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The Effects Of Caffeine Supplementation On Vertical Jump Performance

Lucas Paul Bloms

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THE EFFECTS OF CAFFEINE SUPPLEMENTATION ON VERTICAL JUMP
PERFORMANCE

By

Lucas Paul Bloms
Bachelor of Science, University of North Dakota, 2013

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

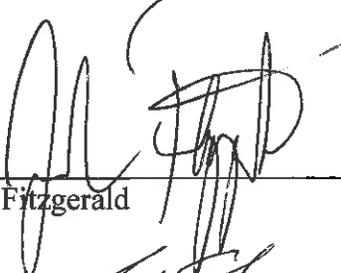
for the degree of

Master of Science

Grand Forks, North Dakota

August
2015

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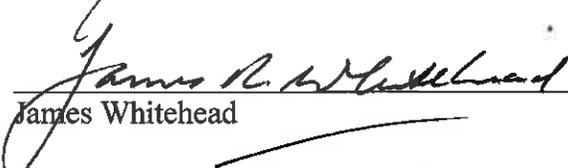


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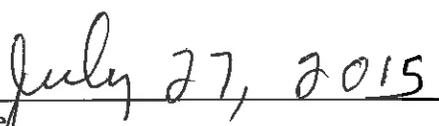


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ABSTRACT

The Effects of Caffeine Supplementation on Vertical Jump Performance. **Introduction:** Caffeine enhances performance of many types of exercise, but its effects on vertical jump are unclear. **Purpose:** To investigate the effects of caffeine on vertical jump tests on a force platform. **Methods:** The study was a single-blind, randomized, crossover design. Participants consumed either caffeine (5 mg/kg body weight) or placebo. After a sixty-minute waiting period participants performed three squat jumps and three countermovement jumps separated by 30 seconds each while standing on a force platform. There were two minutes of rest between the two different types of jumps. **Results:** In comparison to placebo, caffeine increased squat jump height (34.5 ± 6.7 vs. 32.7 ± 6.2 cm; $p < .05$) and countermovement jump height (37.9 ± 7.4 vs. 36.4 ± 6.9 cm; $p < .05$). Squat jump time to half peak force was decreased with caffeine supplementation (0.074 ± 0.038 vs. 0.084 ± 0.041 s, $p < .05$). Caffeine increased average rate of force development ($7,229 \pm 4,049$ vs. $6,371 \pm 3,435$ N·s⁻¹; $p < .05$), peak force ($12,453 \pm 6,716$ vs. $10,979 \pm 5,029$ N; $p < .05$), S-Gradient ($9,487 \pm 6,342$ vs. $7,995 \pm 4,337$ N; $p < .05$), and A-Gradient ($6,558 \pm 3,253$ vs. $5,813 \pm 3,147$ N; $p < .05$) in countermovement jump. **Discussion:** Caffeine supplementation (5 mg/kg) improved vertical jump performance in NCAA Division I athletes.

CHAPTER I

INTRODUCTION

Extensive research has shown caffeine has many physiological effects on human performance. Although much of the existing literature is conflicting, caffeine is widely accepted as an ergogenic aid at moderate doses for most modes of exercise (Keisler & Armsey, 2006). Areas of research include endurance, strength, team sports, recovery, and hydration. Caffeine research is important so athletes will know the most efficient way to supplement caffeine for their particular sport. The most conflicting area of research seems to be in the area of strength and power performance. Caffeine supplementation research for strength and power performance is still limited and results are varied. Some studies find significant increases in strength and power, while others find no difference when compared to controls or placebo groups (Warren, Park, Maresca, McKibans, and Millard-Stafford, 2010). Several studies also find increases in upper body strength and/or power but not in the lower body. It isn't clear if the differences are due to different training modalities, different fitness levels of participants, or other factors. More research is needed in the area of strength-power sports with caffeine supplementation. The vertical jump is widely accepted as an indicator of lower body explosive strength and power. Therefore, testing the effects of caffeine on the vertical jump will provide information about lower body force and power production changes.

The purpose of this study was to examine the effects of caffeine supplementation on vertical jump performance in NCAA Division I athletes. Little is known about the effects

caffeine may have on jump height and peak force developed during a vertical jump. It was hypothesized that collegiate athletes trained in weight lifting and jumping will show significant increases in both jump height and peak force development after caffeine consumption. The study was limited to Division I collegiate athletes aged 18 to 23 years old at the University of North Dakota. The study was one of very few on the topic of caffeine supplementation and vertical jump performance. It is important to learn if caffeine has the potential to significantly improve jumping performance in high-level athletes. Improved performance with caffeine supplementation has been shown in endurance exercise, high-intensity exercise, intermittent bouts of exercise, and team sports settings. However, there is very little research looking specifically at vertical jump performance, which is an important skill in various sports.

CHAPTER II

LITERATURE REVIEW

The use of caffeine as an ergogenic aid for sports is widely researched. Performance improvements have been demonstrated in many studies of endurance exercise (Goldstein et al., 2010), but the research is more varied in strength-power sports (Warren, Park, Maresca, McKibans, and Millard-Stafford, 2010). The ingestion of 3 to 9 mg/kg of caffeine per kg body mass has shown to be effective in improving several exercise modalities. Doses lower and higher than the range either do not produce significant results or are similar in magnitude to the moderate dosages between 3 to 9 mg/kg. There is very little research on the effects of caffeine supplementation on vertical jump performance (Goldstein et al., 2010). Studies on caffeine supplementation and weight lifting performance are somewhat conflicting (Forbes, Candow, Little, Magnus, and Chilibeck, 2007). However, studies examining caffeine supplementation on sprint performance yield more consistent performance improvements in trained athletes (Glaister et al., 2008).

Sprinting is a very short-term, high-intensity bodyweight exercise similar to vertical jump. There is a lot of transfer between sprinting performance and vertical jump performance. Concentric force development as in a vertical jump is critical to sprint starting performance. Therefore, maximal concentric jumping is related to acceleration in sprinting (Sleivert, Taingahue, 2004). Commonly, the fastest sprinters are also the highest jumpers and vice versa. Both skills involve being able to transfer force into the ground quickly.

Table 1. Caffeine Supplementation and Sprint Performance.

Source	Caffeine Supplementation	Participants & Procedure	Results
Caffeine supplementation and multiple sprint running performance.	5 mg/kg body weight	Twenty-one physically active men aged 18-24 years old. Performed 12 x 30 meter sprints with 35-second rest intervals.	Caffeine group sprinted 1.4% faster than placebo group, but suffered a 1.2% increase in fatigue throughout repeated bouts.
Multiple effects of caffeine on simulated high-intensity team-sport performance.	6 mg/kg body weight	Nine high level rugby players aged 21-29 years old. Fourteen circuits of 3-14 seconds were performed. Circuits included sprinting and agility drills.	Caffeine group sprinted ~1-4% faster than the placebo group in all but one circuit.
Effects of a caffeine-containing energy drink on simulated soccer performance.	3 mg/kg body weight	Nineteen semi-professional soccer players aged 19-23 years old. Performed 7 x 30 meter sprints with 30 seconds of active recovery in between.	Caffeine group increased sprinting speed by an average of 2.8% over the placebo group.

Maximal half squat strength, sprint performance, and jump height have all been strongly correlated to predict one another in high level athletes (Wisløff et al., 2004). The exact mechanisms of action which caffeine has within the body still remains largely unknown. There are several possible explanations for the performance increases often seen in caffeine supplementation trials. To investigate the plausibility of caffeine impacting vertical jump performance, characteristics of caffeine, caffeine and high-intensity exercise, caffeine and

intermittent bouts of exercise, several studies on energy drinks, and studies on vertical jump were reviewed.

Mechanism of Action

It is important to understand how caffeine interacts with the body's various tissues and systems to understand its potential for performance enhancement. Caffeine (1,3,7-trimethylxanthine) is extracted from the raw fruit of over 60 species of coffee plants, tea, kola nuts, cocoa, and can be manufactured synthetically in the lab. Once caffeine is ingested, it quickly absorbs through the gastrointestinal tract and is metabolized by the liver. Elevated caffeine levels can be seen in the blood within 15-45 minutes of ingestion with peak concentrations occurring around one hour post-consumption. Caffeine is lipid soluble allowing it to easily cross the blood-brain barrier as well as other cellular membranes. Caffeine clearance varies depending on the rate at which it is absorbed and metabolized, but blood concentrations are decreased approximately 50-75% within three to six hours after consumption in the majority of people (Graham, 2001).

There have been several mechanisms proposed for the effects of caffeine on human physiology. One of the most widely accepted mechanisms of action is caffeine acting as an adenosine antagonist competing at receptor sites (Glaister et al., 2010). One of the main sites of action is the central nervous system (CNS). However due to its ability to cross membranes of both muscle and nerve cells, its effects are likely a combination of both the CNS and the peripheral nervous system (PNS). As with several drugs, there is rarely just one mechanism to

fully explain the effects on human physiology. Caffeine is a cardiovascular stimulant that acts to increase epinephrine output. Caffeine also has the potential to increase secretion of B-endorphins, which may lead to decreases in pain perception during exercise. Decreased pain perception could lead to a consequent increase in effort. Caffeine is also known to produce a thermogenic effect, which may be beneficial to metabolism and exercise performance. Caffeine may enhance calcium release from the sarcoplasmic reticulum enabling faster and stronger muscle contractions (Goldstein et al., 2010).

Overall, caffeine combines effects on both central and peripheral nervous systems to improve running, cycling, and many other types of performance in most individuals. Several factors may determine how large or small the effect is on performance. Conditioning of the athlete seems to be a large factor, as does the specific type of exercise being performed. The timing and dosage of caffeine is also very important (Goldstein et al., 2010). Caffeine research will continue to inform athletes as to when they should use caffeine prior to competition as well as how much is needed.

After the removal of caffeine from the World Anti-Doping Agency list, many professional athletes began regularly consuming it again. Caffeine concentration was recently measured in urine samples of 20,686 athletes in national and international competition (Del Coso, Munoz, and Munoz-Guerra, 2011). The results from the urine samples showed that almost 3/4 of competitors consumed caffeine before or during sports competition. Older competitors 30 years and older had higher levels of caffeine than their younger counterparts. It is apparent that many high-level athletes regularly consume caffeine with the intention of improving

performance. Caffeine research is important to inform those athletes of the best ways to use caffeine for their particular sport or situation.

Form and Dose of Caffeine

Various different forms and dosages of caffeine have been tested. The anhydrous form (capsule, powder) appears to exert the most powerful effects. Caffeine coming in the form of coffee is less effective for a variety of possible reasons (Glaister et al., 2010). Chlorogenic acids produced when roasting coffee has been proposed to possibly reduce caffeine's ability to inhibit adenosine (Goldstein et al., 2010). The anhydrous form is a more readily available source of caffeine, whereas caffeine found in coffee is combined with other ingredients found in the beans. The majority of caffeine research waits 60 minutes after consumption to ensure optimal absorption, although performance increases have been observed 15-30 minutes after consumption with increases in the blood concentrations (Graham, 2001). Low-to-moderate dosages (~3-6 mg/kg) appear to be most effective for exercise performance increases (Goldstein et al., 2010). No further benefits have been found at high dosages (>9 mg/kg) or at lower dosages (<3 mg/kg). The vast majority of studies have used a moderate dosage between 3 and 9 mg/kg of anhydrous form caffeine with a wait of 60 minutes before testing performance (Goldstein et al., 2010).

Caffeine Habituation and Performance

Well-designed studies account for daily caffeine intake of all the participants. The purpose of this is to observe potential differences between regular caffeine users and non-users. The concept of habituation and tolerance to the drug is the importance. Most studies have shown performance improvements for both habitual users and non-users (Goldstein et al., 2010). However, the effects usually last longer in non-users. Feelings of energy, restlessness, and tremor are also enhanced in non-users compared to habitual caffeine users.

Caffeine and Hydration

There is wide belief that caffeine consumption causes dehydration. However, caffeine consumed at rest versus during exercise has different effects and the diuresis seen at rest cannot be applied to exercise scenarios. Current literature does not support caffeine-induced diuresis during exercise. Most research shows no changes in factors like sweat rate, total water loss, or negative fluid balance changes (Goldstein et al., 2010).

High-Intensity Exercise and Intermittent Sports

There is a lot of evidence and support for enhanced performance following caffeine supplementation in endurance exercise. However, there is much less known about the effects of caffeine supplementation on very brief high-intensity exercise such as sprinting or jumping lasting less than one minute. The research for high-intensity exercise and intermittent bouts of exercise with caffeine supplementation is much more varied. Many studies have demonstrated no

significant results in untrained adults. Significant performance improvements have been seen with studies using higher-level, conditioned athletes (Glaister et al., 2010). Several different team sports such as soccer and rugby have been tested showing small improvements in sprint performance, time to exhaustion, and intensity level in repeated bouts of exercise (Del Coso et al., 2012). Possible explanations for this phenomenon are the high variability seen in untrained subjects and possible physiological adaptations to high-intensity training in high-level athletes. Highly trained anaerobic athletes have demonstrated significant increases in peak power with moderate dosages of caffeine. The current research suggests that moderate caffeine supplementation in the range of 3-9 mg/kg can be advantageous to high-intensity exercise, but the effects have only been seen in trained athletes.

One study examined caffeine's effects on simulated high-intensity team sport performance (Stuart, Hopkins, Cook, and Cairns, 2005). There were nine high-level rugby players that participated in the study. The participants were males 25 ± 4 years in age. A moderate dose of 6 mg/kg of body weight was chosen in the form of gelatin capsules. The test consisted of several circuits to simulate a rugby game. Most of the circuits included all-out straight sprints and agility sprinting lasting 3-14 seconds, which is very brief and maximal in intensity similar to jumping. The caffeine group saw improvements in mean performance for 20-meter sprint speed, offensive sprint speed, Drive 1 power, and defensive sprint speed. This study was one of the first to demonstrate beneficial effects on intermittent high-intensity exercise. Most of the improvements were in the range of 0.5-2.9%, which is similar to results seen in endurance exercise. Improvements of only 0.5-2.9% may not seem like much. However, in high-level sports

it can be the difference between winning and losing, especially in a track and field competition. Reported improvements in sprint speeds suggest caffeine influence force production in time-restricted tasks, which is important for vertical jump.

Table 2. Caffeine Supplementations and Strength/Power Exercise.

Source	Caffeine Supplementation	Participants & Procedure	Results
Effect of Red Bull energy drink on repeated Wingate cycle performance and bench-press muscle endurance.	2 mg/kg body weight	Fifteen healthy adults aged 16-27. Performed bench press repetitions at 70% 1RM and three Wingate cycle tests.	Caffeine group increased upper body muscle endurance in the bench press, but not lower body power in the Wingate tests when compared to the placebo group.
Dose response effects of a caffeine-containing energy drink on muscle performance: a repeated measures design.	Either 1 mg/kg body weight or 3 mg/kg body weight	Twelve active adults aged 23-37 years old. Performed bench press or half-squat with loads from 10-100% 1RM.	1 mg/kg supplementation didn't enhance performance compared to placebo. 3 mg/kg increased both bench press and half-squat power by ~7% over the placebo group.
Effects of a caffeine-containing energy drink on simulated soccer performance.	3 mg/kg body weight	Nineteen semi-professional soccer players aged 19-23 years old. Jumped as high as possible repeatedly for 15 seconds.	Caffeine group increased jump height and power output ~3-4% over the placebo group.

In a study on multiple sprint performance, a randomized double-blind design, 19 physically active men aged 14-18 years old consumed a moderate dose of caffeine (5 mg/kg) in the form of a gelatin capsule or a placebo sixty minutes before running repeated sprints. The test

included 12 x 30 meter sprints with 35-second rest intervals between sets. Compared to the placebo group, the caffeine group ran faster than the next fastest sprint time by 1.4%. However, it also led to a 1.2% increase in fatigue in the following sprints (Glaister et al., 2008). These results indicate that caffeine may have the potential to improve high-intensity exercise in an immediate single bout that, in theory, should transfer well to vertical jump. The results were similar to previous research, which generally reported increased performance early on, and an increase in fatigue thereafter. A systematic review of literature on caffeine and short-term high-intensity exercise showed caffeine improved performance of team sports and power-based sports in 11 of 17 studies. As with many other studies, the effects were more common in elite athletes (Astorino & Roberson, 2010). The same review found significant benefits for resistance training in 6 of 11 studies.

Maximal weightlifting is similar to a vertical jump as maximal effort and intent to move fast are required. A study examined the effect of caffeine on lifting at percentages of one-repetition maximum (1-RM) (Del Coso et al., 2012). In the study, 22 resistance trained men consumed placebo or caffeine (6 mg/kg) sixty minutes before testing in a double-blind, crossover design. The lifts in the test included barbell bench press and leg press. The participants lifted at 60% of 1-RM to failure. The study found no difference between caffeine and placebo groups on muscular strength. The muscular endurance was improved, but not significantly. A study on resistance trained women showed increases in upper body strength with caffeine supplementation. Fifteen women consumed caffeine (6 mg/kg) or placebo and tested one-repetition maximum on barbell bench press. The caffeine trial had a significantly greater

maximum bench press (Goldstein, Jacobs, Whitehurst, Penhollow, & Antonio, 2010). Another randomized, double-blind, crossover study tested 18 male athletes in leg press, chest press, and Wingate following the ingestion of caffeine (5 mg/kg). The study didn't find significant improvements in the leg press, but both chest press and the Wingate test were improved in the caffeine trial (Woolf, Kathleen, Bidwell, & Carlson, 2008). The results of a meta-analysis on the effect of caffeine on muscular strength and endurance reported an effect of caffeine on performance (Warren et al., 2010). The results of the meta-analysis included 34 studies between the years of 1939 and 2008. Of the 34 studies, 27 of them measured caffeine's effects on maximum voluntary contraction (MVC) strength. MVC strength is closely related to vertical jump with the goal being to fire as many motor units as fast as possible. In the 34 studies, a total of 726 participants were tested. Of the 27 studies examining MVC strength, 23 of them showed performance increases over placebo. The average increase was approximately 4% greater in the caffeine groups compared to the placebo groups. The lower-body increases were even better than the average of 4%. Caffeine appears to improve knee extensor MVC strength by approximately 7% in caffeine groups compared to placebo. Those results show promise that caffeine supplementation before exercise could enhance vertical jump.

Caffeine in Energy Drinks

Caffeine is widely consumed in the form of commercially available energy drinks. In a recent position stand on energy drinks by the International Society of Sports Nutrition (ISSN), caffeine appears to be the primary and most common ingredient found in energy drinks

(Campbell et al., 2013). Energy drinks typically have around 100 mg of caffeine per serving and each can typically have one to three servings depending on the size. Consuming an energy drink 10-60 minutes before exercise has the potential to improve anaerobic performance (Campbell et al., 2013). Caffeine ingested prior to anaerobic work has shown significant improvements in upper body strength, but the evidence is mixed for lower-body strength and power. The Wingate cycle test is often used as a measure of lower body power. Many studies show caffeine's ability to increase maximum voluntary contraction in grip strength and knee extensor strength, but they fail to show any significant improvements in the Wingate cycle test.

A study examined Wingate cycle performance and bench press after consuming Red Bull energy drink (Forbes, Candow, Little, Magnus, and Chilibeck, 2007). Fifteen healthy young adults either consumed non-caffeinated placebo or Red Bull at a low dose (2 mg caffeine per kg of body mass). Wingate cycling tests consisting of 3 x 30 seconds were performed with two minutes of recovery between each test to determine peak and average lower body power output. Similar to most caffeine research on lower body power, the Red Bull had no effect on Wingate peak or average power. It did however significantly increase the upper-body endurance in the bench press tests. According to the results of this study, 2 mg/kg of body mass is not enough caffeine supplementation to significantly affect lower-body power output.

Improved performance was found in a recent study examining the effects of a caffeine-containing energy drink on upper- and lower-body power-load tests (Del Coso et al., 2012). Twelve active participants between the ages of 30 ± 7 years old ingested either 1 mg of caffeine per kg of body weight, 3 mg/kg in an energy drink, or the same drink without caffeine. After one

hour, power production in the half-squat and bench press was tested with increasing loads from 10% to 100% of one repetition maximum. In comparison to the placebo, the 3 mg/kg energy drink group significantly increased maximal power in both the half-squat and the bench press. Maximal power output was increased $7 \pm 4\%$ in the half-squat and $7 \pm 2\%$ in the bench press in comparison to the placebo group. The 1 mg/kg failed to produce significant differences in performance. According to their findings, a dosage of 3 mg/kg of caffeine can significantly improve both upper body and lower body muscle power. A potential $7 \pm 4\%$ improvement in the half-squat is a large performance enhancement in lower body strength and could possibly transfer to a better vertical jump for athletes.

A study on adolescent basketball players found vertical jump improvements with caffeine supplementation. Participants were sixteen young basketball players aged 14.9 ± 0.8 years. They ingested caffeine (3 mg/kg) or a placebo and waited 60 minutes to ensure absorption. Participants performed a countermovement maximal jump and a 15 second repeated maximal jump test. Both the countermovement jump (38.3 ± 4.4 vs. 37.5 ± 4.4 cm) and the mean jump height of the repeated maximal jumps (30.2 ± 3.6 vs. 28.8 ± 3.4 cm) were significantly increased by the energy drink (Abian-Vicen et al., 2014).

Another recent study examined the effects of a caffeine-containing energy drink on a simulated soccer performance (Del Coso et al., 2012). In the study, nineteen semiprofessional soccer players aged 21 ± 2 years performed two experimental trials. The participants either consumed sugar-free Red Bull at approximately 3 mg/kg of body mass or a placebo. One hour after consumption of the Red Bull, the participants performed a maximal jump test measured by

flight time. The test required the participants to jump as high as possible repeatedly for 15 seconds. Five minutes after the jump test, participants performed a repeated sprint ability test. They ran 7 x 30 meter sprints with 30 seconds of active recovery between repetitions. The energy drink group increased their mean jump height higher on average than the placebo group. The energy drink group increased their mean peak running speed greater on average than the placebo group. Overall, the ingestion of the caffeine-containing energy drink improved the mean jump height by $3.2 \pm 3.3\%$ and power output by $3.8 \pm 4.0\%$ during the jump test. The energy drink group improved mean running speed by $2.8 \pm 2.0\%$ in the repeated sprint test. This is one of the few studies examining jumping qualities after caffeine supplementation. Performance enhancements in both the repeated jumps and repeated sprints tests show caffeine's potential for improving high-intensity exercise quality in highly trained athletes.

Vertical Jump Research

It was important to design an effective warm-up for the vertical jump test and to make sure that it was followed for each participant. For this purpose, a look into vertical jump warm-up studies was needed. Church, Wiggins, Moode, and Crist (2001) examined the effect of three different types of warm-ups before vertical jump testing. The three warm-up conditions were a general warm-up, a general warm-up with static stretching, and a general warm-up with proprioceptive neuromuscular facilitation (PNF). The participants of the study were forty Division I NCAA female athletes aged 20.3 ± 1.6 years old. The results of the study showed a significant decrease in vertical jump performance following the PNF treatment group compared

to the general warm-up and general warm-up with static stretching groups. Therefore, PNF treatment before maximal vertical jump may be detrimental to performance.

A more recent study from the same journal also examined the effects of different warm-ups on vertical jump performances (Burkett, Phillips, and Ziuraitis, 2005). The purpose of the study was to compare specific warm-ups with nonspecific warm-ups. Nonspecific warm-ups involve movements that are not directly related to the test being performed, whereas specific warm-ups involve movements that are similar to the test being performed. The test was done with a Vertec measuring tool, which all the participants were familiar with. The participants were 29 Division I NCAA men's football players aged 18-23 years old. The football players were all speed position players (running backs, receivers, and defensive backs). The study utilized four different warm-up conditions. The conditions were a sub maximal jump warm-up, a weighted jump warm-up, a stretching warm-up, and no warm-up. Following each warm-up, three vertical jumps were measured and the results were based on the best jump. The results showed a significant improvement between the weighted jump warm-up and all the others. The study found that a weighted resistance jumping warm-up produced the highest vertical jumps by a difference of 1.67 centimeters. Possible explanations behind this are neurological in nature (Church, Moode, & Crist, 2001). By utilizing a specific warm-up, the body gets neurologically prepared for the test activity. The use of resistance in the warm-up touches on the theory of the *treppe* concept (staircase). The resistance is an added stimulus forcing each successive jump to recruit more motor units in the specific muscles used for the vertical jump test (Church, Moode, & Crist, 2001). With greater motor unit recruitment, there is greater muscle contraction

producing larger lower body power outputs. The study shows the importance of creating a specific warm-up for testing protocols. It uses the principles of specificity and overload to produce greater performance results.

Several studies have shown caffeine's ability to improve weightlifting measures of strength and power. Vertical jump is often used as a test for lower body strength and power. A recent study assessed vertical jump of 64 USA national-level weightlifters on a switch mat. Squat jump and countermovement jump were both tested with a hands-on-hips method. Peak power of the vertical jump were measured to estimate weightlifting ability. Results indicated that peak power derived from vertical jump tests was strongly associated with weightlifting ability (Carlock et al., 2004).

One study looked at training rest interval effects on vertical jump performance. Twenty-one NCAA Division I athletes performed a countermovement jump, followed by five repetitions of squat, followed by countermovement jumps at ten seconds, one, two, three, and four minutes after the squat. Jump height and peak force were measured with a force platform. The squats appeared to decrease the jump performance immediately after. There was a trend toward jump improvement towards the final jumps. Therefore, recovery greater than four minutes is needed before attempting maximal vertical jumps (Jensen & Ebben, 2003).

Summary

There is still much more research needed in the area of short-term, high-intensity exercise after caffeine supplementation. With such a large percentage of high-level athletes consuming

caffeine prior to competition, it is important to know what performance effects can be expected. The results of the studies on weightlifting, sprinting, and team sports are varied. However, the majority of the studies showed positive performance enhancements after caffeine supplementation when compared to placebo. With the majority of vertical jump research focused on different warm-up protocols and different ways to test jumping, there appears to be a gap in the area of caffeine supplementation. Sports like volleyball, basketball, long jump, high jump, and many others rely on the ability to jump high. If caffeine has the ability to improve vertical jump it would be beneficial for these athletes. The use of a force platform is useful for precise measurement of jump height and the ability to look at force production. Jump mechanography using force plates provides the ability to look at force-time variables to better understand the mechanisms of a vertical jump. In conclusion, we feel that a moderate dose (3-9 mg/kg) of caffeine would improve performance in the vertical jump.

CHAPTER III

METHODS

The study was a single-blind crossover design to investigate the effects of caffeine supplementation on jumping mechanography components such as jump height, peak force, and rate of force development. The purpose was to determine if caffeine supplementation is beneficial for high-level athletes competing in short duration, high-intensity sports.

Participants

NCAA Division I collegiate athletes from the University of North Dakota were recruited for this study. High-level collegiate athletes were recruited because ergogenic effects of caffeine are usually only seen in trained athletes due to factors such as more consistent performances and differences in physiology due to training (Goldstein et al., 2010). Teams were training eight to twenty hours per week depending on when their season was with a combination of sport practice and weight lifting. The target number of participants was approximately thirty males and females ranging from 18 to 23 years of age. The study was limited to collegiate level athletes, and the results may not transfer to the general population or lower level athletes. Athletes were excluded if they have had a lower body injury in the past 6 months that has removed them from competition.

Instruments

Ground reaction force was measured using a force platform (Bertec Force Plate, Bertec Corporation, USA). Mechanography data from a force platform is strongly correlated with data from cameras for jump height ($r = .96$). The four different methods commonly used to measure vertical jump also showed excellent reliability on the force platform ($r = .97$) (Aragón, 2000).

Procedure

Approval to conduct the study was granted by the University of North Dakota Institutional Review Board. An initial meeting was scheduled with all of the athletes to inform them of the procedures, risks, and expectations that were placed on those willing to participate. Participation was voluntary and all participants were provided written and verbal consent before the start of the study. Participants were free to quit the study at any time, for any reason, and without consequences.

The study was conducted in the biomechanics lab in the Hyslop Sports Center at the University of North Dakota. The study took approximately one week for participants to complete with the second session scheduled a week after the first session. Participants were encouraged to continue with their normal eating habits during the study except for special instructions the day of their testing. Participants were instructed not to eat 3 hours before testing or consume caffeine on the day of testing. Participants performed both sessions at the same time of day before any exercise. A single-blind, crossover design was used. Participants were randomly assigned to which treatment they received first. The following protocol was used for each test. Participants

either consumed caffeine (5mg/kg body weight) in the form of a pill or a placebo 60 minutes prior to testing. Pill form (anhydrous) of caffeine was chosen because studies have shown it to be the most efficient form of absorption (Goldstein et al., 2010). Anthropometric measurements of height and weight were recorded using a stadiometer and force platform, respectively.

Participants performed a ten-minute dynamic warm-up specific to jumping prior to testing. All participants performed three squat jumps and three countermovement jumps on the force platform separated by 30 seconds of rest in-between jumps and two minutes between the different styles of jumps. Hands were placed on the hips to ensure only lower body power was assessed. Arm swing has been shown to increase both height of jump and velocity at take off (Lees, Vanrenterghem, & Clercq, 2004). For the squat jump, participants were told to slowly lower to a self-selected depth, pause for approximately three seconds, and then jump as high as possible. For the countermovement jump, participants were told to simply jump as high as possible without a pause at the bottom position. Testing occurred on two occasions separated by at least five to seven days. Each testing session took approximately 70 minutes to complete (60 minute waiting period and approximately 10 minutes of actual testing).

Several jumping outcome variables were tested. Jump height (m) was measured by vertical velocity of center of mass at takeoff² divided by 2 gravity (Moir, Garcia, & Dwyer, 2009). Jump execution time (s) was measured by time from jump commencement to takeoff. Peak force (n) was measured by highest vertical force trace prior to takeoff. Time to peak force (s) was measured by time from jump commencement to peak force. Time to half peak force was measured by time from jump commencement to half peak force. Peak rate of force development

(n/s) was measured by peak time derivative of the vertical force trace. Average rate of force development (n/s) was the peak force divided by time to peak force. Force gradient (n/s) was measured by half peak force divided by time to half peak force (Zatsiorsky & Kraemer, 2006). Acceleration gradient (n/s) was measured by half peak force divided by time to peak force minus time to half peak force (Zatsiorsky & Kraemer, 2006). All variables were reported as the average of three jumps for each technique.

Statistical Analysis

Data was analyzed using SPSS version 23.0 (IBM, Armonk, New York). Descriptive statistics are expressed as means \pm standard deviations. Data were inspected to determine if criteria for normal distributions were met. Paired samples t-tests were used to compare the differences between the supplement and placebo conditions. An eta squared statistic was used to indicate effect size. With our target recruitment of 32 participants this investigation has 80% power to detect large effects (7.5%). Statistical significance was set at $p < 0.05$.

CHAPTER IV

RESULTS

A total of twenty-five athletes were included in the study. The sports included in the study were track and field (throwers, sprinters, jumpers), football, and baseball. There were 16 men and 9 women. Of the twenty-five athletes, fifteen were not regular consumers of caffeine. Ten of the participants consumed caffeine of a regular basis in the form of coffee, energy drinks, or pre-workout.

Jump Height

Caffeine supplementation was positively correlated with both squat jump height and countermovement jump height ($p = 0.001$; $p = 0.000$). Squat jump height and countermovement jump height were significantly improved $\sim 5.3\%$ and $\sim 4.2\%$ respectively, in the caffeine trial compared to placebo. The Eta-squared statistic for squat jump height (.09) and countermovement jump height (.10) indicated a moderate effect size. The jump height results are presented in Tables 3 and 4.

Peak Force Production

Caffeine supplementation was not correlated with peak force production in the squat jump ($p = .760$); however, it was positively correlated with peak force production in the countermovement jump ($p = .032$). The force production results are presented in Table 4.

Rate of Force Development

Caffeine supplementation was positively correlated with average rate of force development for countermovement jump ($p = .037$), but not for squat jump ($p = .312$). Average rate of force development results are presented in Table 4.

Time to Half Peak Force

Caffeine supplementation was positively correlated with time to half peak force for squat jump ($p = .019$), but not for countermovement jump ($p = .721$). Time to half peak force results are presented in table 3.

Starting Gradient

Caffeine supplementation was positively correlated with starting gradient for countermovement jump ($p = .040$), but not for squat jump ($p = .077$). Starting gradient results are presented in Table 4.

Acceleration Gradient

Caffeine supplementation was positively correlated with acceleration gradient for countermovement jump ($p = .040$), but not for squat jump ($p = .791$). Acceleration gradient results are presented in Table 4.

Table 3. Squat Jump Variables.

Variable	Caffeine Mean (SD)	Placebo Mean (SD)	p-value
Jump height (cm)	34.5 (6.7)	32.7 (6.2)	.001
Peak force (N)	1,246 (431)	1,253 (388)	.760
Time to half peak force (s)	0.074 (0.038)	0.084 (0.041)	.019
Time to peak force (s)	0.225 (0.074)	0.228 (0.072)	.652
Peak rate of force development ($N \cdot s^{-1}$)	14,452 (7,784)	13,329 (7,540)	.197
Average rate of force development ($N \cdot s^{-1}$)	6,644 (4,163)	6,267 (3,601)	.312
S-Gradient (N)	10,904 (6,507)	9,793 (6,304)	.077
A-Gradient (N)	5,431 (3,501)	5,333 (3,166)	.791
Take off time (s)	0.344 (0.057)	0.342 (0.061)	.798

Table 4. Countermovement Jump Variables.

Variable	Caffeine Mean (SD)	Placebo Mean (SD)	p-value
Jump height (cm)	37.9 (7.4)	36.4 (6.9)	.000
Peak force (N)	12,453 (6,716)	10,979 (5,029)	.032
Time to half peak force (s)	0.087 (0.039)	0.088 (0.027)	.721
Time to peak force (s)	0.209 (0.87)	0.219 (0.868)	2.58
Peak rate of force development (N·s ⁻¹)	12,453 (6,716)	10,979 (5,029)	.069
Average rate of force development (N·s ⁻¹)	7,229 (4,049)	6,371 (3,435)	.037
S-Gradient (N)	9,487 (6,342)	7,995 (4,337)	.040
A-Gradient (N)	6,558 (3,253)	5,813 (3,147)	.040
Take off time (s)	0.456 (0.061)	0.460 (0.057)	.502

CHAPTER V

DISCUSSION

The primary aim of this study was to evaluate the effect of caffeine supplementation on vertical jump performance in NCAA Division I athletes of multiple different sports. Our hypothesis was supported. Squat jump ($p = .001$) and countermovement jump ($p = .000$) heights were significantly improved with caffeine supplementation. It appears that caffeine supplementation affects both height and execution of the jumping, though the extent of change in the execution appears to be dependent on the jumping technique. These results are consistent with other studies on caffeine's effects on strength and power (Warren et al., 2010).

Caffeine supplementation predicting increases in lower body power is consistent with previous literature examining high-level athletes (Sökmen, Bülent, et al., 2008). Improvements in repeat sprint ability and a 15-second maximal jump test were demonstrated in a simulated soccer performance. (Del Coso et al., 2012). Improvements in sprint ability have also been seen on the cycle ergometer. A recent double-blind study tested ten male team-sport athletes after ingestion of placebo or 6 mg/kg of body weight caffeine. Participants performed 2 x 36 minute halves consisting of 18 x 4 second sprints followed by two minutes of active recovery. The caffeine trial performed 7-8% more sprint work in both the first and second halves. The caffeine trial also had 6-7% greater peak power in both halves (Schneiker et al., 2006). Caffeine's ability to improve repeat sprint ability is well documented, while jumping is less researched. Our study shows that caffeine does have the potential to improve jump height and rate of force development in athletes.

While several jump execution variables were not changed with caffeine supplementation for both jump styles, jump execution was altered to a greater extent during the countermovement jump compared to the squat jump. A possible reason for the greater change in countermovement jump execution may be the technique. The rapid transition from an eccentric contraction to a concentric contraction is thought to utilize the stretch-shortening cycle. Because of the countermovement, this technique also has an increased movement time compared to squat jump. The increased movement time allows for greater impulse and time to produce force. It may be that caffeine positively influences stretch-shortening activity and associated force production. Our data appear to support this as average rate of force development, S-gradient, A-gradient, and peak force were enhanced with caffeine supplementation. Interestingly, these same changes in jump execution were not mirrored in the squat jump even though the effect size for increased jump height was slightly larger for the squat jump, 5.3% and 4.2% respectively. The only statistically significant change in jump execution for the squat jump was time to half peak force ($p = 0.019$). During the squat jump, it appears that caffeine effects force production only during the initial portion of the jump. This is also supported by the trend for increased S-gradient ($p = 0.077$), which reflects the average rate of force development during the first half of concentric force production. The lack of peak force change during the squat jump may be due to the increased velocity obtained during the initial portion of the jump, reducing the force produced during the most advantageous position.

After a comprehensive search of PubMed and Google Scholar, many of the associations in this study between caffeine supplementation and vertical jump variables appear to be novel.

The exact mechanism responsible for the effect of caffeine supplementation on vertical jump performance is not known. Caffeine exerts effects on many systems within the body including both the central and peripheral nervous systems (Tarnopolsky, 2008). One of caffeine's primary sites of action is at the central nervous system, which has the ability to enhance cognitive functions such as concentration and arousal (Goldstein et al., 2010). All of the testing sessions were conducted in the morning, so caffeine's ability to enhance arousal may have influenced the results. Caffeine may improve muscular function by increasing force production as we have documented in the countermovement jump. The increased force production may result from enhanced calcium release and uptake from the sarcoplasmic reticulum (Spriet, 1995). It could also be due to central mechanisms, increased recruitment of muscle fibers, or increased rate coding (Goldstein et al., 2010). Caffeine increased starting gradient in countermovement jump and trended towards increasing it in squat jump. Starting gradient was moderately correlated to jump height during the countermovement ($r = 0.42, p = 0.035$) and squat jump ($r = 0.42, p = 0.036$). Interestingly, starting gradient was the only jump execution variable associated with squat jump height after caffeine supplementation explaining approximately 18% of the variance in jump height. Starting gradient and other rate of force development measures may be influenced by numerous factors such as sarcoplasmic calcium kinetics and action potential propagation (Tarnopolsky, 2008). It is most likely a combination of several factors contributing to the increases in performance observed in our athletes.

This study has several limitations. Only twenty-five participants completed the study coming from five different sports (sprinters, jumpers, throwers, baseball, football). Large

discrepancies in the athletes' weights, heights, limb lengths, and jump styles may have introduced more variability in the jump execution variables reducing our ability to detect meaningful change. Reliability of jump execution variables may be different between jumping techniques. There is possibility that athletes may have been able to guess which pill was placebo and which was caffeine. A 5 mg/kg of body weight dose of caffeine is easily detected by most people, which makes it difficult to hide with a placebo. Many of the participants were able to correctly guess which treatment was the supplement a couple hours after the testing. The athletes were in different stages of their seasons. It is difficult to account for a collegiate athlete's total physical activity in a given week. Sport participation may have exposed the athletes to activities very similar to jumping which can lead to fatigue. However, this is not a likely explanation for our observed results due to the randomized, crossover design.

In conclusion, the supplementation of caffeine by collegiate athletes appears to have the ability to improve jump height and rate of force development. Scientific literature on caffeine is extensive. However, the study's findings provide evidence for further research into caffeine as an ergogenic aid for athletes participating in sports requiring explosive strength.

Practical Application

Caffeine supplementation (5 mg/kg of body weight) significantly improved jump height in Division I collegiate athletes of various sports. Our data indicates that caffeine can be a beneficial tool for high-level athletes to improve their vertical jump when used properly. Current

research states a recommended dose of 3-9 mg/kg of body weight in anhydrous (capsule/powder) form (Goldstein et al., 2010). Caffeine should be supplemented approximately 60 minutes before competition (Graham, 2001). Our data shows athletes participating in football, track & field, women's basketball, and baseball can benefit from caffeine supplementation. It is important to note that the caffeine supplementation only improved a vertical jump test. If the task involves a high level of precision as well, it may have other effects on those skills. Our study was conducted on collegiate athletes and the results may not transfer to lower-level athletes.

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