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Effects of a commercially available energy drink on anaerobic performance

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Effects of a Commercially Available

Energy Drink on Anaerobic Performance

by

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ABSTRACT

In an attempt to improve aerobic and anaerobic performance, athletes and fitness enthusiasts consume a variety of supplements. Because of this, energy drinks are quickly becoming more and more popular every day. Despite its highly addictive nature, caffeine, which is the main active ingredient in energy drinks, is gaining recognition as an ergogenic aid. However, due to the many factors that affects the action of caffeine, and because the research on caffeine and anaerobic performance is limited, the potential for studying energy drinks and anaerobic performance is quite large. PURPOSE: To determine if a commercially available energy drink has any ergogenic effects on lower body and upper body resistance exercise performance. METHODS: In a block randomized, double-blind, placebo-controlled, crossover study thirteen recreationally trained male and female volunteers (mean $\pm$ SD age = 22.5 $\pm$ 3.4 years) performed 4 sets of the leg press and 4 sets of the bench press exercises (at 80% of 1 RM with all sets separated by 2 minutes). Acting as their own controls, participants were tested on each dependent variable (i.e., bench press total volume, leg press total volume and total workout volume) twice, after ingesting a Venom® Energy Drink and after ingesting a placebo drink. RESULTS: Data were tested via a dependent samples *t*-test with *p* value set at < 0.05. No significant differences were found for any of the three dependent variables. DISCUSSION: The major finding of this study is that consumption of a Venom® Energy Drink does not produce an ergogenic effect by improving anaerobic exercise performance when the exercises are performed forty-five minutes following ingestion. Future studies should focus more on examining the factors behind the actions of caffeine. More specifically, the exercise performed, the training status of the participants, individual differences of the participants, and the dose of caffeine.

Chapter One

Introduction

Athletes and fitness enthusiasts are always looking for ways to improve their *edge* on performance. In doing so, they consume different types of supplements in an attempt to improve aerobic and anaerobic performance. One of the most popular supplements today is energy drinks. This popularity can be seen by the number of energy drinks currently on the market today and by the consistent influx of new drinks into the market. The active ingredient in these commercially available energy drinks is caffeine and the range of dosage is quite large. Caffeine is one of the most common drugs used in America, and possibly worldwide.[17,36] In addition, it's quickly taking on recognition, and popularity, as an ergogenic aid. An ergogenic aid is any substance that can increase physical or mental performance, usually by reducing symptoms of fatigue. The potential for investigations into caffeine as an ergogenic aid, especially in the form of energy drinks, is quite large because caffeine action depends on many factors, such as:

- the exercise performed (type, intensity, and duration)
- the individual's training status (trained vs. untrained)
- individual differences, the environment, nutritional status, and the dose of caffeine.[9]

Although there is still some debate among the literature as to the specific ergogenic effects of caffeine and the physiological factors behind these effects, most researchers do agree that 1) caffeine does enhance aerobic endurance performance (i.e., prolonged, submaximal intensity)[3,9,16] and 2) that the literature on the effects of caffeine on anaerobic performance (i.e., short-term, near-maximal or maximal intensities) is quite limited.[3,6,9]

Purpose of the Study

The purpose of the present study will be to determine if a commercially available energy drink (Venom®) has any ergogenic effects on upper body and lower body resistance exercise endurance performance.

Independent and Dependent Variables

The independent variables will be Venom® supplementation, a commercially available energy drink produced and marketed by Dr. Pepper/Seven Up® and containing 160 mg of caffeine (80 mg/8 oz of liquid), and placebo supplementation. Ingredients in the Venom® Energy Drink are very similar to Red Bull® Energy Drink: *carbonated water, sugar, glucose, citric acid, maltodextrin, taurine, sodium citrate, glucuronolactone, natural and artificial flavors, ginseng extract, L-carnitine, inositol, caffeine, sodium benzoate (preservative), caramel color, potassium sorbate (preservative), niacinamide (vitamin B3), guarana, sucralose, pyridoxine hydrochloride (vitamin B6), riboflavin (vitamin B2), and cyanocobalamin (vitamin B12).* Dependent variables will include: upper body resistance exercise endurance performance, lower body resistance exercise endurance performance, and whole body total lifting volume.

Hypotheses

Ho_1: There will be no difference in bench press total lifting volume between the energy drink group and the placebo group.

Ho_2: There will be no difference in leg press total lifting volume between the energy drink group and the placebo group.

Ho_3: There will be no difference in whole body total lifting volume between the energy drink group and the placebo group.

Chapter Two

Review of Literature

A multitude of clinical studies have investigated the effects of caffeine on exercise performance. The majority of these investigations have focused on aerobic exercise performance, with limited attention investigating anaerobic exercise performance. The following review of literature will summarize the potential mechanisms of action for caffeine's ergogenic effect and provide an overview of caffeine ingestion and its effects on:

- Aerobic exercise performance
- Anaerobic exercise performance
- Resistance exercise performance

Following this, the effects of energy drinks (a caffeine-containing beverage) on resistance training performance will be summarized. Finally, a discussion of common doses, side effects, and menstrual cycle issues in conjunction with caffeine ingestion will be presented.

Possible Reasons behind Caffeine's Ergogenic Effect

It is believed that caffeine affects performance by arousal of the central nervous system (CNS), mobilization of FFA for use by the muscles (which has a glycogen-sparring effect), enhancement of neuromuscular transmission, and enhancement (possibly) of the strength of muscle contractions.[25,27,38] Studies have shown that during long-term, submaximal aerobic exercise caffeine does stimulate the CNS (sympathomimetic effect), improve neuromuscular transmission, and increase skeletal muscle contractility.[10,13,25,30,36,37,38] However, some of these same studies showed no improvements in these same parameters during short-term, intense exercise (such as muscular strength exercises or high intensity endurance exercise). Tarnopolsky & Cupido[37] looked at low-frequency potentiation of skeletal muscle in habitual and non-habitual caffeine users. They found no difference between habitual and non-habitual caffeine consumption on any of the dependent variables. In addition, they found that during aerobic endurance activity, a portion of the ergogenic effect of caffeine comes directly from skeletal muscle activity due to an increase in the release of calcium from the sarcoplasmic reticulum, increased sensitivity of the skeletal muscles to calcium, and improvements in neuromuscular transmission (and possibly motor unit recruitment and firing rates). One of the primary mechanisms responsible for the ergogenic effects of caffeine is its inhibition of adenosine receptors.[10] Caffeine appears to improve our ability to handle mental and physical tasks, mainly through this inhibition of the adenosine receptor. Stimulation of these receptors (more specifically the A1 receptors) inhibits nerve cells and has a profound effect on the heart by lowering heart rate and slowing atrioventricular nodal conduction (a parasympathetic action). On the other hand, if these receptors are inhibited, as seen with caffeine ingestion, nerve cells are stimulated and heart rate is increased. Therefore, caffeine provides a sympathomimetic effect on the CNS and neuromuscular transmission by inhibiting adenosine receptor activity. Although studies are limited, the inhibition of adenosine receptor activity that caffeine possesses *may* also help in force production (strength and power) by increasing motor unit recruitment and firing rates.[6]

While it is not considered the primary mechanism behind the ergogenic effects of caffeine on submaximal endurance performance,[16] there is quite a bit of evidence suggesting that caffeine consumption increases plasma FFA for skeletal muscle to use as an energy substrate.[10,16,27,28,30,31,32,35,36] Caffeine promotes the breakdown of fat tissue during endurance exercise which increases FFA in the blood. With the increased availability of this energy substrate for the skeletal muscles, there is a reduced reliance on glycogen stores allowing the sparing of glycogen to be used later, thereby, improving endurance performance. Hence, caffeine is said to have a "glycogen-sparing" effect during prolonged, submaximal exercise. In addition, research shows that caffeine consumption before performing prolonged, submaximal exercise increases VO_2 (and fat oxidation) post exercise as well.[16,28,30]

Caffeine and Aerobic Exercise Performance

Graham & Spriet[15] demonstrated that low to moderate doses (3 - 6 mg/kg of body weight) of caffeine produced a greater effect on endurance performance, that is, time to exhaustion (TTE) at 85% of their maximum aerobic capacity (VO_{2MAX}), than high doses (9 mg/kg of body weight). In addition, acute caffeine consumption prior to exercise has been shown to improve aerobic performance and fitness parameters, whereas, prolonged consumption (along with aerobic training) has no effect on aerobic performance and fitness.[23] While most studies agree that moderate amounts of caffeine improves aerobic performance (endurance and speed) and enhances fat mobilization (resulting in an increase in plasma free fatty acids, or FFA) for use as energy,[10,13,14,16,27,31,33,35,36,37] some studies disagree and show no ergogenic effects.[14,16,19,27,29,32] In these studies that disagree, caffeine showed no significant effect on aerobic endurance performance, VO_{2MAX}, heart rate, respiratory exchange ratio (RER) and substrate utilization (i.e. FFA), or ratings of perceived exertion (RPE). In a very recent study, Beck et al. (2008) examined the effects of a caffeine supplement on time to running exhaustion (TRE) at 85% VO_{2PEAK} in thirty-one untrained and moderately trained men. They concluded that, while it may be possible that the acute effects of caffeine are affected by one's training status (i.e., provides more of an ergogenic effect in trained individuals) and the relative intensity of the task being performed (i.e., provides more of an ergogenic effect at low to moderate intensities), their results failed to validate caffeine as having an ergogenic effect on running performance. This supports what was previously mentioned about the actions on caffeine depending of several factors including *dose and training status.* In addition, the time lapse (acute vs. chronic) from ingestion of caffeine to the testing protocol may have had an impact on the ergogenic effects of caffeine.

Caffeine and Anaerobic Exercise Performance

Research on whether or not caffeine produces an effect on anaerobic performance is still in its infancy. Research does seem to lean in favor of caffeine improving muscular endurance (dynamic and specific), but not muscular power, and it is still in disagreement for caffeine improving maximal muscular strength.[2,3,5,7,12,17,18,19,38] Lopes et al.[22] and Tarnopolsky & Cupido[37] reported similar findings relative to the effects caffeine has on the tension developed within skeletal muscle during maximal voluntary contraction

(MVC) and tetanic stimulation (Hz) at different frequencies. Low frequency tetanic stimulation (20, 30, and 40 Hz) produced greater tension during the caffeine trials, after ingesting 6 mg of caffeine/kg of body weight (i.e., a moderate dose of caffeine[15]), than the placebo trials due to an increase in calcium release from the sarcoplasmic reticulum and an increase in the sensitivity of the skeletal muscles to calcium. The same was not true for peak twitch stimulation (100 Hz) or MVC. Therefore, caffeine directly stimulates skeletal muscle during endurance events (dynamic and specific), but not during events that require maximal strength. This has been shown to be true during anaerobic endurance cycling events where caffeine improves time to exhaustion (TTE) and allows one to maintain max speed for a set period of time (20 second sprints), even at intensities as high as 125% VO_{2PEAK},[2,7,20] but it may not be true during anaerobic endurance running events, i.e., time to running exhaustion (TRE at 85% VO_{2MAX}).[6] Caffeine may also have the potential to improve jumping endurance, which could be important for athletes such as basketball players and volleyball players. Low doses (2 mg/kg) of caffeine have been shown to increase the number of jumps performed at various heights in rats.[40]

Possible limitations to the studies on anaerobic performance and caffeine that could explain the conflicting results of previous studies are the doses of caffeine used, time lapse from ingestion to test, the use of mostly men, and the tests chosen. Most studies have used only low to moderate doses of caffeine (2mg/kg – 6mg/kg). One study stated their reason for using 6mg/kg was that it is strong enough to elicit an effect without violating the limits set by the International Olympic Committee (IOC).[17] It may be possible that stronger doses of caffeine are needed to improve anaerobic performance, however, the results of these studies would not benefit athletes and coaches. The time lapse from ingestion of caffeine to the test trials may also be responsible for conflicting results. All but one of the studies reported exercise testing 45 – 100 minutes after caffeine ingestion with the majority at 60 minutes post-ingestion. The study with the shortest time lapse had only 30 minutes from ingestion to test (i.e., ability to maintain max speed during 20 second cycle sprints) and successfully demonstrated an increase in the ability to maintain maximum speed with caffeine.[2]

The final limitation in these studies is the limited variability of tests chosen for testing maximal muscular strength (i.e., 1RM in the bench press and leg press) and lower body anaerobic power (i.e., standard 30s Wingate Anaerobic Test, or WAnTs, and 20s cycle sprints). Stickley, Hetzler, and Kimura[34] found that a 20 second WAnT protocol produced the same results without the ill effects that come with the standard 30 second WAnT protocol. Perhaps in the current studies the ill effects of the 30 second protocol outweighed the ergogenic effects of caffeine. More research into the effects of caffeine on anaerobic performance, especially upper and lower body resistance exercise endurance performance, maximal muscular strength and lower body power, is needed. Future studies should focus on including more females, investigating consumption of caffeine through common methods (i.e., commercially available energy drinks), use other durations in time from ingestion to test that have not been reported in the literature, and look at using different anaerobic tests. Also, more studies on caffeine's adenosine receptor antagonist action and motor unit recruitment and firing rates are needed to possibly explain the mechanism of action responsible for caffeine's ability, if any, to improve anaerobic performance.

Caffeine and Resistance Exercise Performance

In addition to dynamic muscular endurance, specific muscular endurance is also improved through the ingestion of caffeine. However, the research thus far only supports improvements in upper body muscular endurance, specifically the bench press exercise.[3,12,39] While not all investigations have reported significant improvements in muscular endurance for the bench press, one such investigation reported an 11-12% increase in repetitions to failure during the caffeine trial (using a dose of 6 mg/kg)[3] as compared to the placebo condition. Despite these studies showing no significant improvements in the leg press exercises, more total weight was still lifted during the caffeine trials.[3,39] Therefore, caffeine allows one to perform more total repetitions during bench press exercises, and possibly during leg press exercises, at moderate intensity (approximately 70% 1RM).

Equivocal data limit the conclusions that can be made relative to caffeine's effects on bench press and leg press 1RM.[3,6,7] In fact, two studies reported conflicting results despite the use of the same dose of caffeine and same exercise protocol.[6,7] Beck et al.[5] and Beck et al.[6] used the same 1RM bench press equipment and protocol and administered the same dose of caffeine (201 mg) to their participants. The difference between the two studies was the training background of the participants. In the first study,[5] the participants regularly engaged in resistance training (at least four sessions per week), whereas, in the second study[6] participants were untrained and not experienced with resistance training. It was the former study that demonstrated an ergogenic effect of caffeine on 1RM bench press while the latter study *did not.* The researchers concluded that a possible explanation for this may have been the differences in training status and experience of the participants. This reinforces the hypothesis that the ergogenic effects of caffeine depends on training status (favoring trained over untrained) and it demonstrates the need for further investigation into caffeine, training status, and maximal muscular strength.

Energy Drinks and Bench Press and Leg Press Exercise Performance

Studies that have examined the effects of energy drinks (which contain caffeine as the primary ergogenic ingredient) on anaerobic exercise performance have shown conflicting results. Forbes et al.[12] looked at the effects of Red Bull® Energy Drink on bench press muscle endurance performance. Sixty minutes following ingestion of a Red Bull® Energy Drink (with a caffeine dose of 2.0 mg/kg of body mass) or placebo drink, sixteen men and women performed three sets of the bench press exercise at 70% of their one-repetition maximum (with 1 minute rest between sets). The study demonstrated a significant improvement in upper body muscle endurance during the bench press exercise.

Woolf, Bidwell, and Carlson[39] studied the effects of a caffeine-containing "energy-shake" on anaerobic performance. They looked at total weight lifted during the leg press and bench press exercises. Nineteen male athletes consumed a caffeine-containing shake (with a caffeine dose of 5 mg/kg of body mass), or a placebo shake, 60 minutes prior to performing the exercise tests. After a ten minute dynamic and static warm-up, all participants performed the bench press and leg press exercises in a block randomized order. Results showed significant increases in the total weight lifted during the bench press exercise but not during the leg press exercise.

Both of these energy drink studies utilized a block randomized, double-blind, placebo-controlled, cross-over design. The main difference between the energy drink and the placebo drink was caffeine content (i.e., caffeine vs. no caffeine). In addition, all participants in these studies were either physically active or were athletes. Therefore, it is possible that the improvement in anaerobic performance was likely do to caffeine [(12,39)].

Dose, Side Effects, and Health Implications

There is still much debate as to the dose, the side effects, and health implications of chronic and acute caffeine consumption.[16] When considering caffeine dose, important questions to be asked (and studied) include:

- *What amount is the optimal (& safe) amount?*
- *How is it delivered?*
- *What are the correct methods, modes, and patterns of administration?*

The dose of caffeine in the Venom® Energy Drink that will be used in the current study is similar to Red Bull® Energy Drink (i.e., 80 mg / 8 oz of liquid). The common side effects of excessive intake of caffeine (i.e., $\geq$ 9mg/kg of body weight or > 500 mg total), especially for non-habitual consumers, are dependence, tolerance, diuresis, tremors, irritability, mood shifts, and agitation.[16,26] These side effects are especially important in competitive settings and why caffeine has been banned by some sport governing bodies. The debate concerning health implications revolve around insulin resistance (which can lead to Type II Diabetes Mellitus) and potential cardiovascular risks (especially if combined with ephedrine).[16]

Caffeine, Exercise, and the Menstrual Cycle

There are two phases to the menstrual cycle that are determined by the concentrations of estrogen and progesterone: 1) follicular phase (first 2 weeks of the cycle) where both hormone levels are low, however, near the end of this phase (right before ovulation) estrogen levels become high; and 2) luteal phase (final 2 weeks of cycle) where both hormone levels are high.[21] Due to the differences in the concentration levels of these hormones throughout the cycle, inter- and intra-individual differences within the study sample, and the variability in effect of the interaction between the two hormones (i.e., opposing vs. synergistic), timing of study tests *may* be important during aerobic exercise.[21] Although most research has found no differences, during the luteal phase both body temperature and cardiovascular strain increase *possibly* creating a negative effect on prolonged exercise performance.[21]

Research that has examined maximal strength and muscle contractile characteristics of women during their menstrual cycle show conflicting results.[21] Some show increased strength mid-cycle (i.e., near the end of the follicular phase) with a subsequent decrease in strength at, or around, ovulation claiming a positive effect of estrogen followed by an opposing effect of the interaction between estrogen and progesterone. However, other studies show negative effects of estrogen on strength. Research has also claimed a positive effect of progesterone, and possibly a synergistic effect of the interaction between estrogen and progesterone on strength by demonstrating increased strength during the luteal phase. Still, other studies show no differences in strength during the entire menstrual cycle.[21]

Two major limitations in these studies are: 1) most did not use true tests of maximal muscular strength (i.e., superimposed electrical stimulus) and 2) most did not provide verification of hormone levels by testing their participants. The measurement and verification of estrogen and progesterone levels is important in research that involves women who are eumenorrheic.[21] The majority of the studies that did measure and provide verification of hormone levels saw no change in strength, muscle contractile characteristics, or lactate response (fatigability) in eumenorrheic women. Therefore, it would be unnecessary to adjust for the menstrual cycle when studying muscular strength and/or endurance of women experiencing normal menstruation. Nor would it be necessary to make adjustments for competition or while training normal eumenorrheic women who are involved in strength-specific, intense anaerobic or intense aerobic sport.

The menstrual cycle, as well as gender or exercise, has not been shown to effect how caffeine is absorbed, metabolized, distributed, or eliminated.[24] However, caffeine intake may affect the *length* of a woman's menstrual cycle. Fenster et al.[11] looked at habitual caffeine consumption and menstrual function in healthy premenopausal women. They found that habitual caffeine consumption affected the length of the menstrual cycle. Women who consumed more than 300 mg of caffeine a day (considered heavy consumption) were a third less likely to have a long cycle and, in fact, actually increased (doubled) their risk for a shorter cycle. Researchers believe that there are two reasons behind these findings. First, caffeine affects luteinizing hormone and follicle-stimulating hormone by inhibiting adenosine. These two hormones are involved in the menstrual cycle and may affect the length of the cycle. Second, caffeine is a vasoconstrictor, therefore high consumption would be expected to constrict the uterine blood vessels thereby reducing blood flow and possibly shortening the menstrual cycle.[11]

Summary

Energy drinks are becoming very popular among athletes and fitness enthusiasts as a way of giving them an edge on performance. The main active ingredient in energy drinks is caffeine. While research supports the theory that caffeine ingestion improves *aerobic* endurance performance, research on the effects of caffeine on *anaerobic* performance is limited. Research has provided much insight as to the possible mechanisms behind the ergogenic effects of caffeine, mainly for aerobic performance. First, inhibition of adenosine receptors appears to be the most important during aerobic activity. Inhibition of these receptors improves nerve cell function (improving neuromuscular transmission and possibly motor unit recruitment and firing rates) and provides a sympathomimetic effect on the body (stimulates the CNS). Second, caffeine increases the strength of skeletal muscle contraction by stimulating the release of calcium from the sarcoplasmic reticulum and increases the muscle tissue's sensitivity to calcium. Finally, and to a lesser effect, caffeine promotes increases in FFA in the blood to be used by the skeletal muscles for energy during prolonged, submaximal activity, allowing the muscles to "spare" their glycogen stores. All of these mechanisms have been shown to improve aerobic endurance performance. Tolerance to the effects of caffeine has been observed in the literature demonstrating that caffeine consumption status (i.e., habitual vs. non-habitual) does not affect aerobic performance.[37]

Research on caffeine and *anaerobic* performance is somewhat limited. Therefore, potential for future studies into the effects of caffeine ingestion on *anaerobic* performance is high, especially with focus on direct testing of muscular endurance, strength, and power as well as on adenosine receptor antagonist action and force production (i.e., motor unit recruitment and firing rates). When taken in moderate amounts, caffeine *can* be used by athletes and non-athletes as a way of improving their time to exhaustion (i.e. performance) during prolonged, submaximal exercise but data is conflicting on more intense, short-term exercise. There is also evidence indicating that moderate amounts of caffeine enhance dynamic and specific muscular endurance. However, more research needs to be conducted in relation to caffeine ingestion and its effects on muscular endurance, strength and power.

Chapter Three

Methodology

Study Design

The study was consistent with previous studies in that utilized a block randomized, double-blind, placebo-controlled, crossover design.

Participants

Thirteen recreationally trained (physically active at least three times a week) volunteers, 18 to 35 years of age, participated in the study. The sample consisted of 8 males (body mass index, or BMI = 25.0 $\pm$ 3.0 kg/m^2) and 5 females (BMI = 21.4 $\pm$ 1.9 kg/m^2). Since the menstrual cycle does not affect anaerobic exercise, we did not control for women who were eumenorrheic. Participants were randomly assigned to one of two groups: an energy drink group (ENE) and a placebo drink group (PLA). Each participant visited the laboratory for four separate sessions (Table 1).

Table 1

Description of Laboratory Visits

Session	Description
1	Screening that included a physical exam, informed consent, and personal/medical history questionnaires
2	Familiarization and baseline testing that included bench press and leg press 1RM testing, a run through of the testing protocol to be used, and verbal/written pre-testing session rules
3	Random assignment to either ENE or PLA group and testing session 1
4	Testing session 2

Entry and Physician Clearance Session

Participants were recruited by word-of-mouth from the University of South Florida and the surrounding Tampa Community. Participants, 18 to 35 years of age, who were apparently healthy and who participate in some form of physical activity at least three times per week were invited to attend *Session 1* at the University's Exercise and Performance Nutrition Laboratory. During this session participants 1) completed personal and medical history questionnaires, 2) signed an informed consent statement, and 3) were cleared to participate by a licensed physician.

Familiarization and Baseline Testing Session

Participants who met the entry criteria and who were cleared to participate were invited back to the lab to attend *Session 2*. They were also instructed to refrain from resistance training for 4 days prior to attending *Session 2*. This instruction was given at the time they accepted the offer to participate. *Session 2* consisted of four parts. First, participants were familiarized to the study via a verbal and written explanation outlining the study design. Next, participants had their one-repetition maximum (1RM) tested in both the bench press (BP) and leg press (LP) exercises using standard procedures.[1] For both exercises, 1RM was determined within 6 sets with 2 minute rests between sets. Participants warmed-up by completing 2 sets of 10 repetitions at 50% of their perceived capacity for each exercise. Participants then performed successive 1RM lifts of both exercises starting with a weight that is within their perceived capacity (approximately 70% of capacity). For the BP weight was increased by 10 – 20 pounds and for the LP weight was increased by 30 – 40 pounds. The final weight successfully lifted one time, for each exercise, was recorded as the participant's 1RM. Third, participants were familiarized with the testing protocol by having them complete all sets and rest periods in the order to be used during the testing sessions, as outlined in the *Methods and Materials* section. Finally, participants were instructed to refrain from resistance training during the course of the study ($\leq$ 2 weeks) as well as refrain from any *exhaustive* exercise for 48 hours prior to each testing session. They were also instructed to refrain from ingesting caffeine 48 hours prior to each testing session. To help facilitate this, participants were instructed verbally and in writing to 1) avoid consuming caffeine-containing foods and medications (Appendix 1), 2) to read nutrition labels of any food item to see if caffeine is an ingredient, and 3) try to eat the same foods the day prior to each training session. Testing took place in the morning; therefore, participants were also instructed to fast for 10 hours prior to each testing session.

Testing Protocol

Sessions 3 and *4* consisted of the participants performing the BP and LP exercises in a *back-to-back* fashion, as outlined in the *Methods and Materials* section, took take place approximately 7 days following *Session 2*. Initially, participants were randomly assigned to either the ENE group or the PLA group. During *Session 3* the ENE group consumed the energy drink and the PLA group consumed the placebo drink. Seven days later, at the same time of the day, all participants returned to attend *Session 4*. This time, however, the ENE group from *Session 3* became the PLA group and the PLA group became the ENE group. Figure 1 displays the outline of *Sessions 3* and *4*.

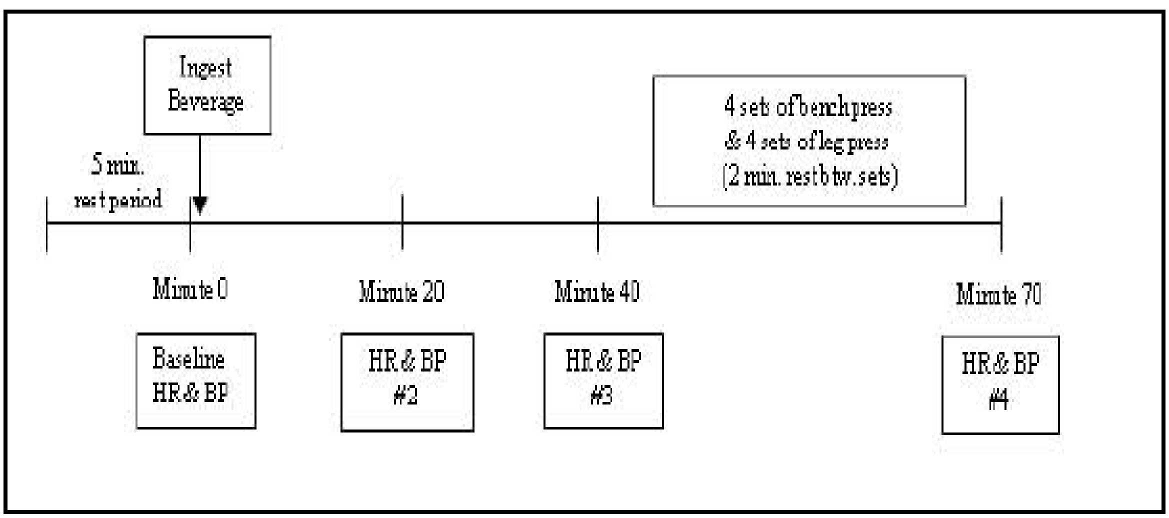

Figure 1. Outline of Sessions 3 and 4 (resistance exercise sessions).

Supplementation Protocol

Participants were randomly assigned to one of two groups: ENE group or PLA group. Upon arriving at the laboratory for each session, participants sat and rested in a chair for 5 minutes. Then, in a double-blind manner, one group consumed a shake that contained Venom® Energy Drink, a 16 oz energy drink containing 160 mg of caffeine (ENE group; approximately 2 – 3 mg of caffeine/kg of body weight), while the other group consumed a placebo shake of similar volume, texture, and carbohydrate content as the energy drink shake (PLA group). Supplements were prepared by a third party. The beverages were transferred to a Styrofoam cup with a straw and were labeled with the participant's initials. Before ingestion, each participant was blindfolded and a clip was placed on their nose. Forty-five minutes following ingestion participants began the session's tests as outlined in the *Methods and Materials* section.

Methods and Materials

Body weight and height. Participant's body mass and height were obtained using the "Health-O-Meter" Professional® height and weight scale.

Heart rate and blood pressure. All heart rate measurements were determined by palpation of the radial artery using standard procedures.[1] All blood pressure measurements were determined in the seated position using a mercurial sphygmomanometer using standard procedures.[1] After arriving at the lab and resting for 5 minutes, and prior to ingesting the energy or placebo drink, resting heart rate and blood pressure were recorded. Heart rates and blood pressures were again recorded pre-test at

20 and 40 minutes post-ingestion. A final heart rate and blood pressure were recorded 5 minutes post-test.

Caffeine consumption status evaluation. Although an individual's caffeine intake history (i.e., habitual versus non-habitual caffeine consumption) has been shown to not affect *aerobic* performance,[37] each participant in the current study was surveyed, as part of their personal history questionnaire, as to the status of their current caffeine intake. On a scale of 1-5 [1 = *never* (< 1 day/week), 2 = *rarely* (1-2 days/week), 3 = *sometimes* (3-4 days/week), 4 = *often* (5-6 days/week), or 5 = *daily* (≥ 7 days/week)] the questionnaire (17 questions) asked the participants how often they consume/take the caffeine-containing foods and medications listed in Table 1.[8] A score of 59 was used as the cutoff point between habitual and non-habitual caffeine consumption. Therefore, a score of 59 or less (which equated to ≤ 3 days of caffeine consumption per week) meant the participant is a non-habitual caffeine consumer and a score of 60 or higher (which equated to ≥ 4 days of caffeine consumption per week) meant the participant is a habitual caffeine consumer. After reviewing all questionnaires, it was determined that all participants were non-habitual caffeine consumers (the highest score was a 32)

Resistance exercise tests. The LP and BP exercises were performed *back-to-back*, in a rotated fashion as follows: LP set 1, 2 minute rest, BP set 1, 2 minute rest, LP set 2, 2 minute rest, BP set 2, 2 minute rest, LP set 3, 2 minute rest, BP set 3, 2 minute rest, LP set 4, 2 minute rest, and BP set 4. For both exercises, participants performed all 4 sets to volitional fatigue at 80% of their 1RM.

Research design and data analysis. Each participant served as his or her own control and was tested on each dependent variable two times (after ingesting the energy drink shake and after ingesting the placebo shake). Null hypotheses were tested via a dependent samples *t* test and the criterion for significance for all tests was set at $p < 0.05$. Effect sizes were calculated by subtracting mean one from mean two and dividing by the average of the two standard deviations involved (Cohen's *d*).

Chapter Four

Results

Thirteen physically active volunteers participated in the study (8 males and 5 females). Descriptive statistics for age, weight, height, and BMI are presented in Table 2, descriptive statistics for 1 RM in both exercises are presented in Table 3, and descriptive statistics for repetitions completed per set (and the range of repetitions) are presented in Table 4. To test the null hypotheses, dependent samples *t*-tests were conducted to determine if there were significant differences in bench press total volume (kg) between the two groups, in leg press total volume (kg) between the two groups, and in total workout volume (kg) between the two groups. Effect sizes (Cohen's *d*) for each dependent variable were also calculated to determine if there is any significance in the outcomes of the *t*-tests. These values are summarized and listed in Table 5.

Table 2

Characteristics of Study Participants (N = 13).

Variable	Mean	Standard Deviation
Age (yrs)	22.5	3.4
Height (total; cm)	174.9	11.2
Height (males; cm)	181.8	6.2
Height (females; cm)	163.7	7.3
Weight (total; kg)	73.2	17.9
Weight (males; kg)	83.3	15.4
Weight (females; kg)	57.1	4.1
BMI (total; kg/m^2)	23.6	3.1
BMI (males; kg/m^2)	25.0	3.0
BMI (females; kg/m^2)	21.4	1.9

Table 3

One-Repetition Maximum in the Bench Press and Leg Press Exercises (Expressed as Absolute and Relative).

Variable	Mean	Standard Deviation
Absolute BP 1 RM (total; kg)	79.0	38.5
Absolute BP 1 RM (males; kg)	106.3	17.5
Absolute BP 1 RM (females; kg)	35.5	7.1
Relative BP 1 RM (total)	1.0	0.4
Relative BP 1 RM (males)	1.3	0.2
Relative BP 1 RM (females)	0.6	0.1
Absolute LP 1 RM (total; kg)	268.9	117.4
Absolute LP 1 RM (males; kg)	346.9	72.0
Absolute LP 1 RM (females; kg)	144.1	25.5
Relative LP 1 RM (total)	3.6	1.0
Relative LP 1 RM (males)	4.2	0.5
Relative LP 1 RM (females)	2.6	0.6

Note. RM = repetition maximum. Relative was calculated by dividing the absolute 1 RM (kg) by the sample's weight in kg. BP = bench press; LP = leg press.

Table 4

Repetitions Completed per Set and Repetition Range per Set.

	Males		Females	
Variable	(Mean ± SD)	Range	(Mean ± SD)	Range
ENE Group				
BP Set 1 repetitions	8.5 ± 2.7	10	10.0 ± 3.1	9
BP Set 2 repetitions	6.6 ± 2.3	8	8.4 ± 1.1	4
BP Set 3 repetitions	5.8 ± 2.3	8	5.8 ± 0.4	2
BP Set 4 repetitions	4.3 ± 1.4	5	5.0 ± 1.0	3
LP Set 1 repetitions	12.5 ± 6.2	20	15.8 ± 7.5	21
LP Set 2 repetitions	9.8 ± 3.2	12	13.6 ± 6.0	16
LP Set 3 repetitions	7.1 ± 2.5	8	11.0 ± 5.1	15
LP Set 4 repetitions	5.8 ± 2.1	6	9.4 ± 5.3	15
PLA Group				
BP Set 1 repetitions	9.6 ± 2.3	8	11.8 ± 1.3	4
BP Set 2 repetitions	7.0 ± 1.7	6	8.2 ± 0.8	3
BP Set 3 repetitions	5.0 ± 1.5	5	6.4 ± 0.5	2
BP Set 4 repetitions	4.6 ± 1.6	6	5.2 ± 1.1	4
LP Set 1 repetitions	12.1 ± 6.2	20	13.2 ± 6.4	17
LP Set 2 repetitions	8.8 ± 4.0	12	9.2 ± 3.3	9
LP Set 3 repetitions	7.0 ± 1.8	5	8.2 ± 2.9	9
LP Set 4 repetitions	4.8 ± 1.4	5	8.4 ± 4.7	14

Note. ENE Group = energy drink group; PLA Group = placebo drink group; BP = bench press; LP = leg press.

Table 5

Test Comparisons for Dependent Variables

Variable	ENE (mean ± SD; kg)	PLA (mean ± SD; kg)	*p* Value	Effect Size (Cohen's *d*)
BP TV	1,639 ± 891	1,711 ± 832	.314	.08
LP TV	8,099 ± 3,293	7,139 ± 3,197	.108	.3
TWV	9,738 ± 3,744	8,849 ± 3,560	.150	.2

Note. Data were analyzed using Dependent Samples *t*-Tests. BP TV = Bench Press Total Volume (kg x reps); LP TV = Leg Press Total Volume (kg x reps); TWV = Total Workout Volume (BP TV + LP TV).

Bench Press Total Volume

Ho_1 stated there will be no difference in bench press total lifting volume between the energy drink group and the placebo group. No statistically significant differences were found in bench press total volume between the energy drink trials and the placebo drink trials (ENE = 1,639 ± 891 kg; PLA = 1,711 ± 832 kg; p = .314; effect size = .08). Therefore, based on the non-significant results, we fail to reject the null hypothesis (Ho_1).

Leg Press Total Volume

Ho_2 stated there will be no difference in leg press total lifting volume between the energy drink group and the placebo group. No statistically significant differences were found in leg press total volume between the energy drink trials and the placebo drink trials (ENE = 8,099 ± 3,293 kg; PLA = 7,139 ± 3,197 kg; p = .108; effect size = .3). Therefore, based on the non-significant results, we fail to reject the null hypothesis (Ho_2).

Total Workout Volume

Ho_3 stated there will be no difference in whole body total lifting volume between the energy drink group and the placebo group. No statistically significant differences were found in total workout volume between the energy drink trials and the placebo drink trials (ENE = 9,738 ± 3,744 kg; PLA = 8,849 ± 3,560 kg; p = .150; effect size = .2). Therefore, based on the non-significant results, we fail to reject the null hypothesis (Ho_3).

Chapter Five

Discussion

The major, *statistical*, finding of this study is that consumption of a commercially available energy drink does not produce an ergogenic effect by improving anaerobic exercise performance in regards to resistance exercise lifting volume (i.e., bench press total volume, leg press total volume, or total workout volume) when the exercises are performed forty-five minutes following ingestion. However, due to the small effect size of each *t*-test, the non-significant results of this study do not necessarily imply that there is no difference between the two groups. There was a 13% increase in leg press total volume and a 10% increase in total workout volume during the energy drink trials. Therefore, from a practical sense, consumption of a commercially available energy drink *does* produce an ergogenic effect by improving anaerobic exercise performance in regards to resistance exercise lifting volume.

An interesting finding was that for bench press total volume the placebo drink group lifted more total volume (9% more) than the energy drink group. Previous studies that have examined energy drink consumption (containing caffeine) on bench press performance have demonstrated improvements in bench press endurance performance.[3,12,39] Both Forbes et al.[12] and Woolf, Bidwell, and Carlson[39] demonstrated statistically significant increases in bench press endurance performance after participants consumed an energy drink or "energy shake." In the former study, physically active men, who participated in moderate physical activity 2-3 days per week, consumed a Red Bull®

energy drink (approximately 2.0 mg of caffeine/kg of body weight) 60 minutes before performing the bench press exercise on a lever chest press machine. Participants performed 3 sets, to volitional fatigue, at 70% of their one-repetition maximum (1RM) with 1 minute rests between sets. In the latter study, participants were athletes who participated in at least 12 hours per week of some type of programmed physical activity that included 2-4 hours per week of strength, endurance, and movement training. Sixty minutes after ingesting a caffeine-containing "energy shake" (approximately 5 mg of caffeine/kg of body weight), participants completed 1 set each, to volitional fatigue, of the bench press exercise and leg press exercise, on Keiser Exercise Equipment, with 1 minute rest between the two exercises. Percentage of 1RM for each exercise was not reported. Although the results of one of these previous studies that showed improvement in bench press endurance performance, Astorino, Rohman, and Firth,[3] were not significant, the caffeine trials did show an 11-12% increase in repetitions to failure (using a sample size of 22, the statistical power was .2 for the bench press and .1 for the leg press). In this study, participants (who were experienced with resistance training) consumed pharmaceutical-grade caffeine anhydrous (approximately 6 mg of caffeine/kg of body weight), rested for 60 minutes, and then completed (on separate days) the bench press exercise and leg press exercise on standard free-weight equipment (i.e., a barbell and horizontal bench and a 45^{o} plate-loaded sled, respectively). The exercises were completed immediately after they were tested for their 1RM and the protocol called for 1 set of each, to volitional fatigue, at 60% of their 1 RM.

Of the previous studies that demonstrated improvements in bench press endurance performance[3,12,39] only one had similar participants (men and women who were physically active 2-3 days/week; $N = 15$), similar supplementation (2.0 mg of caffeine/kg of body weight compared to the current study's 2 – 3 mg/kg of body weight), and a similar lifting scheme (3 sets to volitional fatigue).[12] The major differences were the time from ingestion to testing (60 minutes compared to the 45 minutes in the current study), the equipment used (a lever chest press machine compared to a standard barbell and bench in the current study), and the intensity used (70% of 1RM compared to the 80% of 1RM in the current study). The other bench press studies share no similarities to the current study,[3,39] except one that used the same equipment (i.e., a barbell and standard bench).[3] The current study used men and women (compared to just men; $N = 22$ and $N = 8$), used 45 minutes from ingestion of the energy drink to testing (compared to 60 minutes), only screened for participants who were physically active (compared to athletes or individuals who were experienced with resistance exercise), used an energy drink with a caffeine dose of approximately 2-3 mg/kg of body weight (compared to an "energy shake" with a caffeine dose of approximately 5 mg/kg of body weight or a caffeine pill with a caffeine dose of approximately 6 mg/kg of body weight), had participants complete 3 sets to volitional fatigue (compared to 1 set to volitional fatigue), and used an exercise intensity of 80% of 1RM (compared to 60% of 1RM) .

After examining the similarities and differences between the bench press endurance studies, there are two possible reasons for the failure of the current study to demonstrate an ergogenic effect of Venom® Energy Drink on bench press endurance performance.. First, it is possible that the 80% of 1RM used was too heavy to allow for more volume to be lifted. It's known that caffeine action on the body depends on several factors, one of which is the relative intensity of the task being performed.[9] The previous studies that reported the percentage of 1RM used had participants lift 10-20% less (than the 80% used in the current study) of their 1RM. Second, it is possible that the 45 minutes from ingestion to testing was not long enough to allow for peak caffeine absorption. Sixty minutes is the approximate time it takes for caffeine to reach its peak concentration in the blood,[12] which was the time from ingestion to testing used in the previous studies.[3,12,39] Therefore, since Forbes et al.[12] was similar to the current study in so many aspects *except* for the intensity used and the time from ingestion to testing, these are plausible conclusions to the current study's findings regarding the effects on an energy drink on bench press performance.

The results of the current study relating to leg press endurance performance does agree with previous studies that have examined caffeine or energy drink consumption and leg press exercise performance.[3,39] Although these previous studies, as well as the current study, showed no significant improvements in the leg press exercise, the data trended towards significance. Previous studies that examined caffeine/energy drinks and leg press endurance performance share no similarities to the current study, [3,39] except one that used the same equipment (i.e., a standard 45^{o} plate-loaded sled).[3] After examining these differences, which are the same as the differences noted previously in the discussion on bench press endurance performance, it is believed that the failure of the current study to demonstrate an ergogenic effect of Venom® Energy Drink on leg press endurance performance is related to the dose of caffeine and one of the possible reasons behind caffeine's ergogenic effect on skeletal muscle. As mentioned in the literature review, a portion of the ergogenic effect of caffeine comes directly from skeletal muscle activity due to an increase in the release of calcium from the sarcoplasmic reticulum, increased sensitivity of the skeletal muscles to calcium, improvements in neuromuscular transmission, and possibly motor unit recruitment and firing rates).[37] In addition, inhibition of adenosine receptor activity may also help in force production by increasing motor unit recruitment and firing rates.[6] If caffeine has the potential to increase force production by increasing motor unit recruitment, individuals with larger muscle mass (e.g., athletes and resistance trained individuals) and exercises that involve the larger muscles/muscle groups in the body (e.g., legs versus the chest) would require larger doses of caffeine to activate the greater number of motor units that come with larger muscle mass. Therefore, because the upper leg is composed of such a large amount of muscle fibers, it's possible that a caffeine dose as high as 6 mg/kg of body weight may not be enough to produce an ergogenic effect. Since the variable "total workout volume" in the current study is simply the sums of the total volumes for the bench press and leg press exercises, and given that there were no significant differences in total volume for each exercise separately, it is no surprise that there were no significant differences in total workout volume between the energy drink trials and the placebo trials.

There are some limitations to the current study that could possibly explain the results for the bench press trials conflicting with the results of previous studies. First, as mentioned above, the time frame from ingestion of the energy drink to performing the bench press exercise may not have been long enough to allow for peak absorption of caffeine into the blood. Second, also mentioned above, the percentage of the participant's one repetition maximum used in the bench press exercise may have been too much. Lastly, the training background (i.e., experience with resistance training) may partially explain the lack of improvement in bench press performance. The current study used recreationally trained participants, meaning that they only needed to be physically active at least three times a week. While conducting the study, it was apparent to the researchers that some of the participants were not experienced in the bench press exercise. Two previous studies, Beck et al.[5] and Beck et al.[6] investigated caffeine and one-repetition maximum (1 RM) bench press performance. The major difference between the two studies was the training background of the participants. In one study the participants regularly participated in resistance exercise (and demonstrated a significant improvement in bench press 1 RM)[5] while those in the other study[6] were not experienced with resistance exercise (and did not demonstrate an improvement in 1 RM). The two noteworthy strengths of the current study are: 1) its block randomized, double-blind, placebo-controlled, crossover design which is consistent with previous studies and 2) its inclusion of female research participants.

In conclusion, the current study does not support the use of a commercially available energy drink to increase bench press exercise or leg press exercise endurance performance. Our findings, in regards to the leg press exercise, share two aspects with previous studies: 1) that there were no *statistically* significant improvements in total leg press performance and 2) the energy drink trials lifted more total volume. On the other hand, our findings regarding bench press performance is in contrast to other studies. Previous studies[3,12,39] have demonstrated that the ingestion of caffeine and/or energy drinks may allow one to perform more total repetitions during bench press exercises, and possibly during leg press exercises, at moderate intensity (approximately 70% 1RM). However, results from the current study cannot be used to support this statement.

In light of these findings, more research on the effects of energy drinks and resistance training performance is recommended. These future studies need to focus on the factors behind the actions of caffeine. Specifically, the exercises performed (i.e., the type, intensity, and duration), the training status of the participants, individual differences of the participants (i.e., specific caffeine consumption status), and the dose of caffeine. For exercises performed, future studies should include other common exercise and not just the bench press and leg press. In addition, the duration of the exercise session should be lengthened by having participants perform more than just two exercises, possibly focusing on a full workout to see if the effects of caffeine wear off. The intensities used should also be varied, since not everyone uses an intensity of 80% of their 1 RM.

As for the participants themselves, future research should focus on examining trained versus untrained participants in the same study. This would allow for comparison in training status of the participants, that is, those experienced with resistance exercise and those with no experience. In addition, including participants based on a more specific analysis of their caffeine consumption status (i.e., the actual mg of caffeine they consume each week) may provide a different insight into the ergogenic effects of caffeine/energy drinks on anaerobic exercise performance.

Lastly, the dose of caffeine needs to be increased in future studies. The current research primarily has focused on low to moderate doses of caffeine (2 mg/kg of body weight – 6 mg/kg of body weight). For some exercises, and muscle groups, higher doses of caffeine may be needed to produce significant increases in performance. Since caffeine and anaerobic exercise performance is still in its infancy, and due to the many different factors behind caffeine action, the future research potential is quite large.

References Cited

1. American College of Sports Medicine (8th Ed.). (2010). *Guidelines for exercise testing and prescription.* Philadelphia, PA: Lippincott, Williams & Wilkins.
2. Alford, C., Cox, H., and Wescott, R. (2001). The effects of Red Bull Energy Drink on human performance and mood. *Amino Acids*, *21*, 139 – 150.
3. Astorino, T. A., Rohman, R. L., and Firth, K. (2008). Effect of caffeine ingestion on one-repetition maximum muscular strength. *European Journal of Applied Physiology, 102(2),* 127 – 132.
4. Baechle, T. R., & Earle, R. W. (Eds.). (2000). *Essentials of strength training and Conditioning.* Champaign, IL: Human Kinetics.
5. Beck, T. W., Housh, T. J., Schmidt, R. J., Johnson, G. O., Housh, D. J., Coburn, J. W. and Malek, M. H. (2006). The acute effects of a caffeine-containing supplement on strength, muscular endurance, and anaerobic capabilities. *Journal of Strength and Conditioning Research, 20(3),* 506 – 510.
6. Beck, T. W., Housh, T. J., Malek, M. H., Mielke, M., and Hendrix, R. (2008). The acute effects of a caffeine-containing supplement on bench press strength and time to running exhaustion. *Journal of Strength and Conditioning Research, 22(5),* 1654 – 1658.
7. Bell, D. G., Jacobs, I., and Ellerington, K. (2001). Effect of caffeine and ephedrine ingestion on anaerobic exercise performance. *Medicine and Science in Sports and Exercise*, *33(8),* 1399 – 1403.

8. Caffeineindependence.org. (2003). *Johns Hopkins Bayview Medical Center's Information about Caffeine Dependence*. Retrieved April 21, 2009, from http://www.caffeinedependence.org/caffeine_dependence.html#intoxication.

9. Denadai, B. S. and Denadai, M. L. (1998). Effects of caffeine on time to exhaustion in exercise performed below and above the anaerobic threshold. *Brazilian Journal of Medicine and Biological Research, 31(4),* 581 – 585.

10. Dodd, S. L., Herb, R. A., and Powers, S. K. (1993). Caffeine and exercise performance. An update. *Sports Medicine, 15(1),* 14 – 23.

11. Fenster, L., Quale, C., Waller, K., Windham, G. C., Elkin, E. P., Benowitz, N., and Swan, S. H. (1999). Caffeine consumption and menstrual function. *American Journal of Epidemiology, 149(6),* 550 – 557.

12. Forbes, S. C., Candow, D. G., Little, J. P., Magnus, C., and Chilibeck, P. D. (2007). Effects of Red Bull Energy Drink on repeated Wingate cycle performance and bench-press muscle endurance. *International Journal of Sports Nutrition and Exercise Metabolism, 17,* 433 – 444.

13. French, C., McNaughton, L., Davies, P., and Tristram, S. (1991). Caffeine ingestion during exercise to exhaustion in elite distance runners. *Journal of Sports Medicine and Physical Fitness, 31(3),* 425 – 432.

14. Graham, T. E. and Spriet, L. L. (1991). Performance and metabolic responses to a high caffeine dose during prolonged exercise. *Journal of Applied Physiology, 71(6),* 2292 – 2298.

15. Graham, T. E. and Spriet, L. L. (1995). Metabolic, catecholamine, and exercise performance responses to various doses of caffeine. *Journal of Applied Physiology, 78(3),* 867 – 874.

16. Graham, T. E. (2001). Caffeine, coffee and ephedrine: impact on exercise performance and metabolism. *Canadian Journal of Applied Physiology, 26,* 103 – 119.

17. Greer, F., McLean, C., and Graham, T. E. (1998). Caffeine, performance, and metabolism during repeated Wingate exercise tests. *Journal of Applied Physiology, 85(4),* 1502 – 1508.

18. Greer, F., Morales, J., and Coles, M. (2006). Wingate performance and surface EMG frequency variables are not affected by caffeine ingestion. *Applied Physiology, Nutrition, and Metabolism, 31(5),* 597 – 603.

19. Hunter, A. M., St. Clair-Gibson, A., Collins, M., Lambert, M., and Noakes, T. D. (2002). Caffeine ingestion does not alter performance during a 100-km cycling time-trial performance. *International Journal of Sports, Nutrition, and Exercise Metabolism, 12(4),* 438 – 452.

20. Jackman, M., Wendling, P., Friars, D., and Graham, T. E. (1996). Metabolic catecholamine, and endurance responses to caffeine during intense exercise. *Journal of Applied Physiology, 81(4),* 1658 – 1663.

21. Janse de Jonge, X. A. K. (2003). Effects of the menstrual cycle on exercise performance. *Sports Medicine, 33(11),* 833 – 851.

22. Lopes, J. M., Jardim, A. J., Aranda, J. V., and Macklem, P. T. (1983). Effect of caffeine on skeletal muscle function before and after fatigue. *Journal of Applied Physiology, 54(5),* 1303 – 1305.

23. Malek, M. H., Housh, T. J., Coburn, J. W., Beck, T. W., Schmidt, R. J., Housh, D. J., and Johnson, G. O. (2006). Effects of eight weeks of caffeine supplementation and endurance training on aerobic fitness and body composition. *Journal of Strength and Conditioning Research, 20(4),* 751 – 755.

24. McLean, C., and Graham, T. E. (2002). Effects of exercise and thermal stress on caffeine pharmacokinetics in men and eumenorrheic women. *Journal of Applied Physiology, 93,* 1471 – 1478.

25. Nelig, A. and Debry, G. (1994). Caffeine and sports activity: a review. *International Journal of Sports Medicine, 15(5),* 215 – 223.

26. Paluska, S. A. (2003). Caffeine and exercise. *Current sports and medicine reports, 2(4),* 213 – 219.

27. Powers, S. K. and Dodd, S. (1985). Caffeine and endurance performance. *Sports Medicine, 2(3),* 165 – 174.

28. Roberts, M. D., Taylor, l. W., Wismann, J. A., Wilborn, C. D., Kreider, R. B., and Willoughby, D. S. (2007). Effects of ingesting JavaFit Energy Extreme functional coffee on aerobic and anaerobic fitness markers in recreationally-active coffee consumers. *Journal of the International Society of Sports Nutrition, 4,* 25.

29. Roy, B. D., Bosman, M. J., and Tarnopolsky, M. A. (2001). An acute oral dose of caffeine does not alter glucose kinetics during prolonged dynamic exercise in trained endurance athletes. *European Journal of Applied Physiology, 85(3-4),* 280 – 286.

30. Ryu, S., Choi, S. K., Joung, S. S., Suh, H., Cha, Y. S., Lee, S., and Lim K. (2001). Caffeine as a lipolytic food component increases endurance performance in rats and athletes. *Journal of Nutrition Science and Vitaminology, 47(2),* 139 – 146.

31. Sachan, D. S. and Hongu, N. (2000). Increases in VO2max and metabolic markers of fat oxidation by caffeine, carnitine, and choline supplementation in rats. *Journal of Nutritional Biochemistry, 11(10),* 521 – 526.

32. Sasaki, H., Takaoka, I, and Ishiko, T. (1987). Effects of sucrose and caffeine ingestion on running performance and biochemical responses to endurance running. *International Journal of Sports Medicine, 8(3),* 203 – 207.

33. Sasaki, H., Maeda, J., Usui, S., and Ishiko, T. (1987). Effect of sucrose and caffeine ingestion on performance of prolonged strenuous running. *International Journal of Sports Medicine, 8(4),* 261 – 265.

34. Stickley, C. D., Hetzler, R. K., and Kimura, I. F. (2008). Prediction of anaerobic power values from an abbreviated WAnT Protocol. *Journal of Strength and Conditioning Research, 22(3),* 958 – 965.

35. Tarnopolsky, M. A., Atkinson, S. A., MacDougall, J. D., Sale, D. G., and Sutton, J. R. (1989). Physiological responses to caffeine during endurance running in habitual caffeine users. *Medicine and Science in Sports and Exercise, 21(4),* 418 – 424.

36. Tarnopolsky, M. A. (1994). Caffeine and endurance performance. *Sports Medicine, 18(2),* 109 – 125.

37. Tarnopolsky, M. and Cupido, C. (2000). Caffeine potentiates low frequency skeletal muscle force in habitual and nonhabitual caffeine consumers. *Journal of Applied Physiology, 89(5),* 1719 – 1724.

38. Williams, J. H. (1991). Caffeine, neuromuscular function and high-intensity exercise performance. *Journal of Sports Medicine and Physical Fitness, 31(3),* 481 – 489.

39. Woolf, K., Bidwell, W. K., and Carlson, A. G. (2008). The effect of caffeine as an ergogenic aid in anaerobic exercise. *International Journal of Sport Nutrition and Exercise Metabolism, 18(4),* 412 – 429.

40. Zheng, S. and Shu-Zhi, L. (1987). Effects of amphetamine and caffeine on jumping behavior and brain NADH in rats. *Acta Pharmacologica Sinica, 8(2),* 97 – 100.

Appendices

Appendix 1

Typical Caffeine Content of Common Foods and Medications.[8]

Substance	Serving Size (volume or weight)	Caffeine Content (range)	Caffeine Content (typical)
Coffee: Brewed/Drip	6 oz	77-150 mg	100 mg
Coffee: Instant	6 oz	20-130 mg	70 mg
Coffee: Espresso	1 oz	30-50 mg	40 mg
Coffee: Decaffeinated	6 oz	2-9 mg	4 mg
Tea: Brewed	6 oz	30-90 mg	40 mg
Tea: Instant	6 oz	10-35 mg	30 mg
Tea: Canned or Bottled	12 oz	8-32 mg	20 mg
Caffeinated Soft Drinks	12 oz	22-71 mg	40 mg
Caffeinated Water	16.9 oz	50-125 mg	100 mg
Cocoa/Hot Chocolate	6 oz	2-10 mg	7 mg
Chocolate Milk	6 oz	2-7 mg	4 mg
Coffee Ice Cream or Yogurt	8 oz	8-85 mg	50 mg
Milk Chocolate Candy Bar	1.5 oz	2-10 mg	10 mg
Dark Chocolate Candy Bar	1.5 oz	5-35 mg	30 mg
Caffeinated Gum	1 stick	50 mg	50 mg
Analgesics (e.g., Excedrin, Midol)	2 tablets	64-130 mg	64 or 130 mg
Stimulants (e.g., NoDoz, Vivarin)	1 tablet	75-350 mg	100 or 200 mg
Caffeine Pills	2-3 tablets	80-200 mg	80-200 mg
Energy Drinks	8 – 16 oz	50-400 mg	80-160 mg