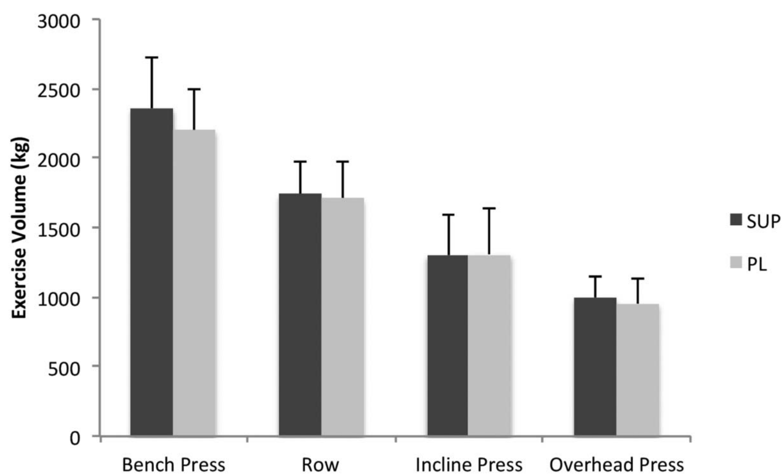

Figure 6. Upper-body resistance exercise volume for the bench press, bent-over row, incline press, and overhead press expressed as mean ± 95% confidence interval. The resistance exercise protocol involved 8 exercise (4 lower body and 4 upper body) performed in 4 supersets. Each superset consisted of 1 lower-body and 1 upper-body exercise performed at 75% of the 1 repetition maximum for 4 sets of 10 repetitions or to failure. The exercise volume was calculated as the product of the total number of repetitions and the weight lifted. See Figures 1 and 2 for a description of the resistance exercise protocol.

isokinetic leg extension and flexion peak torque were analyzed with separate, 1-way repeated-measures analyses of variance (ANOVAs) and least significant different paired samples *t*-tests. The HR and systolic and diastolic blood pressure values were examined with separate 2 (time [15 minutes after arrival and 25 minutes after ingestion]) × 2 (condition [SUP, PL]) repeated-measures ANOVAs and follow-up pairwise comparisons. The CP and AWC values were analyzed with separate 2 (time [prefatigue, postfatigue]) × 2 (condition [SUP, PL]) repeated-measures ANOVAs and follow-up pairwise comparisons. In addition, the total caloric (kilocalories) and macronutrient (grams of carbohydrate, protein, and fat) intake were analyzed with separate 2 (time [24 hours before testing, day of testing]) × 2 (condition [SUP, PL]) repeated-measures ANOVAs. An alpha level of $p \leq 0.05$ was considered statistically significant for all analyses. All statistical analyses were performed with Statistical Package for the Social Sciences software (v.23.0.; IBM SPSS, Inc., Chicago, IL, USA).

Results

The descriptive characteristics of the subjects are presented in Table 2. The HR and blood pressure analyses revealed no time × condition interactions and no main effects for time or condition for HR and systolic blood pressure. However, there was a main effect for time for diastolic blood pressure ($F = 8.99$; $p = 0.012$, $p\eta^2 = 0.45$), which indicated an increase from 15 minutes after arrival (72 ± 8 mm Hg) and 25 minutes (79 ± 4 mm Hg) after ingestion of the PL or SUP but no main effect for condition (Table 3). The results of the statistical analyses for volume of exercise indicated that the total-body (SUP = 14,908 ± 3,163 kg; PL = 13,668 ± 2,731 kg) and lower-body (SUP = 8,507 ± 2,006 kg; PL = 7,493 ± 1,552 kg) volume were significantly greater (total body: $t = 3.594$, $p = 0.004$; lower body: $t = 3.105$, $p = 0.010$) for the SUP than for the PL (Figure 3). In addition, the SUP resulted in a greater total volume of exercise for 9 of the 12 subjects compared with the PL (Figure 4). There was, however, no difference ($t = 1.090$; $p = 0.30$) between the SUP (6,401 ± 1,565 kg) and PL (6,175 ± 1,565 kg) for

Table 4. Mean ± *SD* and 95% confidence intervals for the strength and power performance testing completed after the resistance exercise protocol.

	Time		
Variable	Baseline	PL	SUP
Vertical jump height (m)	63.7 ± 8.5 58.3–69.1	59.9 ± 9.7* 53.7–66.1	60.4 ± 9.0* 54.7–66.1
Bench throw test velocity (cm·s^{-1})	141.7 ± 10.5 135.0–148.3	133.3 ± 17.6* 122.2–144.5	134.8 ± 19.5 122.4–147.2
Isokinetic leg extension strength 30°·s^{-1} (N·m)	221.7 ± 70.5 191.0–252.4	191.5 ± 49.1* 160.3–222.7	179 ± 65.1* 137.8–220.5
Isokinetic leg flexion strength 30°·s^{-1} (N·m)	114 ± 27.4 105.0–123.8	111.5 ± 23.2 96.8–126.3	123.4 ± 20.4 110.4–136.4

*Significantly less ($p \leq 0.05$) than the baseline value.

Table 5. Mean ± *SD* and 95% confidence intervals for critical power (CP) and anaerobic work capacity (AWC) measured before (prefatigue) and after (postfatigue) the resistance exercise protocol for the placebo (PL) and the supplement (SUP).*

	Time	
Condition	Prefatigue	Postfatigue
CP (W)		
PL	215 ± 31	203 ± 35
	196–235	181–226
SUP	219 ± 32	215 ± 37
	199–239	191–239
AWC (kJ)		
PL	15.2 ± 2.9	14.1 ± 3.0
	13.3–17.1	12.2–16.1
SUP	16.1 ± 2.8	13.7 ± 4.0
	14.3–17.8	11.2–16.2
Marginal means	15.6 ± 2.8	13.9 ± 3.5†
	13.9–17.5	11.8–16.1

*There was no interaction and no main effects for CP and no interaction or main effect for condition for AWC. There was a main effect for time for AWC. See Results section for a description of overall and follow-up analyses.
†Significantly less ($p \leq 0.05$) than the prefatigue value.

upper-body volume of exercise (Figure 3). The volume of exercise for the back squat was greater for the SUP (2,649 ± 685 kg) than for the PL (2,286 ± 693 kg), but there were no differences between SUP and PL for any of the other exercises (deadlift, front squat, reverse lunge, flat bench press, incline press, bent-over row, and standing overhead press) (Figures 5 and 6).

The results of the statistical analyses for the power and strength performance parameters are provided in Table 4. The results of the 1-way repeated-measures ANOVA indicated significant differences among the means for the VJ height ($F = 10.57$; $p = 0.001$; $p\eta^2 = 0.49$), isokinetic leg extension peak torque ($F = 3.76$; $p = 0.04$; $p\eta^2 = 0.26$), and bench throw velocity ($F = 3.37$; $p = 0.05$; $p\eta^2 = 0.24$). The follow-up pairwise comparisons indicated that there were significant decreases from baseline in the VJ height and isokinetic leg extension peak torque for the SUP and PL, but there were no significant differences between conditions. In addition, the bench throw velocity decreased significantly from baseline for the PL but not for the SUP. There were, however, no significant differences among the 3 time points (baseline, PL, SUP) for the isokinetic leg flexion peak torque values ($F = 2.16$; $p = 0.14$; $p\eta^2 = 0.16$).

The results of the 2 × 2 repeated-measures ANOVA for CP indicated no time × condition interaction ($F = 2.35$; $p = 0.15$; $p\eta^2 = 0.18$), and there were no main effects for time ($F = 4.52$; $p = 0.06$; $p\eta^2 = 0.29$) or condition ($F = 2.97$; $p = 0.11$; $p\eta^2 = 0.21$) (Table 5). The results of the 2 × 2 repeated-measures ANOVA for AWC indicated no time × condition interaction ($F = 2.84$; $p = 0.12$; $p\eta^2 = 0.21$) and no main effects for condition ($F = 0.19$; $p = 0.68$; $p\eta^2 = 0.02$); however, there was a main effect for time ($F = 9.04$; $p = 0.01$; $p\eta^2 = 0.45$). The follow-up pairwise comparison indicated that AWC significantly decreased from prefatigue (15.6 ± 2.8 J) to postfatigue (13.9 ± 3.5 J) (Table 5). There were no significant differences in total caloric intake or macronutrients consumed 24 hours before, and the day of, the experimental protocol for the SUP and PL conditions.

Discussion

The primary purpose of this study was to examine the effects of a multi-ingredient preworkout supplement on the total volume of resistance exercise. The current findings indicated a 9% increase in the total-body volume of exercise and a 14% increase in lower-body volume of exercise for the SUP compared with the PL, with no effect on exercise volume for the upper body between the SUP and PL. The resistance training protocol in this study included 8 separate exercises, divided into 4 supersets of a lower-body and an upper-body exercise. When each exercise was examined separately, the volume was only greater for the SUP than for the PL for the back squat (~16%) (Figures 5 and 6). The back squat was superset with the bench press and was the first exercise performed in the resistance training protocol, 45 minutes after supplementation. A number of recent studies have examined the effects of preworkout supplements containing similar ingredients to the SUP in this study (22,23,27,31). When performed in isolation, an increase in lower-body (22,23) and upper-body (27) exercise volume has previously been reported after acute ingestion of a multi-ingredient preworkout supplement. Preworkout supplementation has also been reported to have no effect on exercise volume for the bench press or leg press preformed at 70% of the 1RM to failure (31). This study was unique in the inclusion of 4 supersets of multiple resistance exercises (4 lower body and 4 upper body), a common practice by individuals who perform whole-body resistance training programs. The increases in the volume of exercise after multi-ingredient preworkout supplementation were likely related to the acute effects caffeine and its role as an adenosine receptor antagonist (14,15,18,40). Caffeine has been shown to decrease the ratings for perceived exertion (14) and increase subjective ratings of task motivation (34), focus (23), and energy (23). The caffeine contained in the SUP in this study resulted in a mean relative dose of 4.2 ± 0.6 $mg \cdot kg^{-1}$, which was higher than the relative dose (~3.5 $mg \cdot kg^{-1}$) in preworkout supplements previously reported (22,23,27,31) to be effective for improving exercise volume or cognitive performance. The increased exercise volume observed in the present study may also be attributed to the acute ingestion of 6 g of citrulline-malate in SUP, which can increase the vasodilatory

response (44,45) and improve muscular efficiency (17), whereas ingestion of amino acids, leucine and tyrosin, and huperzine A have enhanced cognitive function and focus during exercise (26,48,51). It is possible that these ingredients (caffeine, citrulline-malate, amino acids, and huperzine A) worked synergistically to increase exercise volume by increasing blood flow and the removal of metabolic by-products and improving focus and decreasing perceptions of fatigue. Thus, the current findings suggested that the multi-ingredient preworkout was most effective for increasing exercise volume within the first 45 minutes of supplementation and for exercise involving large muscle groups of the lower body.

A secondary purpose of this study was to examine the effect of the SUP on strength and power performance following a high volume resistance training session. In contrast to previous studies (5,36,46) that have shown acute increases in performance of lower-body parameters (i.e., muscular strength and power) after preworkout or caffeine supplementation, there were similar decreases in the lower-body power (VJ), quadriceps strength (isokinetic leg extension peak torque), and anaerobic cycle ergometry performance (AWC) for the SUP and PL after the resistance exercise. These findings, however, indicated that the increased lower-body volume of exercise performed for the SUP did not result in greater lower-body power and quadriceps strength performance decrements compared with the PL. Thus, although the SUP did not improve subsequent lower-body strength and power performance after an exhaustive resistance exercise protocol, it is possible the multi-ingredient preworkout supplement examined in this study could increase lower-body volume of exercise without altering subsequent performance to a greater extent than a lower volume exercise program. In addition, the upper-body power (i.e., bench throw test) was maintained for the SUP but not for the PL. These findings suggested that the upper body did not demonstrate the same level of fatigue as the lower body for the SUP. In addition, there was no decrease in leg flexor strength for either the SUP or PL, which indicated that the protocol was not fatiguing for the hamstrings muscle group. One limitation of the present study, however, was the ~20-minute delay between the completion of the final resistance exercise and the measurement of lower-body strength. This delay may have allowed some recovery of muscular strength. Taken together, these findings suggested that the current protocol demonstrated the greatest fatigue and potential effect for the SUP for the quadriceps muscle group.

In summary, the preworkout supplement examined in this study resulted in a 9% increase in the total-body volume of exercise and a 14% increase in lower-body volume of exercise for the SUP compared with the PL, with no effect on exercise volume for the upper body between the SUP and PL. These findings suggested that the SUP was most effective for increasing exercise volume within the first 45 minutes of supplementation and for exercise involving large muscle groups of the lower body. The increased lower-body volume for the SUP did not result in greater lower-body strength and power performance decrements after exhaustive exercise, when compared with the PL. In addition, the upper-body power was maintained in the SUP after the exhaustive exercise. Taken together, these findings suggested the potential for the SUP to increase resistance exercise volume, without greater impairment in performance, when compared with a PL.

Practical Applications

The multi-ingredient preworkout supplement examined in this study was effective for increasing the total volume of resistance exercise, primarily related to increases in lower-body volume of exercise. Although volume is an important aspect of resistance training adaptations (38), the 9–14% differences in exercise volume between SUP and PL may not be large enough to elicit greater adaptions for the SUP than for the PL. It is possible that the acute increases in exercise volume for the SUP observed in this study may translate into greater strength and performance adaptations if the effects of the supplement are maintained with a chronic dosing strategy (i.e., before each training session for >4 weeks). Future studies should examine the effects of the preworkout supplement used in this study on resistance exercise volume and performance adaptations with chronic (i.e., > 4 weeks) supplementation to determine if increases in exercise volume are maintained and translate into greater adaptations. In addition, there is some evidence (30) that 4 and 8 weeks of preworkout supplementation before resistance training may improve 1RM strength and cognitive function to a greater degree, compared with a placebo. It was suggested (30) that these adaptations were the result of longer-term supplementation of ingredients such as beta-alanine and creatine nitrate contained in the preworkout supplement. Many of the ingredients in the SUP do not have acute effects, but they may have implication for strength and power performance parameters after longer-term dosing strategies (>4 weeks). For example, longer-term (~4 weeks) dosing strategies for creatine and beta-alanine have been shown to result in increases in energy stores (i.e., phosphocreatine) (24) and intramuscular buffering capacity (i.e., increased levels of carnosine) (12,20,21), respectively. These adaptations have been shown to increase strength and power (8,9,11,25) and augment the effects of caffeine by delaying neuromuscular fatigue (12,41,42), allowing a greater number of repetitions to be completed via mechanisms other than adenosine receptor antagonism. The supplement in this study, however, contained only 2 g of creatine hydrochloride, which is reported to be less effective at increasing intramuscular phosphocreatine levels than creatine monohydrate, and the dosage was lower than typically recommended (5 $g \cdot d^{-1}$ for 30 days or 20 $g \cdot d^{-1}$ for 5–7 days) (7). In addition, the amount of beta-alanine in the SUP in this study was less

than previously shown (47) to be effective at increasing intramuscular carnosine levels (3–6 $g \cdot d^{-1}$ for 2–4 weeks). Thus, it is unclear if the amount of creatine and beta-alanine contained in this study would be sufficient to increase intramuscular phosphocreatine and carnosine levels. In addition, future studies should measure intramuscular levels of phosphocreatine and carnosine after chronic supplementation to determine if the lower doses of creatine and beta-alanine (2 g and 1.6 g, respectively) result in increased energy stores and intramuscular buffering capacity, which have the potential to effect strength and performance adaptations.

Acknowledgments

The supplement examined in this study was provided by MusclePharm, Inc. (MusclePharm, Denver, CO), and the placebo was provided by True Nutrition (True Nutrition, Vista, CA).

References

1. Allen, DG and Westerblad, H. The effects of caffeine on intracellular calcium, force and the rate of relaxation of mouse skeletal muscle. *J Physiol* 487: 331–342, 1995.
2. Anthony, JC, Anthony, TG, Kimball, SR, and Jefferson, LS. Signaling pathways involved in translational control of protein synthesis in skeletal muscle by leucine. *J Nutr* 131: 856S–860S, 2001.
3. Barnes, RH, Labadan, BA, Siyamoglu, B, and Bradfield, RB. Effects of exercise and administration of aspartic acid on blood ammonia in the rat. *Am J Physiol* 207: 1242–1246, 1964.
4. Beavo, JA, Robers, NL, Crofford, OB, Hardman, JG, Sutherland, EW, and Newman, EV. Effects of xanthine derivatives on lipolysis and adenosine 3', 5'–Monophosphate phosphodiesterase activity. *Mol Pharmacol* 6: 597–603, 1970.
5. Beck, TW, Housh, TJ, Schmidt, RJ, Johnson, GO, Housh, DJ, Coburn, JW, and Malek, MH. The acute effects of a caffeine containing supplement on strength, muscular endurance, and anaerobic capabilities. *J Strength Cond Res* 20: 506–510, 2006.
6. Bergstrom, HC, Housh, TJ, Zuniga, JM, Camic, CL, Traylor, DA, Schmidt, RJ, and Johnson, GO. A new single work bout test to estimate critical power and anaerobic work capacity. *J Strength Cond Res* 26: 656–663, 2012.
7. Buford, TW, Kreider, RB, Stout, JR, Greenwood, M, Campbell, B, Spano, M, Ziegenfuss, T, Lopez, H, Landis, J, and Antonio, J. International society of sports nutrition position stand: Creatine supplementation and exercise. *J Int Soc Sports Nutr* 4: 6, 2007.
8. Camic, CL, Housh, TJ, Zuniga, JM, Traylor, DA, Bergstrom, HC, Schmidt, RJ, Johnson, GO, and Housh, DJ. The effects of polyethylene glycosylated creatine supplementation on anaerobic performance measures and body composition. *J Strength Cond Res* 28: 825–833, 2014.
9. Camic, CL, Hendrix, CR, Housh, TJ, Zuniga, JM, Mielke, M, Johnson, GO, Schmidt, RJ, and Housh, TJ. The effects of polyethylene glycosylated creatine supplementation on muscular strength and power. *J Strength Cond Res* 24: 3343–3351, 2010.
10. Clark, IE, Murray, SR, and Pettitt, RW. Alternative procedures for the three-minute all-out exercise test. *J Strength Cond Res* 27: 2104–2112, 2013.
11. Cotrell, GT, Coast, JR, and Herb, RA. Effect of recovery interval on multiple-bout sprint cycling performance after acute creatine supplementation. *J Strength Cond Res* 16: 109–116, 2002.
12. Derave, W, Ozdemir, MS, Harris, RC, Pottier, A, Reyngoudt, H, Koppo, K, Wise, JA, and Achten, E. Beta-Alanine supplementation augments muscle carnosine content and attenuates fatigue during repeated isokinetic contraction bouts in trained sprinters. *J Appl Physiol* 103: 1736–1743, 2007.
13. Doan, BK, Newton, RU, Marsit, N, Triplett-McBride, T, Koziris, LP, Fry, AC, and Kraemer, WJ. Effects of increased eccentric loading on bench press 1RM. *J Strength Cond Res* 16: 9–13, 2002.
14. Doherty, M and Smith, PM. Effects of caffeine ingestion on rating of perceived exertion during and after exercise: A meta-analysis. *Scan J Med Sci Sports* 15: 69–78, 2005.
15. Fredholm, BB. Are methylxanthine effects due to antagonism of endogenous adenosine? *Trends Pharmacol Sci* 1: 129–132, 1980.
16. Fredholm, BB, Battig, K, Holmen, J, Nehlig, A, and Zvartau, EE. Actions of caffeine in the brain with special reference to factors that contribute to its widespread use. *Pharmacol Rev* 51: 83–133, 1999.
17. Giannesini, B, Le Fur, Y, Cozzone, PJ, Verleye, M, Le Guern, M, and Bendahan, D. Citrulline malate supplementation increases muscle efficiency in rat skeletal muscle. *Eur J Pharmacol* 667: 100–104, 2001.
18. Goldstein, ER, Ziegenfuss, T, Kalman, D, Kreider, R, Campbell, B, Wilborn, C, Taylor, L, Willoughby, D, Stout, J, Graves, SB, Wildman, R, Ivy, JL, Spano, M, Smith, AE, and Antonio, J. International society of sports nutrition position stand: Caffeine and performance. *J Int Soc Sports Nutr* 7: 5, 2011.
19. Graham, TE. Caffeine and exercise: Metabolism, endurance and performance. *Sports Med* 31: 785–807, 2001.
20. Harris, RC, Tallon, MJ, Dunnett, M, Boobis, L, Coakley, J, Kim, HJ, Fallowfield, JL, Hill, CA, Sale, C, and Wise, JA. The absorption of orally supplied beta-alanine and its effect on muscle carnosine synthesis in human vastus lateralis. *Amino Acids* 30: 279–289, 2006.
21. Hill, CA, Harris, RC, Kim, HJ, Harris, BD, Sale, C, Boobis, LH, Kim, CK, and Wise, JA. Influence of beta-alanine supplementation on skeletal muscle carnosine concentrations and high intensity cycling capacity. *Amino Acids* 32: 225–233, 2007.
22. Hoffman, JR, Kang, J, Ratamess, NA, Hoffman, MW, Tranchina, CP, and Faigenbaum, AD. Examination of a pre-exercise, high-energy supplement on exercise performance. *J Int Soc Sports Nutr* 6: 2, 2009.
23. Hoffman, JR, Ratamess, NA, Faigenbaum, AD, Ross, R, Kang, J, Stout, J, and Wise, JA. Short-duration beta-alanine supplementation increases training volume and reduces subjective feelings of fatigue in college football players. *Nutr Res* 28: 31–35, 2008.
24. Hultman, E, Soderlund, K, Timmons, JA, Cederblad, G, and Greenhaff, PL. Muscle creatine loading in men. *J Appl Physiol* 81: 232–237, 1996.
25. Izquierdo, M, Ibanez, J, Gonzalez-Badillo, JJ, and Gorostiaga, EM. Effects of creatine supplementation on muscle power, endurance, and sprint performance. *Med Sci Sports Exerc* 34: 332–343, 2002.
26. Jackman, SR, Witard, OC, Jeukendrup, AE, and Tipton, KD. Branched-chain amino acid ingestion can ameliorate soreness from eccentric exercise. *Med Sci Sports Exerc* 45: 962–970, 2010.
27. Jagim, AR, Jones, MT, Wright, GA, St Antoine, C, Kovacs, A, and Oliver, JM. The acute effects of multi-ingredient pre-workout ingestion on strength performance, lower body power, and anaerobic capacity. *J Int Soc Sports Nutr* 13: 11, 2016.
28. Jongkees, BJ, Hommel, B, Kühn, S, and Colzato, LS. Effect of tyrosine supplementation on clinical and healthy populations under stress or cognitive demands–A Review. *J Psych Res* 70: 50–57, 2015.
29. Joy, JM, Lowery, RP, Falcone, PH, Vogel, RM, Mosman, MM, Tai, C, Carson, LR, Kimber, D, Choate, D, Kim, MP, Wilson, JM, and Moon, JR. A multi-ingredient, pre-workout supplement is apparently safe in healthy males and females. *Food Nutr Res* 59: 27470, 2015.
30. Jung, YP, Earnest, CP, Koozehchian, M, Cho, M, Barringer, N, Walker, D, Rasmussen, C, Greenwood, M, Murano, PS, and Kreider, RB. Effects of ingesting a pre-workout dietary supplement with and without synephrine for 8 weeks on training adaptations in resistance-trained males. *J Int Soc Sport Nutr* 14: 1, 2017.

31. Jung, YP, Earnest, CP, Koozehchian, M, Galvan, E, Dalton, R, Walker, D, Rasmussen, C, Murano, PS, Greenwood, M, and Kreider, RB. Effects of acute ingestion of a pre-workout dietary supplement with and without *p*-synephrine on resting energy expenditure, cognitive function and exercise performance. *J Int Soc Sports Nutr* 14: 3, 2017.
32. Kalmar, JM and Cafarelli, E. Effects of caffeine on neuromuscular function. *J Appl Phsyiol* 87: 801–808, 1999.
33. Kawada, T, Sakabe, S, Watanabe, T, Yamamoto, M, and Iwai, K. Some pungent principles of spices cause the adrenal medulla to secrete catecholamine in anesthetized rats. *Proc Soc Exp Biol Med* 188: 229–233, 1988.
34. Lieberman, HR, Tharion, WJ, Shukitt-Hale, B, Speckman, KL, and Tulley, R. Effects of caffeine, sleep loss, and stress on cognitive performance and mood during U.S. Navy seal training. *Psychopharmacology* 164: 250–261, 2002.
35. Lowery, RP, Joy, JM, Dudeck, JE, Olivera de Souza, E, McCleary, SA, Wells, S, Wildman, R, and Wilson, JM. Effects of 8 weeks of Xpand 2X pre workout supplementation on skeletal muscle hypertrophy, lean body mass, and strength in resistance trained males. *J Int Soc Sports Nutr* 10: 44, 2013.
36. Meyers, BM and Cafarelli, E. Caffeine increases time to fatigue by maintaining force and not by altering firing rates during submaximal isometric contractions. *J Appl Physiol* 99: 1056–1063, 2005.
37. Norton, LE, Wilson, GJ, Layman, DK, Mouton, CJ, and Garlick, PJ. Leucine content of dietary proteins is a determinant of postprandial skeletal muscle protein synthesis in rate. *Nutr Metabol* 9: 57, 2012.
38. Ratamess, NA, Alvar, BA, Evetovich, TK, Housh, TJ, Kibler, B, Kraemer, WJ, and Triplett, NT. Progression models in resistance training for healthy adults. Position Stand. *Med Sci Sports Exerc* 41: 687–708, 2009.
39. Robbins, DW. Relationships between national football league combine performance measures. *J Strength Cond Res* 26: 226–231, 2012.
40. Rekling, JC, Funk, GD, Bayliss, DA, Dong, XW, and Feldman, JL. Synaptic control of motoneuronal excitability. *Physiol Rev* 80: 767–852, 2000.
41. Smith, AE, Moon, JR, Kendall, KL, Graef, JL, Lockwood, CM, Walter, AA, Beck, TW, Cramer, JT, and Stout, JR. The effects of beta-alanine supplementation and high-intensity interval training on neuromuscular fatigue and muscle function. *Eur J Appl Physiol* 105: 357–363, 2009.
42. Snow, RJ, McKenna, MJ, Selig, SE, Kemp, J, Stathis, CG, and Zhao, S. Effect of creatine supplementation on sprint exercise performance and muscle metabolism. *J Appl Physiol* 84: 1667–1673, 1998.
43. Spradley, BD, Crowley, KR, Tai, C, Kendall, KL, Fakuda, DH, Esposito, EN, Moon, SE, and Moon, JR. Ingesting a pre-workout supplement containing caffeine, B-vitamins, amino acids, creatine, and beta-alanine before exercise delays fatigue while improving reaction time and muscular endurance. *Nutr Metab* 9: 28, 2012.
44. Sureda, A, Crdova, A, Ferrer, MD, Pérez, G, Tur, JA, and Pons, A. L-Citrulline-malate influence over branched chain amino acid utilization during exercise. *Eur J Appl Physiol* 110: 341–351, 2010.
45. Sureda, A, Cordova, A, Ferrer, MD, Tauler, P, Pérez, G, Tur, JA, and Pons, A. Effects of L-citrulline oral supplementation on polymorphonuclear neutrophils oxidative burst and nitric oxide production after exercise. *Free Radic Res* 43: 828–835, 2009.
46. Timmins, TD and Saunders, D. Effect of caffeine ingestion on maximal voluntary contraction strength in upper- and lower-body muscle groups. *J Strength Cond Res* 28: 3239–3244, 2014.
47. Trexler, ET, Smith-Ryan, AE, Stout, JR, Hoffman, JR, Wilborn, CD, Sale, C, Kreider, RB, Jager, R, Earnest, CP, Bannock, L, Campbell, B, Kalman, D, Ziegenfuss, TN, and Antonio, J. International society of sports nutrition position stand: Beta-Alanine. *J Int Soc Sports Nutr* 12: 30, 2015.
48. Walker, TB, Smith, J, Herrera, M, Lebegue, B, Pinchak, A, and Fisher, J. The influence of 8 weeks of whey-protein and leucine supplementation on physical and cognitive performance. *Int J Sport Nutr Exerc Metab* 20: 409–417, 2010.
49. Wallace, BJ, Kernozek, TW, Mikat, RP, Wright, GA, Simons, SZ, and Wallace, KL. A comparison between back squat exercise and vertical jump kinematics: Implications for determining anterior cruciate ligament injury risk. *J Strength Cond Res* 22: 1249–1258, 2008.
50. Wax, B, Kavazis, AN, Weldon, K, and Sperlak, J. Effects of supplemental citrulline malate ingestion during repeated bouts of lower-body exercise in advanced weightlifters. *J Strength Cond Res* 29: 786–792, 2015.
51. Zangara, A. The psychopharmacology of huperzine a: An alkaloid with cognitive enhancing and neuroprotective properties of interest in the treatment of Alzheimer's disease. *Pharmacol Biochem Behav* 75: 675–686, 2003.