

Research article

Acute effects of a thermogenic nutritional supplement on cycling time to exhaustion and muscular strength in college-aged men

Ashley A Walter[†], Trent J Herda[†], Eric D Ryan[†], Pablo B Costa[†],
Katherine M Hoge[†], Travis W Beck[†], Jeffery R Stout[†] and Joel T Cramer^{*}

Address: Biophysics Laboratory, Department of Health and Exercise Science, University of Oklahoma, Norman, Oklahoma, USA

Email: Ashley A Walter - ashannwalter@ou.edu; Trent J Herda - tjh@ou.edu; Eric D Ryan - eryan@ou.edu; Pablo B Costa - pcosta@ou.edu;
Katherine M Hoge - katiehoge@ou.edu; Travis W Beck - tbeck@ou.edu; Jeffery R Stout - jrstout@ou.edu; Joel T Cramer* - jcramer@ou.edu

* Corresponding author †Equal contributors

Published: 13 July 2009

Received: 23 March 2009

Accepted: 13 July 2009

Journal of the International Society of Sports Nutrition 2009, **6**:15 doi:10.1186/1550-2783-6-15This article is available from: <http://www.jissn.com/content/6/1/15>

© 2009 Walter et al; licensee BioMed Central Ltd.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/2.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract

Background: The purpose of the present study was to examine the acute effects of a thermogenic nutritional supplement containing caffeine, capsaicin, bioperine, and niacin on muscular strength and endurance performance.

Methods: Twenty recreationally-active men (mean \pm SD age = 21.5 \pm 1.4 years; stature = 178.2 \pm 6.3 cm; mass = 76.5 \pm 9.9 kg; $\text{VO}_{2\text{ PEAK}} = 3.05 \pm 0.59$ L/min⁻¹) volunteered to participate in this randomized, double-blinded, placebo-controlled, cross-over study. All testing took place over a three-week period, with each of the 3 laboratory visits separated by 7 days (\pm 2 hours). During the initial visit, a graded exercise test was performed on a Lode Corival cycle ergometer (Lode, Groningen, Netherlands) until exhaustion (increase of 25 W every 2 min) to determine the maximum power output (W) at the $\text{VO}_{2\text{ PEAK}}$ (Parvo Medics TrueOne[®] 2400 Metabolic Measurement System, Sandy, Utah). In addition, one-repetition maximum (1-RM) strength was assessed using the bench press (BP) and leg press (LP) exercises. During visits 2 and 3, the subjects were asked to consume a capsule containing either the active supplement (200 mg caffeine, 33.34 mg capsaicin, 5 mg bioperine, and 20 mg niacin) or the placebo (175 mg of calcium carbonate, 160 mg of microcrystalline cellulose, 5 mg of stearic acid, and 5 mg of magnesium stearate in an identical capsule) 30 min prior to the testing. Testing included a time-to-exhaustion (TTE) ride on a cycle ergometer at 80% of the previously-determined power output at $\text{VO}_{2\text{ PEAK}}$ followed by 1-RM LP and BP tests.

Results: There were no differences ($p > 0.05$) between the active and placebo trials for BP, LP, or TTE. However, for the BP and LP scores, the baseline values (visit 1) were less than the values recorded during visits 2 and 3 ($p \leq 0.05$).

Conclusion: Our findings indicated that the active supplement containing caffeine, capsaicin, bioperine, and niacin did not alter muscular strength or cycling endurance when compared to a placebo trial. The lack of increases in BP and LP strength and cycle ergometry endurance elicited by this supplement may have been related to the relatively small dose of caffeine, the high intensity of exercise, the untrained status of the participants, and/or the potential for caffeine and capsaicin to increase carbohydrate oxidation.

Introduction

The combination of nutritional supplements, such as caffeine and capsaicin, are commonly used as thermogenic aids to improve metabolism and performance [1-6]. Caffeine is sometimes consumed to enhance performance, whether that is athletic [1-5], cognitive [7,8], or immunological [9]. Extensive research has reported caffeine as a metabolic stimulant [6]. Capsaicin, the pungent component of hot red peppers, has been reported to evoke similar effects as caffeine [10-12]. In fact, the combination of caffeine, capsaicin, niacin, and bioperine has been reported to stimulate thermogenesis (i.e., burn more calories) when compared to a placebo [13]. Ryan et al. [13] reported that this particular combination of ingredients may be useful in maintaining a negative energy balance by increasing resting and low intensity energy expenditure. Therefore, there are limited data suggesting that the combination of caffeine, capsaicin, niacin, and bioperine may elicit metabolic adaptations to enhance exercise performance as well as resting energy expenditure.

Background

Caffeine is among the most widely used drugs in the world and can be found in many foods including soft drinks, coffee, tea, and chocolate [14-17]. Caffeine has been shown to enhance exercise performance [18,19]. However, most previous studies have examined the effects of caffeine or caffeine-containing supplements on energy expenditure [13,20-22] or endurance performance [2,4,5,8,14,17,23-29]. It has been suggested that caffeine may augment catecholamine concentrations [30-32], potentiate calcium release from the sarcoplasmic reticulum in rodents and amphibians [33-37], and increase levels of muscle activation [15,38]. Therefore, potential mechanisms exist for caffeine to affect strength as well as endurance exercise performance. Indeed, several studies have reported improvements in aerobic running [23,24,27], cycling [4,5,8,26,29], and swimming [25] performance after caffeine supplementation. However, conflicting evidence exists regarding the effects of caffeine on anaerobic performance [7,39-42]. Beck et al. [39] administered a caffeine-containing supplement and demonstrated increases in bench press strength, but no changes in bench press endurance, leg extension strength or endurance, or power output during the Wingate test. Kalmar and Cafarelli [15] reported caffeine-induced increases in isometric leg extensor strength and endurance [15], whereas Astornio et al. [43] did not find improvements in leg press strength after caffeine supplementation. Make note, however, that the ergogenic potential of caffeine may be related to the training status of individuals [8,14,24,25,29,30,44], the amount of caffeine consumed [5,8,45,46], and the intensity and duration of exercise [4,5,7,19,47,48].

Capsaicin, the pungent component of hot red peppers, has been reported to evoke similar effects as caffeine. Watanabe et al. [10] suggested that the primary mechanism of capsaicin is the β -adrenergic stimulation that induces catecholamine release. Kawada et al. [49] reported an increase and then decrease in the respiratory quotient (RQ) after capsaicin ingestion, suggesting an increase in carbohydrate and then fat mobilization. Kim et al. [50] and Ohnuki et al. [51] reported increases in lipolysis after ingesting $10 \text{ mg} \cdot \text{kg}^{-1}$ body weight of capsaicin in mice. The authors suggested that the increases were due to the glycogen sparing effect of capsaicin during exercise, while fatty acids were used as fuel. Additionally, Yoshioka et al. [11,12] suggested that the capsaicin-induced increases in energy expenditure were due to sympathetic nervous system activation, which can influence fat oxidation and catecholamine release. This hypothesis has been supported by Kim et al. [50] and Oh et al. [52,53]. In contrast, Lim et al. [54] reported the opposite effect (i.e. carbohydrate oxidation), such that the RQ was higher after ingesting capsaicin when compared to a control. The authors [54] suggested that endurance performance may have been limited by exhausting the glycogen stores, rather than utilizing fat as fuel.

In addition to caffeine and capsaicin, bioperine (black pepper extract) and niacin (vitamin B₃) may also enhance thermogenesis when taken as a nutritional supplement. Bioperine, the thermogenic ingredient in black pepper, has been reported to increase the metabolism in rats [55,56]. Furthermore, niacin has been used in medications to help lower cholesterol by increasing fatty acid mobilization and may act as a peripheral vasodilator [57]. Thus, the combination of various nutritional supplements that may enhance the metabolic rate, such as caffeine, capsaicin, bioperine, and niacin, may also result in acute improvements in performance. Additionally, the combination of ingredients in this nutritional supplement may have a synergistic effect because the caffeine and capsaicin have similar properties, in addition to the niacin which would increase blood flow and fatty acid mobilization. Therefore, the purpose of the present study was to examine the acute effects of a thermogenic nutritional supplement containing caffeine, capsaicin, bioperine, and niacin on muscular strength and endurance performance.

Methods

Subjects

Twenty healthy men (mean age \pm SD; 21.5 ± 1.4 years; height: 178.2 ± 6.3 cm; weight: 76.5 ± 9.9 kg; $\text{VO}_2 \text{ PEAK}$: 3.05 ± 0.59 L/min⁻¹) volunteered for this investigation. Each subject completed a pre-exercise health status questionnaire and signed a written informed consent document. This study was approved by the University of Oklahoma Institutional Review Board for human subjects

research. All of the subjects reported being recreationally active (5.4 ± 3.02 hours of exercise per week), however, none of the subjects were competitive athletes. In addition, none of the subjects reported or exhibited any of the following: (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 medications that might have significantly affected the study outcome; (c) use of nutritional supplements (e.g., creatine, protein drinks, amino acids, or vitamins) in the 9 weeks prior to this study; or (d) participation in another clinical trial or ingestion of another investigational product within 30 days prior to this study.

Study Design

This study used a randomized, double-blind, placebo-controlled, cross-over design. All testing took place over a three-week period, with each laboratory visit separated by 7 days (± 2 hours). During the first week, participants completed the baseline testing, which included a graded exercise test (GXT) on a cycle ergometer to determine maximal oxygen consumption rate ($VO_{2\text{ PEAK}}$) and one-repetition maximums (1-RM) for the leg press (LP) and bench press (BP) to assess muscle strength. During weeks 2 and 3, the subjects were asked to consume a capsule containing either the active supplement or the placebo (in random order) 30 min prior to the testing, which included a time-to-exhaustion (TTE) ride on a cycle ergometer at 80% of the previously-determined $VO_{2\text{ PEAK}}$ followed by 1-RM LP and BP tests.

Supplementation Protocol

For the final two laboratory visits (weeks 2 and 3), subjects received either the supplement or the placebo in random order. The thermogenic pepper blend (TPB) supplement contained 200 mg of caffeine, 33.34 mg of capsicum extract (0.67 mg of capsaicin at 100,000 scoville heat units), 20 mg of niacin, and 5 mg of bioperine (black pepper extract). The placebo (PL) contained 175 mg of calcium carbonate, 160 mg of microcrystalline cellulose, 5 mg of stearic acid, and 5 mg of magnesium stearate. Both the TPB and PL capsules were dark, opaque, and similar in appearance to maintain the double blind nature of the experiment. In addition, 3rd party random laboratory testing (Nutra Manufacturing Inc., Greenville, SC) was performed to confirm that the ingredients in the TPB and PL capsules were within $\pm 5\%$ of the ingredients claimed above.

Graded Exercise Test Protocol

The GXT was completed on an electronically-braked cycle ergometer (Lode, Groningen, Netherlands). Prior to any bike tests, participants' seat height was measured and recorded for consistency between trials. Participants stood

next to the bike to estimate proper seat height (greater trochanter), then mounted to ensure there was a slight bend at the knee at the bottom of the pedal stroke, not full or hyperextension. Once the seat height was set and comfortable, the foot straps were secured and were used to prevent the participant's feet from slipping off the pedals during the test. After a five minute warm-up at 50 W, the workload increased an additional 25 W every two minutes. Participants were encouraged to maintain 70 rpm, but the test was terminated when the participant could no longer maintain 60 rpm (volitional exhaustion). Each participant's rating of perceived exertion (RPE) was also recorded during every stage using a standard Borg scale [58]. A true $VO_{2\text{ PEAK}}$ was determined if three of the five indicators were met during the test according to the American College of Sports Medicine Guidelines [59].

Determination of Maximal Oxygen Consumption Rate

Respiratory gases were collected and monitored using a metabolic cart (Parvo Medics TrueOne[®] 2400 Metabolic Measurement System, Sandy, Utah). The metabolic cart was calibrated prior to each test with room air and standard gases of known volume and concentration for the O_2 and CO_2 analyzers. Flowmeter calibration was also performed prior to each GXT. Respiratory gases were collected by use of a two-way rebreathing valve (Hans-Rudolph Inc., Shawnee, Kansas) and mouthpiece attached to headgear, which held them in place. Participants wore a nose clip to ensure that breathing occurred entirely through the mouth. O_2 and CO_2 were analyzed through a sampling line after the gasses passed through a heated pneumotach and mixing chamber. The metabolic cart software reported the values as ventilated oxygen and carbon dioxide (VO_2 and VCO_2 , respectively) and calculated $VO_{2\text{ PEAK}}$ automatically.

Muscular Strength Assessment

Subjects performed tests to determine 1-RM for the incline leg press (LP) and bench press (BP) exercises. The LP exercise was performed using a plate-loaded hip sled with a 45° incline (Paramount Fitness Corp., Los Angeles, California). Subjects sat in the seat with their back flat against the backrest and were instructed to grasp the handles of the device tightly to avoid the buttocks losing contact with the seat during the exercise. Subjects placed their feet in the middle of the platform at shoulder's width apart, and this foot position remained constant for all the subsequent leg press tests. Subjects were instructed to lower the platform until the legs reached 90° of flexion at which point they were instructed to fully extend the legs (i.e., 0° of leg flexion). The BP exercise was performed on a standard free-weight bench (TuffStuff, Pomona, California) with an Olympic bar. After receiving a lift-off from a spotter, subjects lowered the bar to their chest, paused briefly, and then pressed the bar to full extension of the forearms.

If a repetition for either the LP or BP exercises did not meet the aforementioned criteria, it was not counted, and another attempt was allowed after a 2-min rest period. For both the LP and BP exercises, 1-RM strength was determined by applying progressively heavier loads until the subject could not complete a repetition through the full range of motion. If an attempt was failed and a lower weight not attempted, additional trials were performed with the lighter load, and successive increases in weight until the 1-RM was determined, which was usually achieved within 5 trials. Two minutes of rest were allowed between trials [60].

Time to Exhaustion

During the final two laboratory visits (weeks 2 and 3), TTE was also measured on the same cycle ergometer as the GXTs. The seat height was adjusted to the previously-recorded height. The test began with a warm-up consisting of 5 min of cycling at 70 rpm against a resistance of 50 W. Following the warm-up, participants cycled at a workload associated with 80% of the previously-determined VO₂ PEAK. Participants were instructed to maintain 70 rpm, but the test was terminated when the participant could no longer maintain 60 rpm (volitional exhaustion). Participants were provided verbal encouragement throughout the duration of the test. Time was measured using a digital stopwatch and was recorded in seconds. RPE was also assessed every minute throughout the duration the test.

Statistical Analyses

Two separate one-way repeated measures analyses of variance (ANOVAs) (baseline vs. trial 1 vs. trial 2) were calculated for the 1-RM LP and BP scores. When appropriate, post hoc pair-wise comparisons with Bonferroni adjustments were completed. In addition, paired-samples t-tests were used to compare the mean TTE and RPE values between weeks 2 and 3. Prior to all statistical analyses, the alpha level was set at $p \leq 0.05$ to determine statistical significance. Data were analyzed using SPSS for Windows version 14.0 (SPSS Inc., Chicago, IL).

Results

There were no differences ($p > 0.05$) between the TPB and PL trials for BP, LP, TTE, or RPE. However, for the BP and LP scores, the baseline values were less than the TPB and PL values ($p \leq 0.05$) (Table 1).

Discussion

Our findings indicated that the TPB supplement containing caffeine, capsaicin (red pepper extract), bioperine (black pepper extract) and niacin did not significantly ($p \leq 0.05$) alter the BP or LP 1-RMs, TTE at 80% VO₂ PEAK, or RPE during the TTE test. Even though the TTE was approximately 5% greater for the TPB supplement compared to the PL (Table 1), this finding did not reach statistical significance ($p = 0.403$). This experiment was unique in that strength- and endurance-related variables were examined in response to a combination of caffeine and capsaicin, both of which have been studied separately [12,14,43,48,54]. We are aware of only a few other studies that have examined the effects of a similar blend of supplements on exercise performance and/or energy expenditure [11,13,20,61]. For example, Yoshioka and colleagues [11] reported higher energy expenditure after a meal containing red pepper and caffeine when compared to a control meal. Similarly in obese individuals, capsaicin and caffeine (among other ingredients) enhanced resting metabolic rate by 90 kJ, which suggested that these supplements exhibited a thermogenic effect at rest [20]. In addition, Ryan et al. [13] indicated that a caffeine- and capsaicin-containing supplement increased energy expenditure in healthy sedentary subjects before, during, and after 1 hour of light aerobic exercise. Therefore, these results collectively suggested that the potential thermogenic benefits of supplements containing caffeine and capsaicin may be more realized at rest (5,19,22) and during light aerobic exercise (19) than during anaerobic (1-RMs) and high-intensity aerobic (TTE at 80% VO₂ PEAK) exercises as indicated by the results of the present study.

Several studies have examined the ergogenic benefits of caffeine supplementation as indicated by several thorough literature reviews [3,5,16,18,41,62-64]. Most of this literature focuses on the effects of caffeine supplementa-

Table 1: Mean(SE) values for bench press and leg press 1-RM, time-to-exhaustion, and rating of perceived exertion

	Bench Press 1-RM (kg)	Leg Press 1-RM (kg)	Time to Exhaustion (s)	Rating of Perceived Exertion
Baseline	80.80 (5.21)	215.00 (12.45)	----	----
Placebo	82.39* (5.08)	225.80* (12.54)	602.23 (51.78)	15.80 (0.25)
Supplement	82.73* (5.36)	224.04* (12.93)	633.19 (52.88)	15.70 (0.22)

*denotes a significant ($p \leq 0.05$) difference from baseline

tion on relatively low- to moderate-intensity endurance performance [2,5,14,16,17,62]. Fewer studies have reported changes in muscle strength after caffeine supplementation [15,39,43]. Beck et al. [39] and Kalmar and Cafarelli [15] reported caffeine-induced increases in 1-RM bench press strength and voluntary muscle activation, respectively. However, Astorino et al. [43] and Beck et al. [39] also reported no caffeine-related changes in 1-RM leg press and leg extension exercises, respectively. In addition, Bond et al. [42] and Jacobson et al. [45] reported no changes in isokinetic strength of the leg extensors and flexors after various doses of caffeine. It has been suggested that calcium is more readily available for release from the sarcoplasmic reticulum after caffeine administration in rodents and frogs [33-37]. In addition, caffeine may alter the activation thresholds of motor neurons, resulting in increased motor unit firing and activation of more muscle [32]. In the present study, however, there was only 200 mg of caffeine in the TPB supplement, which is less than most caffeine doses administered in previous studies [15,32,42,43,45,65,66]. Therefore, the lack of observed differences in the present study may have been due to the relatively small dose of caffeine in the TPB supplement, since the ergogenic effects of both caffeine [2,17,67] and capsaicin [22,52] may be dose-dependent.

Although the effects of caffeine on strength measures are relatively inconclusive, studies have reported improvements in endurance performance after caffeine supplementation [2,5,14,16,17,62]. For example, increases in TTE with caffeine supplementation in well-trained subjects have been demonstrated [8,14,24,25,29,44]. However, other studies that have tested untrained subjects [26,65,68] have found no changes in TTE after caffeine ingestion. Arguments have been made that the subjects' initial training status is the primary limiting factor for TTE performance [65], especially at relatively high workloads, such as those used in the present study. In support of this hypothesis, Hogervorst et al. [8] reported an 84% increase in TTE after a 2.5-h bout of cycling at 60% of the VO_{2MAX} with well-trained cyclists after only 100 mg of caffeine was taken at several intervals. Therefore, the ergogenic effects of lower doses of caffeine may be more profound in trained individuals at lower-intensity, longer-duration endurance events. Since the participants in the present study were untrained and the exercise intensity was relatively high (80% VO_{2PEAK}), the caffeine-induced improvements in performance may have been less evident.

As with many ergogenic aids, the amount of caffeine supplementation may be proportional to the magnitude of performance improvements. Jenkins et al. [5] reported increases in cycling performance with as low as 2 mg of caffeine per kilogram of body mass ($mg \cdot kg^{-1}$) in trained cyclists. In contrast, Pasman et al. [29] reported no dose-

response relationship between caffeine consumption and TTE at 80% of the maximal cycling wattage (W) with 5, 9, and 13 $mg \cdot kg^{-1}$. However, even the minimal dose administered by Pasman et al. [29] was approximately 360 mg (5 $mg \cdot kg^{-1} \times$ mean body mass of 72 kg). The absolute caffeine dose administered in the present study was only 200 mg ($\sim 2.6 mg \cdot kg^{-1}$), which may have limited the potential ergogenic effects that are often observed with caffeine consumption. Nevertheless, our findings were similar to those of Bell et al. [65], which used a workload at 85% of the VO_{2MAX} and reported mean TTE values of 14.4 and 12.6 min for the caffeine (5 $mg \cdot kg^{-1}$) and placebo trials, respectively. The results of the present study indicated that the TTE for the TPB supplement was 5% greater than the PL trial (Table 1), although this finding was not statistically significant ($p = 0.403$). Therefore, because the caffeine dose administered in the present study was lower than what has been used in previous studies [15,32,42,43,45,65,66], the consequent ergogenic effects of caffeine may also have been limited.

The combination of caffeine and capsaicin supplements may potentially yield synergistic, ergogenic effects. For example, the elevation of plasma catecholamines after caffeine or capsaicin ingestion have previously resulted in increased lypolysis [14,17,44] and decreased carbohydrate utilization [69]. Yoshioka et al. [12] suggested that the primary mechanism of capsaicin is the β -adrenergic stimulation that induces thermogenesis. Recently, Lim et al. [70] reported a glycogen-sparing effect in rats during 2 h of treadmill running with a consequent increase in lypolysis after ingesting 6 $mg \cdot kg^{-1}$ of capsaicin. However, a more recent study by Lim et al. [54] reported that 10 g of red peppers (containing capsaicin) taken before exercise increased carbohydrate oxidation, which the authors suggested could limit endurance performance by exhausting glycogen stores. These findings [54] may, in part, explain the results of the present study, which found no differences in cycling endurance time between the TPB and PL trials. Additional ingredients in the TPB supplement included black pepper extract (i.e., bioperine), which is purported to have same metabolic effects as capsaicin. It is possible that the combined effects of caffeine, capsaicin, bioperine, and niacin may be most evident at higher doses during longer duration, lower intensity endurance exercises – particularly in trained individuals [8,24]. Future research is necessary to examine the potential dose-response mechanisms for the TPB supplement ingredients during a range of exercise intensities.

An interesting outcome was that the BP and LP 1-RM values at baseline were less than the 1-RM values recorded for the TPB and PL trials (Table 1). These results suggested that the participants experienced a learning effect from the baseline trial to the TPB or PL trials [71]. Hylleberg,

Mood, and Morrow [71] recommend using a baseline familiarization or "learning" trial to overcome the confounding influences of the learning effect. Therefore, the inclusion of the baseline measurement in the present study may have been helpful to avoid the learning effect for the 1-RM scores. In addition, the average TTE was approximately 5% greater for the TPB trial than the PL trial (Table 1). Perhaps the relatively high variability in TTE scores (coefficient of variation = 37.5%) may have prevented this difference from reaching statistical significance.

Conclusion

Overall, the results of the present study indicated that the TPB supplement containing 200 mg of caffeine, 33.34 mg of capsaicin extract, 20 mg of niacin, and 5 mg of bioperine did not improve the 1-RM scores for the BP or LP exercises, TTE at 80% $\dot{V}O_{2\text{PEAK}}$, or RPE during the TTE test. Even though the TTE for the TPB supplement was 5% greater than the PL trial (Table 1), this finding did not reach statistical significance ($p = 0.403$). The lack of observed ergogenic effects may have been related to a combination of factors including: (a) the dose of caffeine was too low, (b) the exercise intensity was too high for a metabolic-enhancing supplement like TPB, (c) the participants were not well-trained, and/or (d) the caffeine and capsaicin may have increased carbohydrate oxidation (as opposed to the glycogen sparing effect [17]), which may have counteracted any potential ergogenic effects of the TPB. Although these findings are useful for understanding the TPB supplement, future studies should consider these factors when designing studies to examine the efficacy of metabolic/thermogenic nutritional supplements.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

AAW was the primary author of the manuscript and played an important role in data collection and assessment. TJH, EDR, PBC, and KMH played an important role in data collection and manuscript preparation. JRS and TWB played an important role in study design and manuscript preparation. JTC was the senior author and played an important role in the grant procurement, study design, data analysis and interpretation, and manuscript preparation. All authors have read and approved the final manuscript.

Acknowledgements

This study was funded by a grant from the General Nutrition Corporation, 300 6th Avenue, Pittsburgh, PA, <http://www.gnc.com>.

References

- Bell DG, McLellan TM: **Exercise endurance 1, 3, and 6 h after caffeine ingestion in caffeine users and nonusers.** *J Appl Physiol* 2002, **93**(4):1227-1234.
- Bell DG, McLellan TM: **Effect of repeated caffeine ingestion on repeated exhaustive exercise endurance.** *Med Sci Sports Exerc* 2003, **35**(8):1348-1354.
- Graham TE: **Caffeine, coffee and ephedrine: impact on exercise performance and metabolism.** *Can J Appl Physiol* 2001, **26**(Suppl):S103-119.
- Jackman M, Wendling P, Friars D, Graham TE: **Metabolic catecholamine, and endurance responses to caffeine during intense exercise.** *J Appl Physiol* 1996, **81**(4):1658-1663.
- Jenkins NT, Trilk JL, Singhal A, O'Connor PJ, Cureton KJ: **Ergogenic effects of low doses of caffeine on cycling performance.** *Int J Sport Nutr Exerc Metab* 2008, **18**(3):328-342.
- Rudelle S, Ferruzzi MG, Cristiani I, Moulin J, Mace K, Acheson KJ, Tappy L: **Effect of a thermogenic beverage on 24-hour energy metabolism in humans.** *Obesity (Silver Spring)* 2007, **15**(2):349-355.
- Crowe MJ, Leicht AS, Spinks WL: **Physiological and cognitive responses to caffeine during repeated, high-intensity exercise.** *Int J Sport Nutr Exerc Metab* 2006, **16**(5):528-544.
- Hogervorst E, Bandelow S, Schmitt J, Jentjens R, Oliveira M, Allgrove J, Carter T, Gleeson M: **Caffeine improves physical and cognitive performance during exhaustive exercise.** *Med Sci Sports Exerc* 2008, **40**(10):1841-1851.
- Mandal A, Poddar MK: **Long-term caffeine consumption reverses tumor-induced suppression of the innate immune response in adult mice.** *Planta Med* 2008, **74**(15):1779-1784.
- Watanabe T, Kawada T, Yamamoto M, Iwai K: **Capsaicin, a pungent principle of hot red pepper, evokes catecholamine secretion from the adrenal medulla of anesthetized rats.** *Biochem Biophys Res Commun* 1987, **142**(1):259-264.
- Yoshioka M, Doucet E, Drapeau V, Dionne I, Tremblay A: **Combined effects of red pepper and caffeine consumption on 24 h energy balance in subjects given free access to foods.** *Br J Nutr* 2001, **85**(2):203-211.
- Yoshioka M, Lim K, Kikuzato S, Kiyonaga A, Tanaka H, Shindo M, Suzuki M: **Effects of red-pepper diet on the energy metabolism in men.** *J Nutr Sci Vitaminol (Tokyo)* 1995, **41**(6):647-656.
- Ryan ED, Beck TW, Herda TJ, Smith AE, Walter AA, Stout JR, Cramer JT: **Acute effects of a thermogenic nutritional supplement on energy expenditure and cardiovascular function at rest, during low-intensity exercise, and recovery from exercise.** *J Strength Cond Res* 2009, **23**(3):807-817.
- Costill DL, Dalsky GP, Fink WJ: **Effects of caffeine ingestion on metabolism and exercise performance.** *Med Sci Sports* 1978, **10**(3):155-158.
- Kalmar JM, Cafarelli E: **Effects of caffeine on neuromuscular function.** *J Appl Physiol* 1999, **87**(2):801-808.
- Paluska SA: **Caffeine and exercise.** *Curr Sports Med Rep* 2003, **2**(4):213-219.
- Spriet LL, MacLean DA, Dyck DJ, Hultman E, Cederblad G, Graham TE: **Caffeine ingestion and muscle metabolism during prolonged exercise in humans.** *Am J Physiol* 1992, **262**(6 Pt 1):E891-898.
- Spriet LL: **Caffeine and performance.** *Int J Sport Nutr* 1995, **5**(Suppl):S84-99.
- Tarnopolsky MA: **Caffeine and endurance performance.** *Sports Med* 1994, **18**(2):109-125.
- Belza A, Frandsen E, Kondrup J: **Body fat loss achieved by stimulation of thermogenesis by a combination of bioactive food ingredients: a placebo-controlled, double-blind 8-week intervention in obese subjects.** *Int J Obes (Lond)* 2007, **31**(1):121-130.
- Diepvens K, Westerterp KR, Westerterp-Plantenga MS: **Obesity and thermogenesis related to the consumption of caffeine, ephedrine, capsaicin, and green tea.** *Am J Physiol Regul Integr Comp Physiol* 2007, **292**(1):R77-85.
- Inoue N, Matsunaga Y, Satoh H, Takahashi M: **Enhanced energy expenditure and fat oxidation in humans with high BMI scores by the ingestion of novel and non-pungent capsaicin analogues (capsinoids).** *Biosci Biotechnol Biochem* 2007, **71**(2):380-389.

23. Davis JM, Zhao Z, Stock HS, Mehl KA, Buggy J, Hand GA: **Central nervous system effects of caffeine and adenosine on fatigue.** *Am J Physiol Regul Integr Comp Physiol* 2003, **284(2)**:R399-404.
24. Graham TE, Spriet LL: **Performance and metabolic responses to a high caffeine dose during prolonged exercise.** *J Appl Physiol* 1991, **71(6)**:2292-2298.
25. MacIntosh BR, Wright BM: **Caffeine ingestion and performance of a 1,500-metre swim.** *Can J Appl Physiol* 1995, **20(2)**:168-177.
26. Rodrigues LO, Russo AK, Silva AC, Picarro IC, Silva FR, Zogaib PS, Soares DD: **Effects of caffeine on the rate of perceived exertion.** *Braz J Med Biol Res* 1990, **23(10)**:965-968.
27. Tarnopolsky MA, Atkinson SA, MacDougall JD, Sale DG, Sutton JR: **Physiological responses to caffeine during endurance running in habitual caffeine users.** *Med Sci Sports Exerc* 1989, **21(4)**:418-424.
28. Greer F, Friars D, Graham TE: **Comparison of caffeine and theophylline ingestion: exercise metabolism and endurance.** *J Appl Physiol* 2000, **89(5)**:1837-1844.
29. Pasman WJ, van Baak MA, Jeukendrup AE, de Haan A: **The effect of different dosages of caffeine on endurance performance time.** *Int J Sports Med* 1995, **16(4)**:225-230.
30. Bangsbo J, Jacobsen K, Nordberg N, Christensen NJ, Graham T: **Acute and habitual caffeine ingestion and metabolic responses to steady-state exercise.** *J Appl Physiol* 1992, **72(4)**:1297-1303.
31. Jones G: **Caffeine and other sympathomimetic stimulants: modes of action and effects on sports performance.** *Essays Biochem* 2008, **44**:109-123.
32. Walton C, Kalmar JM, Cafarelli E: **Effect of caffeine on self-sustained firing in human motor units.** *J Physiol* 2002, **545(Pt 2)**:671-679.
33. Connett RJ, Ugol LM, Hammack MJ, Hays ET: **Twitch potentiation and caffeine contractures in isolated rat soleus muscle.** *Comp Biochem Physiol C* 1983, **74(2)**:349-354.
34. MacIntosh BR, Kupsh CC: **Staircase, fatigue, and caffeine in skeletal muscle in situ.** *Muscle Nerve* 1987, **10(8)**:717-722.
35. Weber A, Herz R: **The relationship between caffeine contracture of intact muscle and the effect of caffeine on reticulum.** *J Gen Physiol* 1968, **52(5)**:750-759.
36. Weber A: **The mechanism of the action of caffeine on sarcoplasmic reticulum.** *J Gen Physiol* 1968, **52(5)**:760-772.
37. Oba T, Hotta K: **The effect of changing free Ca²⁺ on light diffraction intensity and correlation with tension development in skinned fibers of frog skeletal muscle.** *Pflugers Arch* 1983, **397(3)**:243-247.
38. Plaskett CJ, Cafarelli E: **Caffeine increases endurance and attenuates force sensation during submaximal isometric contractions.** *J Appl Physiol* 2001, **91(4)**:1535-1544.
39. Beck TW, Housh TJ, Schmidt RJ, Johnson GO, Housh DJ, Coburn JW, Malek MH: **The acute effects of a caffeine-containing supplement on strength, muscular endurance, and anaerobic capabilities.** *J Strength Cond Res* 2006, **20(3)**:506-510.
40. Nishijima Y, Ikeda T, Takamatsu M, Kiso Y, Shibata H, Fushiki T, Moritani T: **Influence of caffeine ingestion on autonomic nervous activity during endurance exercise in humans.** *Eur J Appl Physiol* 2002, **87(6)**:475-480.
41. Juhn M: **Popular sports supplements and ergogenic aids.** *Sports Med* 2003, **33(12)**:921-939.
42. Bond V, Gresham K, McRae J, Tearney RJ: **Caffeine ingestion and isokinetic strength.** *Br J Sports Med* 1986, **20(3)**:135-137.
43. Astorino TA, Rohmann RL, Firth K: **Effect of caffeine ingestion on one-repetition maximum muscular strength.** *Eur J Appl Physiol* 2008, **102(2)**:127-132.
44. Ivy JL, Costill DL, Fink WJ, Lower RW: **Influence of caffeine and carbohydrate feedings on endurance performance.** *Med Sci Sports* 1979, **11(1)**:6-11.
45. Jacobson BH, Edwards SV: **Influence of two levels of caffeine on maximal torque at selected angular velocities.** *J Sports Med Phys Fitness* 1991, **31(2)**:147-153.
46. Denaro CP, Brown CR, Wilson M, Jacob P 3rd, Benowitz NL: **Dose-dependency of caffeine metabolism with repeated dosing.** *Clin Pharmacol Ther* 1990, **48(3)**:277-285.
47. Doherty M, Smith P, Hughes M, Davison R: **Caffeine lowers perceptual response and increases power output during high-intensity cycling.** *J Sports Sci* 2004, **22(7)**:637-643.
48. Engels HJ, Wirth JC, Celik S, Dorsey JL: **Influence of caffeine on metabolic and cardiovascular functions during sustained light intensity cycling and at rest.** *Int J Sport Nutr* 1999, **9(4)**:361-370.
49. Kawada T, Watanabe T, Takaishi T, Tanaka T, Iwai K: **Capsaicin-induced beta-adrenergic action on energy metabolism in rats: influence of capsaicin on oxygen consumption, the respiratory quotient, and substrate utilization.** *Proc Soc Exp Biol Med* 1986, **183(2)**:250-256.
50. Kim KM, Kawada T, Ishihara K, Inoue K, Fushiki T: **Increase in swimming endurance capacity of mice by capsaicin-induced adrenal catecholamine secretion.** *Biosci Biotechnol Biochem* 1997, **61(10)**:1718-1723.
51. Ohnuki K, Haramizu S, Oki K, Watanabe T, Yazawa S, Fushiki T: **Administration of capsiate, a non-pungent capsaicin analog, promotes energy metabolism and suppresses body fat accumulation in mice.** *Biosci Biotechnol Biochem* 2001, **65(12)**:2735-2740.
52. Oh TW, Oh TW, Ohta F: **Dose-dependent effect of capsaicin on endurance capacity in rats.** *Br J Nutr* 2003, **90(3)**:515-520.
53. Oh TW, Ohta F: **Capsaicin increases endurance capacity and spares tissue glycogen through lipolytic function in swimming rats.** *J Nutr Sci Vitaminol (Tokyo)* 2003, **49(2)**:107-111.
54. Lim K, Yoshioka M, Kikuzato S, Kiyonaga A, Tanaka H, Shindo M, Suzuki M: **Dietary red pepper ingestion increases carbohydrate oxidation at rest and during exercise in runners.** *Med Sci Sports Exerc* 1997, **29(3)**:355-361.
55. Kawada T, Sakabe S, Watanabe T, Yamamoto M, Iwai K: **Some pungent principles of spices cause the adrenal medulla to secrete catecholamine in anesthetized rats.** *Proc Soc Exp Biol Med* 1988, **188(2)**:229-233.
56. Reanmongkol W, Janthasoot W, Wattanatorn W, Dhumma-Upakorn P, Chudapongse P: **Effects of piperine on bioenergetic functions of isolated rat liver mitochondria.** *Biochem Pharmacol* 1988, **37(4)**:753-757.
57. Capuzzi DM, Morgan JM, Brusco OA Jr, Intenzo CM: **Niacin dosing: relationship to benefits and adverse effects.** *Curr Atheroscler Rep* 2000, **2(1)**:64-71.
58. Borg G: **Borg's Rating of Perceived Exertion and Pain Scale.** Champaign, IL: Human Kinetics; 1998.
59. Whaley M: **ACSM's Guidelines for Exercise Testing and Prescription.** 7th edition. Lippincott, Williams, & Wilkins; 2005.
60. Cramer JT, Coburn JW: **Fitness Testing Protocols and Norms, in NSCA's Essentials of Personal Training.** Champaign, IL: Human Kinetics; 2004.
61. Graham TE, Helge JW, MacLean DA, Kiens B, Richter EA: **Caffeine ingestion does not alter carbohydrate or fat metabolism in human skeletal muscle during exercise.** *J Physiol* 2000, **529(Pt 3)**:837-847.
62. Graham TE: **Caffeine and exercise: metabolism, endurance and performance.** *Sports Med* 2001, **31(11)**:785-807.
63. Doherty M, Smith PM: **Effects of caffeine ingestion on rating of perceived exertion during and after exercise: a meta-analysis.** *Scand J Med Sci Sports* 2005, **15(2)**:69-78.
64. Magkos F, Kavouras SA: **Caffeine use in sports, pharmacokinetics in man, and cellular mechanisms of action.** *Crit Rev Food Sci Nutr* 2005, **45(7-8)**:535-562.
65. Bell DG, Jacobs I, Zamecnik J: **Effects of caffeine, ephedrine and their combination on time to exhaustion during high-intensity exercise.** *Eur J Appl Physiol Occup Physiol* 1998, **77(5)**:427-433.
66. Cole KJ, Costill DL, Starling RD, Goodpaster BH, Trappe SW, Fink WJ: **Effect of caffeine ingestion on perception of effort and subsequent work production.** *Int J Sport Nutr* 1996, **6(1)**:14-23.
67. Graham TE, Spriet LL: **Metabolic, catecholamine, and exercise performance responses to various doses of caffeine.** *J Appl Physiol* 1995, **78(3)**:867-874.
68. Butts KN, Crowell D: **Effect of caffeine ingestion on cardiorespiratory endurance in men and women.** *Res Q Exerc Sport* 1985, **56**:301-305.
69. Matsuo T, Yoshioka M, Suzuki M: **Capsaicin in diet does not affect glycogen contents in the liver and skeletal muscle of rats before and after exercise.** *J Nutr Sci Vitaminol (Tokyo)* 1996, **42(3)**:249-256.
70. Lim K, Kim KM, Yoshioka M: **Effects of capsaicin on carbohydrate and fat metabolism in exercise rats.** *Korean Journal of Physical Education* 1995, **34**:248-256.

71. Hyllegard R, Mood DP, Morrow JR: **Interpreting Research in Sport and Exercise Science**. St. Louis, MO: Mosby-Year Book, Inc; 1996.

Publish with **BioMed Central** and every scientist can read your work free of charge

"BioMed Central will be the most significant development for disseminating the results of biomedical research in our lifetime."

Sir Paul Nurse, Cancer Research UK

Your research papers will be:

- available free of charge to the entire biomedical community
- peer reviewed and published immediately upon acceptance
- cited in PubMed and archived on PubMed Central
- yours — you keep the copyright

Submit your manuscript here:
http://www.biomedcentral.com/info/publishing_adv.asp

