The Effect of Ephedra and Caffeine on Maximal Strength and Power in Resistance-Trained Athletes

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Abstract

Caffeine and ephedrine-related alkaloids recently have been removed from International Olympic Committee banned substances lists, whereas ephedrine itself is now permissible at urinary concentrations less than 10 $\mu g \cdot mL^{-1}$. The changes to the list may contribute to an increased use of caffeine and ephedra as ergogenic aids by athletes. Consequently, we sought to investigate the effects of ingesting caffeine (C) or a combination of ephedra and caffeine (C + E) on muscular strength and anaerobic power using a double-blind, crossover design. Forty-five minutes after ingesting a glucose placebo (P: 300 mg), C (300 mg) or C + E (300 mg + 60 mg), 9 resistance-trained male participants were tested for maximal strength by bench press [BP; 1 repetition maximum (1RM)] and latissimus dorsi pull down (LP; 1RM). Subjects also performed repeated repetitions at 80% of 1RM on both BP and LP until exhaustion. After this test, subjects underwent a 30-second Wingate test to determine peak anaerobic cycling power, mean power, and fatigue index. Although subjects reported increased alertness and enhanced mood after supplementation with caffeine and ephedra, there were no significant differences between any of the treatments in muscle strength, muscle endurance, or peak anaerobic power. Our results do not support the contention that supplementation with ephedra or caffeine will enhance either muscle strength or anaerobic exercise performance.

Key Words caffeine, ephedra, strength, power

Introduction

Athletic performance is dependent on a range of factors including genetic potential, motivation, and training and nutritional status. The manipulation of diet to improve performance is widely used by and potentially of benefit to, many athletes, particularly those already undertaking optimal training loads. Two nutritional supplements that have potential ergogenic benefits and have been recently removed from the International Olympic Committee-banned substances lists are caffeine and ephedrine-related alkaloids such as pseudoephedrine and phenylpropanolamine (1).

The use of the stimulants caffeine and ephedrine has been studied extensively in humans and been reported to result in increased postprandial thermogenesis (29) and to assist weight reduction in a variety of populations (2,22,25). When taken individually, both caffeine and ephedrine have been reported to enhance both anaerobic (6,34) and aerobic (4,5, 7,30) exercise performance. Caffeine stimulates the sympathetic nervous system and its potential ergogenic properties include increasing muscle contractility by elevating intracellular calcium handling and inhibiting adenosine receptors (32). Ephedrine is a sympathomimetic agent and its major mechanism of action appears to be through direct stimulation of the sympathetic nervous system (28), although it may also directly stimulate the adrenoceptors (19). It has been proposed that the combination of caffeine and ephedrine in a supplement may result in synergistic benefits to performance; however, studies investigating the effects of combinations of these supplements have reported mixed findings (4,5,7,23). Consequently, the effect of combining these supplements requires further investigation.

Although supplementation with ephedrine appears to enhance athletic performance, supplementation with ephedrine alkaloids such as pseudoephedrine have been less conclusive, with several studies reporting no benefit (13,21) whereas another has reported supplementation to improve performance in a variety of athletic events (20). The herb ephedra (Ma Huang) contains a mixture of ephedrine and related alkaloids (12). Several well-designed studies have shown this herbal "equivalent" to ephedrine mixed with caffeine to be effective for weight loss and fat reduction (10,24). However, although many recreational athletes use these supplements in the belief that consumption will enhance athletic performance, no study has yet attempted to determine the efficacy of this practice.

The purpose of this study was to determine whether a combination of caffeine and ephedra (C + E) could enhance

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performance in short duration exercise and whether any improvements would be greater than those of caffeine (C) alone. It was hypothesized that in a group of young resistance-trained males, supplementation with C + E would result in greater increases in maximal muscle strength and muscle endurance and increased peak power and decreased fatigability during a 30-second cycle ergometer test compared to supplementation with C alone.

Methods

Experimental Approach to the Problem

The experimental design was double blinded and involved 9 healthy young resistance-trained males in a randomized crossover design. Each participant took a capsule containing either a glucose placebo (300 mg), a caffeine supplement (300 mg), or a supplement containing both caffeine (300 mg) and ephedra (60 mg). Muscle strength and anaerobic exercise performance measures were conducted between 1 hour and 2.5 hours after ingestion of the supplement. Trials were separated by at least a week but no more than 2 weeks, and all testing sessions were conducted at the same time of day following an overnight fast.

Subjects

Nine healthy young, resistance-trained, men (age: 26.2 ± 4.3 years, weight: 84.1 ± 10.3 kg; training age: 4.8 ± 2.4 years, mean ± SD) volunteered to participate in this study. All subjects were performing a minimum of 3 training sessions each week and were using the Max-OT™ training program (AST Sport Science, Denver, CO) that we have described previously (14–16). Before their acceptance into the study, volunteers were screened for any medical problems that may affect their ability to complete the study and were required to gain medical clearance from their doctor to participate. To be eligible to participate, potential candidates were required to confirm they (1) had no current or past history of anabolic steroid use; (2) had a minimum of 2 years of current resistance training experience; (3) were currently training at least 3 days per week; and (4) agreed not to ingest any nutritional supplement considered by the researchers to potentially affect performance in the fortnight before or over the duration of the study. Preliminary diet sheets submitted by many of the participants indicated that their habitual caffeine intake was low, for example, one cup of coffee per day. None of the subjects appeared to be heavy users. Each participant gave their informed consent to participate in the study following an explanation of all risks and potential benefits associated with the supplements. The study conformed to National Health and Medical Research Council of Australia guidelines for the involvement of human subjects for research and was approved by the Human Research Ethics Committee at Victoria University.

Procedures

Experimental Design. A randomized double-blind crossover, experimental design was used in which each subject completed 3 experimental trials, one with glucose (300 mg, AST Sports Science, Golden, CO), one with caffeine alone (300 mg, AST Sports Science) and one with a combination of caffeine and ephedra (60 mg ephedra alkaloids, 300 mg caffeine, AST Sports Science). To mask the trials, the doses were placed in gelatin capsules. Supplements were tested to comply with label ingredients before leaving the place of manufacture. The trials were separated by at least a week but no more than 2 weeks, and testing occurred at the same time each day. All participants were requested to refrain from consuming any food or drink containing caffeine for 48 hours before each testing session and attended the laboratory after an overnight, water-only fast. An initial session, in which participants were familiarized to the maximal strength and anaerobic power tests without any supplementation was completed by each participant between 7 and 14 days before the first experimental trial. Participants also were provided with food diaries and requested to record all food and beverage consumption for the day before all test sessions so that diet could be replicated for subsequent sessions. Food diary data was analyzed for carbohydrate, fat, protein, and caffeine content with Foodworks dietary analysis software (Foodworks Professional Edition, v3.02.581, Xyris Software, 2004). Upon entry to the laboratory on the morning of the trial, all participants were measured for height and weight and given their supplement to consume. After consumption, they were

Table 1. Nutrient consumption in the day prior to each experimental protocol.

	Glucose	Caffeine	Caffeine + Ephedra	Significance (P)
Total energy (kJ)	12,244 ± 1226	11,229 ± 1205	10,981 ± 963	0.710
Carbohydrate (%)	42.8 ± 3.1	45.3 ± 3.1	43.6 ± 1.8	0.808
Fat (%)	30.8 ± 2.7	29.3 ± 3.1	29.4 ± 3.1	0.918
Protein (%)	23.6 ± 1.8	23.7 ± 2.1	24.3 ± 2.6	0.967
Caffeine (mg)	60 ± 22	45 ± 20	68 ± 26	0.773

Data presented as mean ± *SEM*.

Table 2. Muscle strength and endurance data (means ± *SEM*).

	Placebo	Caffeine	Caffeine + Ephedra	Significance (P)
Bench press				
1RM (kg)	108.9 ± 6.5	109.5 ± 4.9	114.4 ± 6.7	0.885
Endurance (kg)	489.1 ± 72.9	537.1 ± 40.1	580.7 ± 56.3	0.691
Lat Pulldown				
1RM (kg)	194.9 ± 5.6	202.5 ± 5.1	204.9 ± 5.4	0.587
Endurance (kg)	1236.0 ± 132.3	1302.1 ± 73.8	1303.5 ± 117.0	0.859

asked to sit quietly for 45 minutes to allow for absorbance of the oral supplement into the bloodstream.

Performance Measures. At 45 minutes after consumption of the supplement, participants proceeded to the weights room, where they were tested for muscle strength. After a standard warm-up protocol, participants were tested for muscle strength with the barbell bench press (BP) and front latissimus dorsi pull down (LP) with the 1 repetition maximum (1RM) method, which we have described previously (15). In brief, the participant's maximal lift was determined within no more than 5 single-repetition attempts after 3 progressively heavier warm-up sets, and participants were required to successfully lift each weight before attempting a heavier weight. After the 1RM test and a 5-minute recovery period, participants were requested to lift 80% of their 1RM weight for as many repetitions as possible before they became too fatigued to continue. The number of repetitions achieved with this weight was multiplied by the load to give an indication of strength endurance.

A short rest period of approximately 15 minutes followed the strength testing, after which participants performed a 30-second Wingate anaerobic sprint test (3) with a custom-made air-braked cycle ergometer fitted with SRM cranks (SRM GmBH, Julich, Germany). This test was chosen because of its reliability (Inter class correlation 0.991; coefficient of variation 2.0%) and because it induces a similar metabolic response to a similar duration athletic event (e.g., 200- to 400-m sprint, 50-m freestyle swim). Before the anaerobic sprint test, the participants warmed up by cycling at 100W for 3 minutes and then rested for 1 minute immediately before performing the Wingate test. All cycle ergometer measurements were set and recorded during the familiarization session such that they were standardized for each individual participant throughout the study. Peak power attained during the test was taken as an average of the highest 3 of the first 5 seconds and was recorded in watts (W). Minimum power was defined as the average power (W) attained in the lowest 3 of the last 5 seconds. Total work performed during the 30-second Wingate test was recorded in kilojoules. Fatigue index was calculated as the difference between peak power and minimum power divided by peak power, and expressed as a percentage. All test protocols were completed within 2.5 hours of taking the supplement.

Questionnaires. After consumption of their supplement and throughout each experimental trial, participants were requested to answer questions seeking to determine their perceptions of energy levels, fatigue, and mood. The questionnaires asked specific questions about overall mood and perceptions of fatigue during the weight lifting exercise and the anaerobic power test. Participants were requested to respond to questions using a 5-point rating scale, with 1 equating to a poor mood or high perception of fatigue and 5 equating to an excellent mood or abundance of energy.

Statistical Analyses

Participant characteristics are reported as means ± *SD*. All other values are reported as mean ± *SEM*. Comparisons of

Table 3. Wingate test data (means ± *SEM*).

	Placebo	Caffeine	Caffeine + Ephedra	Significance (P)
Peak power (W)	1221 ± 37	1253 ± 48	1273 ± 50	0.745
Mean power (W)	783 ± 25	801 ± 31	795 ± 29	0.956
Fatigue index (%)	61.8 ± 2.0	62.5 ± 1.9	64.4 ± 1.3	0.536

Table 4. Participant perceptions of effort (means ± *SEM*).

	Placebo	Caffeine	Caffeine + Ephedra	Significance (P)
Attitude 1 hour after supplementation	2.7 ± 0.4	2.9 ± 0.6	4.4 ± 0.3*	0.022
Alertness during exercise	2.7 ± 0.2	3.6 ± 0.4	4.1 ± 0.3*	0.024
Fatigue during strength testing	2.1 ± 0.3	2.7 ± 0.5	3.4 ± 0.4	0.121
Fatigue during Wingate test	2.4 ± 0.4	2.1 ± 0.3	3.4 ± 0.5	0.104

*$P < 0.05$ compared with placebo condition.

differences between trials were made using single-factor analysis of variance (SPSS, v.12.0.1). A P value of less than 0.05 was considered significant. In the event of a significant result, post hoc testing was conducted using paired t-tests to determine which trials were significantly different. Test-retest reliability trials using a minimum of 5 participants were performed for strength and anaerobic power testing before commencement of the study. Intraclass correlations for the reliability data ranged between 0.972 and 0.991, and coefficients of variation (CV) calculated from this data were between 1% and 5%. Consequently, changes in the measured variables of 10% after supplementation were identified as appropriate to determine a true effect. Power testing was conducted to determine the number of participants required to obtain statistical significance in the event that a clinically significant improvement of 10% was observed. The power at a 2-tailed alpha level of 0.05 is 0.80 (80%) for the 9 participants who completed the study. Effect size and observed power were calculated and are reported for each dependent variable.

Results

No differences were observed in body weight or total energy consumption across any of the trials. Analysis of the dietary diaries revealed no difference between the total calories or the contribution of any of the energy nutrients consumed by the participants prior to any of the trials (Table 1). Caffeine ingestion in the day before testing was not different between any of the experimental trials. No adverse side effects were reported by any of the participants to any of the supplement protocols.

Muscle Strength

Analysis of variance revealed no differences between any of the treatments in the 1RM achieved in either the BP (partial $\eta^2 = 0.010$; observed power = 0.067) or the LP (partial $\eta^2 = 0.043$; observed power = 0.129; Table 2). There was no difference in the total weight lifted in the muscular endurance test in either of the exercises (BP: partial $\eta^2 = 0.030$; observed power = 0.103; LP: partial $\eta^2 = 0.013$; observed power = 0.071) (Table 2).

Anaerobic Power

No differences were observed in peak power (partial $\eta^2 = 0.017$; observed power = 0.079), mean power (partial $\eta^2 = 0.004$; observed power = 0.056), or fatigue index (partial $\eta^2 = 0.051$; observed power = 0.145) as a result of any of the treatments investigated (Table 3).

Perceptions of Performance

Self-reported participant attitude to the exercise testing ($P = 0.001$) and alertness ($P = 0.016$) during the exercise bouts were significantly greater during the caffeine and ephedra trial compared to the placebo condition (Table 4). No significant differences existed in participants self reported perceptions of fatigue during strength or anaerobic power testing across any of the supplementation protocols (Table 4).

Discussion

The major findings of the current study are that neither a combined dose of ephedra and caffeine nor caffeine alone is associated with a change in performance during either a maximal anaerobic power test or a maximal strength test. These results are consistent with the majority of previous studies that have investigated the effects of pseudoephedrine on exercise performance and reported no differences between treatments in any of the performance variables measured (13,21,27). Concordant with the results observed in several other studies (6,30,33), the current study also failed to find any improvement in maximal strength or anaerobic power following supplementation with caffeine alone. Conversely, only a single study has reported improvements in peak power after supplementation with caffeine (34). Despite the lack of any improvement in athletic performance after supplementation, the attitude of participants to, and alertness during the exercises were significantly better after consumption of C + E compared with the placebo supplement.

The current study was unique in that it was the first to examine the effects of the herbal supplement ephedra, the active ingredients of which include a mixture of ephedrine and related alkaloids, including pseudoephedrine, norephedrine, and norpseudoephedrine (12). Given the widespread

use of this supplement both alone and in combination with caffeine among recreational athletes, the removal of ephedrine alkaloids from banned substances lists, and claims that have been made about the efficacy of ephedra supplementation on performance by many commercial suppliers, it was considered important to test a commercially available ephedra product. There was no effect of supplementation with a dose of ephedra standardized to contain 60 mg of active alkaloids on exercise performance in the current study. This is in accordance with the findings of several previous studies (13,21,27) examining the effects of supplementation with ephedrine or related alkaloids on performance measures but contrasts with the findings of a number of others (5–8,20,30). The reasons for the conflicts in the literature are uncertain but are potentially dose and/or substance related. Studies that have reported exercise performance benefits have generally used ephedrine as the supplement studied, whereas those that have reported no effect have used related alkaloids such as pseudoephedrine. Ephedrine and its related alkaloids are sympathomimetic agents that stimulate the sympathetic nervous system, increasing circulating catecholamines (28). However, in addition to the actions it shares with pseudoephedrine, ephedrine also appears to have some direct (α) adrenoceptor-stimulating actions (19). Previously, it has been noted that pseudoephedrine is approximately 2.5-fold less potent than ephedrine (21), which is likely because of ephedrine's direct actions. Consequently, any study investigating the potential benefits of supplementation with pseudoephedrine may require larger doses than those required if the supplement was ephedrine. This is supported by the results of several studies that have investigated the effect of pseudoephedrine on muscle strength or anaerobic power and reported no performance benefits at doses of 60 mg (27), or 120 mg (13), whereas a dose of 180 mg (20) resulted in significant improvements in peak power during a Wingate test and isometric leg extension compared to a placebo trial. In contrast, doses of between 0.8 and 1.0 $mg \cdot kg^{-1}$ of ephedrine are sufficient to increase muscle strength (30) and peak power output (6) during a 30-second cycle ergometer test.

Although daily intakes of ephedra of between 40 mg and 90 mg combined with caffeine have been shown to be safe and effective for weight loss (9,10,31), the effects of a combination of these supplements on exercise performance have not previously been investigated. With its mixture of active ingredients, the dose of ephedra used in the current study (60 mg) may have been insufficient to elicit improvements in performance that would exist with a larger dose. However, the dose was selected as it is equivalent to a therapeutic dose of pseudoephedrine found in common cold and flu medications (35). As such, it actually exceeds Consumer Healthcare Products Association dose guidelines of no more than 25 mg of ephedrine alkaloids per unit dose (as cited in reference 12) and is comparable with the range of dose generally recommended by supplement companies (10–80 mg). In addition, the 60-mg dose of ephedra alkaloids used in the current study was similar to a dose of ephedrine (0.8 $mg \cdot kg^{-1}$) that has previously been demonstrated to have ergogenic properties (8,30).

Supplementation with 300 mg of caffeine did not result in improvement to either muscle strength or anaerobic power in the current study. These findings are consistent with those of previous studies that have reported caffeine to have no effect on performance during a Wingate test (6,26), repeated 20-m sprints (33), or time to exhaustion during exercise at an intensity of 85% of VO_2max (5). Although the authors of a more recent meta analysis (17) concluded that caffeine improves performance in subjects during high-intensity exercise, these benefits seem limited to fixed intensity, time to exhaustion protocols where caffeine's ability to spare glycogen stores through enhanced lipid metabolism may delay fatigue. There is no evidence to suggest that this mechanism of action would have any effect on muscle strength or anaerobic power.

It has been suggested that a combination of caffeine and ephedrine alkaloids may impart synergistic benefits to exercise performance (23). Several studies have previously reported combinations of caffeine and ephedrine to result in greater increases in time to exhaustion during constant intensity submaximal cycling than either caffeine or ephedrine alone (5). However, a further study by the same group (6), reported that although a combination of caffeine and ephedrine resulted in higher power output during an anaerobic cycle test than caffeine alone, there was no significant difference in peak power output between the caffeine and ephedrine or ephedrine-alone trial. The current study did not compare a combination of ephedra and caffeine with ephedra alone and although the mean result for peak power output was greater in the caffeine and ephedra group than the caffeine group, which in turn was greater than the placebo group, the differences were small and insignificant. Although these results may be partially a result of the small dose of ephedra used in the current study, they do not currently support the hypothesis of a synergistic effect with a combination of these supplements.

In the current study, participants reported feeling that they were more alert and motivated after taking the caffeine and ephedra supplement than they were with the placebo alone (Table 4). In addition there were trends toward greater alertness ($P = 0.10$) and motivation ($P = 0.052$) after consumption of the caffeine and ephedra than the caffeine supplement alone. Participants also tended to be more alert following consumption of caffeine than the placebo ($P = 0.14$). Additionally, although there were trends towards reduced feelings of fatigue in the caffeine and ephedra trial compared with the placebo trial, these were not significant and did not equate to improved performance in either the strength or anaerobic power testing. The trend towards reduced feelings of fatigue are not surprising, because a recent meta-analysis of studies examining the effect of caffeine consumption on ratings of perceived effort during exercise, reported reduced ratings of perceived exertion at any given

exercise intensity following caffeine consumption (18). Similarly, ephedrine and caffeine supplementation has been associated with reduced ratings of perceived exertion compared to placebo or caffeine supplementation during high intensity exercise to fatigue (5). The findings in the current study suggest that although the supplements did not improve exercise performance, they were sufficient to stimulate the central nervous system. It is possible therefore that supplementation at the doses used in this study may enable athletes to train for a prolonged period of time at high intensity, ultimately leading to better adaptations and improved performance. However, the investigation of this hypothesis was beyond the scope of the current study.

A potential limitation with the current study was that the doses of the supplements that were used may be below a critical threshold required to obtain benefits in performance. The majority of studies that have investigated the effects of caffeine ingestion on exercise performance have used dosages (>5.0 mg·kg^{-1}) greater than those used in the current study. However, the 300-mg dose used in the current study equated to a dose of approximately 4 mg·kg^{-1}, which is in the accepted range of doses (3–6mg·kg^{-1}) for ergogenic benefits (11,22). The small dose of ephedra also may have prevented us achieving significant improvements in performance although as noted earlier it is comparable with doses of ephedrine that have previously been observed to have ergogenic attributes (7,30). This study was the first to examine the effects of ephedra on exercise performance and used safe therapeutic doses in a range previously reported to enhance resting metabolism and thermogenesis and recommended by manufacturers to enhance performance.

The length of time between supplementation and performance testing is also a potential source of limitation in this study. When taken in a powdered form within a gelatin capsule as was the case in the current study, ephedra concentration has been observed to peak in the plasma at just under 4 hours after consumption (36). However, it reaches half its peak plasma concentration within 1 hour after ingestion and 75% of peak concentration with 2 hours. In capsule form, caffeine concentration in the plasma peaks at around an hour after consumption (32). We chose to begin testing at 1 hour, where the effects of the caffeine would be expected to be greatest but where there would also be a significant concentration of ephedra alkaloids in the plasma. All tests were completed by 2.5 hours after consumption of the capsules at a stage where plasma caffeine concentrations were still elevated. Nevertheless, performance testing was completed prior to the time expected for peak ephedra concentration in the plasma and this may have adversely affected our chances of observing a positive effect with supplementation.

No blood samples were taken during the current study. Consequently, we have no empirical evidence that the doses of supplement used in the current study were sufficient to increase plasma concentrations of the active ingredients or to substantially elevate catecholamine levels. However, the participants' perceptions of alertness were significantly greater following supplementation with ephedra suggesting that this was not an issue.

In accordance with the methodology of several other studies (11,26,30), participants in the current study were requested to refrain from consuming any caffeine or ephedrine containing products in the 48 hours before each experimental trial. Compliance to this request on the day before testing was monitored through the use of food diaries. A number of participants did not comply with this request and this non-compliance may potentially have resulted in the lack of significance in this study as there is a habituation effect with chronic use of caffeine. No ephedrine- or pseudoephedrine-containing medication was reported as being taken in the 24 hours before any experimental trial. Whereas the noncompliance with the request regarding prior caffeine consumption may have altered our results it is consistent with behaviors in a free living state. Few athletes would limit their caffeine consumption in foods to gain the best possible result with supplementation.

In conclusion, this study used a randomized cross-over design to examine the effects of supplementation with C + E, C or P on muscle strength and maximal power production during a Wingate test. The results suggest that when consumed in safe therapeutic doses, a single dose of caffeine and ephedra will not enhance either muscle strength or anaerobic power. This finding is in accord with several studies that have examined the effect of ephedrine alkaloids as opposed to ephedrine alone, on exercise performance (13,21,27). However, these findings do not exclude the possibility of ergogenic effects existing in response to repeated doses of these supplements over an extended period of time.

Practical Applications

Although the results of this study indicate that participants felt more motivated and were likely to feel more alert following consumption of the ephedra and caffeine supplement, these feelings did not translate to any improvement in performance. Consequently, the findings of this study suggest that supplementation with caffeine or caffeine and ephedra in doses that are generally regarded as therapeutic will not enhance performance in events in which maximal strength or power determine success. If strength or power athletes choose to use these supplements in an attempt to enhance performance, doses need to be greater than those used in the current study.

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References

1. Anonymous. 2006. World Anti Doping Code–The 2006 Prohibited List. World Anti Doping Agency. Available at: http://www.wada-ama.org/rtecontent/document/2006_LIST.pdf. Accessed January 20, 2006.
2. Astrup, A, Toubro, S, Cannon, S, Hein, P, and Madsen, J. Thermogenic synergism between ephedrine and caffeine in healthy volunteers: a double-blind, placebo-controlled study. *Metabolism* 40: 323–329, 1991.
3. Bar-Or, O. The Wingate anaerobic test. An update on methodology, reliability and validity. *Sports Med* 4: 381–394, 1987.
4. Bell, DG and McLellan, TM. Effect of repeated caffeine ingestion on repeated exhaustive exercise endurance. *Med Sci Sports Exerc* 35: 1348–1354, 2003.
5. Bell, DG, Jacobs, I, and Zamecnik, J. Effects of caffeine, ephedrine and their combination on time to exhaustion during high-intensity exercise. *Eur J Appl Physiol Occup Physiol* 77: 427–433, 1998.
6. Bell, DG, Jacobs, I, and Ellerington, K. Effect of caffeine and ephedrine ingestion on anaerobic exercise performance. *Med Sci Sports Exerc* 33: 1399–1403, 2001.
7. Bell, DG, McLellan, TM, and Sabiston, CM. Effect of ingesting caffeine and ephedrine on 10-km run performance. *Med Sci Sports Exerc* 34: 344–349, 2002.
8. Bell, DG, Jacobs, I, McLellan, TM, and Zamecnik, J. Reducing the dose of combined caffeine and ephedrine preserves the ergogenic effect. *Aviat Space Environ Med* 71: 415–419, 2000.
9. Boozer, CN, Nasser, JA, Heymsfield, SB, WangV, Chen, G, and Solomon, JL. An herbal supplement containing Ma Huang-Guarana for weight loss: a randomized, double-blind trial. *Int J Obes Relat Metab Disord* 25: 316–324, 2001.
10. Boozer, CN, Daly, PA, Homel, P, Solomon, JL, Blanchard, D, Nasser, JA, Strauss, R, and Meredith, T. Herbal ephedra/caffeine for weight loss: a 6-month randomized safety and efficacy trial. *Int J Obes Relat Metab Disord* 26: 593–604, 2002.
11. Bridge, CA and Jones, MA. The effect of caffeine ingestion on 8 km run performance in a field setting. *J Sports Sci* 24: 433–439, 2006.
12. Bucci, LR. Selected herbals and human exercise performance. *Am J Clin Nutr* 72S: 624–636, 2000.
13. Chu, KS, Doherty, TJ, Parise, G, Milheiro, JS, and Tarnopolsky, MA. A moderate dose of pseudoephedrine does not alter muscle contraction strength or anaerobic power. *Clin J Sport Med* 12: 387–390, 2002.
14. Cribb, PJ and Hayes, A. Effects of supplement timing and resistance exercise on skeletal muscle hypertrophy. *Med Sci Sports Exerc* 38: 1918–1925,2006.
15. Cribb, PJ, Williams, AD, Carey, MF, and Hayes, A. The effect of whey isolate and resistance training on strength, body composition, and plasma glutamine. *Int J Sport Nutr Exerc Metab* 16: 494–509, 2006.
16. Cribb, PJ, Williams, AD, Stathis, CG, Carey, MF, and Hayes, A. Effects of whey isolate, creatine, and resistance training on muscle hypertrophy. *Med Sci Sports Exerc* 39: 298–307, 2007.
17. Doherty, M and Smith, PM. Effects of caffeine ingestion on exercise testing: a meta-analysis. *Int J Sport Nutr Exerc Metab* 14: 626–646, 2004.
18. Doherty, M and Smith, PM. Effects of caffeine ingestion on rating of perceived exertion during and after exercise: a meta-analysis. *Scand J Med Sci Sports* 15: 69–78, 2005.
19. Dulloo, AG. Ephedrine, xanthines and prostaglandin-inhibitors: Actions and interactions in the stimulation of thermogenesis. *Int J Obes Relat Metab Disord* 17S: 35–40, 1993.
20. Gill, ND, Shield, A, Blazevich, AJ, Zhou, S, and Weatherby, RP. Muscular and cardiorespiratory effects of pseudoephedrine in human athletes. *Br J Clin Pharmacol* 50: 205–213, 2000.
21. Gillies, H, Derman, WE, Noakes, TD, Smith, P, Evans, A, and Gabriels, G. Pseudoephedrine is without ergogenic effects during prolonged exercise. *J Appl Physiol* 81: 2611–2617, 1996.
22. Graham, TE. Caffeine and exercise: Metabolism, endurance and performance. *Sports Med* 31: 785–807, 2001.
23. Graham, TE. Caffeine, coffee and ephedrine: Impact on exercise performance and metabolism. *Can J Appl Physiol* 26S: 103–119, 2001.
24. Greenway, FL, De Jonge, L, Blanchard, D, Frisard, M, and Smith, SR. Effect of a dietary herbal supplement containing caffeine and ephedra on weight, metabolic rate, and body composition. *Obes Res* 12: 1152–1157, 2004.
25. Greenway, FL, Ryan, DH, Bray, GA, Rood, JC, Tucker, EW, and Smith, SR. Pharmaceutical cost savings of treating obesity with weight loss medications. *Obes Res* 7: 523–531, 1999.
26. Greer, F, McLean, C, and Graham, TE. Caffeine, performance, and metabolism during repeated Wingate exercise tests. *J Appl Physiol* 85: 1502–1508, 1998.
27. Hodges, AN, Lynn, BM, Bula, JE, Donaldson, MG, Dagenais, MO, and McKenzie, DC. Effects of pseudoephedrine on maximal cycling power and submaximal cycling efficiency. *Med Sci Sports Exerc* 35: 1316–1319, 2003.
28. Hoffman, BB. Adrenoceptor-activating and other sympathomimetic Drugs. In: *Basic and Clinical Pharmacology* (8th ed). Katzung BG, ed. Lange Medical, 2001, pp. 120–137.
29. Horton, TJ and Geissler, CA. Post-prandial thermogenesis with ephedrine, caffeine and aspirin in lean, pre-disposed obese and obese women. *Int J Obes Relat Metab Disord* 20: 91–97, 1996.
30. Jacobs, I, Pasternak, H, and Bell, DG. Effects of ephedrine, caffeine, and their combination on muscular endurance. *Med Sci Sports Exerc* 35: 987–994, 2003.
31. Kalman, D, Incledon, T, Gaunaurd, I, Schwartz, H, and Krieger, D. An acute clinical trial evaluating the cardiovascular effects of an herbal ephedra-caffeine weight loss product in healthy overweight adults. *Int J Obes Relat Metab Disord* 26: 1363–1366, 2002.
32. Magkos, F and Kavouras, SA. Caffeine use in sports, pharmacokinetics in man, and cellular mechanisms of action. *Crit Rev Food Sci Nutr* 45: 535–562, 2005.
33. Paton, CD, Hopkins, WG, and Vollebregt, L. Little effect of caffeine ingestion on repeated sprints in team-sport athletes. *Med Sci Sports Exerc* 33: 822–825, 2001.
34. Stuart, GR, Hopkins, WG, Cook, C, and Cairns, SP. Multiple effects of caffeine on simulated high-intensity team-sport performance. *Med Sci Sports Exerc* 37: 1998–2005, 2005.
35. Taverner, D, Danz, C, and Economos, D. The effects of oral pseudoephedrine on nasal patency in the common cold: a double-blind single-dose placebo-controlled trial. *Clin Otolaryngol Allied Sci* 24: 47–51, 1999.
36. White, LM, Gardner, SF, Gurley, BJ, Marx, MA, Wang, PL, and Estes, M. Pharmacokinetics and cardiovascular effects of ma-huang (*Ephedra sinica*) in normotensive adults. *J Clin Pharmacol* 37: 116–122, 1997.