2016

The Effect of Caffeine Supplementation on Muscular Endurance in Recreationally Active College Age Males

Mark Gauvin

University of Rhode Island, mark_gauvin@my.uri.edu

Follow this and additional works at: <https://digitalcommons.uri.edu/theses>

Recommended Citation

Gauvin, Mark, "The Effect of Caffeine Supplementation on Muscular Endurance in Recreationally Active College Age Males" (2016). *Open Access Master's Theses*. Paper 866.
<https://digitalcommons.uri.edu/theses/866>

This Thesis is brought to you for free and open access by DigitalCommons@URI. It has been accepted for inclusion in Open Access Master's Theses by an authorized administrator of DigitalCommons@URI. For more information, please contact digitalcommons-group@uri.edu.

THE EFFECT OF CAFFEINE SUPPLEMENTATION ON MUSCULAR
ENDURANCE IN RECREATIONALLY ACTIVE COLLEGE AGE MALES

BY
MARK GAUVIN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
NUTRITION AND FOOD SCIENCES

UNIVERSITY OF RHODE ISLAND

2016

MASTER OF SCIENCE THESIS
OF
MARK R. GAUVIN

APPROVED:

Thesis Committee:

Major Professor Kathleen Melanson

Ingrid Lofgren

Disa Hatfield

Nasser H. Zawia
DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND

2016

ABSTRACT

Objective: Caffeine is a drug consumed regularly by approximately 90% of adults worldwide, primarily due to its ability to reduce fatigue and increase wakefulness. The benefit of caffeine consumption on athletic performance in large doses (3-9 mg/kg body weight or BW) is frequently documented in aerobic athletes. The benefits of caffeine supplementation in resistance training variables, such as muscular endurance, has shown mixed results, partially due to the inconsistency of testing variables. Furthermore, while caffeine supplementation shows promising ergogenic effects in muscular endurance in elite athletes, it is unknown if this effect translates to the recreational athlete. Therefore, the purpose of this study is to observe the potential ergogenic effect caffeine supplementation may have in recreational athletes and to consider how caffeine habituation may influence individuals' response to a high dosage of 7 mg/kg BW.

Design: This study used a randomized, double-blind crossover design. Subjects performed bench press and Smith machine squat repetitions to failure using 60% of their respective one repetition maximum (1RM), vertical jump, and isometric squat tests. Subjects consumed either caffeine equivalent to 7 mg/kg BW or placebo 60 minutes prior to testing. Test sessions were separated by 7 days. Number of complete bench press and Smith machine squat repetitions, vertical jump height, and isometric power were evaluated. Rating of perceived exertion (RPE) was also recorded and assessed. A repeated measures analysis of variance (ANOVA) was used to determine differences between treatments.

Subjects: Subjects were healthy college age males with at least 6 months of prior strength training experience ($n=23$, 22.0 ± 2.2 years).

Results: There was no effect of treatment order. There was a significant increase in bench press repetitions to failure between caffeine (18.9 ± 3.7) and placebo (17.3 ± 3.7 , $p=0.002$). There was a significant increase in Smith machine squat repetitions to failure between caffeine (17.2 ± 4.7) and placebo (15.3 ± 4.5 , $p=0.018$). No significant difference was found in vertical jump or isometric force plate tests between treatments. RPE was not statistically different between treatments.

Conclusions: This study suggests that acute caffeine supplementation equivalent to 7 mg/kg BW has an ergogenic effect in recreationally trained males in resistance training exercises. RPE was not statistically different between treatments, indicating that caffeine supplementation may also reduce perception of exertion relative to the amount of work performed immediately following a bout of high-intensity resistance exercise to failure.

ACKNOWLEDGEMENTS

First and foremost, I would like to give my greatest thanks to my major professor, Dr. Kathleen Melanson. The enthusiasm you demonstrated sports nutrition is why I found such an interest in your research lab, and I am forever grateful to have been a part of it for the past four years.

I would also like to recognize my thesis committee members. Thank you to Dr. Ingrid Lofgren for challenging me more than anyone else in the department, and for being one of the most influential people in both my undergraduate and graduate career. Also, thank you to Dr. Disa Hatfield for sharing your expertise and assistance – without you and the kinesiology department, I surely would not have found the success I have. Last but not least, thank you to Dr. Matt Delmonico for serving as my defense chair and providing insightful questions; because of you, I now know why plants make caffeine.

Thank you to Linda Sebelia and Cathy English for the many opportunities that have been provided to me over the years. I am fortunate enough to have had the pleasure to be both a student and a worker for you both, and the experiences I have gained are incomparable to any other.

To the dietetic interns - Chelsea, Greg, Jacqueline, Laura, and Kelsi – working and learning alongside all of you has been the greatest experience, and I believe we have grown together immensely in such a short time. To Mike Macarthur, I hope to one day be able to help another with statistics the way you have helped me. To Eric Nelson, our competition as undergraduates is partially the reason why I am here today,

so I thank you. I also extend my thanks to all of the other graduate students, as you have made this seemingly endless process not only endurable, but enjoyable.

Additionally, I would like to thank my parents, Lenora and Ron, and my grandfather, Ray, who have supported and encouraged me since day one. I would also like to thank my brothers, Adam and Jeff, who have helped make me who I am today. Last but not least, to my girlfriend Michelle, I thank you especially - for being by my side for the past eight years and believing in me every step of the way.

Finally, I would like to thank both my grandmother, Ruth, and my uncle, Rusty, to whom I dedicate this to. I wish you were both here to celebrate this moment with me, and I can only be so lucky that you were such a monumental part of my life.

PREFACE

This thesis was written to comply with the University of Rhode Island Graduate School Manuscript Thesis Format. This thesis contains one manuscript entitled “The Effect of Caffeine Supplementation on Muscular Endurance in Recreationally Active College Age Males”. This manuscript has been written in a form suitable for publication in *The Journal of Strength and Conditioning Research*.

TABLE OF CONTENTS

ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iv
PREFACE.....	vi
TABLE OF CONTENTS.....	vii
LIST OF TABLES.....	ix
LIST OF FIGURES.....	x
MANUSCRIPT.....	1
ABSTRACT.....	3
INTRODUCTION.....	4
METHODOLOGY.....	5
RESULTS.....	11
DISCUSSION.....	11
PRACTICAL APPLICATIONS.....	18
REFERENCES.....	20
APPENDICES.....	27
APPENDIX 1: REVIEW OF THE LITERATURE.....	27
APPENDIX 2: CONSENT FORM.....	46
APPENDIX 3: STUDY TIMELINE.....	50
APPENDIX 4: TEST DAY TIMELINE.....	51
APPENDIX 5: PRE-SCREENING QUESTIONNAIRE.....	52
APPENDIX 6: PERSONAL HEALTH HISTORY QUESTIONNAIRE.....	53
APPENDIX 7: CAFFEINE FREQUENCY QUESTIONNAIRE.....	56

APPENDIX 8: BORG CR-10 SCALE.....	58
APPENDIX 9: ADDITIONAL TABLES AND FIGURES.....	59
APPENDIX 10: FLYER.....	67
BIBIOLOGRAPHY.....	68

LIST OF TABLES

TABLE	PAGE
Table 1: Subject Characteristics.....	26
Table 2: Correlations Between Exercise Performance with Caffeine Based on Lean Body Mass and Self-Reported Habitual Consumption.....	59
Table 3: Mean $\pm$ SD of RPE Before and After Bench Press and Smith Machine Squat Tests with Caffeine and Placebo Treatments.....	60

LIST OF FIGURES

FIGURE	PAGE
Figure 1: Number of Bench Press and Squat Repetitions by Treatment.....	23
Figure 2: Calculated Vertical Jump Height in cm by Treatment.....	24
Figure 3: Force Generated During Isometric Force Test by Treatment.....	25
Figure 4: Relationship Between 1RM Squat and 1RM Bench Press.....	61
Figure 5: Proportion of Subjects Receiving Varying Dosages of Caffeine Based on Lean Body Mass.....	62
Figure 6: Difference in Individual Number of Bench Press Repetitions to Failure in Subjects Identified as Low Caffeine Consumers.....	63
Figure 7: Difference in Individual Number of Bench Press Repetitions to Failure in Subjects Identified as High Caffeine Consumers.....	64
Figure 8: Difference in Individual Number of Smith Machine Repetitions to Failure in Subjects Identified as Low Caffeine Consumers.....	65
Figure 9: Difference in Individual Number of Smith Machine Repetitions to Failure in Subjects Identified as High Caffeine Consumers.....	66

MANUSCRIPT INTRODUCTION PAGE

MANUSCRIPT – 1

To be submitted to the Journal of Strength and Conditioning Research

**The Effect of Caffeine Supplementation on Muscular Endurance
in Recreationally Active College Age Males**

Mark R. Gauvin, Ingrid E. Lofgren, Disa L. Hatfield, Kathleen J. Melanson

Corresponding Author: Kathleen Melanson, PhD, RD, LDN
Department of Nutrition and Food Sciences
Energy Balance Lab
The University of Rhode Island
41 Lower College Rd, 117D Fogarty Hall
Kingston, RI 02881
Phone: 401.874.4477
Email: kmelanson@uri.edu

**The Effect of Caffeine Supplementation on Muscular Endurance
in Recreationally Active College Age Males**

ABSTRACT

Caffeine is a substance consumed regularly by approximately 90% of adults worldwide, primarily due to its ability to reduce fatigue and increase wakefulness. The benefit of caffeine consumption on athletic performance in moderate doses (3-9 mg/kg body weight or BW) is frequently documented in cardio-respiratory endurance athletes. The benefits of caffeine supplementation in resistance training variables, such as muscular endurance, have shown mixed results, partially due to the inconsistency of testing variables. Whether recreational athletes experience ergogenic results in resistance activity from caffeine supplementation is currently unknown. This study evaluated caffeine's potential effects at 7 mg/kg BW on resistance training variables in recreational athletes.

Male subjects ($n=23$, 22.1 ± 2.2 years) were recruited for this randomized, double-blind crossover trial. Subjects performed bench press and Smith machine squat repetitions to failure using 60% 1RM, vertical jump, and isometric squat tests. Subjects consumed either caffeine equivalent to 7 mg/kg BW or placebo 60 minutes prior to testing.

Number of complete bench press and Smith machine squat repetitions, vertical jump height, isometric power, and rating of perceived exertion (RPE) were assessed.

Repeated measures ANOVA was used to determine differences between treatments.

Significance was set at $p\leq0.05$. There was no effect of treatment order. There was a significant increase in bench press repetitions ($p=0.002$) and Smith machine squat ($p=0.018$). This study suggests that acute caffeine supplementation equivalent to 7 mg/kg BW has an ergogenic effect in recreationally trained males in these two resistance training exercises.

Key words: *resistance exercise, repetitions to failure, ergogenic aid*

INTRODUCTION

Caffeine, a drug sought for its ability to increase wakefulness and reduce fatigue, is one of the most widely consumed drugs in the world (29). Caffeine is found in products such as coffee and tea, soda and energy drinks, ice cream, chocolate, and nutrition supplements. Evidence suggests caffeine consumption may have an ergogenic effect in a wide variety of athletic performance, including cardiorespiratory endurance events and high-intensity, short-duration activities (2, 13, 14, 22, 27). While the effects of caffeine on aerobic performance have been investigated extensively in exercises such as running, cycling, and rowing, the effect of caffeine in resistance training variables such as muscular endurance are inconclusive (5, 13).

A common method of measuring muscular endurance in caffeine trials is by having subjects perform repetitions to failure using a percentage of their maximum lifting ability, or 1-repetition maximum (1RM) (10). A study by Woolf, et al. (34) found no significance between treatments in bench press to fatigue in caffeine-naïve collegiate football athletes using 5 mg/kg, while Duncan, et al. (11) found significance in bench press repetitions to failure using the same dosage in University-level rugby, football, and basketball players. A study by Astorino, et al. (2) found no differences between treatments in resistance-trained men who ingested caffeine equivalent to 6 mg/kg. While a limited amount of literature exists evaluating lower doses of caffeine, the consensus suggests there is not an ergogenic effect in muscular endurance at 5-6 mg/kg body weight (BW) (2, 10).

The majority of existing research focuses on subjects of elite athletic status, often with several years of experience in resistance training exercise. Less research has been performed on the impact of acute caffeine ingestion on strength and endurance in the average individual who participates in light to moderate consistent physical activity. Therefore, in our study, we had recreationally trained athletes perform a combination of resistance exercises incorporating large muscle groups in both upper and lower body while ingesting a dose of caffeine equivalent to 7 mg/kg of body weight. Our primary hypothesis is that acute caffeine ingestion in the amount of 7 mg/kg of body weight will increase the number of bench press repetitions to failure compared to placebo ingestion in college age, recreational male athletes. Our secondary hypotheses is that acute ingestion of caffeine will also increase the number of squat repetitions to failure, increase the amount of force generated from a vertical jump and isometric squat exercise, and decrease rating of perceived exertion (RPE) at the time of testing, when compared to placebo ingestion.

Furthermore, previous studies have not taken body composition into consideration for caffeine dosing (2, 13, 22). Considering caffeine metabolism does not occur in adipose tissue (1), our exploratory hypothesis is that subjects with lower body fat percentage will demonstrate a significant increase in repetitions to failure in bench press and squat exercises when ingesting caffeine when compared to subjects with a higher body fat percentage.

METHODS

Experimental Approach to the Problem

This study employed a within-subjects, repeated-measures design. Through informed consent, subjects were notified they were participating in a research study examining the effect of caffeine as an ergogenic aid on resistance exercise performance. Subjects were made aware they would be asked to perform a 1RM test on the bench press and Smith machine squat, and on two subsequent testing sessions they would be required to perform bench press and Smith machine squat exercises to failure at an intensity of 60% 1RM following ingestion of capsules containing either caffeine equivalent to 7 mg/kg BW or a placebo. Subjects were told they would not be informed which order they would receive each treatment, and that the researchers performing the study were also unaware. Since prior research has demonstrated that acute caffeine ingestion may impact a range of physiological and performance variables, the experimental design (caffeine vs. placebo ingestion) was used to examine the effect of the independent variable on the following dependent variables that previous authors have suggested are influenced by caffeine ingestion: bench press repetitions to failure, Smith machine squat repetitions to failure, vertical jump height, isometric force, and RPE. All testing took place within the institution's health fitness laboratory.

Subjects

After approval from the university's Institutional Review Board and collection of subjects' individually signed informed consents, 24 males (22.1 ± 2.2 years) completed the testing protocol. As inclusion criteria, all subjects were free from any musculoskeletal pain or disorders, and reported a minimum of 6 months of consistent resistance training for at least two days a week. Subjects with a weight greater than

225 lbs. (102 kg) were not enrolled in the study in order to prevent dosages exceeding double the daily amount generally recognized as safe (400 mg) (19). Additional exclusion criteria included smoking, medical history significant for hypertension, diabetes, renal insufficiency, cardiac abnormality, or other chronic disease. Subjects were asked to refrain from vigorous exercise 48 hours before testing. In addition, subjects were provided a list of caffeine-containing products and were asked to abstain from caffeine-containing products beginning at 6:00pm the evening before each testing session. This was verified via a modified caffeine consumption questionnaire completed for the 24-hour period before each session, as well as a 24-hour food recall. Of the 24 subjects recruited, 1 subject was removed for not adhering to the pre-testing protocol.

Procedures

Subjects attended the Health Fitness Laboratory (HFL) during each visit, all on an individual basis. The first visit also included collection of anthropometric data in the Body Composition Laboratory (BCL), where height, weight, and body fat percentage were collected. Height in centimeters was measured using a Seca 216 stadiometer (Seca, Hanover, MD) to the nearest tenth of a centimeter. Weight was measured in kilograms with a Tanita scale (Tanita Corporation, Japan) to the nearest tenth of a kilogram. Height and weight were measured using standard procedures (24), and body mass index (BMI) was calculated as kg/m^2 . Body composition was assessed by air displacement plethysmography using a Bod Pod and its respective software (Cosmed, Concord, CA). Standard procedures, including Bod Pod calibration prior to data collection, were followed (31). Total body estimates of percent fat were

computed from the measured body volume using the Siri equation (28). During the initial visit, 1RM strength testing for the bench press and squat exercises was conducted using National Strength and Conditioning Association (NSCA) guidelines in the HFL (3). In addition, subjects completed a health history questionnaire and caffeine frequency questionnaire for screening and descriptive purposes, during the initial visit.

Muscular Strength

During the pre-test visit, subjects were asked to estimate their 1RM for the bench press and Smith machine squat. For each exercise, fifty percent of their stated 1RM was calculated, and subjects were asked to perform 5-10 complete repetitions. After 3 minutes of rest, subjects were asked to perform 3-5 complete repetitions based on 70% of their stated 1RM. Subjects then would perform 1-2 repetitions of gradually increasing weights, with three minute rests in between, until they were no longer able to complete a full repetition. This was performed to estimate the maximum amount of weight the subject can lift one time and served as the value for calculating the amount of weight to be used during testing visits (9).

Muscular Force and Calculated Vertical Jump Height

Muscular power was assessed by an isometric squat and vertical jump exercise. Force and power were measured using a force plate and Accupower software (AMTI, Watertown, MA). Following subject familiarization of the isometric squat protocol, subjects were asked to stand on the force plate in a quarter-squat position under a Smith machine squat bar. Once in position, subjects were asked to push against the stationary bar maximally for 10 seconds. Knee angle was measured with a goniometer.

Angle of the knee can be within a range of 100-135 degrees; this number was the same for both test trials (18).

Subjects were also familiarized with the vertical jump protocol and asked to perform three consecutive, maximal effort jumps. Procedure for the vertical jump required subjects to have hands placed on their hips and feet shoulder-length apart during the exercise. Subjects performed this exercises an additional two times, with 2-3 minutes of rest between each set. The highest force, power, and jump height in the three sets were recorded and averaged.

Muscular Endurance

Muscular endurance for both the bench press and Smith machine squat were assessed using 60% of the subjects' measured 1RM. Following familiarization of the exercise protocol, subjects were asked to perform a single set of repetitions of each exercise until failure. A trained tester was used to count the number of repetitions completed and to ensure each repetition was completed with proper form. A second trained tester was present to assist with counting complete repetitions performed.

Rating of Perceived Exertion

RPE was assessed before and after each exercise using the Borg CR-10 scale (8). Prior to the start of exercises, instructions on how to use the Borg CR-10 scale were read to each subject. The scale is ranked from 0 (resting state) to 10 (maximal effort) and assesses how strenuously the subject perceived he worked, based on the self-reported number chosen.

Caffeine and Placebo Administration

Subjects were supplied caffeine in the form of encapsulated powder. Seven mg/kg BW were used to determine the total dose for each subject. Placebo capsules were filled with microcrystalline cellulose free of the eight major allergens as well as gluten. Caffeine or placebo was ingested one hour prior to experimental trials to achieve maximum plasma concentration (16). Subjects were provided 12 fluid ounces of water to aid in capsule ingestion. Once the subject had ingested caffeine or placebo capsules, he remained stationary for 45 minutes, viewing TED Talks© or reading magazines. At 45 minutes, subjects were tested for hydration status by using a refractometer. Inadequate hydration was determined by a specific gravity of 1.024 or greater (25). Subjects who were found to be inadequately hydrated were provided an additional 12 fluid ounces of water to consume.

Statistical Analysis

G-power (G*Power, Version 3.1.9.2) was used to determine sample size using results from a similar study analyzing bench press repetitions in collegiate athletes ingesting 5 mg/kg body weight of caffeine versus placebo (12). An alpha level of 0.05, with an effect size = 1 and power = 0.8; this revealed an adequate sample size of 23 subjects. Data were analyzed using SPSS (version 23; SPSS, Inc. Chicago, IL). A repeated measures analysis of variance (ANOVA) was used to analyze the primary and secondary hypotheses. Assumptions for normality were tested and met for all variables using skewness and kurtosis. Pearson correlations were run to examine exploratory hypotheses. For RPE, a 2x2 repeated measures ANOVA was run to compare pre and post RPE values with both the caffeine and placebo treatment. Significance for all analyses were set at $p \leq 0.05$.

RESULTS

Subject demographics are presented in Table 1. Mean BMI was 25.5 ± 3.0 kg/m². Body fat percentage was 15.8 ± 16.4 . Mean 1RM was 92.2 ± 22.8 kg in the bench press and 114.7 ± 22.9 kg in the squat test.

Results indicated that subjects completed significantly more repetitions to failure with the caffeine treatment compared to placebo in both the bench press (mean difference of 1.4 repetitions, $p=0.006$) and Smith machine squat (mean difference of 1.5 repetitions, $p=0.032$) (Figure 1). Treatment order was not significant in either test. There were no significant differences in average vertical jump height (Figure 2) or isometric force (Figure 3) between treatments.

With respect to lean body mass, no correlations were found with performance in the caffeinated condition in the bench press or Smith machine squat tests. No correlations were found in bench press or Smith machine squat tests with self-reported caffeine habituation under the caffeinated condition. Data not shown.

Rating of perceived exertion was not significantly influenced by condition bench press or squat tests, as determined by 2 (time) x 2 (treatment) repeated measures ANOVA. Rating of perceived exertion was significant in the isometric squat test between treatment and time; however, significance was lost when controlling for treatment order.

DISCUSSION

Both the bench press and Smith machine squat tests resulted in a significant increase in number of repetitions when subjects received the caffeine treatment compared to placebo (Figure 1). These results are consistent with previous studies

performed in individuals with a greater training status (2, 11). Astorino et al. (2) observed 19.9 ± 4.3 repetitions in the caffeine condition versus 18.4 ± 4.0 with placebo in a study evaluating 22 resistance-trained males with a training history of 6.0 ± 2.8 years. This mean difference of 1.5 repetitions in the bench press is nearly identical to that observed in the present study (1.4 repetitions) (2). Duncan et al. (11) observed an average of 22.4 ± 3.0 repetitions in the caffeine condition and 20.4 ± 3.4 with placebo, resulting in an increase of 2 repetitions - 0.6 repetitions greater than observed in the present study. In that study, all subjects were highly experienced in the respective sport (rugby, basketball, football) at the University level and have been competing in their sport for a mean time of 10.4 ± 2.3 years (11). Therefore, the present study suggests that caffeine supplementation in recreational athletes has similar ergogenic effects to that which has been observed in athletes trained in their respective sports for longer durations.

This study examined the acute effect of a high dose of caffeine on muscular endurance and sought to address gaps in the literature by employing a design where multiple resistance exercises were utilized and a population of recreationally trained athletes was analyzed. Employing the bench press, Smith machine squat, and isometric force plate arguably create a greater level of fatigue than studies examining performance in a single exercise. The bench press test in particular is an exercise frequently used in studies evaluating the impact of caffeine in muscular endurance; employing this test in our study allows us to compare efficacy in our population with groups that have been previously evaluated (2, 5, 32). The present study also sought to

recruit subjects who participate in resistance training activity on a recreational basis, which was defined as a minimum of twice a week for a period of at least six months.

Other researchers have suggested that caffeine may have different effects for upper- versus lower-body exercise (5, 10). Davis et al reported that the ergogenic effect of caffeine may not elicit effects for leg musculature until later into an exercise, when fatigue plays a more prominent role, compared to earlier sets of repetitions (10). In contrast, tests using upper-body musculature have shown greater improvements in earlier sets, such as a study by Beck et al which found significant increases in bench press repetitions to failure, but not in bilateral leg extension (5).

The increases in both upper and lower endurance exercises observed in the present study are not consistent with previous literature, and may be explained due to the population recruited. Previous literature has questioned whether the ergogenic properties of caffeine are limited by the amount of muscle mass recruited and the total number of repetitions performed (10). This question is plausible given the absorptive properties of caffeine: when absorbed, caffeine is able to distribute freely into intracellular tissue water, allowing the transport to metabolic tissue such as the muscle and brain (1). Therefore, our exploratory hypothesis sought to determine whether subjects with a lower body fat percentage (and thus a higher percentage of metabolically active tissue) would benefit from the ergogenic effects of caffeine than those with a higher body fat percentage. To the researchers' knowledge, this is the first study examining the dosage each subject received based on lean body mass. The range of body fat percentages recorded was 5.8-27.1%, and the caffeine dosage averaged 8-9 mg per kg lean tissue. Despite this, there were no significant correlations between

calculated body fat percentage and performance in any of the four tests when subjects received the caffeine treatment. This suggests that the ergogenic effect of caffeine was not greater in individuals with a lower body fat percentage.

Additionally, there was no correlation in performance in the bench press or Smith machine squat tests with caffeine habituation. An early review article by Graham concluded that any differences caused by caffeine habituation do not appear to be significant (16). Moreover, a study by Astorino et al. evaluated the efficacy of 6 mg/kg BW caffeine versus placebo on bench press, leg press, lat row, and shoulder press; results found that 66% of subjects who demonstrated increases in the caffeine condition were relatively heavy caffeine users, while subjects who had reduced performance in the caffeine condition consumed less than 150 mg/day (2). Of note, the study had a sample size of 14 men with resistance training experiences >2 days/week for 7.5 ± 1.2 years, who all identified as daily caffeine consumers; as a result, it cannot be concluded that caffeine habituation has a significant impact on resistance training variables (2).

Bloms et al. reported significantly higher vertical jump performance in Division I collegiate athletes who consumed 5 mg/kg BW of caffeine (7). They concluded the ergogenic of caffeine in vertical jump performance is likely to only be observed in subjects who are frequently exposed to repeated ballistic tasks, such as basketball and volleyball players (7). The current study did not recruit individuals based on experience in sports or other activities that may predispose individuals to activities requiring frequent jumping (Figure 2). Furthermore, subjects were not familiarized with the vertical jump protocol prior to the test visits. To our knowledge,

there has not been a caffeine trial in vertical jump exercises in recreationally active athletes naïve to ballistic activity. Therefore, is it plausible that the proposed conclusion by Bloms et al. may explain the results witnessed in the present study, which found no significant difference in calculated vertical jump height (7).

Previous literature has hypothesized that caffeine does not alter maximal force-generating capacity of a muscle, but may extend time to fatigue by altering pain perception (10). This would explain the results observed from the isometric force test, which had no significance between the caffeine treatment and placebo (Figure 3). To the researchers' knowledge, this may be the first study to use the isometric force test in order to measure maximal isometric force generation in recreational athletes. Results from the present study support the hypothesis that caffeine does not significantly alter maximal force-generating capacity.

While there are several mechanisms that may play a role in the observed ergogenic effects of caffeine, the most prominent mechanism of action involves caffeine's ability to inhibit adenosine receptors (20). Adenosine, a molecule similar in structure to caffeine has been shown to enhance pain perception, induce sleep, and reduce arousal, among other functions (6, 23, 30). Caffeine, which has a nonselective affinity to adenosine receptors, can bind to adenosine receptors in the brain and peripheral tissues (15). The resulting inability of adenosine to bind to receptor sites prevents the adenosine-induced suppression of dopamine release (10). This contributes to the reported increase in arousal and alertness frequently associated with caffeine intake (26). As a result, it is believed that the primary mechanism of action is inhibitory effects on adenosine modifying pain perception while sustaining motor unit

firing rates, resulting in an overall ergogenic effect (10). The resulting inhibition of adenosine in the presence of caffeine may justify why a significant improvement was found in the two tests that utilized muscular endurance, but not in the tests that evaluated a short-duration (<10 second) bout of force, such as the isometric force test, or the vertical jump test, which arguably did not drastically increase subjects' perceived exertion (7, 10).

Rating of perceived exertion was not significantly different in the bench press or Smith machine squat test between treatments. These results are consistent with a range of studies that have also found no difference in RPE with resistance exercise (4, 11, 17, 33). A proposed reason for the lack of a dampening effect on RPE following caffeine ingestion is the short duration in exercise to failure in a given exercise (such as bench press or squats) is insufficient to elicit a perceived difference in exertion between treatments (11). Evaluating caffeine supplementation at later time points following resistance training exercise has shown decreased perception of exertion in caffeine treatments. For example, Hurley et al (21) found decreased perception of exertion following bench press exercises at 72 hours post-exercise.

Despite the non-significant findings in this current study, subjects had improved performance in the bench press and squat tests without having a significant change in RPE between treatments. This is in opposition of the results of a study by Duncan et al, where subjects had no significant difference in number of bench press repetitions between 5 mg/kg caffeine and placebo, but did have a lower RPE in the caffeine condition (13). As a result, it can be argued that RPE was not reduced as a result of the caffeine treatment in the present study, but perception of exertion was

maintained in the caffeine treatment while subjects completed an additional 1.4 repetitions, on average.

There were several limitations to this study. This study sought out to evaluate a population of recreationally trained athletes. While all subjects recruited met the minimum requirements, there was large variability in training experience among subjects, ranging from the minimum requirements to amateur power lifter. Number of years of resistance training experience was not documented. Subjects were primarily Caucasian; future research should recruit a more diverse population to increase generalizability. Additionally, some subjects noted discomfort when using the Smith machine – particularly when performing the ISO test, which required subjects to exert themselves onto a bar anchored in place. For this reason, subjects may have unconsciously chose to exert themselves less on the second visit compared to the first. However, to control for potential order effects, the order that subjects received each treatment was randomized; no significant differences were found in perceived exertion between the first and second visit. Also, there were two investigators who conducted the subjects' test sessions. However, both testers were trained by the same researcher. Furthermore, analysis determined there was no significant difference in any of the four tests when controlled for investigator.

In contrast to the limitations, there were many strengths to the study. First, the study was a double-blind, cross-over design. Also, each subject acted as his own control. This randomization of treatment order limits the chance of improvement due to test familiarization. Finally, several steps were taken to ensure that all measures were taken in an identical manner. Hydration status was tested to ensure subjects were

adequately hydrated prior to testing by determining urine specific gravity. Subjects met at the same time of day for each visit. Subjects abstained from physical activity for 48 hours prior to test days and caffeine-containing products from 6:00pm the evening before testing. Additionally, subjects were instructed to consume the same meal on each test day; this was confirmed by performing a 24-hour food recall prior to testing. Finally, this study evaluated recreational athletes, a population that makes up a greater percentage of the population when compared to elite athletes. For this reason, the results of this study are applicable to a larger population.

PRACTICAL APPLICATIONS

The effectiveness of caffeine supplementation to improve performance in resistance training exercise in recreational athletes remains somewhat unclear. The results of this investigation demonstrate that caffeine increases number of repetitions in muscular endurance exercises that employ large upper and lower muscle groups such as the bench press and Smith machine squat. Caffeine habituation status does not appear to have an impact on the potential ergogenic effects of caffeine. While the average increase in repetitions was considerably low (1.4 repetitions in the bench press and 1.5 repetitions in squats), the increases in repetitions over time may be favorable in the population observed, due to a chronic training effect. While one set of repetitions to failure was employed for this test, future research should evaluate the same population using multiple sets of repetitions, as caffeine supplementation may increase muscular endurance while maintaining RPE as demonstrated in the present study. However, despite the observed increases in muscular endurance measures, a

high dose of caffeine was required to achieve the observed results. The practical use of such a dosage (7 mg/kg BW) in a free-living environment is questionable. As with any supplement study, there will be subjects who respond to treatment and those who not only do not respond, but also experience an undesirable effect. For this reason, health professionals and educators should consider recommending caffeine trials to clients on an individual basis to determine if supplementation will yield desired results.

REFERENCES

1. Arnaud MJ. The pharmacology of caffeine. *Prog Drug Res* 31: 273-313, 1987.
2. Astorino TA, Rohmann RL, Firth K. Effect of caffeine ingestion on one-repetition maximum muscular strength. *Eur J Appl Physiol* 102: 127-132, 2008.
3. Baechle T, Earle R. *Essentials of Strength Training and Conditioning*. Champaign, IL, 2008.
4. Beck TW, Housh TJ, Malek MH, Mielke M, Hendrix R. Acute effects of a caffeine containing supplement on bench press strength and time to exhaustion. *J Strength Cond Res* 22: 1654-1658, 2008.
5. Beck TW, Housh TJ, Schmidt RJ, Johnson GO, Housh DJ, Coburn JW, Malek MH. The acute effects of a caffeine-containing supplement on strength, muscular endurance, and anaerobic capabilities. *J Strength Cond Res* 20: 506-510, 2006.
6. Bjorness TE, Greene RW. Adenosine and sleep. *Current Neuropharmacology* 7: 238-245, 2009.
7. Bloms LP, Fitzgerald JS, Short MW, Whitehead JR. The effects of caffeine on vertical jump height and execution in collegiate athletes. *J Strength Cond Res*, 2015.
8. Borg GA. *Human Kinetics: Borg's perceived exertion and pain scales*. Champaign, IL, 1998.
9. Brown LE, Weir JP. ASEP procedures recommendation i: accurate assessment of muscular strength and power. *J Exercise Physiology* 4: 1-21, 2001.
10. Davis JK, Green JM. Caffeine and anaerobic performance: ergogenic value and mechanisms of action. *Sports Med* 39: 813-832, 2009.
11. Duncan MJ, Oxford SW. The effect of caffeine ingestion on mood state and bench press performance to failure. *J Strength Cond Res* 25: 178-185, 2011.
12. Duncan MJ, Oxford SW. Acute caffeine ingestion enhances performance and dampens muscle pain following resistance exercise to failure. *J Sports Med Phys Fitness* 52: 280-285, 2012.
13. Duncan MJ, Stanley M, Parkhouse N, Cook K, Smith M. Acute caffeine ingestion enhances strength performance and reduces perceived exertion and muscle pain perception during resistance exercise. *Eur J Sport Sci* 13: 392-399, 2013.
14. Dunford M, Doyle JA. *Nutrition for Sport and Exercise*. Belmont, CA: Peter Adams, 2008.
15. Fredholm BB, Battig K, Holmen J, Nehlig A, Zvartau EE. Actions of caffeine in the brain with special reference to factors that contribute to its widespread use. *Pharmacol Rev* 51: 83-133, 1999.
16. Graham TE. Caffeine and exercise: metabolism, endurance and performance. *Sports Med* 31: 785-806, 2001.
17. Green J, Wickwire P, McLester J, Gendle S, Hudson G, Pritchett R, Laurent C. Effects of caffeine on repetitions to failure and ratings of perceived exertion during resistance training. *Int J Sports Phys Perf* 2: 250-259, 2007.

18. Harris GR, Stone MH, Obryant HS, Proulx CM, Johnson RL. Short-term performance effects of high power, high force, or combined weight-training methods. *J Strength Cond Res* 14, 2000.
19. Heckman MA, Weil J, Gonzalez de Mejia E. Caffeine (1,3,7-trimethylxanthine) in foods: a comprehensive review on consumption, functionality, safety, and regulatory matters. *J Food Sci* 75(3): R77-87, 2010.
20. Holtzman SG, Mante S, Minneman KP. Role of adenosine receptors in caffeine tolerance. *J Pharmacol Exp Ther* 256: 62-68, 1991.
21. Hurley CF, Hatfield DL, Riebe DA. The effect of caffeine ingestion on delayed onset muscle soreness. *J Strength Cond Res* 27: 3101-3109, 2013.
22. Jacobson BH, Weber MD, Claypool L, Hunt LE. Effect of caffeine on maximal strength and power in elite male athletes. *Br J Sp Med* 26: 276-280, 1992.
23. Kalmar JM. The influence of caffeine on voluntary muscle activation. *Med Sci Sports Exerc* 37: 2113-2119, 2005.
24. Lohman TG, Roche AF, Martorell R. *Anthropometric standardization reference manual*. Champaign, IL: Human Kinetics Books, 1988.
25. Minton DM, O'Neal EK, Torres-McGehee TM. Agreement of urine specific gravity measurements between manual and digital refractometers. *J Athletic Training* 50: 59-64, 2015.
26. Nehlig A. Is caffeine a cognitive enhancer? *J Alzheimers Dis* 20: 85-94, 2010.
27. Norager CB, Jensen MB, Madsen MR, Laurberg S. Caffeine improves endurance in 75-yr-old citizens: a randomized, double-blind, placebo-controlled crossover study. *J Appl Physiol* 99: 2302-2306, 2005.
28. Siri WE. *Body composition from fluid space and density*. Washington, DC: National Academy of Science, 1961.
29. Spriet LL. Caffeine and performance. *Int J Sports Nutrition* 5: S84-99, 1995.
30. Sylvén C, Jonzon B, Fredholm BB, Kaijser L. Adenosine injection into the brachial artery produces ischaemia like pain or discomfort in the forearm. *Cardiovasc Res* 22: 674-678, 1988.
31. Wagner DR, Heyward VH, Gibson AL. Validation of air displacement plethysmography for assessing body composition. *Med Sci Sports Exerc* 32: 1339-1344, 2000.
32. Williams AD, Cribb PJ, Cooke MB, Hayes A. The effect of ephedra and caffeine on maximal strength and power in resistance-trained athletes. *J Strength Cond Res* 22: 464-470, 2008.
33. Woolf K, Bidwell WK, Carlson AG. The effect of caffeine as an ergogenic aid in anaerobic exercise. *Int J Sports Nut Exerc Metab* 18: 412-429, 2008.
34. Woolf K, Bidwell WK, Carlson AG. Effect of caffeine as an ergogenic aid during anaerobic exercise performance in caffeine naïve collegiate football players. *J Strength Cond Res* 25: 1363-1369, 2009.

ACKNOWLEDGEMENTS

This work was funded by the Undergraduate Research Initiative Grant and the Continuing Research Grant at the University of Rhode Island. Results of this study do not constitute endorsement of the product by the authors or the NSCA.

FIGURES

Figure 1: Number of Bench Press and Squat Repetitions by Treatment

BP=Bench press, S=Squat. (n=23) Data analyzed using repeated measures ANOVA. There was a significant increase in repetitions to failure between caffeine and placebo treatments in both the bench press and squat tests. * $p < 0.05$, ** $p < 0.01$.

Figure 2: Calculated Vertical Jump Height in cm by Treatment

(n=23) Average calculated vertical jump height in cm by treatment. Subjects performed three sets of three jumps, with the highest average jump height recorded. Data analyzed using repeated measures ANOVA. No significance found between caffeine and placebo treatment.

Figure 3: Force Generated During Isometric Force Test by Treatment

(n=23) Force generated in isometric force plate test by treatment. Data analyzed using repeated measures ANOVA. No difference between caffeine and placebo treatment.

TABLES

Table 1. Subject Characteristics

Characteristics of subjects (n=23). 1RM Squat = 1 repetition maximum in squat exercise, 1RM Bench Press = 1 repetition maximum in bench press exercise. Anthropometrics are presented as mean $\pm$ SD.

Gender	
Male	23 (100%)
Ethnicity	
African-American	2 (8.7%)
Asian-American	1 (4.3%)
Caucasian	18 (78.3%)
Hispanic/Latino	2 (8.7%)
Height (cm)	176.4 $\pm$ 6.4
Weight (kg)	79.5 $\pm$ 9.9
BMI (kg/m ²)	25.5 $\pm$ 3.1
Body fat (%)	15.8 $\pm$ 6.6
Age (years)	22.1 $\pm$ 2.2
1RM Squat (kg)	115.8 $\pm$ 22.7
1RM Bench press (kg)	93.1 $\pm$ 22.8
Self-Reported Caffeine Intake ^a	
Abstain	4 (17.4%)
Low	11 (47.8%)
Moderate	4 (17.4%)
High	4 (17.4%)

^aSelf-reported caffeine intake is defined as: abstain: $\leq$ 8 oz. caffeine-containing products per week; low: $\leq$ 8 oz. caffeine-containing products per day; moderate: 8-16 oz. caffeine-containing product per day; high: $>$ 16 oz. per day.

Appendix I: Review of the Literature

Overview

This literature review will discuss different types of resistance training variables – specifically, muscular strength and muscular endurance – and provide a synopsis of the previous literature on cardio-respiratory endurance and resistance training trials utilizing caffeine as an ergogenic aid. First, we will define strength and endurance and provide methods of measuring muscular strength, muscular endurance, and vertical jump height. Then, we will discuss the availability of caffeine in the diet along with its absorption, metabolism, and several potential mechanisms that may explain its ergogenic effects in athletic exercises. Finally, we will provide an overview of the previous literature describing caffeine as an ergogenic aid in both cardio-respiratory endurance and resistance training.

Resistance Training Variables

Muscular Strength

Muscular strength is defined as the maximum force or torque produced by a muscle group in an isometric action at a specific joint angle (42). The 1-repetition maximum (1RM) is currently the gold standard for determining isotonic strength (15). The American Society of Exercise Physiologists recommend performing 1RM squat and 1RM bench press tests to assess lower body and upper body strength, respectively (15). However, 1RM testing is perceived as a potentially dangerous test to perform; for that reason, methods that employ using a submaximal weight ($<1\text{RM}$) to estimate 1RM in athletes are often used (15). Repetitions with a submaximal weight ($<1\text{RM}$) are used to accurately estimate 1RM performance in strength endurance exercises,

such as the bench press (49). Estimated 1RM can be accurately calculated by employing up to 10 repetitions using submaximal weight, such as in a 5RM or 10RM test (65).

Previous studies have shown that lighter loads, such as 40 and 60% 1RM, lifted to exhaustion can accurately predict 1RM bench press strength (5, 38). However, absolute load tests are alternative methods to predicting 1RM by utilizing a constant weight; these methods have also been found to be accurate predictors of 1RM in college-age men (38). The most common absolute load test, utilized by the National Football League as well as at the college and high school level, employs performing the maximum number of repetitions possible using constant weight of 225 pounds (50). Results from this test, known as the NFL-225 Test, has been shown to accurately calculate 1RM; however, the absolute load test is only able to be used in subjects whose 1RM bench press is greater than 225 pounds (15, 50). In research such as the present study where subjects recruited have a wide range of strength training experience, this method of calculating 1RM is not suitable. For this reason, we utilized each subject's own submaximal weight as a method to calculate 1RM. This way, the amount of weight used for each subject was relative to his individual resistance training ability.

Muscular Endurance

In most laboratory studies, endurance performance is measured as the time taken to reach exhaustion at a given power output (70). Resistance training programs that emphasize muscular endurance typically involve many repetitions – typically 12 or more – per set (4). Despite this high number of repetitions, loads lifted are lighter

than in exercises evaluating muscular strength, and fewer repetitions (usually 2-3) are performed (4). This is in contrast to strength training exercises, where loads used are typically higher and the number of repetitions are lower (6 or less) (4). A common method of measuring muscular endurance performance is by using repetitions to failure (17). Repetitions to failure involve performing sub-maximal force production in several repetitions until fatigue, and is usually performed with a percentage of 1RM (17).

Table 1: Volume Assignments Based on Training Load (4)

Training goal	Goal repetitions	Sets*
Strength	≤6	2-6
**Power		
Single-effort event	1-2	3-5
Multiple-effort event	3-5	3-5
Hypertrophy	6-12	3-6
Muscular endurance	≥12	2-3

*These assignments do not include warm-up sets and typically apply to core exercises only.

**The repetition assignments shown for power in this table are *not consistent* with the %1RM-repetition relationship. On average, loads equaling about 80% of the 1RM apply to the two- to five-repetition range.

Vertical Jump Height

The vertical jump (VJ) test is the primary test used to assess muscular power in the legs (15). There are two forms of the VJ test utilized: the squat jump (SJ) and the counter-movement jump (CMJ) (15). Both the SJ and CMJ can be performed with or without the use of arm motions (15). When arm motions are not allowed, subjects are required to place hands on their hips (15). While the CMJ generally results in higher jump heights than the SJ, Sayers, et al has argued that SJ is a preferred testing method due to the variability in CMJ technique as well as the accuracy in calculating peak power (68).

Caffeine

Intake & Metabolism

Caffeine (1,3,7-trimethylxanthine), found in coffee, tea, soft drinks, and dietary supplements, is the most used pharmacologically active substance in the world, with the average American adult consuming 2.4 mg/kg/day (76). Consumption of up to 400 mg (equivalent to 4 mg/kg body weight in a 90 kg person) of caffeine per day has been determined to be a safe level in adults (35). The average US adult's coffee consumption is about two cups per day (about 280 mg of caffeine). In addition, hundreds of caffeinated beverages exist, ranging from 50 to 500 mg per can or bottle (equivalent to 0.5-5.5 mg/kg body weight in a 90 kg person) (64).

Caffeine can be absorbed via oral, rectal, or parenteral route, and maximum blood concentration of caffeine in humans is achieved in one hour after absorption through the gastrointestinal tract (63). Peak absorption has been determined to be around 30 minutes in popular products such as colas and coffees, and around 60 minutes in encapsulated forms (44). The half-life of caffeine has a range of 2-12 hours; however, plasma concentration is dependent on time since previous consumption and other dietary factors, such as fiber (a structural polysaccharide that resists chemical breakdown by digestive enzymes (1, 29, 33, 51).

Caffeine binds to plasma proteins and is able to distribute freely into intracellular tissue water, accounting for 10-30 percent of the total plasma pool; caffeine is also lipophilic and is able to cross the blood-brain barrier (1, 71). Metabolism of caffeine occurs in the liver through processes of demethylation and oxidation (33). The primary route of caffeine metabolism is 3-ethyl demethylation to

paraxanthine; this step makes up approximately 75-80 percent of caffeine metabolism and involves cytochrome P4501A2 (1). Caffeine is also metabolized to theophylline and theobromine, however metabolism to paraxanthine is the primary metabolic pathway (1). Caffeine is also reabsorbed by the renal tubules, however only a small amount of caffeine is excreted in urine unchanged (1). Repeated ingestion of caffeine does not alter absorption or metabolism of caffeine (28). Research does suggest menstrual cycles or use of oral contraceptives may alter caffeine clearance (43).

Physiology

Caffeine is both water and fat soluble, which allows distribution to all tissues of the body (1, 2, 54, 71, 73). As a result, a specific mechanism of action in regards to exercise performance has yet to be chosen (73). There are several principle mechanisms that have been proposed to explain the ergogenic potential of caffeine during exercise: 1) increased myofilament affinity for calcium and/or the increased release of calcium from the sarcoplasmic reticulum (SR) in skeletal muscle; 2) cellular action caused by the accumulation of cyclic-3'-5'-adenosine monophosphate (cAMP) in tissues such as skeletal muscle and adipocytes; 3) cellular actions mediated by the competitive inhibition of adenosine receptors in somatic cells and the central nervous system (19). Additionally, early research by Powers et al. suggest that the ergogenic effects of caffeine in aerobic exercise is related to an increase in fatty acid oxidation, leading to the sparing of muscle glycogen (62). Increased oxidation of fatty acids inhibits glycogen phosphorylase activity, switching the preference from glycogen to fat (60, 67). This resulting increase in free fatty acids is hypothesized to decrease cellular lactic acid production, a pathway that has been linked to fatigue during heavy

exercise (62). Recent research, however, has found little evidence to support the hypothesis that caffeine has ergogenic effects due to enhanced fat oxidation (31). Graham, et al conclude individuals may respond differently to the effects of caffeine, which could be explained by genetic variations (31). Further potential mechanisms are described below.

Caffeine may reduce the excretion of calcium (Ca^{2+}) that occurs during exercise (30). Tallis, et al performed a review of numerous isolated muscle studies examining the direct effects of caffeine (73). Results showed a greater release of Ca^{2+} into the intramuscular space, increased myofibrillar Ca^{2+} sensitivity, slowing of the sarcoplasmic reticulum Ca^{2+} pump and increased SR Ca^{2+} permeability (73). This combination of events significantly modified the performance of skeletal muscle, most notably by increasing muscle relaxation time (73). However, Tallis et al concluded that caffeine's ability to cause significant improvements in muscle contractility is likely a result of a number of synergistic effects, and less likely a single mechanistic action (73).

Another proposed role of the ergogenic effect of caffeine involves calcium and phosphodiesterase inhibition (17). *In vitro* studies have shown that caffeine inhibits phosphodiesterase enzymes, allowing an increase in cAMP (17, 25). An increase in cAMP, along with an increase in blood catecholamines (such as epinephrine), results in the activation of hormone sensitive lipase (34). The resulting free fatty acids are mobilized from the cell membrane of the adipocyte and are transported to tissues and are oxidized for energy (34). However, this mechanism is unlikely to explain the ergogenic effect of caffeine observed during athletic activity; while *in vitro* studies

have demonstrated inhibitory effects on phosphodiesterase, *in vivo* studies would require toxic doses of caffeine to observe a physiological benefit (17).

Arguably the most favored mechanism of action involves caffeine's ability to inhibit adenosine receptors (36). Adenosine, a molecule similar in structure to caffeine has been shown to enhance pain perception, induce sleep, and reduce arousal, among other functions (12, 41, 72). Caffeine, which has a nonselective affinity to adenosine receptors, can bind to adenosine receptors in the brain and peripheral tissues (26). The resulting inability of adenosine to bind to receptor sites prevents the adenosine-induced suppression of dopamine release (17). This contributes to the reported increase in arousal and alertness frequently associated with caffeine intake (55). As a result, it is believed that the main mechanism of action is inhibitory effects on adenosine modifying pain perception while sustaining motor unit firing rates, resulting in an ergogenic effect (17).

Caffeine ingestion before exercise may cause the undesired effect of an increase in the inflammatory response, demonstrated by increases in markers of muscle damage and leukocyte cells (6, 75). As a result, an additional mechanism that may aid in the ergogenic effect of caffeine involves creatine kinase (CK), a physiological marker that indicates muscle damage and is associated with higher levels of pain perception after acute episodes of resistance exercise (48). Creatine kinase de-phosphorylates creatine phosphate to enable rapid phosphorylation of ADP to ATP for quick, intense muscle contractions (24). Previous literature suggests resistance exercise results in an increase in CK concentrations (37, 48). Additionally, other researchers have found that caffeine causes an increase in circulating

catecholamines, such as epinephrine and norepinephrine, which are responsible for the increase in leukocytes frequently observed post-exercise (11). Bassini-Cameron et al. hypothesized the fatigue delaying effect of caffeine may even enhance the extent of muscle damage occurring during intense exercise, as subjects can potentially perform a higher volume of work following acute caffeine ingestion (6). However, this does not explain the potential ergogenic effect during exercise, but instead addresses muscle injury, and related muscle soreness, post-exercise. A study employing caffeine equivalent to 4.5 mg/kg BW found that an acute ingestion prior to resistance exercise does not appear to cause greater muscle cell injury, as CK and leukocytes observed were not above levels that occurred in resistance exercise alone (48). Furthermore, peak blood levels of CK and associated muscle soreness do not occur until 24 and 48 hours post-exercise (56). Recent literature shows caffeine ingestion before resistance training may result in lower levels of soreness 2 and 3 days post-exercise (37). This suggests that the potential negative effect caffeine may have on increasing CK and leukocyte concentrations during exercise may be outweighed by both the ergogenic effect frequently observed during exercise as well as the reduced muscle soreness observed within the following days post-exercise.

Additional Effects of Caffeine

Caffeine has been noted to have multiple effects in the body. Caffeine acutely raises blood pressure as a result of sympathetic system stimulation and the antagonistic effect on adenosine (26, 69). These effects on the cardiovascular system generally return to baseline after 10-60 hours, depending on the amount of caffeine ingested (33). Both mood and cognitive ability improve following both acute and

chronic caffeine consumption (26). Furthermore, caffeine has been shown to increase alertness and ability to concentrate, and has long been used to treat headaches due to its synergistic effects with analgesics; as a result, caffeine is an ingredient used both alone or in conjunction with other medications, such as acetaminophen (9, 26, 47, 69). Persons who abstain from caffeine overnight (8-12 hours) have a significant depletion of caffeine by early morning; as a result, subjects are more sensitive to the stimulant effects upon reintroduction into the body (66).

Caffeine's impact on athletic performance has been investigated in a range of athletic exercises, including endurance events, team sports, and high-intensity, short-duration activities (3, 23, 24, 39, 57). Due to the observed effects of caffeine, the World Anti-Doping Agency has caffeine placed on the 2015 monitoring program (79). While there is no restriction set to the amount of caffeine to be consumed prior to an athletic event, caffeine concentration is monitored for potential repetitive misuse (10, 40, 79). Previously, the International Olympic Committee (IOC) prohibited urinary caffeine concentrations in excess of 12 mcg/mL (52). This currently unrestricted limit of caffeine can allow athletes to consume amounts of caffeine associated with ergogenic benefits prior to athletic events. In a meta-analysis of caffeine studies examining various types of physical activity performance, the amount of caffeine commonly shown to improve endurance is between 3 and 6 mg/kg of body mass, consumed no more than 60 minutes before activity (27).

Considering the multiple proposed mechanisms of caffeine, the remaining sections of the literature review will review the effects of caffeine in aerobic and anaerobic athletic performance.

Aerobic Performance

The effects of caffeine on aerobic performance have been investigated extensively in aerobic exercises, particularly in running, cycling, and rowing. Several meta-analysis report that caffeine has an ergogenic effect on aerobic performance (20, 27). Doherty, et al (20) reviewed 40 double-blind studies evaluating a combination of cycling, running, and rowing exercises in subjects with mixed reported habitual caffeine intakes; the consensus was that 3-10 mg/kg of caffeine is necessary to have a positive impact on exercise performance. Compared to placebo, caffeine improved test outcomes by 12.3% on average (20). Ganio, et al (27) presented lower findings, citing a mean improvement of $4.4 \pm 5.0\%$ in 21 cycling trials, $0.9 \pm 0.7\%$ in 6 running trials, and $1.1 \pm 0.3\%$ in 4 rowing trials. Ganio, et al determined that quantities above 3 mg/kg are needed for improvement and that athletes consume up to 6 mg/kg no more than 60 minutes before exercise (27).

Desbrow, et al (18) compared the ergogenic effects of two different dosages of caffeine, 3 mg/kg and 6 mg/kg, to placebo in 16 well-trained male cyclists. In this randomized, double-blind study, participants performed cycling ergometer time trials after receiving either 3 or 6 mg/kg of caffeine or placebo (18). Both treatments had significant enhancements in endurance cycling, with 4.2% enhancement in the low dose (3 mg/kg) treatment and 2.9% in the high dose (6 mg/kg) treatment (18). The authors concluded that greater levels of circulating caffeine from higher dosages do not equate to better performance outcomes (18).

In a double-blind crossover study performed by Bruce, et al, eight competitive male rowers completed three trials of a 2000-m rowing test, each one hour after

consuming either 6 or 9 mg/kg BW of caffeine or placebo (16). Both 6 and 9 mg/kg BW caffeine led to an improvement in 2000-m simulated rowing time trial performance (16). The 6 mg/kg and 9 mg/kg caffeine treatments had similar improvements in performance; however, one-third of the subjects had urinary caffeine concentrations at or above 12 mcg/L when they received 9 mg/kg BW caffeine, which exceeds the limit set by the IOC (10, 16). As a result, Bruce, et al recommends utilizing trial doses of caffeine equivalent to ~6 mg/kg for competitive male athletes (16).

In a double-blind, placebo-controlled trial performed by O'Rourke et al, 15 recreational and 15 well-trained runners (gender was undisclosed) completed two 5 kilometer time-trials following ingestion of either 5 mg/kg caffeine or placebo (58). The caffeine treatment had significant improvements in performance in both recreational and well-trained groups (1.0% and 1.1%, respectively) (58). However, the authors questioned the practical significance of the results, citing a small beneficial effect (58).

Paton, et al utilized a dose of 6 mg/kg caffeine or placebo in a randomized, double-blind, crossover experiment with 16 male team-sport athletes (59). Subjects performed 10 sets of 10-second sprints, with each sprint followed by 10 seconds of rest (59). The observed effect of caffeine was not significant in sprint performance and on fatigue; in fact, the caffeine treatment was found to have a slight decrease in agility (59).

Despite the extent of which the effect of caffeine has in aerobic performance, a specific recommendation on dosage has yet to be determined. Based on two meta-

analyses, a wide range of dosage recommendations are proposed: Doherty, et al propose an effective range of 3-10 mg/kg, while Ganio, et al offers an arguably smaller range of 3-6 mg/kg (20, 27). In the research performed by Desbrow, et al, it was concluded that higher doses of caffeine do not equate to better performance, while Bruce, et al concluded that doses of 6 mg/kg and 9 mg/kg resulted in similar performance, but the latter dose exceeded limits set by the IOC (16, 18). Despite the variability in dosing amongst studies, the general consensus among meta-analyses is that dosage of caffeine no more than 60 minutes prior to exercise may provide ergogenic benefits, however dosage amounts are to be further investigated on an individual level that accounts for multiple factors, such as subject habituation, ingestion timing, and ingestion mode (capsule versus liquid, for example) (27). Ganio et al. also recommend that subjects abstain from caffeine for 7 days before use to give caffeine the greatest chance of optimizing the ergogenic effect (27).

Anaerobic Performance

Similarly to aerobic performance, the effects of caffeine supplementation in anaerobic exercise have been reviewed at length. However, testing methods chosen in anaerobic testing have been less consistent, partially because anaerobic performance can be more difficult to quantify (30). A review of the literature indicates uncertainty towards whether the perception of athletic improvement is related to maximum strength, power, or rate of fatigue (30).

Conflicting results have been found in the literature regarding caffeine and 1RM. Beck et al examined 1RM for bench press and leg extension exercises in 37 resistance-trained males (7). A significant improvement was found in bench press

1RM but not in the leg extension (7). However, Williams et al and Astorino et al both failed to find an effect for 1RM in the bench press and leg press in 9 resistance-trained men with a mean of 4.2 years experience and in 22 resistance-trained males, respectively (3, 77). This inconsistency in results suggests that further research is required before a definitive conclusion can be made.

Duncan, et al (23) conducted a double-blind, randomized crossover study involving 9 males and 2 females with specific experience in performing resistance exercise and were actively participating in greater than ten hours per week of programmed strength and conditioning activities. Each subject was provided placebo or 5 mg/kg of caffeine and tested in randomized order for number of repetitions to failure, rating of perceived exertion (RPE) and perception of muscle pain during resistance exercise (23). All subjects were competent in techniques performed in the study, including bench press, deadlift, prone row, and back squat exercises (23). Subjects were asked to refrain from vigorous exercise and to maintain normal dietary patterns for the 48 hours prior to testing, and were asked to cease caffeine use from 6:00 pm the night before testing (23). In the caffeinated condition, subjects had a lower RPE and muscle pain perception compared to the placebo condition. This study determined that caffeine ingestion did not enhance performance in number of repetitions, but did reduce perception of exertion and muscle pain (23).

A power trial performed by Doherty et al evaluated the effect of moderate-dose caffeine on performance during high-intensity cycling (21). Eleven trained male cyclists recruited from local cycling clubs were recruited for this double-blind, randomized, crossover study where they received caffeine equivalent to 5 mg/kg BW

or placebo and participated in a ramp test designed to exhaust participants in 10-12 minutes (21). Mean power output was significantly greater in the caffeine treated group compared to placebo. Additionally, blood lactate was significantly higher in the caffeine treatment group compared to placebo (21). This was hypothesized to be one of the mechanisms that allowed the caffeine treatment group to perform at a higher intensity than the placebo group (21).

Lorino et al. (46) evaluated the effect of caffeine on agility, another measure of anaerobic performance. Agility is a skill that involves speed and reaction time as well as other performance skills. In this study, 17 males consumed placebo or 6 mg/kg BW caffeine in randomized order and performed a proagility run test and 30-second Wingate test (a common test used for anaerobic power) (46). Results showed that caffeine did not improve agility or power output in young, recreationally active males who are not habituated to caffeine (46). In a similar manner, Bell et al. (8) examined the impact of caffeine alone and combined with ephedrine in 16 untrained males through use of a 30-second Wingate test. Like the study by Lorino et al, caffeine did not improve anaerobic power, suggesting that caffeine does not improve the anaerobic parameters of power and agility in recreationally trained athletes (8, 46).

Another double-blind, randomized, crossover study by Astorino et al (3), evaluated 22 resistance-trained men who completed total-body resistance training a minimum of two days per week. Recruited subjects ingested either 6 mg/kg BW of caffeine or a placebo and performed repetitions to failure on both the barbell bench press and leg press using 60% of their determined maximal lifting ability (1RM) (3). Subjects refrained from caffeine intake for 48 hours and strenuous exercise for 24

hours before each visit. There was no significant effect of caffeine on muscular strength or endurance, determined as complete number of repetitions to failure, in subjects when consuming caffeine when compared to placebo when a dosage of 6 mg/kg BW was used (3).

In another crossover study, twenty elite male athletes performed knee extensor and flexor exercises (39). Subjects recruited were intercollegiate Division I varsity American football team members. Exclusion criteria included high daily caffeine consumption (defined as >100 mg/day) or lacking sufficient weight training experience (defined as less than two years). Subjects were required to abstain from exercise for 48 hours and from caffeine for one week prior to testing (39). A significant increase in muscular power was noted in subjects when they ingested capsules containing 7 mg/kg BW, compared to placebo (39).

Woolf, et al (78) performed a randomized crossover study examining the effect of 5 mg/kg BW of caffeine in 17 collegiate football athletes. All participants recruited were considered low caffeine users, with a reported average intake of 16 ± 20 mg/day (78). Participants ingested either caffeine or placebo beverage with a small meal and completed three exercise tests: a 40-yard dash, 20-yard shuttle, and bench press until fatigue using either 185 or 225 pounds, with the lower weight used for participants who were unable to bench 225 pounds (78). No differences were found between treatments for any of the three exercise tests; however, 59% of the participants improved in performance with caffeine with the bench press and 40-yard dash (78). Unlike other studies, which use 60% of participant's calculated 1RM for testing

purposes, this study chose a standardized weight, regardless of each subject's individual ability (3, 78).

In a study by Bloms et al, 25 male and female NCAA Division I collegiate athletes participating in 8-20 hours of training per week were recruited to assess squat jump (SJ) height following ingestion of caffeine equivalent to 6 mg/kg BW (13). Caffeine ingestion had a positive significant effect ($p=0.001$) in SJ height, with an improvement of $5.4\pm 6.5\%$ (13). Of the 16 males enrolled, 9 were identified as responders during the SJ; 78% (7/9) of these subjects who responded to caffeine were identified as habitual consumers (13). Bloms et al. concluded that a dosage of 5 mg/kg of caffeine may positively impact performance in ballistic tasks such as the vertical jump (13). However, the authors note that all subjects recruited were Division I athletes, and that results may not be generalizable to lower-level athletes and the general population (13).

Plaskett, et al performed a randomized, double-blind, repeated measures experiment evaluating a dose of 6 mg/kg in 15 males (61). Subjects performed repeated submaximal contractions of the right quadriceps one hour after ingestion of either caffeine, placebo, or no capsule (61). Results of the study concluded that caffeine increased muscular endurance in repeated submaximal isometric contractions in the quadriceps (61). In this study, all subjects were non-habitual caffeine users, defined as those who reportedly consumed less than 200 mg of caffeine/wk (61). Furthermore, this study did not define the current resistance training status of its participants (61).

Duncan, et al evaluated bench press repetitions to failure in 13 moderately resistance trained men (22). Participants in his study consumed 5 mg/kg caffeine or placebo and performed bench press repetitions to failure using 60% 1RM (22). Participants completed significantly more repetitions to failure and lifted significantly greater weight with the caffeine treatment compared to placebo (22). However, RPE was not significantly different between groups (22). Subjects recruited were all active participants in University team sports, including rugby, football, and basketball, and have been competing in their sport for a mean time of 10.4 ± 2.3 years (22). As a result, the results of this study are likely not generalizable to a broader audience, such as recreational athletes.

Discrepancies in the literature exist regarding caffeine's potential ergogenic effect on anaerobic performance. However, this variability can be due to a number of factors, including testing procedures, caffeine administration dose, subject caffeine habituation, and subject strength training experience. Previous studies have provided subjects with varying amounts of caffeine using similar crossover designs (3, 23, 39, 78). While the amount of caffeine provided varied based on the study, the method of determining the amount was based on a standard equation of milligrams per kilogram of actual subject (mg/kg body weight) (3, 23, 39). Results from the studies performed by Duncan et al (23), Astorino et al (3), and Jacobson et al (39) suggest that 7 mg/kg of BW is an effective dosage to experience a significant change in performance in strength training exercises. As a result, our proposed study also utilizes a caffeine dosage of 7 mg/kg BW.

Conclusions

As previously stated, muscle endurance is commonly measured using repetitions to failure with weights equivalent to a percentage of an individual's 1RM (17). Currently, information published in the literature on resistance training variables is insufficient in terms of concluding whether or not caffeine has an ergogenic effect on resistance training variables, such as muscle endurance, in recreationally trained athletes, as a majority of the literature recruits participants at the collegiate athletic or above level. Additionally, to our knowledge, there is limited research comparing caffeine's effects for resistance training between habitual and non-habitual caffeine users. Therefore, in our study, we ask recreationally trained athletes to perform a combination of resistance exercises incorporating large muscle groups in both upper and lower body – bench press repetition to failure, squat repetitions to failure, isometric force plate, and vertical jump - while ingesting a dose of caffeine equivalent to 7 mg/kg BW.

Currently, research of the potential effect of caffeine on muscular endurance has been performed on subjects demonstrating elite athletic ability (3, 39). Less research has been performed on the impact of acute caffeine ingestion on strength and endurance in the average individual who participates in light to moderate consistent physical activity. Our primary hypothesis is that acute caffeine ingestion in the amount of 7 mg/kg BW will increase the number of bench press repetitions to failure compared to placebo ingestion in college age, recreational male athletes. Our secondary hypothesis is that acute ingestion of caffeine will also increase the number of squat repetitions to failure, increase the amount of force generated from a vertical

jump and isometric squat exercise, and decrease rating of perceived exertion at the time of testing, when compared to placebo ingestion.

Furthermore, previous studies have not taken body composition into consideration (3, 23, 39). Our exploratory hypothesis is that subjects with lower body fat percentage will demonstrate a significant increase in repetitions to failure in bench press and squat exercises when ingesting caffeine when compared to subjects with a higher body fat percentage. To determine this, body fat percentage will be collected prior to testing. As an additional exploratory hypothesis, we believe rating of perceived exertion will be decreased in subjects when ingesting caffeine supplementation compared to placebo.

Appendix 2: Consent Form

Subject Consent Form for Research

The University of Rhode Island
Department of Kinesiology
Kingston, RI 02881

The Effect of Caffeine on Muscular Endurance and
Power in College Male Athletes

You are being invited to take part in a research project described below. The researcher will explain the project to you in detail. You should feel free to ask questions. If you have more questions later, Dr. Kathleen Melanson, the person mainly responsible for this study, (Phone 401-874-4477); Dr. Disa Hatfield, a co-investigator in the Kinesiology department, (Phone 401-874-5183); or Dr. Kelly Matson, a co-investigator in the Pharmacy department, (Phone 401-874-5811), will discuss them with you. You must be at least 18 years old to be in this research project.

Description of the project:

You have been asked to take part in the study that tests the potential effect of a high caffeine dosage on muscular endurance and power.

What will be done:

1. Height, weight, and 1-repetition maximum (the maximum amount of weight that can be moved with one repetition) estimates will be taken.
2. The study will consist of two test days, one week apart, where you will perform repetitions with weights equal to approximately 60% of your respective 1-repetition maximum until failure in two exercises (Smith machine squat and bench press).
3. 24-hours prior to the test day, subjects are asked to abstain from consuming caffeine-containing products.
4. On the test day, a capsule(s) containing either a placebo or a pre-made caffeine supplement equal to 7 milligrams per kilogram of body weight will be provided to the subject for consumption (for example, if a subject weighs 75 kilograms, they will ingest capsules equivalent to 525 milligrams of caffeine). Twelve fluid ounces of water will be provided to aid in pill ingestion.
5. Subjects will remain stationary to allow absorption for one hour after consuming the pill(s).
6. A brief questionnaire will be provided to be completed throughout the testing process.
7. The following tests will be performed:
 - Bench press to failure using weight equivalent to 60% of the 1-repetition maximum weight (calculated from the bench press value obtained during the first visit)

- Smith machine squat to failure using weight equivalent to 60% of the 1-repetition maximum weight (calculated from the leg press value obtained during the first visit)
- Force plate test
- Vertical jump test

8. Subjects are to consistently keep a log for three days following the test procedure. No dietary restrictions will be in place at this time; however, 24-hours prior to the second test day, subjects will be asked to abstain from caffeine-containing products.

9. One week later, subjects will return to perform the same procedure, consuming the alternative capsule(s). Throughout the study, both the subject and the researchers will be unaware as to whether you have consumed the caffeine capsule(s) or the placebo until after all testing has been completed.

Risks or discomfort:

Caffeine is a stimulant, and this test involves the consumption of a significant dosage of caffeine. While the amount consumed is well within the safe limit, there is a risk of: increased blood pressure, reduced control of fine motor movements, and risk of insomnia. Risk is greater in non-habitual consumers. Caffeine withdrawal can also produce headache, fatigue, and decreased alertness. In addition, caffeine has been used as a diuretic, which can be detrimental to athletes performing in long-term endurance events.

In addition to caffeine use, there is risk of injury in performing any form of strength training exercises. This study requires testing for 1-repetition maximum and performing repetitions to failure in different muscle groups.

The amount of caffeine used in this study is well within the safe limits of consumption for healthy, adult males. In addition, many previous studies testing the effect of caffeine on healthy adults during physical activity have incorporated caffeine with doses at and exceeding the dosage used in this study (7 milligrams of caffeine per kilogram of body weight). In order to maintain safety of all subjects, the following criteria warrants exclusion from the study: those with diagnosed high blood pressure, known or suspected allergies/negative reactions to caffeine, and/or known or suspected heart conditions.

Benefits of this study:

Although there will be no direct benefit to you for taking part in this study, the researcher may learn more about caffeine supplementation in regards to strength athletes. Currently, there is significant data to demonstrate the benefit of caffeine consumption prior to cardiorespiratory endurance activities (running, cycling). However, little data is currently available in regards to muscular strength/endurance.

Confidentiality:

Your participation in this study is strictly confidential. None of the results or collected data will identify you by name. All records will be stored in a locked cabinet and viewed solely within the Energy Balance Lab located in Fogarty Hall. Data entered in

any computer programs will not contain information identifiable back to you. Please note, all data is subject to inspection by federal, state, and local agencies, such as the Food and Drug Administration (FDA).

In case there is any injury to the subject: (If applicable)

In the event of an injury during the testing process, the URI emergency medical services will be contacted at (401)-874-5255. If this study causes you any injury, you should write or call the office of the Vice President for Research, 70 Lower College Road, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

Decision to quit at any time:

Participation in this study is up to you. You are in no way required to participate. If you decide to take part in the study, you may quit at any time. Whatever you decide will in no way be recorded, penalize you, affect enrollment status and/or grades. If you wish to quit, you simply inform the lab (Fogarty 205, phone 401-874-2067) of your decision.

Rights and Complaints:

If you are not satisfied with the way this study is performed, you may discuss your complaints with Dr. Kathleen Melanson (401-874-4477), Dr. Disa Hatfield (401-874-5183), or Dr. Kelly Matson (401-874-5811) anonymously, if you choose. In addition, you may contact the office of the Vice President for Research, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

You have read the Consent Form. Your questions have been answered. Your signature on this form means that you understand the information and you agree to participate in this study.

I,

residing at

_____ (zip) _____

telephone _____ age _____ (date of birth)

agree to participate in this research project.

Signature of subject

Signature of Researcher

Typed/printed Name

Typed/printed Name

Date

Date

Please sign both consent forms, keeping one for yourself.

Appendix 3: Study Timeline

Appendix 4: Test Day Timeline

Appendix 5: Pre-Screening Questionnaire

Pre-Screening Questionnaire

How would you describe your weightlifting routine?

0-1 2-3 4-5 5+ (days per week)

How long have you consistently participated in weight-bearing exercise?

<1 month 1-3 months 4-5 months 6-12 months +1 year

Are bench-press exercises incorporated in your typical weight-bearing routine?

yes no

Are leg-press exercises incorporated in your typical weight-bearing routine?

yes no

How would you describe your typical coffee intake (caffeinated)?

0 1 2 3 4 5+ (8 fl oz cups per day)

How would you describe your typical soda intake (caffeinated)?

0 1 2 3 4 5+ (8 fl oz cups per day)

Appendix 6: Personal Health History Questionnaire

Personal Health History Questionnaire

Please complete this as accurately and completely as possible. If you would like clarification on any question, please feel free to ask.

Name: _____ Age: _____ Gender _____

Mailing address: _____

Phone number: _____ Today's date: _____

Email address: _____

Approximate weight: _____ Approximate height: _____

Ethnic Background (circle one)

- African-American
- Asian-American
- Caucasian
- Hispanic-American
- Other _____

General Medical History

Circle One

Do you currently have any medical complaints? Yes No

(please specify) _____

Do you take any prescribed or over-the-counter medication? Yes No

(please specify) _____

Dietary History

Please list any food allergies, intolerances or specific foods you avoid

Do you experience caffeine withdrawal symptoms if you do not consume it in the morning. (i.e., headache)?

Are you able to abstain from alcohol consumption for several days in a row?

Do you have any close blood relatives have or had type 2 diabetes (parents, grandparents, siblings, aunts or uncles)? Yes No

Do you have any close blood relatives have or had heart disease? Yes No

Appendix 7: Caffeine Frequency Questionnaire

Subject ID: _____

Date: _____

CAFFEINE FREQUENCY QUESTIONNAIRE (CFQ)

Please answer the following questions as completely and honestly as you can. This information is **STRICTLY CONFIDENTIAL** - do not write your name anywhere on this page.

Select the box next to each item that best describes your usual intake. Consider intake over the course of the past calendar year.

		Never	Monthly	Weekly	1 serving/ day	2 serving /day	3+ serving/ day
COFFEE	Brewed, generic						
	Brewed, decaf						
	Espresso						
	Espresso decaf						
TEAS	Brewed						
	Snapple						
	Nestea						
	Arizona Iced						
SOFT DRINKS	Coca-Cola						
	Diet Coca-Cola						
	Dr. Pepper						
	Diet Dr. Pepper						
	Pepsi						
	Diet Pepsi						
	Root Beer						
	Diet Root beer						
	Sierra Mist						
	Sprite						

		Never	Monthly	Weekly	1 serving /day	2 serving /day	3+ serving /day
ENERGY DRINKS	Monster						
	Full Throttle						
	Red Bull						
	Vitamin Water						
	Amp						
	5 Hour energy						
FROZEN DESSERTS	Ben & Jerry's Coffee ice cream						
	Starbucks coffee ice cream						
CHOCOLATE	Hershey's chocolate						
	Hershey's Dark chocolate						
	Hershey's kisses						
	Hot cocoa (5 oz)						
MEDICATIONS	Vivarin						
	NoDoz						
	Excedrin						
	Vanquish						
	Anacin						
	Dristan						
	Dexatrim						

Appendix 8: Borg CR-10 Scale of Perceived Exertion

Borg CR-10 Scale of Perceived Exertion		
0	Nothing at all	
0.3		
0.5	Extremely weak	Just noticeable
0.7		
1	Very weak	
1.5		
2	Weak	Light
2.5		
3	Moderate	
4		
5	Strong	Heavy
6		
7	Very strong	
8		
9		
10	Extremely strong	“Maximal”
11		
	Absolute maximum	Highest possible

Appendix 9: Additional Tables and Figures

Table 2: Correlations Between Exercise Performance with Caffeine Based on Lean Body Mass and Self-Reported Habitual Consumption

	Bench Press repetitions				Squat repetitions			
	Caffeine		Δ Treatments		Caffeine		Δ Treatments	
	<i>R</i>	<i>p</i>	<i>R</i>	<i>p</i>	<i>R</i>	<i>p</i>	<i>R</i>	<i>p</i>
mg/kg LBM	.020	.924	.065	.762	-.031	.887	.297	.159
Habitual consumption	.186	.384	.193	.366	-.016	.939	.003	.989

Pearson correlations used. No significant correlations found. Lean body mass calculated by subtracting fat mass from total body mass.

Table 3: Mean±SD of RPE Before and After Bench Press and Smith Machine Squat Tests with Caffeine and Placebo Treatments

	Caffeine		Placebo		<i>p</i>
	Pre	Post	Pre	Post	
Bench Press (n=21*)	2.3±1.9	5.5±1.9	2.6±1.6	5.9±1.9	0.360
Squat (n=23)	1.5±1.3	5.9±1.6	1.9±1.5	6.1±2.1	0.196

2x2 Repeated Measures ANOVA used. No significance between treatments in either bench press or squat.

*2 subjects omitted due to missing data

Figure 4: Relationship Between 1RM Squat and 1RM Bench

Figure 5: Proportion of Subjects Receiving Varying Dosages of Caffeine Based on Lean Body Mass

Mean ($\pm$ SD) dosage received based on total body mass (mg/kg): 7.0 ± 0.1

Mean ($\pm$ SD) dosage received based on lean body mass (mg/kg): 8.3 ± 0.7

Figure 6: Difference in Individual Number of Bench Press Repetitions to Failure in Subjects Identified as Low Caffeine Consumers

Low caffeine consumer defined as ≤ 8 oz of caffeine containing product/day, as determined by self-reported caffeine frequency. (n=15)

Figure 7: Difference in Individual Number of Bench Press Repetitions to Failure in Subjects Identified as High Caffeine Consumers

High caffeine consumer defined as >8oz of caffeine containing product/day, as determined by self-reported caffeine frequency. (n=8)

Figure 8: Difference in Individual Number of Smith Machine Squat Repetitions to Failure in Subjects Identified as Low Caffeine Consumers

Low caffeine consumer defined as ≤ 8 oz of caffeine containing product/day, as determined by self-reported caffeine frequency. (n=15)

Figure 9: Difference in Individual Number of Smith Machine Squat Repetitions to Failure in Subjects Identified as High Caffeine Consumers

High caffeine consumer defined as >8oz of caffeine containing product/day, as determined by self-reported caffeine frequency. (n=8)

Appendix 10: Flyer

DOES CAFFEINE IMPACT WEIGHTLIFTING ABILITY?

You may be eligible to take part in a research study at URI

The URI department of Nutrition and Food Science, in partnership with the department of Kinesiology and Pharmacy, are performing a research study to determine the effect of caffeine on college-age males with experience in weightlifting.

If you:

- Are a male between 19-25 years old
- Have been weightlifting for >6months
- Would like a \$30 stipend and body fat % measurement

CONTACT:
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

Caffeine Study
uricaffeine@gmail.com

BIBLIOGRAPHY

1. Arnaud MJ. The pharmacology of caffeine. *Prog Drug Res* 31: 273-313, 1987.
2. Arnaud MJ. Metabolism of caffeine and other components of coffee. 1993.
3. Astorino TA, Rohmann RL, Firth K. Effect of caffeine ingestion on one-repetition maximum muscular strength. *Eur J Appl Physiol* 102: 127-132, 2008.
4. Baechle T, Earle R. *Essentials of Strength Training and Conditioning*. Champaign, IL, 2008.
5. Ball TE, Rose KS. A field test for predicting maximum bench press lift of college women. *J Appl Sport Sci Res* 5: 169-170, 1991.
6. Bassini-Cameron A, Sweet E, Bottino A, Bittar C, Veiga C, Cameron LC. Effect of caffeine supplementation on haematological and biochemical variables in elite soccer players under physical stress conditions. *Br J Sports Med* 41: 523-530, 2007.
7. Beck TW, Housh TJ, Schmidt RJ, Johnson GO, Housh DJ, Coburn JW, Malek MH. The acute effects of a caffeine-containing supplement on strength, muscular endurance, and anaerobic capabilities. *J Strength Cond Res* 20: 506-510, 2006.
8. Bell DG, Jacobs I, Ellerington K. Effect of caffeine and ephedrine ingestion on anaerobic exercise performance. *Med Sci Sports Exerc* 33: 1399-1403, 2001.
9. Bigal ME, Sheftell FD, Rapoport AM, Tepper SJ, Lipton RB. Chronic daily headache: identification of factors associated with induction and transformation. *Headache* 42: 575-581, 2002.
10. Birkett DJ, Miners JO. Caffeine renal clearance and urine caffeine concentrations during steady state dosing: implications for monitoring caffeine intake during sports events. *Br J Clin Pharm* 31: 405-408, 1991.
11. Bishop NC, Fitzgerald C, Porter PJ, Scanlon GA, Smith AC. Effect of caffeine ingestion on lymphocyte counts and subset activation in vivo following strenuous cycling. *Eur J Appl Physiol* 93: 606-613, 2005.
12. Bjorness TE, Greene RW. Adenosine and sleep. *Current Neuropharmacology* 7: 238-245, 2009.

13. Bloms LP, Fitzgerald JS, Short MW, Whitehead JR. The effects of caffeine on vertical jump height and execution in collegiate athletes. *J Strength Cond Res*, 2015.
14. Borg GA. *Human Kinetics: Borg's perceived exertion and pain scales*. Champaign, IL, 1998.
15. Brown LE, Weir JP. ASEP procedures recommendation i: accurate assessment of muscular strength and power. *J Exercise Physiology* 4: 1-21, 2001.
16. Bruce CR, Anderson ME, Fraser SF, Stepto NK, Klein R, Hopkins WG, Hawley JA. Enhancement of 2000-m rowing performance after caffeine ingestion. *Med Sci Sports Exerc* 32: 1958-1963, 2000.
17. Davis JK, Green JM. Caffeine and anaerobic performance: ergogenic value and mechanisms of action. *Sports Med* 39: 813-832, 2009.
18. Desbrow B, Biddulph C, Devlin B, Grant GD, Anoopkumar-Dukie S, Leveritt MD. The effects of different doses of caffeine on endurance cycling time trial performance. *J Sports Sci*, 2011.
19. Dodd SL, Herb RA, Powers SK. Caffeine and exercise performance: an update. *Sports Medicine* 15: 14-23, 1993.
20. Doherty M, Smith PM. Effects of caffeine ingestion on exercise testing: a meta-analysis. *J Sports Nutrition and Exercise Metabolism* 14, 2004.
21. Doherty M, Smith PM, Hughes MG, Davison RR. Caffeine lowers perceptual response and increases power output during high-intensity cycling. *J Sports Sci* 22: 637-643, 2007.
22. Duncan MJ, Oxford SW. The effect of caffeine ingestion on mood state and bench press performance to failure. *J Strength Cond Res* 25: 178-185, 2011.
23. Duncan MJ, Stanley M, Parkhouse N, Cook K, Smith M. Acute caffeine ingestion enhances strength performance and reduces perceived exertion and muscle pain perception during resistance exercise. *Eur J Sport Sci* 13: 392-399, 2013.
24. Dunford M, Doyle JA. *Nutrition for Sport and Exercise*. Belmont, CA: Peter Adams, 2008.
25. Fox SI. *Human Physiology, 10th edition*. New York, NY: McGraw-Hill, 2008.

26. Fredholm BB, Battig K, Holmen J, Nehlig A, Zvartau EE. Actions of caffeine in the brain with special reference to factors that contribute to its widespread use. *Pharmacol Rev* 51: 83-133, 1999.
27. Ganio MS, Klau JF, Casa DJ, Armstrong LE, Maresh CM. Effect of caffeine on sport-specific endurance performance: a systematic review. *J Strength Cond Res* 23: 315-324, 2009.
28. George J, Murphy T, Roberts R, Cooksley WGE, Halliday KW, Powell LW. Influence of alcohol and caffeine consumption on caffeine elimination. *Clin Exp Pharmacol Physiol* 13, 1986.
29. Gilbert RM. *Caffeine consumption. In the methylxanthine beverages in foods: chemistry, consumption, and health effects.*, 1984.
30. Graham TE. Caffeine and exercise: metabolism, endurance and performance. *Sports Med* 31: 785-806, 2001.
31. Graham TE, Battram DS, Dela F, El-Sohemy A, Thong FS. Does caffeine alter muscle carbohydrate and fat metabolism during exercise? *Applied Physiology, Nutrition, and Metabolism* 33: 1311-1318, 2008.
32. Harris GR, Stone MH, Obryant HS, Proulx CM, Johnson RL. Short-term performance effects of high power, high force, or combined weight-training methods. *J Strength Cond Res* 14, 2000.
33. Hartley TR, Sung BH, Pincomb GA. Hypertension risk status and effect of caffeine on blood pressure. *Hypertension* 36: 137-141, 2000.
34. Harvey RA, Ferrier D. *Biochemistry, 5th edition*. Baltimore, MD: Lippincott Williams & Wilkins, 2011.
35. Heckman MA, Weil J, Gonzalez de Mejia E,. Caffeine (1,3,7-trimethylxanthine) in foods: a comprehensive review on consumption, functionality, safety, and regulatory matters. *J Food Sci* 75: R77-87, 2010.
36. Holtzman SG, Mante S, Minneman KP, . Role of adenosine receptors in caffeine tolerance. *J Pharmacol Exp Ther* 256: 62-68, 1991.
37. Hurley CF, Hatfield DL, Riebe DA. The effect of caffeine ingestion on delayed onset muscle soreness. *J Strength Cond Res* 27: 3101-3109, 2013.
38. Invergo JJ, Ball TE, Looney M. Relationship of push-ups and absolute muscular endurance to bench press strength. *J Appl Sport Sci Res* 5, 1991.

39. Jacobson BH, Weber MD, Claypool L, Hunt LE,. Effect of caffeine on maximal strength and power in elite male athletes. *Br J Sp Med* 26: 276-280, 1992.
40. Jenkinson DM, Harbert AJ. Supplements and sports. *Am Fam Physician* 78: 1039-1046, 2008.
41. Kalmar JM. The influence of caffeine on voluntary muscle activation. *Med Sci Sports Exerc* 37: 2113-2119, 2005.
42. Knudson D. *Fundamentals of biomechanics, 2nd edition*. New York, NY: Springer Science, 2007.
43. Lane JD, Steege JF, Rupp SL, Kuhn CL. Menstrual cycle effects on caffeine elimination in the human female. *Eur J Clin Pharmacol* 43: 543-546, 1992.
44. Liguori A, Hughes JR, Grass JA. Absorption and subjective effects of caffeine from coffee, cola and capsules. *Pharmacology Biochemistry and Behavior* 58: 721-726, 1997.
45. Lohman TG, Roche AF, Martorell R. *Anthropometric standardization reference manual*. Champaign, IL: Human Kinetics Books, 1988.
46. Lorino AJ, Lloyd LK, Crixell SH, Walker JL. The effects of caffeine on athletic agility. *J Strength Cond Res* 20: 851-854, 2006.
47. Lorist MM, Snel J, Kok A, Mulder G. Influence of caffeine on selective attention in well-rested and fatigued subjects. *Psychophysiology* 31: 525-534, 1994.
48. Machado M, Koch AJ, Willardson J, Santos FC, Curty VM. Caffeine does not augment markers of muscle damage or leukocytosis following resistance exercise. *Int J Sports Phys Perf* 5: 18-26, 2010.
49. Mayhew JL, Ball TE, Arnold MD, Bowen JC. Relative muscular endurance performance as a predictor of bench press strength in college men and women. *J Strength Cond Res* 6: 200-206, 1992.
50. Mayhew JL, Ware JS, Bemben MG, Wilt B, Ward TE, Farris B, Juraszek J, Slovak JP. The NFL-225 test as a measure of bench press strength in college football players. *J Strength COnnd Res* 13: 130-134, 1999.
51. McArdle WD, Katch FL, Katch VL,. *Exercise physiology: energy, nutrition, and human performance*. Baltimore, MD: Lippincott Williams & Wilkins, 2001.

52. <http://www.acsm.org/docs/current-comments/caffeineandexercise.pdf>
Accessed 03 May 2015.
53. Minton DM, O'Neal EK, Torres-McGehee TM. Agreement of urine specific gravity measurements between manual and digital refractometers. *J Athletic Training* 50: 59-64, 2015.
54. Nam SW, Choi DJ, Kim SK, Her N, Zoh KD. Adsorption characteristics of selected hydrophilic and hydrophobic micropollutants in water using activated carbon. *J Hazardous Materials* 270: 144-152, 2014.
55. Nehlig A. Is caffeine a cognitive enhancer? *J Alzheimers Dis* 20: 85-94, 2010.
56. Noakes TD. Effect of exercise on serum enzyme activities in humans. *Sports Med* 4: 245-267, 1987.
57. Norager CB, Jensen MB, Madsen MR, Laurberg S. Caffeine improves endurance in 75-yr-old citizens: a randomized, double-blind, placebo-controlled crossover study. *J Appl Physiol* 99: 2302-2306, 2005.
58. O'Rourke MP, O'Brien BJ, Knez WL, Paton CD. Caffeine has a small effect on 5-km running performance of well-trained and recreational runners. *J Sci Med Sport* 11: 231-233, 2007.
59. Paton CD, Hopkins WG, Vollebreght L. Little effect of caffeine ingestion on repeated sprints in team-sport athletes. *Med Sci Sports Exerc* 33: 822-825, 2001.
60. Pesta DH, Angadi SS, Burtcher M, Roberts CK. The effects of caffeine, nicotine, ethanol, and tetrahydrocannabinol on exercise performance. *Nutrition & Metabolism* 10, 2013.
61. Plaskett CJ, Cafarelli E. Caffeine increases endurance and attenuates force sensation during submaximal isometric contractions. *J Appl Physiol* 91: 1535-1544, 2001.
62. Powers SK, Byrd RJ, Tulley R, Callender T. Effects of caffeine ingestion on metabolism and performance during graded exercise. *Eur J Appl Physiol* 50: 301-307, 1983.
63. Rall TW. *Goodman and Gilman's Pharmacological Basis of Therapeutics*. McGraw-Hill, 1993.
64. Ressig CJ, Strain EC, Griffiths RR. Caffeinated energy drinks -- a growing problem. *Drug Alcohol Depend* 99, 2009.

65. Reynolds JM, Gordon TJ, Robergs RA. Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *J Strength Cond Res* 20: 584-592, 2006.
66. Robertson D, Wade D, Workman R, Woosley RL, Oates JA. Tolerance to the humoral and hemodynamic effects of caffeine in man. *J Clin Invest* 67: 1111-1117, 1981.
67. Rush JW, Spriet LL. Skeletal muscle glycogen phosphorylase a kinetics: effects of adenine nucleotides and caffeine. *J Appl Physiol* 91: 2071-2078, 2001.
68. Sayers SP, Harackiewicz DV, Harman EA, Frykman PN, Rosenstein MT. Cross-validation of three jump power equations. *Med Sci Sports Exerc* 31: 572-577, 1999.
69. Smith A. Effects of caffeine on human behavior. *Food Chem Toxicol* 40: 1243-1255, 2002.
70. Spriet LL. Caffeine and performance. *Int J Sports Nutrition* 5: S84-99, 1995.
71. Statland BE, Demas TJ. Serum caffeine half-lives. Healthy subjects vs. patients having alcoholic hepatic disease. *Am J Clin Pathol* 73: 390-393, 1980.
72. Sylvén C, Jonzon B, Fredholm BB, Kaijser L. Adenosine injection into the brachial artery produces ischaemia like pain or discomfort in the forearm. *Cardiovasc Res* 22: 674-678, 1988.
73. Tallis J, Duncan MJ, James RS. What can isolated skeletal muscle experiments tell us about the effects of caffeine on exercise performance? *British Journal of Pharmacology* 172: 3703-3713, 2015.
74. Wagner DR, Heyward VH, Gibson AL. Validation of air displacement plethysmography for assessing body composition. *Med Sci Sports Exerc* 32: 1339-1344, 2000.
75. Walker GJ, Finlay O, Griffiths H, Sylvester J, Williams M, Bishop NC. Immunoendocrine response to cycling following ingestion of caffeine and carbohydrate. *Med Sci Sports Exerc* 39, 2007.
76. Wells SG. Caffeine: implications of recent research for clinical practice. *Am J Orthopsychiatry* 54, 1984.
77. Williams AD, Cribb PJ, Cooke MB, Hayes A. The effect of ephedra and caffeine on maximal strength and power in resistance-trained athletes. *J Strength Cond Res* 22: 464-470, 2008.

78. Woolf K, Bidwell WK, Carlson AG. Effect of caffeine as an ergogenic aid during anaerobic exercise performance in caffeine naïve collegiate football players. *J Strength Cond Res* 25: 1363-1369, 2009.
79. World Anti-Doping Agency. The 2015 monitoring program. [wada-main-prod.s3.amazonaws.com/resources/files/wada-2015-monitoring-program-en.pdf](https://prod.s3.amazonaws.com/resources/files/wada-2015-monitoring-program-en.pdf). Accessed 18 May 2016.