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The Effects of Red Bull Energy Drink on Repeated Wingate Cycle Performance and Elbow Flexor Muscle Endurance

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THE EFFECTS OF RED BULL ENERGY DRINK ON REPEATED WINGATE CYCLE PERFORMANCE AND ELBOW FLEXOR MUSCLE ENDURANCE

By

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This thesis is dedicated to my Dyaddy, who will always be my first love. To my mother, who will forever be the strongest woman I know. To my brobots, Ariel and Alex, who have been unconditional sources of encouragement, humor, and inspiration. And to my Lola Peps, whose life and spirit has taught me to fight… aggressively and persistently.

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ABSTRACT

Caffeine is the most commonly used drug in the world, often consumed in the form of coffee, sodas, teas, energy drinks, and chocolate. It is also generally regarded as very safe to consume. As one of the most thoroughly investigated sport supplements, it has been well established as an ergogenic aid for endurance performance, and has been shown to increase time to exhaustion, increase mean power output during time trials, and decrease perceived exertion. The effects of caffeine on measures of muscular endurance and repeated anaerobic performance are currently much more equivocal, and elicit further investigation.

The first purpose of this study was to determine the effects of Red Bull Energy Drink (2.0mg CAF/kg BW) on anaerobic power using repeated Wingate cycle performance compared to a placebo. Additionally, this study sought to determine the effects of Red Bull Energy Drink on elbow flexor muscle endurance compared to a placebo.

The study used a double-blind, repeated-measures, crossover, counter-balanced design. The eighteen male subjects that participated in this study were between 18 and 35 years old, with a mean age of 23.4 years. They had a mean weight of 81.3 ± 10.2 kg, mean height of 1.81 ± 0.08 m, and mean BMI of 24.76 ± 2.89 kg/m^2.

Three to seven days after the familiarization trial, subjects will be randomly assigned to supplement with Red Bull (2.0 mg/kg caffeine) or an isovolumetric amount of placebo (non-caffeinated Mountain Dew) 60 minutes before performing the exercise tests. The Subjects performed three sets of maximal isokinetic elbow flexion for 60 seconds at 0.52 rad/s (separated by two minute rest intervals) on the Biodex System 3 Isokinetic Dynamometer. Following the isokinetic testing, subjects performed three 30-s Wingate anaerobic cycle tests (separated by two minute rest intervals) at a load corresponding to 0.075 kpal/kg body mass (Bar-Or, 1987). There was no significant difference found for Peak Torque or Decline in Peak Torque for elbow flexor muscle endurance compared to placebo. No significant difference was found in Peak

Power and Mean Power for the Wingate Anaerobic Test. There was a significantly ($p<0.05$) greater decline in Mean Power and Relative Mean Power for Red Bull compared to placebo, inferring that there may be a detrimental effect on repeated anaerobic performance following ingestion. Decline in mean power from the first to the third set of Wingate testing was 182.15 +/- 59.97 W for Red Bull trials, and 153.87 +/- 67.08 W for placebo trials. The relative decline in mean power relative to each subject's body weight for Wingate testing was 2.25 +/- 0.751 W/kg for Red Bull trials, and 1.88 +/- 0.777 W/kg for placebo trials.

While there is unlikely one single mechanism explaining the findings from this study, results may be partially explained by increased concentrations of lactate in either the blood or muscle, or lowered concentrations of plasma potassium following caffeine ingestion compared to placebo.

CHAPTER 1

INTRODUCTION

Caffeine is the most commonly used drug in the world, often consumed in the form of coffee, sodas, teas, energy drinks, and chocolate. It is also generally regarded as very safe to consume. As one of the most thoroughly investigated sport supplements, it has been well established as an ergogenic aid for endurance performance, and has been shown to increase time to exhaustion, increase mean power output during time trials, and decrease perceived exertion. The effects of caffeine on measures of muscular endurance and repeated anaerobic performance are currently much more equivocal, and elicit further investigation.

The results of several studies indicate an improvement in muscular endurance following ingestion of caffeine compared to placebo. Kalmar and Cafarelli (1999) observed a significant increase of 25.80 +/- 16.06% in time to fatigue for isometric contraction of the soleus muscle at 50% of maximal voluntary contraction (MVC) 60 minutes following a caffeine ingestion of 6mg/kg body weight (BW). Using the same timing and dosage, a study by Meyers and Cafarelli (2006) supported these findings, reporting a significant increase in muscular endurance by 20.5 +/- 8.1% BW. The exercise protocol involved intermittent isometric leg extension contractions for 15s at 50% of the previously determined MVC until force dropped below 45% for greater than two seconds. This increase in time to fatigue was not accompanied by any difference in motor unit firing rate between treatments (caffeine versus placebo). Forbes et al. (2007) tested Red Bull (2.0mg/kg BW caffeine) compared to placebo ingestion 60 minutes prior to testing of upper body muscular endurance using total repetitions over three sets to failure of bench press exercise at 80% of 1-repetition maximum. They found a significant increase of 34 +/-9 repetitions for caffeine versus 32+/-8 repetitions for placebo.

Other studies looking at caffeine's effects on muscular endurance do not show any benefit. Jacobs et al. (2003) examined the individual and combined effects of ephedrine and caffeine on muscular endurance. The exercise test involved three supersets, each consisting of leg press exercise (80% 1-RM) to exhaustion, followed by bench press exercise (70% 1-RM) to exhaustion, with two minutes of rest between supersets. Trials following ephedrine and a combination of ephedrine+caffeine resulted in an increase in the mean number of repetitions for both exercises. There was no individual or additive effect of caffeine. To measure muscular endurance, Beck et al. (2006) used one set of bench press and leg extension exercises with a resistance equal to 80% of each subject's 1-RM to fatigue. They found no difference in upper or lower body muscular endurance, following an absolute dosage of 201.0 mg caffeine compared to placebo.

Bell et al. (2001) looked at caffeine's effects on anaerobic performance, and observed a significant increase in time to exhaustion in groups following caffeine ingestion. The time to exhaustion was for a Maximal Accumulated Oxygen Deficit (MAOD) cycling test to fatigue at a resistance equivalent to 125% of each subject's VO2 peak. Doherty (1998) reported a significant increase in time to exhaustion following caffeine ingestion for supramaximal treadmill sprint performance at a pace equivalent to 125% of VO2 max.

Several studies do not support an improvement in anaerobic performance following caffeine ingestion. Crowe et al. (2006) tested caffeine versus placebo using two 60s maximal cycling sprints, separated by three minutes recovery. This group saw no difference in peak power, decline in peak power between bouts, total work, and decrement in work between bouts between treatments. Caffeine treatment did result in increased lactate production and slower time to peak power, indicating a possible negative effect of supplementation. The aforementioned study by Beck et al. (2006) also involved two Wingate Anaerobic Tests, and resulted in no treatment effect of caffeine on peak power or mean power compared with placebo. Greer et al. (1998) used four Wingate tests separated by four minutes of recovery, and saw no treatment effect of caffeine on peak power, average power, or fatigue rate for any of the tests. The previously described study by Forbes et al. used Red Bull energy drink versus placebo to determine the effects on two Wingate tests separated by two minutes recovery. They also saw no significant difference in peak power or average power between treatments.

The mechanisms by which caffeine may enhance exercise performance are still under debate. Current popular explanations for improved physical performance from acute caffeine supplementation include an increased mobilization of intracellular calcium; an increase in free fatty acid oxidation, therefore providing a glycogen-sparing effect; and occupying the receptor for adenosine, therefore inhibiting adenosine's effects on the central nervous system. Adenosine is a nucleoside which plays an integral role in energy transfer and signal transduction. Due to the confounding results of relevant studies, it is likely that caffeine may not elicit its effects due to one independent mechanism, but as a result of a combination working at the same time.

Recent direction for caffeine research has taken the form of acute consumption of such popularized energy drinks as Red Bull. One regular can (250mL) of Red Bull Energy Drink contains 80 mg of caffeine. This study was modeled from the design of the previous study conducted by Forbes et al (2007). The design was enhanced by limiting subjects to only males, as well as only those who had been engaging in resistance training at least twice per week for the previous three months. This allowed for better control of individual differences among subjects relating to gender, training experience, and neuromuscular adaptations. Additionally, the design of the current study used elbow flexion exercise on a Biodex machine to measure muscle endurance, rather than the bench press exercise in the study by Forbes et al (2007). This variation allowed us to obtain data on the torque reached for each elbow flexion repetition, giving more specific quantitative data to observe the effects of Red Bull versus placebo on this exercise. The purpose of this study will thus be to determine the effects of Red Bull Energy Drink on repeated Wingate cycle performance and elbow flexor muscle endurance.

Statement of the Problem

The first purpose of this study will be to determine the effects of Red Bull Energy Drink on anaerobic power using repeated Wingate cycle performance compared to a placebo. Additionally, this study will serve to determine the effects of Red Bull Energy Drink on elbow flexor muscle endurance compared to a placebo.

Research Hypotheses

Based on the evidence provided during the review of the literature, the following hypotheses will be tested:

1. Muscular endurance of the elbow flexors will be significantly greater 60 minutes following acute consumption of Red Bull energy drink (2mg caffeine/kg body weight) compared to a placebo.
2. There will be a significant set effect, but no treatment effect, for mean anaerobic power during the three repeated Wingate anaerobic tests due to acute ingestion of Red Bull energy drink compared to a placebo.
3. There will be a significant set effect, but no treatment effect, for peak anaerobic power during the three repeated Wingate anaerobic tests due to acute Red Bull energy drink ingestion compared to a placebo.
4. Time to 50% peak power will not be significantly different between treatment (Red Bull energy drink) and placebo trials.

Operational Definitions

1. **Muscle endurance:** Ability of the muscle to overcome a submaximal resistance over a period of time.
2. **Peak power:** The highest power output achieved during the first 10 seconds of a specified exercise bout (i.e. 30-second Wingate anaerobic test).
3. **Mean/average power:** The average power output achieved during a specified exercise bout (i.e. 30-second Wingate anaerobic test).
4. **1-RM:** The maximal amount of resistance (1-repetition maximum) one is able to complete through a full range of motion of a specified exercise (i.e. bench press, leg extension, etc.). It is a commonly used test in the field of strength and conditioning to measure low-speed strength.
5. **Superset:** Completion of two or more exercise sets executed in succession without a rest period.

Assumptions

This study is based on the following assumptions:

1. All participants will have abstained from caffeine intake for at least 48 hours prior to each of the experimental trials.

2. All participants will have maintained a similar workout pattern and diet the day preceding and during the study.

3. All participants will have engaged in consistent resistance training exercise at least two times per week for a minimum of three months.

Limitations

The subject population for this study will be limited to resistance-trained males between the ages of 18 and 35 years who were currently residing in the Tallahassee, FL area. Therefore, there will be no randomization of subject selection and there must be limitations placed on the generalizations of the results of this study.

Significance of the Study

The beneficial effects of caffeine on aerobic endurance performance have been thoroughly investigated. Although the results are much more equivocal, studies of muscular endurance and anaerobic performance have also gained recent attention in the scientific and athletic community. These areas elicit much further research to better understand the mechanisms behind caffeine's effects on these measurements, in order to determine criteria for caffeine supplementation recommendations for individuals interested in optimizing athletic performance. The use of Red Bull energy drink has only recently been used for investigation of its effects on such variables. This study improved upon the findings by Forbes et al (2007), by better controlling for gender and training experience among subjects, as well as using an elbow flexion exercise test for muscle endurance that yields better quantitative data for specific torque values. Results may provide valuable information on the ergogenic capabilities of such popular drinks in today's market. The intent of this study is to test the response of Red Bull energy drink versus placebo on the muscular endurance and repeated anaerobic performance of resistance-trained individuals.

CHAPTER 2

REVIEW OF LITERATURE

The following chapter is a review of the current literature that pertains to this investigation. Caffeine has been shown to provide ergogenic effects on endurance performance, by increasing time to exhaustion, increasing mean power output during time trials, and decreasing perceived exertion. The beginning of this review focuses on considerations for using Red Bull Energy Drink, instead of isolated caffeine. Following, caffeine's effects on muscle endurance and anaerobic performance, which are not well established, are discussed .

Red Bull

Red Bull energy drink has been shown to improve aerobic endurance by 9% and anaerobic endurance as much as 24% (Alford et al. 2000). Its use as a form of caffeine administration to test the effects on anaerobic exercise performance are not as clear, and have not been thoroughly investigated at this time. A 250mL serving (one can) of Red Bull contains 80mg of caffeine. For comparison, the caffeine content in the same amount of brewed coffee is 112 mg. The same amount of Coca-Cola Classic contains 24 mg of caffeine. According to a study by Tunnicliffe et al. (2008), the average daily intake of caffeine among elite Canadian athletes was 85 +/- 13 mg/kg body weight. They used 270 self-reported 3-day dietary recalls with athletes from 38 different sports, varying in age from 16-45 years. Although caffeine is regarded as the primary ergogenic ingredient, it is important to not ignore the other potentially influential ingredients found in Red Bull energy drink. These include glucose, the B vitamins, taurine, and glucuronolactone.

Several of the B vitamins are found in Red Bull energy drink. Per standard 250mL serving, there are approximately 20mg of niacin, 5mg of vitamin B6, 5mg of pantothenic acid, and 5μg of vitamin B12. When an individual is depleted of B vitamins, restoration of normal status may improve physical performance by enhancing energy production. Additionally, the effects of B12 on mental performance (i.e. concentration) are yet to be well established (Mayer et al., 1996).

Each 250mL serving of Red Bull contains about 1000 mg of taurine, a sulfonic amino acid primarily found in skeletal muscle. Taurine appears to have an antihypertensive effect, which may counteract experimentally-induced increases in blood pressure (Alford et al. 2000). It is also well established that taurine can modulate stress and behavioral response, as well as mood (Mandel et al. 1985, Belfer et al. 1998). Additionally, in a rodent model, the ingestion of taurine has shown improvements in force production in skinned muscle fibers (Bakker et al. 2002). These increases may be a result of greater calcium release from the sarcoplasmic reticulum and greater sensitivity to calcium for excitation-contraction coupling. Protective effects against cellular stress, as incurred during exercise, may explain taurine's actions (Redmond et al. 1998). One previous study by Zhang et al. (2004) showed improvements during cycle ergometer exercise in endurance time to exhaustion, maximal oxygen consumption, and maximal workload following a seven-day supplementation of 6g/day of taurine powder compared to control. Despite these data, since there is minimal taurine present in Red Bull energy drink, it is not likely to cause a significant effect on exercise performance.

Glucuronolactone (600 mg per 250mL Red Bull) is a metabolic byproduct of glucose metabolism in the liver. At this time, it has only been shown to improve endurance in trained athletes (Geiss et al. 1994). Future research would be helpful in isolating the effects and mechanisms of this chemical's actions.

The proposed study was designed to closely simulate the procedures followed during the study by Forbes et al. (2007). These researchers sought to determine the effects of Red Bull on repeated anaerobic performance using the Wingate cycle test, as well as muscular endurance. They used 15 healthy, physically active subjects who completed the double-blind, repeated measures, crossover, counterbalanced design study. On two separate visits separated by at least seven days, subjects were given either Red Bull (approximately 2.0mg/kg BW) or placebo

(noncaffeinated Mountain Dew, lemon juice, water) 60 minutes prior to exercise testing. The protocol began with a bench-press muscular endurance test. This was measured by lifting 70% of each subject's predetermined 1-RM until failure for three sets, separated by one minute of recovery. Ten minutes following this portion of the test, subjects completed three 30s Wingate tests separated by 2 minutes of recovery. Muscular endurance was defined by the total number of bench-press repetitions completed over three sets. Red Bull energy drink did cause a significant ($p<0.05$) increase in upper body muscular endurance compared to placebo drink treatment (34 +/- 9 versus 32 +/-8 repetitions). These results do not agree with the previously discussed study by Beck et al. (2006), who found no difference in upper or lower body muscular endurance, following an absolute dosage of 201.0 mg caffeine compared to placebo. Another primary difference between these studies is that Beck et al. only used a single set of bench press repetitions. Additionally, the study by Beck et al. only used male subjects, whereas Forbes et al. did not control for gender. With respect to the repeated Wingate anaerobic testing, there was no difference in peak or average power between treatments. The researchers in this study speculated that there may have been no effect as a result of the caffeine dose used, caffeine habituation, and individual training status of the subjects. While they did not control for caffeine habituation in their recruitment of subjects, they saw no difference between caffeine-naïve subjects and those who were regular caffeine users for any of the tests.

While administration of Red Bull energy drink as a form of caffeine has been shown to improve aerobic endurance, effects on anaerobic exercise performance elicit further research. The proposed research study will facilitate the understanding of such effects. It is important to consider other potentially influential ingredients found in Red Bull energy drink other than caffeine. These include glucose, the B vitamins, taurine, and glucuronolactone.

Caffeine and Muscle Endurance

While the potentiating effects of caffeine on muscle twitch and tetanic (sustained contractions requiring energy) tension have been well investigated, it is not certain how caffeine might affect voluntary neuromuscular performance. Kalmar and Cafarelli (1999) conducted a

study to determine the effects of acute caffeine supplementation on maximal force production and endurance of human quadriceps muscle. The 11 male subjects were nonsmokers and were not habitual caffeine consumers. Each participated in three separate trials, where they were randomly assigned caffeine (6 mg/kg BW), placebo, or control (nothing) 60 minutes prior to testing. Muscular endurance was measured by maintaining an isometric contraction of the soleus muscle at 50% of the previously determined maximal voluntary contraction (MVC) to fatigue. The time to fatigue increased significantly ($p < 0.05$) in the caffeine trials by 25.80 +/- 16.06%. Throughout the protocol, surface electromyographic signals were recorded, and showed no change despite the enhanced time to fatigue and MVC observed with caffeine ingestion. This suggests that the mechanism for caffeine's actions is, at least partially, peripheral, by alteration of excitation-contraction coupling or the stimulant effect of caffeine.

A study by Bell et al. (2001), with respect to anaerobic performance, suggests that the primary mechanism by which caffeine and ephedrine elicit their ergogenic effects is through antagonism of adenosine receptors, resulting in stimulation of the central nervous system. Jacobs et al. (2003) looked at the individual and combined effects of caffeine and ephedrine on muscular endurance. Investigators conducted a study utilizing a protocol designed to replicate a typical recreational strength training routine. Twelve active, healthy males aged 18-34 years were used as the subjects for this study; all were required to have engaged in regular resistance training within the past year. Subjects each completed five trials of the same experimental protocol, and were randomly assigned to ingest placebo (two separate trials), caffeine (4 mg/kg BW), ephedrine (0.8 mg/kg BW), or a combination of caffeine and ephedrine 90 minutes prior to exercise testing. The test consisted of three supersets, each consisting of leg press (80% of the previously determined 1-RM to exhaustion), followed by bench press (70% 1-RM to exhaustion) exercises. Subjects rested two minutes between supersets. There was a significant ($p<0.05$) increase in the mean number of repetitions for the trials with ephedrine ingestion (ephedrine, caffeine+ephedrine), compared to non-ephedrine trials (caffeine, placebo) for both leg press and bench press exercises. However, there was no additive effect observed for caffeine ingestion. While both upper and lower body exercises were affected by ephedrine ingestion, the increase in repetitions to exhaustion was relatively greater in magnitude for the leg press exercise. If, in fact, the stimulation of the CNS explains the improvements, certain inhibitory mechanisms may result in increased motor unit recruitment and/or increased time to fatigue. This agrees with the

previously discussed study by Kalmar and Cafarelli (1999), that the level of muscle activation during maximal voluntary isometric contraction is increased with caffeine ingestion.

Meyers and Cafarelli (2005) took a closer look at motor unit (MU) recruitment. Researchers examined single motor unit firing rates during intermittent submaximal contractions. They also wanted to test whether caffeine ingestion caused any effect on time to fatigue. Ten male volunteers, who were non-habitual caffeine consumers, participated in two trials separated by at least four days. They ingested either caffeine (6mg/kg BW) or placebo one hour prior to the experimental protocol. To test motor unit firing rates, tungsten microelectrodes were inserted into the midbelly of the vastus lateralis muscle. Subjects performed intermittent isometric leg extension contractions for 15s at 50% of the previously determined maximal voluntary contraction (MVC), with 2.5s recovery between repetitions. Testing was terminated when force dropped below 45% of the MVC for more than two seconds, indicating the time to fatigue (T_{lim}). Subjects were also given maximal evoked twitches on the leg extensors during the 2.5s intermittent recovery bouts.

They observed a constant firing rate for the duration of muscle contractions regardless of treatment (caffeine or placebo). However, compared to placebo trials, caffeine significantly ($p<0.05$) increased the time to fatigue by 20.5 +/- 8.1%. Additionally, the amplitude of the evoked twitch during recovery bouts and its maximal instantaneous rate of relaxation declined less in the caffeine responders (subjects who showed an increased time to fatigue with caffeine, compared to placebo). Once time to fatigue was reached for each trial, the values for the force of the evoked maximal twitch was 20% higher compared to placebo. The maximal instantaneous rate of relaxation was 30% greater for caffeine trials compared to placebo. These observations indicate that caffeine elicited these declines to a smaller magnitude, supporting the proposed mechanism that the increase in T_{lim} may relate to caffeine's effects on twitch force and the maintenance of calcium reuptake.

Beck et al. (2006) used both upper and lower body exercises to examine caffeine's acute effects on muscular endurance. Thirty-seven male volunteers with at least one year of resistance training experience completed two separate trials with either placebo or an absolute dosage of a supplement containing 201.0 mg caffeine. Potential setbacks of the treatment protocol include the use of an absolute dosage of caffeine, rather than using a dosage relative to each subject's

body weight. The absolute dosage was the equivalent of 2.1-3.0 mg/kg BW for these subjects. Additionally, the caffeine-containing supplement also contained other ingredients (including Yerba Maté, ginger extract, Vitamin B6), not allowing for isolation of caffeine's effects. Subjects were tested for muscular endurance via bilateral leg extension and free-weight bench press exercises to volitional fatigue at a load equal to 80% of their predetermined 1-RM. They found a significant ($p<0.05$) increase of 2.1% in bench press 1-RM strength with caffeine supplementation. While bench press muscular endurance approached a significant increase with treatment ($p=0.074$), no difference was found for either bench press or leg extension testing of muscular endurance.

Forbes et al. (2007) sought to determine the effects of Red Bull on repeated anaerobic performance using the Wingate cycle test, as well as muscular endurance. Fifteen healthy, physically active subjects completed the double-blind, repeated measures, crossover, counterbalanced design study. On two separate visits separated by at least seven days, subjects were given either Red Bull (2.0mg/kg BW) or placebo (noncaffeinated Mountain Dew, lemon juice, water) 60 minutes prior to exercise testing. The protocol began with a bench press muscular endurance test. This was measured by lifting 70% of each subject's predetermined 1-RM until failure for three sets, separated by one minute of recovery. Muscular endurance was defined by the total number of bench-press repetitions completed over three sets. Red Bull energy drink did cause a significant ($p<0.05$) increase in upper body muscular endurance compared to placebo drink treatment (34 +/- 9 versus 32 +/-8 repetitions). These results do not agree with the previously discussed study by Beck et al., which involved a slightly higher caffeine supplementation (2.4 mg/kg), and used a cross-sectional study design. Another primary difference between these studies is that Beck et al. only used a single set of bench press repetitions. Additionally, the study by Beck et al. only used male subjects, whereas Forbes et al. did not control for gender.

Table 1 – Caffeine and muscle endurance studies. Summary of several recent studies on the effects of caffeine on muscle endurance.

Authors (Year)	Caffeine Dosage	Test	Caffeine's Effect
Meyers and Cafarelli (2005)	6 mg/kg BW	Intermittent isometric leg extensions at 50% MVC (15s/2.5s) to fatigue	Significant ($p<0.05$) increase in time to fatigue by 20.5 +/- 8.1%
Kalmar and Cafarelli (1999)	6 mg/kg BW	Isometric contraction of soleus at 50% 1-RM to fatigue	Significant ($p<0.05$) increase in time to fatigue by 25.80 + 16.06%
Beck et al. (2006)	201.0 mg (~3mg/kg BW)	BP, LE at 80% 1-RM to fatigue	NSD
Forbes et al. (2007)	2.0 mg/kg BW (Red Bull)	Total BP reps over three sets	Significant ($p<0.05$) increase in upper body muscular endurance
Bell et al. (2001)	4 mg/kg BW	Mean reps over three supersets of LP (80% 1-RM), BP (70% 1-RM) with 2 min recovery	NSD

Caffeine and Anaerobic Performance

The ergogenic effects of caffeine on endurance performance have been thoroughly investigated. It is well established that acute ingestion of caffeine can elicit improvements in exercise time to exhaustion (Greer et al. 2000, Pasman et al. 1995), maximal power output (Ivy et al. 1979, Kovacs et al. 1998), and performance time (MacIntosh 1995). Findings on the effects of caffeine on repeated maximal anaerobic performance and muscular endurance are much more equivocal. Research in this area is still of great interest to gain a greater understanding of such effects and their underlying mechanisms. Such knowledge will allow for proper supplementation guidelines for optimal athletic performance.

Bell et al. (2001) looked at both caffeine and ephedrine. Investigators examined the effect of ingesting each individually, as well as in combination, on anaerobic exercise performance. Subjects were assigned to either Wingate testing or Maximal Accumulated Oxygen Deficit (MAOD) testing. Regardless of the assigned exercise group, each subject completed four trials, separated by at least seven days. These double-blind, randomized trials began 1.5 hours following ingestion of either caffeine (5 mg/kg), ephedrine (1 mg/kg), a combination of caffeine and ephedrine, or a placebo. Sixteen healthy males participated in the Wingate protocol, a test where subjects are instructed to cycle as quickly and forcefully as possible for 30s on a cycler ergometer, with the resistance of the flywheel adjusted to 0.08g/kg body weight. Applied force output data were collected as the average of every 5s interval. Eight healthy males completed the MAOD test, where resistance was set to the power output pre-determined to correspond to 125% $\dot{V}O_2$ peak. Subjects cycled at a cadence between 60-100 revolutions per minute until they could no longer maintain 60 rpm. Expiratory gases were collected for calculation of oxygen deficit, the difference between oxygen demand and actual uptake. Blood samples were also taken pre-exercise as well as 3, 5, and 10 minutes post-exercise to assess glucose and lactate concentrations. In the Wingate testing group, power output was significantly greater during the early portion of the test when ephedrine was ingested, either alone or with caffeine, compared to caffeine alone or placebo. This observation suggests that ephedrine has a stimulatory effect on the central nervous system. With respect to the MAOD testing groups, time to exhaustion was significantly increased in the caffeine and combination treatments (117.0 +/- 9.3 s and 113.1 +/- 8.3 s), as compared to ephedrine and placebo (105.3 +/- 7.7 s and 108.2 +/- 8.9 s). This effect of caffeine suggests that it may elicit an ergogenic effect via stimulation of skeletal muscle metabolism. While both treatments showed improvements in anaerobic performance, these data suggest that each treatment works through different mechanisms.

Many studies measure maximal anaerobic performance. While these data provide valuable information, the nature of many team sports relies on repetition of such high-intensity efforts. Crowe et al. (2006) examined how an acute caffeine dose affects blood lactate and performance measurements during two 60s maximal cycling sprints, separated by three minutes recovery. Seventeen healthy, non-smokers (five female) participated in this double-blind, randomized, crossover design study. All subjects completed three trials, each separated by seven days, in randomly assigned order to receive either caffeine (6 mg/kg caffeine), placebo, or nothing

(control) 90 minutes prior to the exercise protocol. The authors failed to describe the resistance applied during the maximal cycling bouts. Blood lactate was measured at baseline, immediately preceding the warm-up, and at 3 and 6 minutes post-exercise. Concentrations of blood lactate were significantly higher post-exercise in the caffeine treatment (17.1 +/- 7.3 mmol/L) compared to the control (16.6 +/- 6.8 mmol/L), but not the placebo treatment (16.8 +/- 7.1 mmol/L). In terms of performance, no difference in the peak power attained for either bout, the decline in peak power between bouts, total work, and the decrement in work between bouts was observed for caffeine treatment compared to placebo or control. Although peak HR did decrease in the second bout compared to the first, with respect to each trial, peak HR was not different for caffeine treatment, placebo, and control. Time to achieve peak power was significantly greater in the second bout of exercise compared to the first. Interestingly, this time to peak power in the second bout was significantly longer in the caffeine trial than both placebo and control (P=0.008). The results of this study indicate that caffeine did not result in significant improvements in anaerobic performance. Ingestion of caffeine may actually have a negative effect on performance, as indicated by the increase in blood lactate concentrations and slower time to peak power for the second exercise bout. These results support some previous studies (Bell 2001, Collomp 1991, Greer 1998), but are contrary to the findings of other similar studies (Bruce, Collomp 1992, Doherty 1998). The authors caution that their results could potentially be attributed to subjects pacing themselves, as opposed to cycling at maximal effort. It is possible that the differences may be explained by the different duration, intensity, and mode of exercise used. Additionally, some studies that did not support the results from Crowe et al. utilized exercise testing of a single bout, which was greater than or equal to 3 minutes in duration. With only one bout of exercise, the differences in lactate and time to peak power between bouts are not means for comparison. The increased duration likely increases the aerobic contribution of energy.

A more recent study looked at the effects of an absolute dosage of caffeine (201.0 mg) on anaerobic power in resistance-trained males. Beck et al. (2006) had 37 male volunteers with at least one year of resistance training experience complete two separate trials with either placebo or an absolute dosage of a supplement containing 201.0 mg caffeine. Potential setbacks of the treatment protocol include the use of an absolute dosage of caffeine, rather than using a dosage relative to each subject's body weight. The absolute dosage was the equivalent of 2.1-3.0 mg/kg

BW for these subjects. Additionally, the caffeine-containing supplement also contained other ingredients (including Yerba Maté, guarana seed extract, black tea extract, ginger extract, Vitamin B6), not allowing for isolation of caffeine's effects. Subjects completed two Wingate Anaerobic Tests to determine peak power and mean power. Subjects were given three minutes active recovery (pedaling with zero resistance), followed by three minutes passive recovery between tests. There was no treatment effect of caffeine found for peak power or mean power, compared to placebo. The results of this study agree with findings from previous related studies (Collomp et al. 1991, Greer et al. 1998). Such conclusions suggest no enhancement of anaerobic performance with caffeine supplementation. The authors (Beck et al. 2006) suggest further investigation exploring various dosages of caffeine on the same measures.

Doherty (1998) assessed the acute effects of caffeine ingestion on maximal accumulated oxygen deficit and short-term, high-intensity running performance. The exercise protocol involved a supramaximal treadmill sprint performance, set at a pace equivalent to 125% of the predetermined VO2max, until the pace could no longer be maintained. Nine active male athletes of various sprint sports volunteered for this double-blind, randomized cross-over study. Expired air was measured during the sprint performances, and analyzed for determination of the maximal accumulated oxygen deficit (MAOD). MAOD was calculated based on the difference between the estimated oxygen demand (determined during preliminary testing) and the measured oxygen uptake of the supramaximal run. Additionally, five minutes following cessation of the sprint performance, an arterialized capillary blood sample was taken from an earlobe for analysis of blood lactate concentrations. Compared to placebo, subjects developed significantly ($p<0.05$) greater MAOD (5.89L O2 for caffeine versus 5.30L O2 for placebo) following administration of caffeine. Additionally, the time to exhaustion was significantly ($p<0.05$) greater during caffeine trials (208.2 s for caffeine versus 181.0 s for placebo). The blood samples taken following completion of the short-term running performance showed no significant difference between treatments for lactate concentration (13.0 mMol for caffeine versus 11.9mMol placebo). Acute caffeine supplementation 60 minutes prior to supramaximal exercise proved to be an effective ergogenic aid in this study by increasing the duration subjects were able to maintain the supramaximal velocity, and enhancing the anaerobic component of exercise. The differences observed in MAOD between trials contributes to the ongoing investigation of the mechanisms explaining caffeine's actions. No difference was found in blood lactate concentrations between

caffeine and placebo treatments. It is therefore suggested that caffeine has a direct influence on the central nervous system and/or upon active muscle during short-term, high-intensity exercise.

During maximal, repeated, anaerobic exercise, Crowe et al. (2006) investigated the effects of a single dose of caffeine (5 mg/kg BW) on not only performance and blood parameters, but cognitive measures as well. Such measures of reaction time and number recall may offer significant insight into further understanding caffeine's mechanisms of action. The exercise protocol for this study involved two 60s maximal cycling bouts, which were completed 90 minutes following either caffeine administration or control treatment (nothing). They found no difference in peak power, work output, rating of perceived exertion, or peak heart rate during exercise testing between treatments. Additionally, no differences in either of the cognitive measurements between treatments were observed. Notably, following caffeine administration, plasma potassium concentrations at rest were lower, and blood lactate concentrations were significantly higher compared to control. While there was no benefit on performance, such blood parameters yield contributing information to the understanding of caffeine's mechanisms. High plasma potassium concentrations have been associated with fatigue (Lindinger 1995), and therefore may be detrimental to performance. Also, increased blood lactate concentrations have previously been reported (Collomp et al. 1991). It was then suggested that increases in epinephrine concentrations in the blood led to elevated carbohydrate metabolism, work output, and blood lactate in the plasma. However, Collomp et al. also observed associated increases in work output, peak power, and plasma epinephrine concentrations. Therefore, in the study by Crowe et al. (2006), it is possible that changes in lactate clearance were responsible for the observed increases in blood lactate.

The effect of caffeine on potassium may contribute to the mechanism of caffeine's actions. A study by Greer et al. (1998) supports this idea, reporting no effect of caffeine on repeated bouts of high-intensity exercise using four successive Wingate tests when plasma potassium concentrations were unchanged. Nine healthy men, all physically active, but not accustomed to intense exercise, underwent the protocol on two separate occasions, given either placebo or caffeine (6mg/kg) 60 minutes prior to testing. Between the four 30s Wingate tests, subjects were given four minutes of rest. The researchers were interested in looking at effects on performance (power output, rate of power loss) and anaerobic metabolism (blood lactate, circulating

catecholamines, respiratory data). Contrary to their hypothesis, caffeine treatment had no effect on peak power, average power, or the fatigue rate for any of the Wingate tests. It is worth noting that in the final Wingate test, the peak power output was significantly ($p<0.05$) greater following caffeine ingestion (994 ± 50W) compared to placebo (921 ±60W). Additionally, the average power in the third and fourth Wingate trials was actually greater for the placebo trial compared to caffeine. Although epinephrine concentrations were significantly elevated 60 minutes following caffeine administration, there was no treatment effect once exercise began. Norepinephrine concentrations were not different immediately preceding exercise, but were significantly greater following caffeine treatment by the fourth Wingate test. Again, there were no differences observed in plasma potassium levels between trials, with both treatments resulting in increased levels immediately following each Wingate test, quickly returning to concentrations below resting levels within the resting intervals. Plasma ammonia (NH3+) increased with each bout in both groups, but was significantly higher following caffeine treatment, with the exception of one time point (immediately prior to the third Wingate test). No effect of caffeine was observed in the volume of oxygen consumed or aerobic contribution throughout the protocol. With respect to this study, caffeine showed no ergogenic effect on performance, and may negatively impact subsequent bouts of exercise. Only the increased NH3+ concentrations provide evidence to support increased anaerobic metabolism with caffeine ingestion. During intense exercise, such as that involved in this protocol, NH3 is produced predominantly through AMP deamination, which occurs to a greater extent in fast compared to slow-twitch muscle fibers. Therefore, the authors offer the possible explanation that the handling of ADP or adenosine may result in increased production or decreased clearance of ammonia.

Forbes et al. (2007) sought to determine the effects of Red Bull on repeated anaerobic performance using the Wingate cycle test. Fifteen healthy, physically active subjects completed the double-blind, repeated measures, crossover, counterbalanced design study. On two separate visits separated by at least seven days, subjects were given either Red Bull (2.0mg/kg BW) or placebo (non-caffeinated Mountain Dew, lemon juice, water) 60 minutes prior to exercise testing. To test repeated anaerobic performance, subjects completed three 30s Wingate tests separated by two minutes of recovery. They saw no difference in peak or average power between treatments. The researchers in this study speculate that there may have been no effect as a result of the caffeine dose used, caffeine habituation, and individual training status of the

subjects. While they did not control for caffeine habituation in their recruitment of subjects, they saw no difference between caffeine-naïve subjects and those who were regular caffeine users for any of the tests.

As evidenced by the review of the recent literature pertaining to acute caffeine supplementation's effects on anaerobic performance, the results are equivocal. This may be explained by differences in exercise testing protocol, training status of subjects, levels of caffeine habituation, or dosage of caffeine. Future investigation is still required to thoroughly understand the parameters for caffeine's ergogenic benefit on exercise relying predominantly on anaerobic energy systems. Moreover, the mechanisms underlying such effects are also yet to be established. The current study will advance knowledge in this area of study by better controlling for gender and training experience among subjects, as well as using an elbow flexion exercise test for muscle endurance that yields better quantitative data for specific torque values.

Table 2 – Caffeine and anaerobic performance studies. Summary of several recent studies on the effects of caffeine on anaerobic measures of performance.

Authors (Year)	Caffeine Dosage	Test	Caffeine's Effect
Bell et al. (2001)	5 g/kg BW	Wingate or MAOD cycling @ 125% VO2 peak	Wingate-NSD. MAOD-Time to exhaustion increased in caffeine groups.
Doherty et al. (1998)	5 mg/kg BW	MOD treadmill sprint at 125% VO2 max to fatigue	Significant ($p<0.05$) greater MAOD (CAF 5.89L O2, PLA 5.30 L O2), inc time to exhaustion (208.2s CAF vs 181.0s PLA)
Crowe et al. (2006)	6 mg/kg BW	2x60s max sprints, 3 min recovery (no given resistance)	NSD Peak P, total W, decline i decrement in work bouts.
Beck et al. (2006)	201.0 mg	2 Wingate tests (6 min rec) for PP, MP	NSD PP, MP
Greer et al. (1998)	6 mg/kg BW	4 Wingate tests (4 min rec) for PP, MP, rate of P loss,	NSD PP, MP, fatigue rate
Forbes et al. (2007)	2.0 mg/kg BW (Red Bull)	3 Wingates (2 min rec) for PP, MP	NSD PP, MP

CHAPTER 3

METHODS

The purpose of this chapter is to outline the methods that were utilized in this investigation. First, the subject protocols are clearly defined. The procedures for the study, including pre-experimental, experimental, treatment, and methodology protocols, are then discussed in detail. At the conclusion of this chapter, the methods of statistical analysis are provided.

Subjects

The subjects for this study were healthy, physically active males between the ages of 18-35 years. Women were excluded from this study, as it will likely increase the variance between subjects, because men tend to be stronger and have greater anaerobic power than women. The aforementioned study by Forbes et al. (2007) used both men and women, and only found a significant effect of acute caffeine ingestion for upper body muscular endurance, but not in the repeated Wingate tests. The within subject variation equation for crossover studies was used to determine the number of subjects needed for this study. The equation is as follows: $n=(16s^2)/d^2$, where n is the number of subjects needed, s is the standard deviation, and d is the effects size (Hopkins et al. 2001). According to this online resource, when sample size is justified using the new approach based on acceptable precision of outcome, the n calculated is halved. This study required the use of at least 15 subjects, based on calculation using the values from the significant

results of a study on caffeine's effect on alactic power (Sullivan 1990). All subjects had participated in regular resistance training exercise greater than or equal to twice/week for a minimum of three months. Subjects will not regularly consume more than 200mg of caffeine per day. All subjects completed a Physical Activity Readiness Questionnaire (PAR-Q), which screens for health problems that might present a risk with performance of physical activity (Thomas et al., 1992). Participants were informed of the risks and purposes of the study before they give their written consent. Participants also completed a Health History form to ensure their eligibility in the study. Exclusion criteria included hypertension, heart conditions, musculoskeletal problems, endocrine problems (such as diabetes), neurologic conditions (such as migraines, familial tremor, seizures, etc.), and mental health issues (such as anxiety, severe stress, attention deficit disorder, insomnia, etc). The study was approved by the Institutional Review Board for research in human subjects.

Procedures

Pre-experimental

The study used a double-blind, repeated-measures, crossover, counter-balanced design. Subjects were asked not to change their diets or physical activity patterns before or during the study. They were instructed to refrain from caffeine for 48 hours, moderate/intense physical activity for 24 hours, and food and drink for three hours prior to testing. The 48 hours of caffeine withdrawal prior to testing would be adequate because the half-life of caffeine is about 4-6 hours (Graham, 2001). All participants were required to come to the laboratory on one occasion before the start of the study. The purpose of this visit was to familiarize the subject with the experimental protocol. Subjects were told that the researchers were testing a potential ergogenic aid, but were not informed of their assignment to the treatment or placebo groups. Subjects then filled out a Health History form, PAR-Q, and were given thorough instructions for the three-day diet record they were asked to maintain for the three days preceding the second visit. A copy of this record was returned to the subject, who was instructed to replicate this diet as closely as possible during the three days prior to the third visit.

During the familiarization visit, subjects were first weighed to determine the volume of Red Bull or placebo to be administered during their second and third visits. Subjects then performed three sets of maximal isokinetic elbow flexion for 60 seconds at 0.52 rad/s (separated by two minute rest intervals) on the Biodex System 3 Isokinetic Dynamometer. Only the dominant arm, the limb associated with writing, was tested. Recruitment of subjects included the limitation of right-handed participants only. For this test, subjects were positioned with their humerus placed on a limb support and resting near horizontal. The axis of rotation of the dynamometer was aligned with the lateral epicondyle of the humerus. The elbow was flexed to approximately 1.57 rad. The joint range of motion was set to 1.75 rad, with zero indicating full elbow extension. The forearem was in a neutral (semi-pronated) position for all tests. Stabilization of the shoulders, trunk, and hips during testing was facilitated by the use of straps attached to the Biodex. The upper arm was secured to the limb support pad with a strap positioned proximal to the cubital fossa (Wood et al.,2008). Following the isokinetic testing, subjects rested for 10 minutes, then performed three 30-s Wingate anaerobic cycle tests (separated by two minute rest intervals) at a load corresponding to 0.075 kg/kg body mass (Bar-Or, 1987).

Experimental

Three to seven days after the familiarization trial, subjects were randomly assigned to supplement with Red Bull (2.0 mg/kg caffeine) or an isovolumetric amount of placebo (non-caffeinated Mountain Dew) 60 minutes before performing the exercise tests. As little as 1 mg/kg and as much as 13 mg/kg of caffeine have shown improvements in endurance events, time to fatigue, and sprint and power events (Sokmen et al. 2008, Graham and Spriet 1995, Cox et al. 2002). Exercise testing was conducted exactly the same as the familiarization protocol. Seven days after this initial supplementation and testing session, subjects returned to the laboratory and ingested the opposite drink (Red Bull or placebo) and performed the same exercises in the same order. The seven day counter balance was chosen to allow subjects adequate recovery between exercise tests. The dependent variables measured were peak torque and absolute decrease in

peak torque during repeated isokinetic elbow flexion tests, as well as peak power, mean power, and the decline in mean power over the three repeated Wingate tests.

A previous related study by Forbes et al. (2007) selected the work-to-rest ratio for the Wingate testing protocol to simulate sports that involve repeated bursts of high-intensity activity, such as hockey. Time motion analyses indicate skating times of 30-40 s between rest intervals of either whistle stops or time on the bench. The selected two-minute interval of recovery was chosen as the average between whistle stops, which average around 27 s, and typical bench time, generally around 227 s (Green et al. 1976, Paterson 1979). According to research conducted by Kristiansen et al. (2005), caffeine-containing supplements are the most popular type of supplement ingested by ice hockey players, enhancing the appropriateness of this study with regard to potential application.

Treatment

The study used a double-blind repeated-measures crossover design. Each subject participated in two trials, performed at the same time of the day and separated by at least one week. Subjects were randomly assigned to a placebo trial using non-caffeinated Diet Mountain Dew, lemon juice, water (PLA) and a Red Bull trial (CAF). Both treatments are carbonated beverages, and were given in isovolumetric, isocaloric quantities. Both beverages were also administered in opaque containers, so that the appearance of the supplements was also blinded. These supplements were administered 60 minutes prior to exercise testing.

Statistical Analysis

A two (supplement: Red Bull vs. placebo) x three (exercise sets) ANOVA with repeated measures on the last two factors was used to assess differences between conditions for time to 50% peak torque for isokinetic elbow flexor muscle endurance, as well as peak power and mean

power for repeated Wingate tests. The equation used to determine the number of subjects for this test was based on a within-subjects design: $n=16s^2/d^2$ (Hopkins 2001), where n=number of subjects, s=standard deviation, d=effect size. Values to obtain this information were taken from a similarly designed study by Sullivan (1990), who found a significant treatment effect of caffeine on anaerobic alactic power. The n calculated is halved when sample size is justified using the new approach based on acceptable precision of outcome. Based on these calculations, 15 subjects were needed for this study. To determine whether one familiarization trial was adequate to eliminate any effects of learning over time, a three (exercise sets) x two (time) repeated measures ANOVA was used to determine whether there were differences across sets for Wingate tests and elbow flexion tests between the familiarization and placebo trials. Tukey's post hoc test was used to determine significant interaction effect between supplement and exercise sets. Statistical significance was set at $p \leq 0.05$. All results were expressed as mean ± standard deviation.

CHAPTER 4

RESULTS

Physical Characteristics

The eighteen male subjects who participated in this study were between 18 and 35 years old, with a mean age of 23.4 years. They had a mean weight of 81.3 ± 10.2 kg, mean height of 1.81 ± 0.08 m, and mean BMI of 24.76 ± 2.89 kg/m^2. Individual subject height, weight, and BMI are presented in Appendix D, Table 1.

Caffeine Dosage

The caffeine dosage for each participant was 2.0 mg/kg body weight. This amount was also capped to an absolute amount of 160mg caffeine, as this is the maximal dose of commercial energy drinks considered safe (Health Canada 2006). For this reason, due to bodyweight (> 80 kg), some subjects were given less than 2.0 mg/kg. All dosages were between 1.5 and 2.0 mg/kg body mass (1.9 ± 0.2 mg/kg body mass). The individual subject caffeine dosage for all subjects is presented in Appendix D, Table 2. Ten subjects received caffeine during their first trial. The remaining eight subjects received the placebo beverage during their first trial. All subjects received the opposite treatment during their second trial.

Peak Torque

Mean peak torque for isokinetic elbow flexion testing was 71.32 +/- 20.41 N*m for all Red Bull trials, and 68.32 +/- 18.25 N*m for all placebo trials. These values for peak torque between treatments were not significantly different (p=0.178). Individual peak torque values for both treatments are presented in Figure 1 and Appendix D, Table 3.

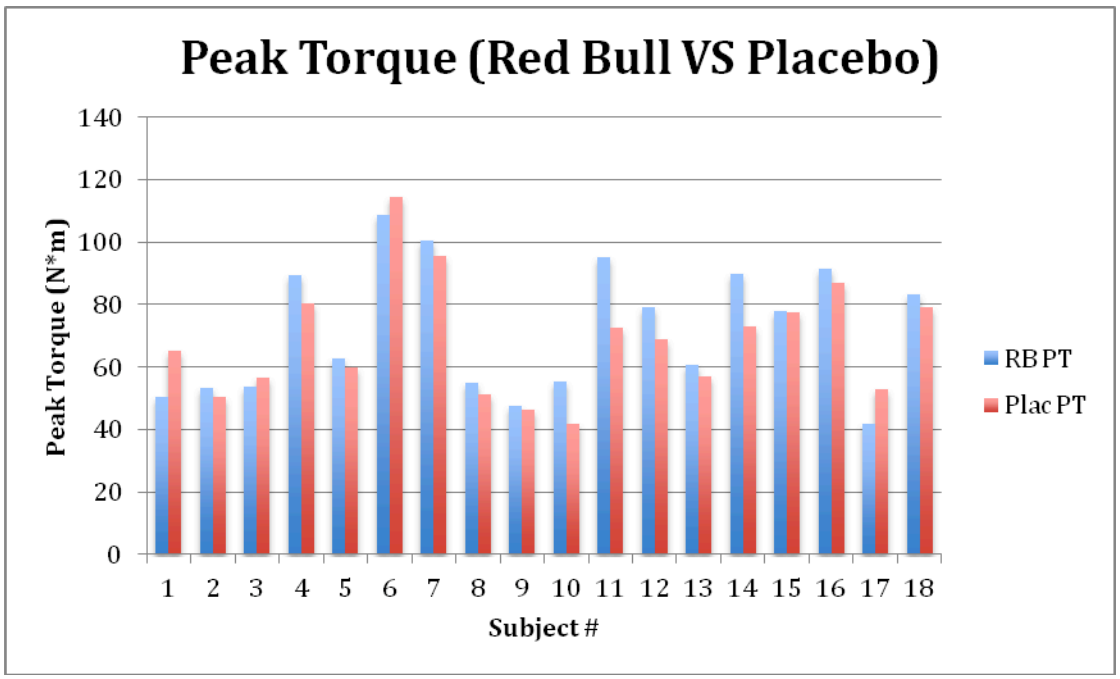

Figure 1. Peak torque (Red Bull VS Placebo). Peak torque (Nm) for each subject during Biodex isokinetic elbow flexion testing for Red Bull and Placebo trials.

Decline in Peak Torque

Mean decline in peak torque between the first and third sets of Biodex testing was 21.67 +/- 7.48 N*m for Red Bull trials, and 20.43 +/- 8.67 N*m for placebo trials. Decline in peak torque was not significantly different between treatments (p=0.547) when analyzed via paired t-tests. Individual peak torque values for both treatments are presented in Figure 2 and Appendix D, Table 4.

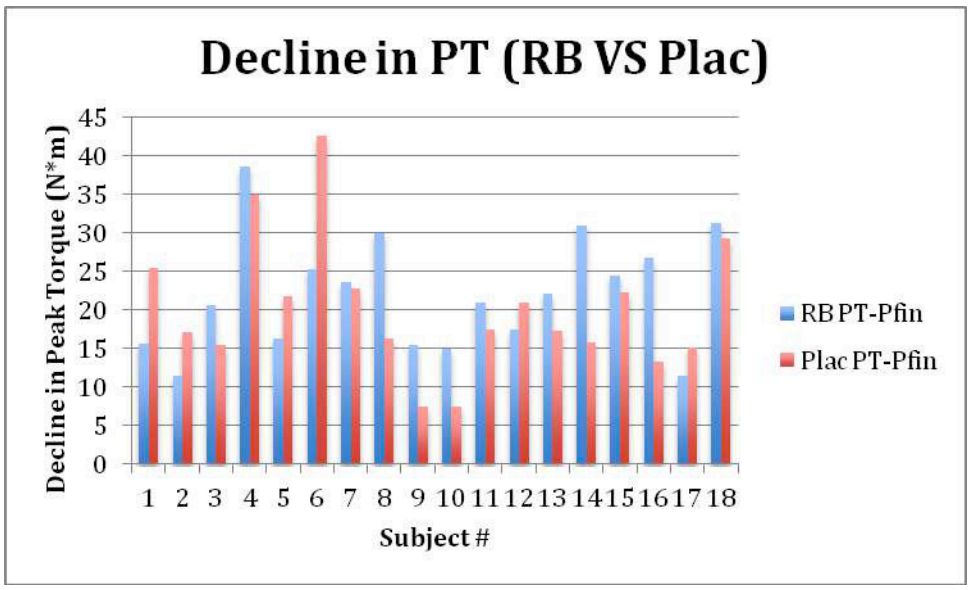

Figure 2. Individual decline in peak torque (Red Bull VS Placebo). Individual Decline in Peak Torque from the peak of the first set, to the average of the final three repetitions of the third set for both Red Bull and Placebo trials.

Wingate Resistance

For Wingate testing, resistance on the cycle ergometer was set to 0.075kg/kg body weight. Resistance for individual subjects ranged from 5.1 to 7.9 kg. Individual resistances are presented in Appendix D, Table 5.

Peak Power

Mean peak power for Wingate testing was 694.95 +/- 102.64 W for Red Bull trials, and 682.89 +/- 155.92 W for placebo trials. Mean values for peak power were not significantly different between treatments (p=0.602). Individual peak power values for both Red Bull and placebo trials are presented in Appendix D, Table 6. Peak power data are presented in Figure 3 and Appendix D, Table 6.

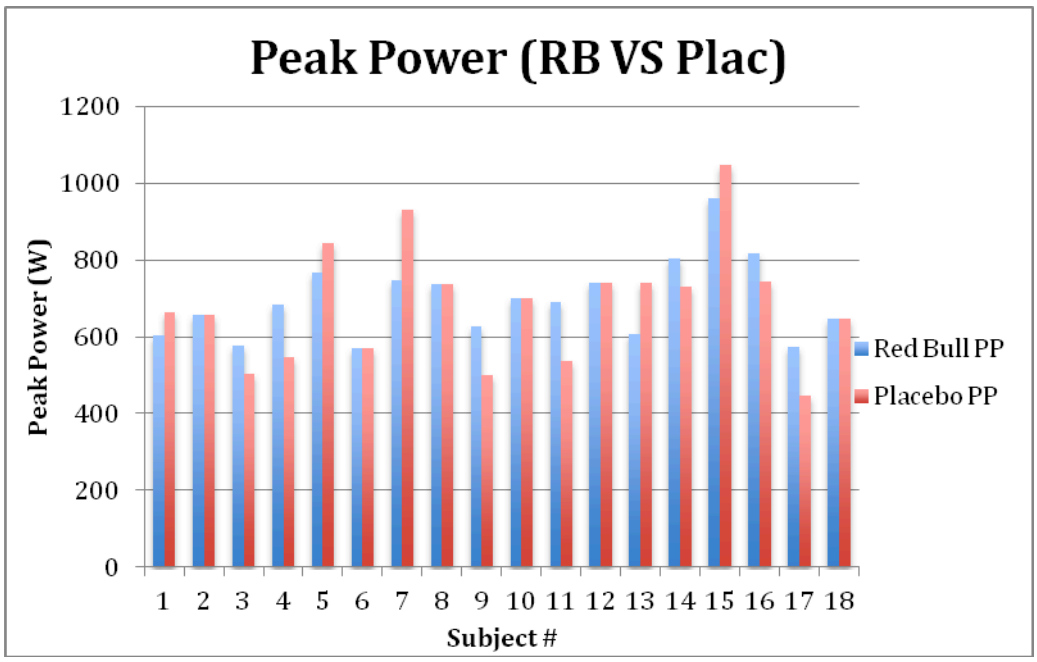

Figure 3. Peak power (Red Bull VS Placebo). Peak Power during Wingate testing for Red Bull and Placebo trials.

Relative Peak Power

Peak power relative to each subject's body weight for Wingate testing was 8.60 +/- 1.17 W/kg for Red Bull trials, and 8.41 +/- 1.58 W/kg for placebo trials. Relative peak power was not significantly different between trials (p=0.479) as analyzed via paired t-tests. Individual values for relative peak power are presented in Appendix D, Table 7.

Mean Power

The mean power during the first set of Wingate testing was 611.67 +/- 86.18 W for Red Bull trials, and 601.08 +/- 93.52 W for placebo trials. Mean power was not significantly different between trials (p=0.209) as analyzed via paired t-tests. Individual values for mean power from both trials are presented in Figure 4 and Appendix D, Table 8.

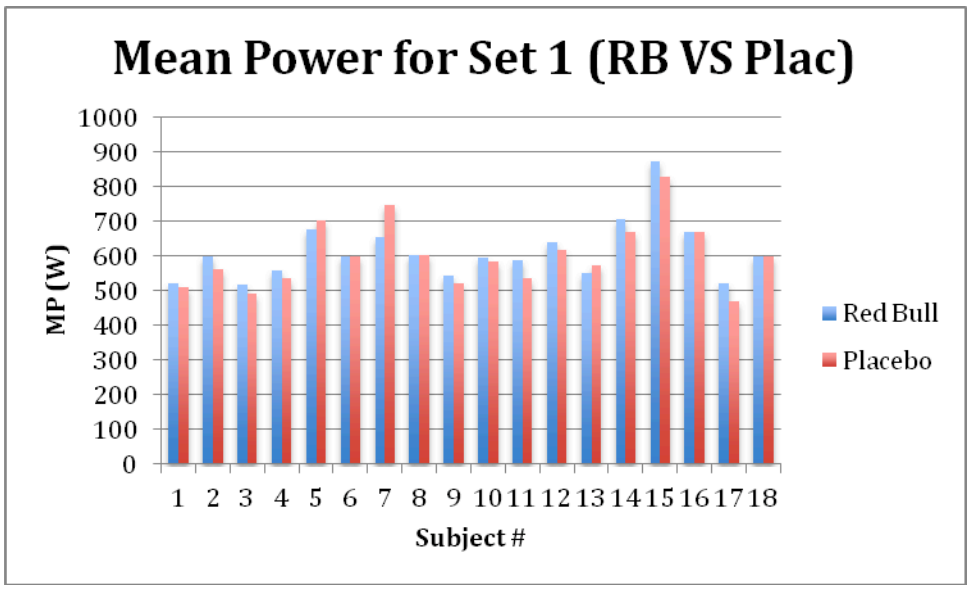

Figure 4. Mean power set 1 (Red Bull VS Placebo). Mean Power for Set 1 during Wingate testing for Red Bull and Placebo trials.

Relative Mean Power

The mean power relative to each subject's body weight during the first set of Wingate testing was 7.55 +/- 0.806 W/kg for Red Bull trials, and 7.41 +/- 0.79 W/kg for placebo trials. Relative mean power was not significantly different between trials (p=0.12). Individual values for relative mean power from Red Bull and placebo trials are presented in Appendix D, Table 9.

Decline in Mean Power

Decline in mean power from the first to the third set of Wingate testing was 182.15 +/- 59.97 W for Red Bull trials, and 153.87 +/- 67.08 W for placebo trials. Decline in mean power for the Red Bull trials was significantly greater than the decline for Placebo trials (p=0.036) as analyzed via paired t-tests. The individual values for decline in mean power are presented in Figure 5 and Appendix D, Table 10.

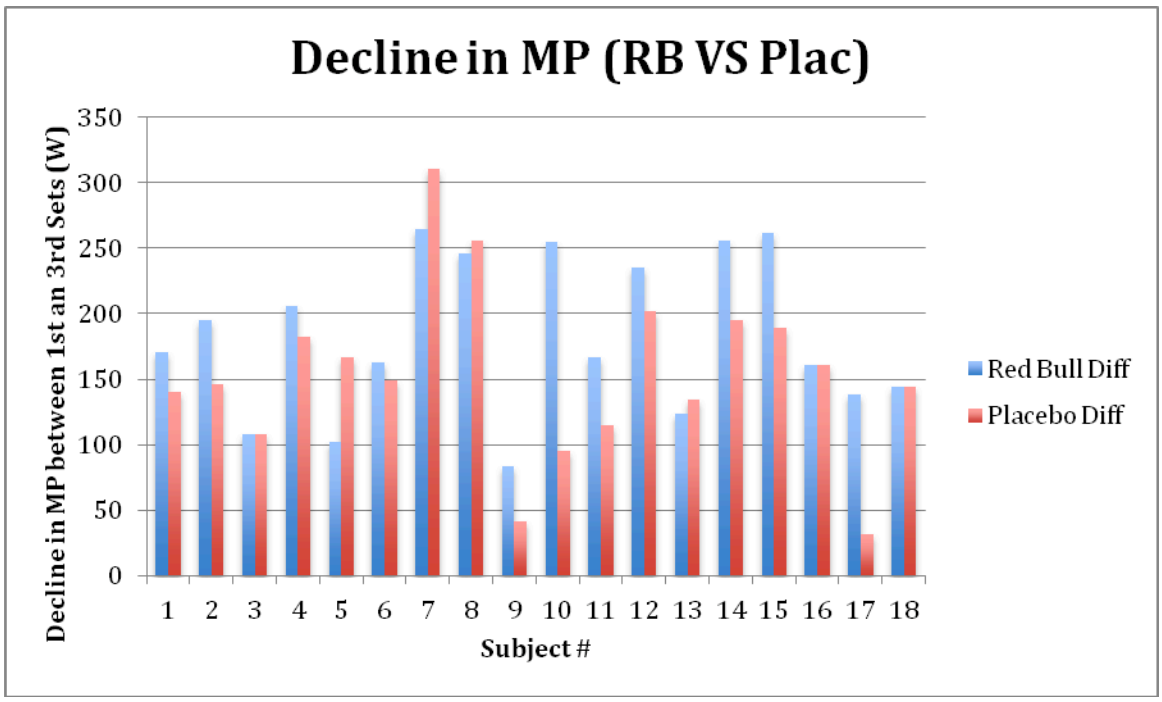

Figure 5. Decline in mean power (Red Bull VS Placebo). Decline in Mean Power between first and third sets of Wingate testing for Red Bull and Placebo Trials. Red Bull showed significantly greater absolute decline compared to placebo (p=0.036).

Relative Decline in Mean Power

The relative decline in mean power relative to each subject's body weight for Wingate testing was 2.25 +/- 0.751 W/kg for Red Bull trials, and 1.88 +/- 0.777 W/kg for placebo trials. The relative decline in mean power for Red Bull trials was significantly greater than the relative decline for placebo trials (p=0.031). Individual values for relative decline in peak power for both trials are presented in Figure 6 and Appendix D, Table 11.

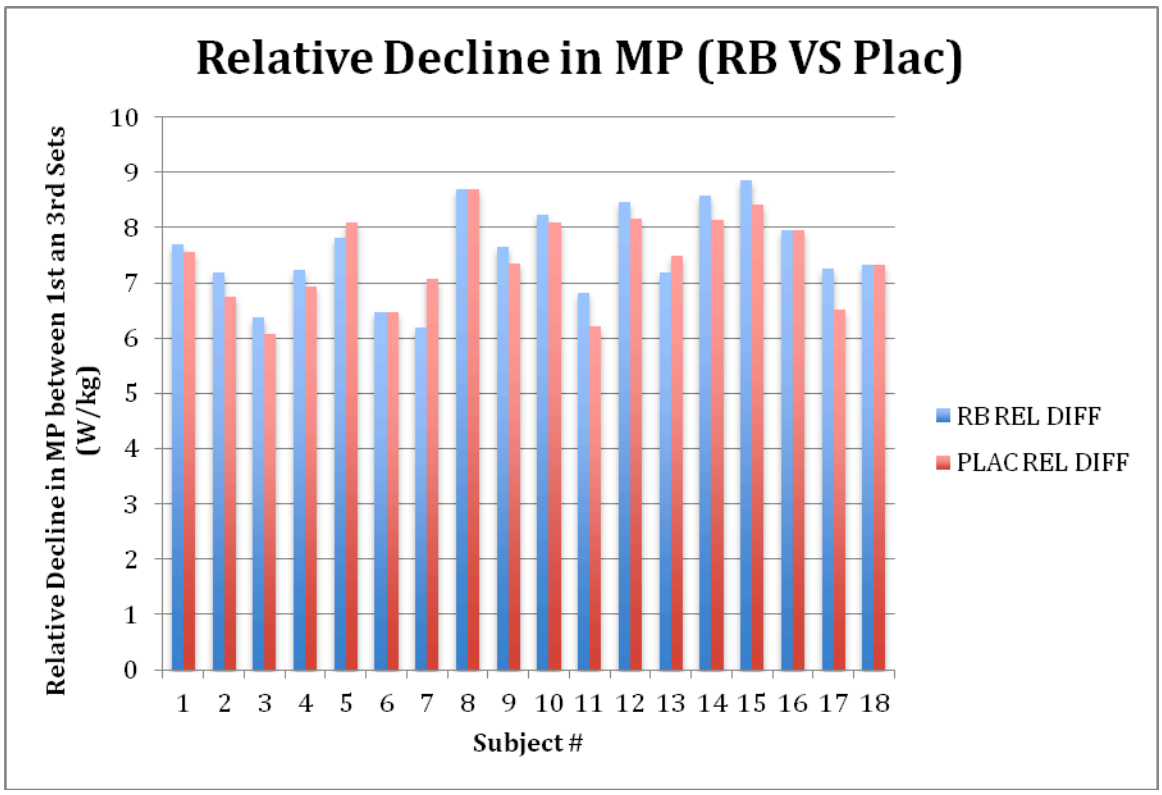

Figure 6. Relative decline in mean power (Red Bull VS Placebo). Relative Decline in Mean Power between first and third sets of Wingate testing for Red Bull and Placebo Trials. Red Bull showed significantly greater relative decline compared to placebo (p=0.031).

CHAPTER 5

DISCUSSION

The purpose of this study was to determine the effects of Red Bull Energy Drink on repeated Wingate cycle performance and elbow flexor muscle endurance. Eighteen resistance-trained male subjects between the ages of 18 and 35 years old participated in this study, which was conducted using a double-blind, repeated-measures, crossover, counter-balanced design. Prior to the experimental trials, subjects reported to the Exercise Physiology Laboratory for familiarization with the experimental protocol. Subjects returned to the laboratory at least three days following familiarization for their first experimental trial. Subjects ingested either Red Bull or placebo 60 minutes prior to exercise testing. The volume of the consumed drink was equivalent to 2mg caffeine/kg body weight for Red Bull, or an isovolumetric amount of placebo, but never exceeding 16.6 oz, the maximal daily dose of commercial energy drinks considered safe (Health Canada 2006). Each subject performed three sets of maximal isokinetic elbow flexion for 60 seconds at 0.52 rad/s (separated by two minute rest intervals) on the Biodex System 3 Isokinetic Dynamometer. Measurements of peak torque as well as decline in peak torque were recorded. Subjects next completed three 30-s maximal Wingate anaerobic cycle tests (separated by two minute rest intervals) at a load corresponding to 0.075 kg/kg body mass (Bar-Or, 1987). Peak power, decline in peak power, mean power, and decline in mean power were all recorded, as well as all respective values relative to each subject's weight. At least 7 days later, subjects returned to the lab, ingesting the opposite beverage as consumed in the first experimental trial 60 minutes prior to exercise testing. Subjects completed the same exercise tests, and the same measurements were recorded for analysis.

Caffeine has been well established as an ergogenic aid for endurance performance, and has been shown to increase time to exhaustion, increase mean power output during time trials,

and decrease perceived exertion. The effects of caffeine on measures of muscular endurance and repeated anaerobic performance are currently much more equivocal, and were thus the foci for this investigation. Additionally, caffeine has become one of the most thoroughly investigated sport supplements in the world, with more than 30 years of research. With the recent rise in popularity of energy drinks such as Red Bull, recent studies have begun to investigate the effects of this more practical, readily consumable means of ingestion. This study has taken the novel approach of looking at caffeine's effects via Red Bull beverage on muscle endurance and repeated anaerobic performance. The design improves upon that of Forbes et al 2006 by limiting subjects to only males, as well as only those who had been engaging in resistance training at least twice per week for the previous three months. This allowed for better control of individual differences among subjects relating to gender, training experience, and neuromuscular adaptations. Additionally, the design of the current study used elbow flexion exercise on a Biodex machine to measure muscle endurance, rather than the bench press exercise in the study by Forbes et al (2007). This variation allowed us to obtain data on the torque reached for each elbow flexion repetition, giving more specific quantitative data to observe the effects of Red Bull versus placebo on this exercise.

Repeated anaerobic performance

The decline in mean power for Wingate testing was 182.15 +/- 59.97 W for Red Bull trials, and 153.87 +/- 67.08 W for placebo trials (d=0.48, r=0.23). The decline in mean power for Red Bull trials was significantly greater than the decline for Placebo trials (p=0.036). The decline in mean power relative to each subject's body weight for Wingate testing was 2.25 +/- 0.751 W/kg for Red Bull trials, and 1.88 +/- 0.777 W/kg for placebo trials (d=0.48, r=0.23). The relative decline in mean power for Red Bull trials was also significantly greater than the relative decline for placebo trials (p=0.031). These potentially negative effects of caffeine on repeated high-intensity exercise parallel the finding from Crowe et al. 2006, who observed significantly greater concentrations of blood lactate for caffeine (6mg/kg body mass) compared to control and placebo when using two maximal 60 s cycling bouts.

Muscle endurance

The observed measure of muscle endurance in this study was the absolute decrease in torque over the course of three sets of maximal isokinetic elbow flexion exercise. The initial intention was to caculate the time to 50% peak torque as a measure of muscle endurance, however subjects were not declining to 50% peak torque during the test. From the data collected, calculations were used to determine the decrease in torque over the course of three sets of maximal isokinetic elbow flexion exercise by finding the difference between the true peak torque reached during set 1 and the mean of the last three repetitions of set 3. Absolute decline in peak torque was not significantly different between treatments (p=0.547). The absolute decline in peak torque between the first and third sets of Biodex testing was 21.67 +/- 7.48 N*m for Red Bull trials, and 20.43 +/- 8.67 N*m for placebo trials.

These findings are in agreement with those by Beck et al. 2006, who found no significant difference in maximum repetitions of bench press or leg extension exercise at 80% of 1-RM following an absolute dosage of 201.0mg caffeine. Similarly, Bell et al. 2001, found no significant effect of caffeine (4mg/kg body mass) on mean repetitions to fatigue over three supersets of leg press (80% 1-RM) and bench press (70%1-RM) compared to placebo.

However, this finding is contradictory to those of Meyers and Cafarelli, 2005, Kalmar and Cafarelli, 1999, and Forbes et al. 2007. While this study modeled the same treatment protocol as Forbes et al., it should be noted that the other two studies used a higher dosage of caffeine (6mg/kg body mass), which was in a caffeine capsule form. It is also possible that these studies saw a significant treatment effect due to the type of exercise used to look at muscle endurance. Using exercises that are more commonly seen in the field to look at muscle endurance, such as isometric time to fatigue at a set percentage of maximal voluntary contraction, or repetitions to volitional fatigue at a submax intensity, may enhance the design of such studies moving forward.

Additionally, the highest peak torque achieved during the first set of isokinetic elbow flexion testing was not significantly different (p=.178) during the Red Bull trial compared to PLA. Mean peak torque was 71.32 +/- 20.41 N*m for Red Bull trials, and 68.32 +/- 18.25 N*m for placebo.

Peak power

The peak power for Wingate testing was 694.95 +/- 102.64 W for Red Bull trials, and 682.89 +/- 155.92 W for placebo trials. These values for peak power were not significantly different between treatments (p=0.602). The peak power relative to each subject's body weight

for Wingate testing was 8.60 +/- 1.17 W/kg for Red Bull trials, and 8.41 +/- 1.58 W/kg for placebo trials. These values were not significantly different (p=0.479).

This finding agrees with that of Forbes et al. 2007, who administered Red Bull at the same dosage to not affect Wingate peak power for the Red Bull trials was not different compared to placebo (Red Bull=701 +/- 124W vs. placebo = 700+/-132W). Additionally, findings from Bell et al. 2000 and Crowe et al. 2006 support the conclusion that caffeine does not have a significant effect on peak power. Additionally, Crowe et al. found that caffeine trials resulted in a significantly slower time to peak power compared to control and placebo.

Mean power

The mean power during the first set of Wingate testing was 611.67 +/- 86.18 W for Red Bull trials, and 601.08 +/- 93.52 W for placebo trials. Mean power was not significantly different between trials (p=0.209). The mean power relative to each subject's body weight during the first set of Wingate testing was 7.55 +/- 0.806 W/kg for Red Bull trials, and 7.41 +/- 0.79 W/kg for placebo trials. Relative mean power was not significantly different between trials (p=0.116).

These findings agree with those of Forbes et al. 2007, who found no effect of the same dosage of Red bull on mean power (Red Bull = 479 +/-74W vs. placebo = 471 +/- 74 W) using the same dosage of Red Bull. Additionally, Crowe et al. (2006) found no difference in the amount of total work completed in two repeated 60s cycling sprints following caffeine ingestion compared to placebo.

Caffeine dosage

During treatment trials, subjects were given Red Bull Energy Drink (2.0 mg/kg caffeine) 60 minutes before performing the exercise tests. As little as 1 mg/kg and as much as 13 mg/kg of caffeine have shown improvements in endurance events, time to fatigue, and sprint and power events (Sokmen et al. 2008, Graham and Spriet 1995, Cox et al. 2002). The majority of studies that have found a significant ergogenic effect of caffeine on measures of exercise performance have utilized a 3-6mg/kg body mass ingestion (Bruce et al. 2000, Doherty et al. 1998, Jackman et al. 1996). Greater amounts of caffeine have also been shown to result in adverse side effects (Graham et al. 2001). One subject from the current study did report symptoms of nausea. It cannot be concluded that this negative effect resulted from caffeine ingestion or increased blood

lactate concentration, as the subject reported feelings of nausea upon completion of the repeated Wingate Anaerobic Cycling Test.

Conclusions

In conclusion, caffeine (2mg/kg body mass) ingested via Red Bull Energy Drink had no ergogenic effect on maximal isokinetic elbow flexion exercise or repeated peak and mean power Wingate anaerobic cycle tests. Caffeine did produce a significant decline in mean power between the first and third trials of the repeated Wingate anaerobic cycle tests compared to the placebo. Consumption may have a negative effect on repeated anaerobic performance by significantly decreasing the mean power compared to placebo, as shown in this study. These findings agree with those of Jackman et al. (1998) and Greer et al. (1996), which suggest that the potentially negative effect of caffeine on repeated bouts of maximal exercise may be explained by increases in plasma ammonia concentrations or decreases in intracellular pH. While there is unlikely one single mechanism explaining the findings from this study, results may be partially explained by increased concentrations of lactate in either the blood or muscle, or lowered concentrations of plasma potassium following caffeine ingestion compared to placebo.

Recommendations for Future Research

Caffeine continues to be an important area of sport supplementation research for further investigation. Despite the widespread popularity of energy drinks in the United States and around the world, very few published studies currently exist that examine the effects of such drinks on measures of exercise performance. While as little as 1 mg/kg and as much as 13 mg/kg of caffeine have shown improvements in endurance events, time to fatigue, and sprint and power events (Sokmen et al. 2008, Graham and Spriet 1995, Cox et al. 2002), the majority of studies recommend a 3-6mg caffeine/kg body weight dosage. Future studies investigating the

effects of similar energy drinks in a 3-6mg caffeine/kg body weight range may be more likely to result in performance measures that are significantly different from placebo/control trial values.

Our observed measure of muscle endurance was the absolute decrease in torque over the course of three sets of maximal isokinetic elbow flexion exercise. This decrease was calculated by finding the difference between the true peak torque reached during set 1 and the mean of the last three repetitions of set 3. It would benefit future studies to examine a more common measure of muscle endurance, such as maximal repetitions to volitional fatigue using a submaximal load as seen in Forbes et al. (2007). Subjects in this study completed three sets of bench press exercise at 70% of their pre-determined baseline 1-RM, with one minute of recovery between sets. Total repetitions over three sets for Red Bull (2.0mg/kg body mass) were significantly greater ($p<0.05$) compared to isoenergetic, isovolumetric, noncaffeinated placebo.

Another common measure of muscle endurance would be to look at time to fatigue of isometric contractions at a specified relative intensity. For example, Meyers and Cafarelli 2005 used intermittent 50% maximal voluntary contractions of the quadriceps to fatigue. Researchers found that caffeine (6mg/kg body mass) ingested 60 minutes prior to exercise, resulted in a significant ($p<0.05$) increase in time to fatigue compared to placebo.

It is important that studies continue to investigate the mechanisms of caffeine's actions, especially with anaerobic exercise. It is necessary to integrate more reliable and sensitive techniques in data collection, such as using interstitial measurements of [K+] rather than plasma measurements, which may help determine why caffeine seems to have an effect on certain types of exercise, but not others. While many theories currently exist, it is likely more than one physiological mechanism that explains the actions of caffeine.

APPENDIX A

HUMAN SUBJECTS APPROVAL

APPROVAL MEMORANDUM

Date: 9/8/2009

To: Adrienne Lufkin Lufkin

Dept.: NUTRITION FOOD AND MOVEMENT SCIENCES

From: Thomas L. Jacobson, Chair

Re: Use of Human Subjects in Research
The effects of Red Bull energy drink on repeated Wingate cycle performance and elbow flexor muscle endurance.

The application that you submitted to this office in regard to the use of human subjects in the research proposal referenced above has been reviewed by the Human Subjects Committee at its meeting on 08/12/2009. Your project was approved by the Committee.

The Human Subjects Committee has not evaluated your proposal for scientific merit, except to weigh the risk to the human participants and the aspects of the proposal related to potential risk and benefit. This approval does not replace any departmental or other approvals, which may be required.

If you submitted a proposed consent form with your application, the approved stamped consent form is attached to this approval notice. Only the stamped version of the consent form may be used in recruiting research subjects.

If the project has not been completed by 8/11/2010 you must request a renewal of approval for continuation of the project. As a courtesy, a renewal notice will be sent to you prior to your expiration date; however, it is your responsibility as the Principal Investigator to timely request renewal of your approval from the Committee.

You are advised that any change in protocol for this project must be reviewed and approved by the Committee prior to implementation of the proposed change in the protocol. A protocol change/amendment form is required to be submitted for approval by the Committee. In addition, federal regulations require that the Principal Investigator promptly report, in writing any unanticipated problems or adverse events involving risks to research subjects or others.

By copy of this memorandum, the Chair of your department and/or your major professor is reminded that he/she is responsible for being informed concerning research projects involving

human subjects in the department, and should review protocols as often as needed to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

This institution has an Assurance on file with the Office for Human Research Protection. The Assurance Number is IRB00000446.

Cc: Emily Haymes, Advisor
HSC No. 2009.2971

INFORMED CONSENT FORM

1. I voluntarily consent to be a participant in the research project entitled "The effects of Red Bull Energy Drink on Repeated Wingate cycle performance and elbow flexor muscle endurance." This research is being conducted by Adrienne K. S. Lufkin, B.Sc., a master student in the Department of Nutrition, Food and Exercise Sciences at Florida State University.

2. The purpose of the research project is to determine the effects of Red Bull Energy Drink on repeated Wingate cycle performance and elbow flexor muscle endurance compared to a placebo.

3. My participation in this project will require my attendance at the Florida State University Exercise Physiology Laboratory for a total of three different days to complete the experimental protocol described below. On the first day of the study I will come to the Exercise Physiology Laboratory for an orientation to the study and to sign an informed consent and must complete a medical history questionnaire. I might not be able to participate in this project after review of my health history questionnaire. The purpose of this visit will be to familiarize myself with the experimental protocol. During the
familiarization visit, I will undergo measurement of weight. I will also be performing maximal isokinetic elbow flexion exercises on the Biodex machine. Following the isokinetic testing, I will rest for 10 minutes, then perform maximal stationary bike sprints.

For the second and third visits, I will be asked not to change my diet or physical activity patterns before or during the study. I will be instructed to refrain from caffeine for 48 hours. Please note that refraining from caffeine consumption for 48 hours may cause withdrawal symptoms in individuals who are regular caffeine consumers. These symptoms may include, but are not limited to, moderate to severe headaches, sleepiness, feelings of depression, mood instability, difficulty concentrating. I will also be instructed to refrain from moderate/intense physical activity for 24 hours, and food or drink for three hours prior to testing. For the second visit, I will return to the lab three to seven days after the familiarization trial, where I will be randomly assigned to supplement with Red Bull Energy Drink or a non-caffeinated placebo drink 60 minutes before performing the exercise tests. Subjects will be given an amount equivalent to 2mg of caffeine per kg body weight of the subject. For example, a subject weighing 70 kg (154 lbs) would be administered 14oz (1.75 cans) of Red Bull Energy Drink (containing 140 mg caffeine), or the same volume of the non-caffeinated placebo drink. This amount of caffeine would be similar to approximately 1.5 cups of coffee. Exercise testing will be conducted exactly the same as the familiarization protocol. Seven days after this initial supplementation and testing session, I will return to the laboratory and ingest the opposite drink (Red Bull or placebo) and perform the same exercises in the same order.

The study will use a double-blind design. My 2nd and 3rd visits will be performed at the same time of the day and separated by at least one week.

4. I understand there is a possibility of a minimal level of risk involved if I agree to participate in this study. The risks will be minimized by using trained technicians and by teaching me proper techniques in testing. I will be performing strenuous exercise during this study that may result in muscle strain/sprain. Immediate first aid will be provided if I am hurt during exercise

testing. If I have high blood pressure (greater than 140/90 mmHg), heart disease or have had a stroke, smoke, or have any contraindications to strength testing, I will not be able to participate in the study. The investigator will determine my participation based on my evaluation and notify me with the final decision regarding my participation status and schedule for further evaluations either by phone or e-mail.

5. The results of this research study may be published but my name or identity will not be revealed. Information obtained during the course of the study will remain confidential, to the extent allowed by law. My name will not appear on any of the results. No individual responses will be reported. Only group findings will be reported in publications. Confidentiality will be maintained by assigning each subject a code number and recording all data by a code number.

6. If I develop health problems during the course of the study, Florida State University will be unable to provide compensation and will not provide medical treatment without charge for any medical charges as a result of this research investigation.

7. I will not be paid for my participation in this research project.

8. Any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by the investigators or they will refer me to a knowledgeable source. I understand that I may contact Dr. Emily Haymes or Adrienne K. S. Lufkin regarding any questions I may have about this research project or my rights. Group results will be sent to me upon request.

9. In case of injury, or if I have questions about my rights as a subject/participant in this research, or if I feel I have been placed at risk, I can contact the chair of the Human Subjects committee, Institutional Review Board, through the Office of the Vice President for Research, at (850) 644-8633.

10. The nature, demands, benefits and risks of the project have been explained to me. I knowingly assume any risks involved.

I have read the above informed consent form. I understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefits to which I may otherwise be entitled. In signing this consent form, I am not waiving my legal claims, rights or remedies. A copy of this consent form will be given to me.

_____

(Subject) (Date)

FSU Human Subjects Committee Approved on 9/8/09 VOID after 8/11/2010 HSC# 2009.2971

APPENDIX B

HEALTH HISTORY

HEALTH HISTORY

SHORT FORM

Please indicate whether any of the following apply to you. If so, please place a check in the blank beside the appropriate item. Thank you.

_____ Hypertension or high blood pressure

_____ A personal OR family history of heart problems or heart disease

_____ Diabetes

_____ Orthopedic problems

_____ Cigarette smoking or other regular use of tobacco products

_____ Asthma or other chronic respiratory problems

_____ Recent illness, fever, or Gastrointestinal Disturbances (diarrhea, nausea, vomiting)

_____ Any other medical or health problems not listed above. (Provide details below.)

_____
_____
_____

List any prescription medications, vitamin/nutritional supplements or over-the-counter medicines you routinely take or have taken in the last five days (including dietary/nutritional supplements, herbal remedies, cold or allergy medications, antibiotics, migraine/headache medicines, aspirin, ibuprofen, etc.)

_____
_____
_____

I certify that my responses to the foregoing questionnaire are true, accurate, and complete.

Signature:_____
Date:_____

APPENDIX C

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

(PAR-Q)

1. **YES** **NO** Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

2. **YES** **NO** Do you feel pain in your chest when you do physical activity?

3. **YES** **NO** In the past month, have you had chest pain when you were not doing physical activity?

4. **YES** **NO** Do you lose your balance because of dizziness or do you ever lose consciousness?

5. **YES** **NO** Do you have a bone or joint problem that could be made worse by a change in your physical activity?

6. **YES** **NO** Is your doctor currently prescribing drugs for your blood pressure or heart condition?

7. **YES** **NO** Do you know of any other reason why you should not do physical activity?

I certify that my responses to the foregoing questionnaire are true, accurate, and complete.

Signature:_____

Date:_____

APPENDIX D

DATA COLLECTION

Table 1. Individual Subject Height, Weight, BMI

Subject	Height (m)	Weight (kg)	BMI (kg/m^2)
1	1.68	67.7	23.99
2	1.7	83.2	28.79
3	1.81	80.9	24.69
5	1.77	77.3	24.67
6	1.77	86.8	27.71
7	1.74	92.3	30.49
8	1.95	105.4	27.72
9	1.72	69.5	23.49
10	1.9	70.9	19.64
11	1.86	72.3	20.90
12	1.98	86.4	22.04
13	1.82	75.5	22.79
14	1.78	76.4	24.11
15	1.82	82.5	24.91
16	1.86	98.6	28.50
17	1.83	84.1	25.11
19	1.77	71.8	22.92
20	1.88	81.8	23.14
Mean ± SD	**1.81 ± 0.08**	**81.3 ± 10.2**	**24.76 ± 2.89**

Table 2. Individual Subject Caffeine Dosage

Subject	Weight (kg)	Absolute Caffeine Dosage (mg)	Treatment Volume (mL)	Relative Caffeine Dosage (mg/kg)
1	67.7	135.4	415	2.0
2	83.2	160.0	491	1.9
3	80.9	160.0	491	2.0
5	77.3	154.6	474	2.0
6	86.8	160.0	491	1.8
7	92.3	160.0	491	1.7
8	105.4	160.0	491	1.5
9	69.5	139.0	426	2.0
10	70.9	141.8	435	2.0
11	72.3	144.6	444	2.0
12	86.4	160.0	491	1.9
13	75.5	151.0	463	2.0
14	76.4	152.8	469	2.0
15	82.5	160.0	491	1.9
16	98.6	160.0	491	1.6
17	84.1	160.0	491	1.9
19	71.8	143.6	441	2.0
20	81.8	160.0	491	2.0

Table 3. Peak Torque Values for Biodex Testing (N*m)

Subject	Caffeine	Placebo
1	50.3	65.2
2	53.3	50.3
3	53.7	56.5
5	89.2	80.5
6	62.8	59.7
7	108.5	114.4
8	100.5	95.5
9	55.1	51.3
10	47.4	46.4
11	55.2	42
12	95.2	72.5
13	79.2	68.9
14	60.7	57
15	90	73.1
16	77.8	77.6
17	91.5	87.1
19	41.8	52.7
20	83.4	79.3

Table 4. Decline in Peak Torque for Biodex Testing (N*m)

Subject	Red Bull	Placebo
1	15.6	25.5
2	11.5	17.1
3	20.6	15.5
5	38.6	34.9
6	16.2	21.8
7	25.2	42.6
8	23.6	22.8
9	29.9	16.3
10	15.5	7.4
11	15	7.5
12	21	17.4
13	17.4	21
14	22.1	17.3
15	30.9	15.7
16	24.4	22.3
17	26.8	13.2
19	11.5	15.1
20	31.3	29.2

Table 5. Individual Subject Wingate Resistance

Subject	Weight (kg)	Resistance (kg)
1	67.7	5.1
2	83.2	6.2
3	80.9	6.1
5	77.3	5.8
6	86.8	6.5
7	92.3	6.9
8	105.4	7.9
9	69.5	5.2
10	70.9	5.3
11	72.3	5.4
12	86.4	6.5
13	75.5	5.7
14	76.4	5.7
15	82.5	6.2
16	98.6	7.4
17	84.1	6.3
19	71.8	5.4
20	81.8	6.1

Table 6. Peak Power for Wingate Testing (W)

Subject	Red Bull	Placebo
1	601.97	662.16
2	658.62	658.62
3	576.00	504.00
5	684.59	547.67
6	767.21	843.93
7	570.10	570.10
8	745.97	932.46
9	736.52	736.52
10	625.57	500.46
11	701.11	701.11
12	690.49	537.05
13	740.07	740.07
14	605.51	740.07
15	804.98	731.80
16	960.79	1048.13
17	817.97	743.61
19	573.64	446.16
20	648.00	648.00

Table 7. Relative Peak Power for Wingate Testing (W/kg)

Subject	Red Bull	Placebo
1	8.89	9.78
2	7.92	7.92
3	7.12	6.23
5	8.86	7.09
6	8.84	9.72
7	6.18	6.18
8	7.08	8.85
9	10.60	10.60
10	8.82	7.06
11	9.70	9.70
12	7.99	6.22
13	9.80	9.80
14	7.93	9.69
15	9.76	8.87
16	9.74	10.63
17	9.73	8.84
19	7.99	6.21
20	7.92	7.92

Table 8. Set 1 Mean Power for Wingate Testing (W)

Subject	Red Bull	Placebo
1	521.70	511.67
2	597.64	561.05
3	516.00	492.00
5	559.08	536.26
6	677.70	703.28
7	597.25	597.25
8	652.72	745.97
9	603.54	603.54
10	542.16	521.31
11	594.89	584.26
12	588.20	537.05
13	639.15	616.72
14	549.44	571.87
15	707.41	670.82
16	873.44	829.77
17	669.25	669.25
19	520.52	467.41
20	600.00	600.00

Table 9. Set 1 Relative Mean Power for Wingate Testing (W/kg)

Subject	Red Bull	Placebo
1	7.71	7.56
2	7.18	6.74
3	6.38	6.08
5	7.23	6.94
6	7.81	8.10
7	6.47	6.47
8	6.19	7.08
9	8.68	8.68
10	7.65	7.35
11	8.23	8.08
12	6.81	6.22
13	8.47	8.17
14	7.19	7.49
15	8.57	8.13
16	8.86	8.42
17	7.96	7.96
19	7.25	6.51
20	7.33	7.33

Table 10. Decline in Mean Power for Wingate Testing (W)

Subject	Red Bull	Placebo
1	170.6	140.5
2	195.1	146.4
3	108.0	108.0
5	205.4	182.6
6	102.3	166.2
7	162.9	149.3
8	264.2	310.8
9	245.5	255.7
10	83.4	41.7
11	255.0	95.6
12	166.2	115.1
13	235.5	201.8
14	123.3	134.6
15	256.1	195.1
16	262.0	189.2
17	161.1	161.1
19	138.1	31.9
20	144.0	144.0

Table 11. Relative Decline in Mean Power for Wingate Testing (W/kg)

Subject	Red Bull	Placebo
1	2.5	2.1
2	2.3	1.8
3	1.3	1.3
5	2.7	2.4
6	1.2	1.9
7	1.8	1.6
8	2.5	2.9
9	3.5	3.7
10	1.2	0.6
11	3.5	1.3
12	1.9	1.3
13	3.1	2.7
14	1.6	1.8
15	3.1	2.4
16	2.7	1.9
17	1.9	1.9
19	1.9	0.4
20	1.8	1.8

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BIOGRAPHICAL SKETCH

Adrienne Krystal Santos Lufkin was born on February 25, 1985 in Saint Petersburg, FL. Her parents are Dr. Robert W. Lufkin and Mrs. Loida S. Lufkin, and her brothers are Ariel E.S. Lufkin and Alexander R.S. Lufkin.

Adrienne attended Florida State University for her Bachelor of Science in Exercise Physiology. During her undergraduate years, she also competed in Varsity Cross Country and Track and Field. During her Master's program, she taught Applied Exercise Physiology and Exercise Testing and Prescription at FSU. Adrienne currently resides in New York, NY, where she is Research Coordinator and an Exercise Specialist for LA PALESTRA Center for Preventative Medicine. She is also a professional latin dancer.