

The Effect of Caffeine Alone or as Part of a Multi-ingredient Pre-workout Supplement on Muscular Endurance in Recreationally Active College Males

Original Research

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Abstract

Introduction: The purpose of this investigation was to examine the independent and combined effects of caffeine (CAF) alone or as a part of a multi-ingredient pre-workout supplement (PWS) on resistance exercise performance in recreationally active males.

Methods: In a single-blind, randomized, placebo (PLA) controlled, crossover design; 10 recreationally active males (20.5 ± 0.9 ; 178.9 ± 7.7 cm; 81.8 ± 11.5 kg) completed three laboratory visits, after determination of one repetition-maximum (1-RM) on the bench press and leg press, where they performed bench press and leg press to failure at a load of 70% 1-RM. Subjects were randomly assigned to ingest either one serving of a commercially available PWS (C4 Original, Cellucor, Bryan, TX, United States), a dosage-matched anhydrous CAF beverage (150 mg), or a taste-matched PLA beverage. Heart rate (HR), affect, rating of perceived exertion (RPE), and mood state was assessed 20 minutes pre and post-substance ingestion, and immediately after exercise.

Results: Participants completed significantly more repetitions to failure ($p = 0.006$) and lifted significantly greater weight ($p = 0.009$) during Leg Press in the PWS and CAF conditions compared to the PLA condition. There was not a significant difference found between CAF and PWS trials ($p > 0.05$).

Conclusions: This data suggests that both CAF and PWS may have a positive effect on exercise performance in leg press but was not effective in increasing muscular endurance in bench press. The commercially available PWS offered no additional ergogenic effects when compared to the CAF.

Key Words: Resistance exercise, repetitions to failure, ergogenic aid

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Introduction

It has been well documented that the ingestion of moderate doses ($3\text{-}6 \text{ mg}\cdot\text{kg}^{-1}$) of caffeine (CAF) may provide an ergogenic benefit during aerobic endurance exercise.¹⁻

³ Further, some investigators have reported that lower doses ($< 3 \text{ mg}\cdot\text{kg}^{-1}$) of CAF

may improve endurance performance.^{4,6} The impact that CAF has on higher intensity, intermittent exercise performance (i.e. muscular power, strength, and endurance) is less clear.^{1,7}

The use of dietary supplements, including CAF-containing sports supplements, has continued to gain popularity in recent years.⁸ One of the most common categories of sports supplements are pre-workout supplements (PWS). These supplements are attractive to athletes and recreational exercisers alike because they are marketed with the claim that they enhance training response and improve exercise performance. Most PWS contain an alleged ergogenic proprietary blend of ingredients (CAF, creatine, glucose, vitamins, amino acids, etc...) developed by the manufacturer. Nonetheless, the claims for the ergogenic effects of the functional ingredients of PWS by manufacturers are ambiguous.

Relatively few studies have examined the effect of PWS on muscular strength and endurance performance. Spradley et al.⁹ reported that ingesting the PWS Assault™ significantly improved lower body endurance and reduced subjective fatigue in 15 recreationally trained males. Similarly, Gonzalez et al.¹⁰ found that taking the PWS Amino Impact™ 10 minutes prior to exercise significantly enhanced peak and mean power performance and increased repetitions to failure during bench press and barbell squat in resistance trained males. Equivocally, Martinez et al.¹¹ demonstrated that PWS consumption did not result in improved upper and lower body power or upper body strength. Lastly, Campbell et al.¹² reported that anaerobic power and muscular endurance were not enhanced with PWS relative to placebo.

Based on the limited and equivocal evidence, the impact of CAF-containing PWS on muscular endurance performance as assessed via repetitions to failure warrants further investigation. Further, the relative portion of PWS potential ergogenic effect that can be attributed to CAF remains unclear. Thus, the purpose of this investigation was to evaluate the independent and combined effects of CAF alone or as a part of a multi-ingredient commercially available PWS (C4 Original, Cellucor, Bryan, TX) on repetitions to failure during leg press and bench press in recreationally active collegiate males. Further, we aimed to assess the impact of CAF and PWS on physiological and perceptual responses to resistance exercise.

Methods

Participants

Ten recreationally active males were recruited to participate in this study. Included were men who (a) participated in resistance training at least three times a week for the past six months, and (b) between the ages of 18 and 25 years. Subjects were prohibited from using any ergogenic aids for one month preceding the study and were asked to refrain from taking any performance enhancing supplement(s) other than the experimental beverage during the course of the study. Subjects were instructed not to change their regular exercise training and dietary habits for the duration of the study and were told not to exercise prior to testing. Subjects were instructed to refrain from CAF and alcohol consumption for 48 hours, physical activity for 24 hours, and food and drink for three hours before each exercise test.^{9,13} The participants were instructed to maintain a training and dietary log for two days before the first experimental trial. They were provided with a copy of their pre-trial log and instructed to have the same dietary intake and physical activity participation during the 48 hours before the other trials. In addition, participants were instructed to keep their CAF consumption stable throughout the period of study participation¹⁴ Subjects were also provided with a habitual caffeine consumption questionnaire before the experimental testing began to assess each subject's daily average caffeine intake. Before enrolling in the investigation, participants were fully informed of any risks and discomforts associated with the experiments prior to giving their written

informed consent to participate. The experimental protocol was approved by the Institutional Review Board of Grove City College. The study conforms to the Code of Ethics of the World Medical Association (approved by the ethics advisory board of Swansea University) and required subjects to provide informed consent before participation.

Table 1. Physical characteristics (mean \pm SD) of subjects ($n = 10$)

Variable	Value
Age, years	20.5 \pm 0.9
Height (cm)	178.9 \pm 6.7
Weight (kg)	81.8 \pm 11.5
Body Fat (%)	17.7 \pm 4.6
Fat-Free Mass (kg)	66.9 \pm 7.1
SBP (mmHg)	119.1 \pm 4.3
DBP (mmHg)	70.1 \pm 7.6
RHR (beats·min ⁻¹)	73.2 \pm 8.2
Bench Press 1-RM (kg)	92.5 \pm 25.7
Leg Press 1-RM (kg)	276.3 \pm 59.4
Caffeine Intake (mg)	245.5 \pm 199.1

Data are Mean \pm SD. *Note.* SBP = resting systolic blood pressure; DPB = resting diastolic blood pressure; RHR = resting heart rate

Protocol

Study Design. This study used a single-blind, cross-over design where subjects were randomized to supplement with a pre-workout supplement (PWS), caffeine (CAF), or a placebo (PLA) 20 minutes before exercise. The three experimental trials were separated by a 7-day washout period. Each subject underwent four days of testing: (a) orientation session and 1-RM test, (b) Experimental Trial I, (c) Experimental Trial II, and (d) Experimental Trial III. Exercise testing occurred at the same time each day. During the first visit to the laboratory, subjects performed a one-rep maximum (1-RM) test on the bench press and leg press. Two to three days after the 1-RM test, subjects were randomly assigned to consume either the PWS, CAF, or PLA beverage 20 minutes before completing bench press and leg press to failure at 70% of their 1-RM. Variables measured were (a) bench press and leg press repetitions to failure, total weight lifted (TWL), heart rate (HR), affect, rating of perceive exertion for overall body (RPE), and mood state (BRUMS). All testing took place within the Exercise Science Laboratory of Grove City College.

Orientation Session and Maximal Strength Test (1-RM). At the first laboratory visit, all the experimental procedures were explained to the subjects. The subjects underwent an orientation involving practice of the lifting procedures and familiarization of the various measurement instruments, equipment, affect measures, perceived exertion, and the mood state questionnaire. Subjects first completed the PAR-Q and the Health History Questionnaire to ensure eligibility. Affect was measured using a validated 11-point Feeling Scale¹⁵, with participants informed that their responses should reflect the affective or emotional components of the exercise and not the physical sensation of effort or strain. The OMNI Resistance Exercise Scale¹⁶ was used to measure RPE. In addition, the Brunel Mood Scale Inventory was used to measure mood state. This measure of mood is a well-established, reliable and valid measure of mood state.^{17,18} Following the orientation session, anthropometric measures were obtained including height (cm), weight (kg), fat free mass (kg) and fat mass (% and kg). Height (cm) was measured using a physician's scale (Detecto, Webb City, MO). Weight (kg) and body composition (fat and lean mass) were measured using a Tanita bioelectrical impedance analyzer (BIA) (TBF-310GS Tanita Corporation of America, Arlington Heights, Illinois).

The first visit to the laboratory involved a briefing session and determination of each participant's 1-RM on the bench press and leg press. All participants had experience performing resistance exercises in general and bench press and leg press exercises in particular. However, before commencing the 1-RM, the bench press and leg press were demonstrated to each participant. Each participant also performed 8–10 unweighted repetitions to minimize any learning effects that could occur in the experimental protocol. The 1-RM was determined according to methods advocated by Kraemer and colleagues.¹⁹ Proper lifting technique was demonstrated for the participants before the 1-RM assessment. The 1-RM value was used to set the 70% 1RM intensity undertaken during the preceding experimental trials.

Experimental Trial I, II, and III. Two to three days after the 1-RM test, subjects underwent the first experimental trial (PWS, CAF, or PLA). Upon arrival to the lab, subjects were fitted with a heart rate (HR) monitor (Polar Electro, Kempele, Finland). Before the drink was administered, HR, affect, mood state, and RPE were measured. The beverages were served cold (~6 °C) and were administered to the subjects 20 minutes before the exercise test began. Each treatment was presented to participants in an opaque sports bottle to prevent the participants from seeing the treatments themselves. The subjects were instructed to drink the beverage within two minutes of receiving it then sit quietly for 20 minutes. Resting HR, affect, mood state, and RPE were remeasured 20 minutes after ingestion.

The subjects then began a five-minute submaximal warm-up on a treadmill ergometer before completing 1 set of bench press and leg press exercise to failure at 70% 1-RM. Subjects rested five minutes between attempts. Lifting procedures was performed using a plate-loaded iso-lateral bench and leg press (Hammer Strength, Cincinnati, OH, USA) and in accordance with protocols previously described for the bench and leg press by Earle and Baechle.²⁰ Before the start of each test, subjects completed one warm up set that consisted of five reps at 50% 1-RM⁹. Subjects then lifted 70% of their 1-RM until failure. A trained spotter was present for all the testing sessions to make sure proper technique was kept. Any lift that did not meet the criteria was not counted. During all conditions, repetitions frequency was paced by a metronome set at 60 b·min⁻¹. This cadence resulted in one complete repetition every second with concentric and eccentric phases comprising two seconds each. Subjects were given verbal encouragement throughout the sessions. Repetitions to fatigue were assessed and recorded at respective weight resistance on subsequent visits. Total weight lifted (kg) for bench press and leg press was calculated by multiplying number of repetitions completed by the mass lifted. Immediately upon cessation of exercise, subjects estimated their RPE and affect, and a final HR measurement was taken. In addition, a final mood state measure was also taken.

Supplementation. Subjects were randomly assigned to consume one serving (6g) of a commercially available PWS C4 Original (Cellucor; Bryan, TX), an equivalent dose of anhydrous CAF (150 mg), and a taste-matched PLA condition. The concentration of ingredients in one serving of PWS consisted of 1.6g of beta-alanine, 1g of creatine nitrate, 1g of arginine alpha ketoglutarate, 250mg of Vitamin C, 30mg of Niacin, 500mcg of Vitamin B6, 250mcg of Folic Acid, 35mcg of Vitamin B12, and 425mg of an energy blend which consisted of N-acetyl-L-tyrosine, 150 mg of caffeine anhydrous, velvet bean seed extract, and theacrine (Figure 1). The PWS, CAF and the PLA drink were similar in volume, texture, and appearance. All conditions consisted of 250 ml of an artificially colored, flavored (Kraft Foods; MiO, Northfield, IL), water beverage (0 mg caffeine, 0 kcal). The taste of the drinks was slightly different, and there remains the possibility that the participants were able to identify the drinks. To avoid the placebo effect in the experimental trials, we did not inform the subjects about the names of the drinks, and we presented all three drinks as having similar ergogenic properties. Volume for the drinks was measured with a graduated cylinder, and the dry ingredients were measured to the nearest 0.001 g on

a calibrated balance scale (Denver Instrument, Bohemia, NY). We conducted taste testing to assess the taste profile of the caffeine and placebo conditions to ensure that it tasted similar to the pre-workout supplement.

SUPPLEMENT FACTS		
Serving Size: 1 scoop (6g)		
Servings Per Container: 60		
	Amount Per Serving	% DV
Vitamin C (as Ascorbic Acid)	250mg	417%
Niacin (as Niacinamide)	30mg	150%
Vitamin B6 (as Pyridoxal-5-Phosphate)	500mcg	25%
Folic Acid	250mcg	62%
Vitamin B12 (as Methylcobalamin)	35mcg	583%
CarnoSyn® Beta-Alanine	1.6g	†
Creatine Nitrate (NO3-T®)	1g	†
Arginine Alpha Ketoglutarate	1g	†
Explosive Energy Blend	425mg	†
N-Acetyl-L-Tyrosine, Caffeine Anhydrous (150mg), Velvet Bean (<i>Mucuna pruriens</i>) seed extract (standardized for L-Dopa), Theacrine (as TeaCrine®)		
†Daily Value not established.		
Other Ingredients: Malic Acid, Natural Flavors, Citric Acid, Silicon Dioxide, Sucralose, Calcium Silicate, Acesulfame Potassium, FD&C Red #40.		

Figure 1. Pre-workout Supplement (PWS) facts panel.

Statistical Analysis

Statistical analyses were performed using SPSS version 23.0 (SPSS Inc., Chicago, IL). Statistical significance was set *a priori* at $p \leq 0.05$. Descriptive statistics were calculated for all variables. Data was tested for normality using the Shapiro-Wilk test. Total repetitions completed, and total weight lifted was analyzed using a one-way repeated measures analysis of variance. A three (condition; CAF vs PWS vs PLA) by three (rest, 20 mins post ingestion, and at end of exercise) repeated measures analysis of variance was conducted to assess the effect of time, treatment, and interaction between time and treatment, on HR, RPE and mood state. Post hoc analyses of significant main and interaction effects were conducted where appropriate using the Bonferonni adjustment to determine which conditions were significantly different. The assumption of sphericity was confirmed using Mauchly's test. Greenhouse-Geisser epsilon corrections were used when the sphericity assumption was violated.

Results

Bench Press

The total number of repetitions to failure and total weight lifted did not differ significantly across conditions ($p = 0.566$ and 0.575 , respectively) (Table 2; Figure 2 A and B)

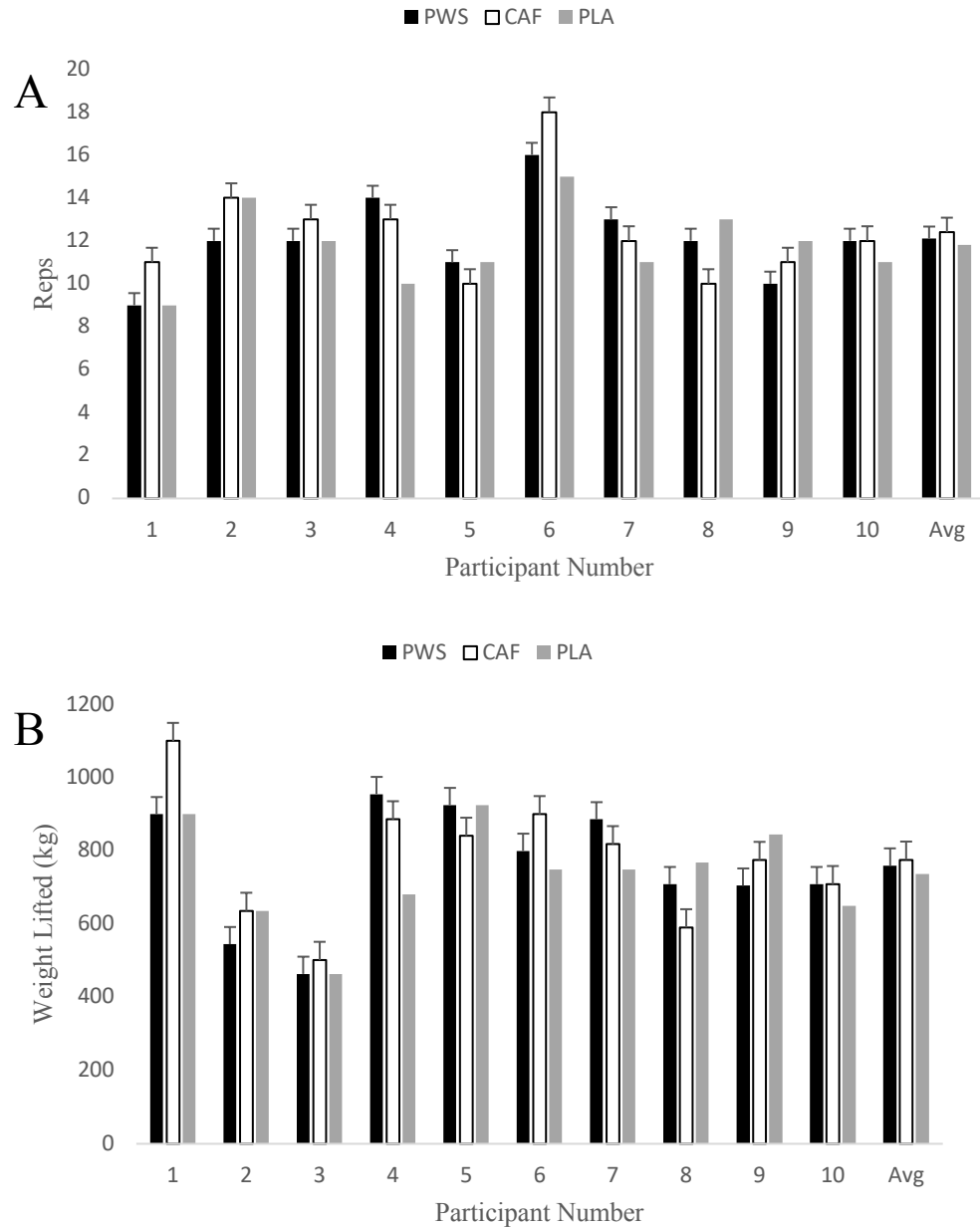


Figure 2. Individual subject response for repetitions to failure (A) and total weight lifted (kg) (B) for bench press at 70% 1-RM in PWS, CAF, and PLA conditions. PWS = Pre-workout supplement; CAF = Caffeine; PLA = Placebo.

Leg Press

Total number of repetitions performed was significantly different across conditions ($p = 0.006$). Results indicated that participants completed significantly more repetitions to failure in the PWS (15.6%) and CAF (8.8%) conditions compared to the placebo condition ($p = 0.008$ and 0.050 , respectively). There was not a significant difference between the PWS and CAF condition ($p = 0.577$) (Table 2; Figure 3A). Total weight lifted was significantly different across conditions ($p = 0.009$). Participants lifted significantly greater weight in the PWS (16.2%) condition

compared to the PLA condition ($p = 0.013$). However, there was no significant difference between PWS and CAF condition ($p = 0.103$) (Table 2; Figure 3B)

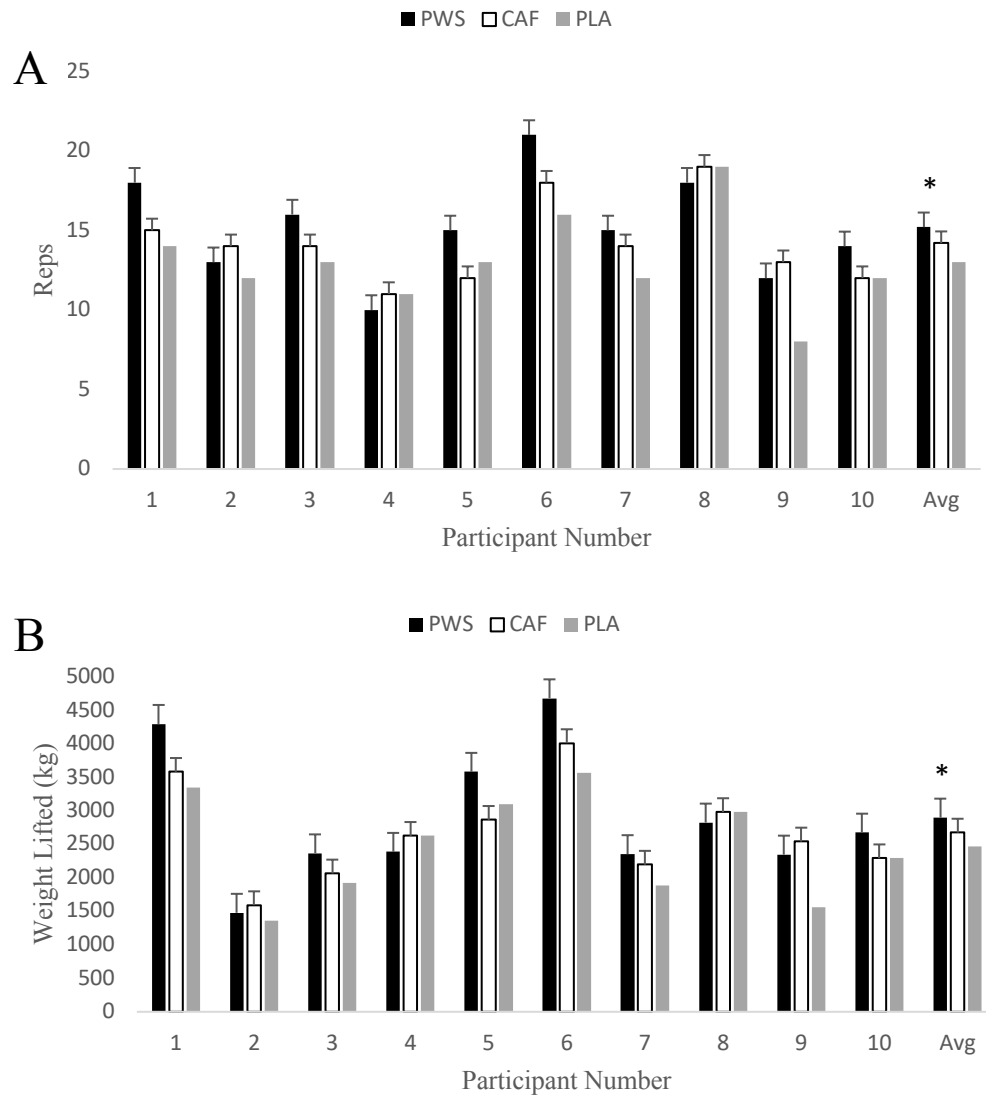


Figure 3. Individual subject response for repetitions to failure (A) and total weight lifted (kg) (B) for leg press at 70% 1-RM in PWS, CAF, and PLA conditions. PWS = Pre-workout supplement; CAF = Caffeine; PLA = Placebo, * $p \leq 0.05$.

Table 2. Reps, Weight lifted, IPE HR, IPE RPE and IPE Affect after bench press and leg press repetitions to failure at 70% 1-RM in PWS, CAF and PLA conditions. * (N=10)

Variable	PWS	CAF	PLA	<i>p</i>
Bench Press				
Reps	12.1 ± 1.9	12.4 ± 2.4	11.8 ± 1.8	0.566
Weight Lifted (kg)	759.8 ± 164.8	775.8 ± 173.8	737.0 ± 137.5	0.575
Leg Press				
Reps	15.2 ± 3.2‡	14.2 ± 2.6**	13.0 ± 2.9	0.006
Weight Lifted (kg)	2897.2 ± 989.3#	2674.0 ± 720.6	2463.3 ± 771.9	0.009

*Data are Mean ± SD. Note. PWS = pre-workout supplement; CAF = caffeine; PLA = placebo

‡Significantly different than placebo, but not caffeine

**Significantly different than placebo, but not the pre-workout supplement

#Significantly different than placebo, but not caffeine

Heart Rate, RPE, Affect and Mood State

Heart rate, and RPE increased significantly over time ($p < 0.001$), however there was not a significant effect for treatment ($p > 0.05$) (Table 3). No significant differences for affect and mood state were observed ($p > 0.05$).

Table 3. Heart Rate, Affect and RPE in PWS, CAF and PLA conditions. * (N=10)

Variable	Heart Rate (b·min ⁻¹)	Affect	RPE
PWS Pre	74.9 ± 12.6	2.7 ± 0.9	0.2 ± 0.4
PWS Post	70.3 ± 16.7	3.1 ± 0.7	0.4 ± 0.5
PWS IPE	128.4 ± 19.5	2.5 ± 1.3	7.0 ± 1.5
CAF Pre	66.8 ± 10.5	2.9 ± 1.4	0.5 ± 0.5
CAF Post	68.8 ± 11.4	2.9 ± 1.4	0.5 ± 0.5
CAF IPE	118.6 ± 18.9	2.4 ± 1.8	6.4 ± 1.4
PLA Pre	66.6 ± 6.5	2.7 ± 1.2	0.5 ± 0.7
PLA Post	66.6 ± 14.2	2.7 ± 0.9	0.5 ± 0.7
PLA IPE	127.1 ± 15.8	2.4 ± 1.8	5.6 ± 2.2
p	0.511	0.924	0.057

*Data are Mean ± SD. Note. Pre = before drink; Post = after drink; IPE = immediately after exercise; HR = heart rate; RPE = rating of perceived exertion (OMNI rating of exertion); PWS = pre-workout supplement; CAF = caffeine; PLA = placebo.

Discussion

The purpose of this investigation was to examine the independent and combined effects of CAF alone or as a part of a multi-ingredient, CAF-containing PWS on muscular endurance exercise performance as well as related physiological and perceptual responses in recreationally active collegiate males. To our knowledge, this is the first study to investigate the isolated effects of one of the main functional ingredients found in the PWS Cellucor C4 Original. The current findings indicated that an 8.8% and 15.6% increase in leg press repetitions to failure for the CAF and PWS respectively, compared with the PLA., with no effect on repetitions to failure for bench press exercise. In addition, an 8.2% and 16.2% increase were observed in total weight lifted for leg press for the CAF and PWS respectively, compared to the PLA, with no effect of total weight lifted for bench press exercise.

The results of the present study are in agreement with Spradley et al.⁹ who demonstrated that lower body, but not upper body muscular endurance was enhanced with a CAF-containing PWS. These findings suggest that CAF-containing PWS may be more beneficial for high intensity activities that utilize a large amount of muscle mass. Further, it is possible that the CAF alone or in the PWS increased subjects' motivation/willingness to work hard. CAF acts as an adenosine antagonist via competitive inhibition.^{21,22} Antagonism of adenosine 2a receptors may potentiate dopaminergic neurotransmission in brain regions that are involved in movement, reward, and motivation.^{23,24}

Duncan and Oxford¹³ reported that upper body muscular endurance was enhanced following CAF ingestion. In the present study we found that neither CAF or PWS treatment improved upper body muscular endurance. One potential explanation for the disparate findings is that Duncan and Oxford¹³ utilized a much larger dose of CAF (5 mg·kg⁻¹) relative to that used here (mean relative dose of 1.9. mg·kg⁻¹). Further, these findings demonstrate that moderate to large doses of CAF may be necessary to derive an ergogenic benefit for upper body muscular endurance.

We acknowledge this study had some limitations. First, we utilized recreationally active subjects; highly trained individuals may have been more appropriate as they demonstrate less day to day variation in outcome measures. Second, the washout period was not always consistent due to scheduling constraints. Lastly, our sample size was small which increased the possibility of a type 2 error.

Our data demonstrated that both a commercially available CAF-containing PWS and CAF alone (dosage matched) improved lower body muscular endurance relative to placebo. Further, HR, RPE, affect, and mood state was unchanged across experimental treatments. We conclude that CAF-containing PWS and CAF alone produce a similar ergogenic benefit for lower body muscular endurance in recreationally active college-aged males.

Media-Friendly Summary

Pre-workout supplements (PWS) are typically consumed by athletes and recreational exercisers prior to training with expectations of improved performance. Common ingredients in PWS include caffeine (CAF), branch chain amino acids (BCAA's), creatine, and beta-alanine. Previous research has shown that a number of the individual ingredients contained in PWS may improve performance as each ingredient is associated with a different physiological mechanism. Acute CAF ingestion has been reported to increase muscular strength, power and endurance during high intensity exercise. It is unclear whether the performance enhancing properties of PWS are the result of synergy between ingredients or isolated effects of one of the main functional ingredients found in the PWS (for example CAF). According to the present study, both a multi-ingredient PWS and CAF alone were equally effective at increasing the number of repetitions to failure and total weight lifted, primarily for lower body resistance exercise. It is possible that these acute increases in muscular endurance performance for the PWS and CAF 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).

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Author Disclosure Statement

Submission of this article involves no financial or other relationship that may be perceived as leading to a conflict of interest.

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