THE EFFECT OF CAFFEINE ON ATHLETIC AGILITY

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ABSTRACT

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Studies have shown that caffeine can improve exercise performance and reaction time. In this study, 16 subjects participated in a randomized, double-blind experiment to determine caffeine's effects on agility. Subjects performed the pro-agility shuttle run one hour after caffeine ingestion (6 mg kg^{-1}). No significant change was observed in the pro-agility run after caffeine ingestion compared with placebo ($t(1,15) = -.069$, $p > .05$). In addition, subjects performed the Wingate anaerobic power test one hour after caffeine ingestion (6 mg kg^{-1}) and were measured in terms of peak power (J), mean power (J), and % power decrease. No significant change was observed in any of these indices. These findings were consistent with previous

studies. The results of this study indicate that caffeine does not have an effect on athletic agility. It is possible, however, that changes in experimental protocol could yield different results. Variables such as caffeine dosage and subject training status could affect the outcome of studies involving caffeine and agility.

CHAPTER I

INTRODUCTION TO THE STUDY

Caffeine is commonly used as an ergogenic aid in all types of athletic performances (5, 11, 31, 36). Despite its popularity as a performance enhancer, research is discordant as to whether caffeine augments different types of physical activity. For instance, caffeine has consistently been shown to enhance aerobic exercise (11, 12, 17, 33), but not anaerobic performance (10, 30, 36). In particular, studies have shown that caffeine intake increases exercise time to exhaustion (3, 6, 13, 19, 33). In a practical setting, therefore, caffeine consumption is expected to enhance a person's ability to sustain a higher absolute level of submaximal steady-state exercise.

Research has suggested that caffeine may enhance performance by increasing fat metabolism (3, 12, 33), stimulating the central nervous system (CNS) (9, 25, 31), and/or augmenting muscular contractility (28, 32, 34, 36). Several studies have shown that caffeine intake increases the rate of fatty acid catabolism during exercise (3, 10, 33, 16). As a result, caffeine intake decreases the rate of glycogenolysis, thus sparing glycogen for later use, and delaying the onset of fatigue during long duration performance (3, 10, 33, 29, 16). Caffeine's ergogenic effect may also be attributed to CNS stimulation (5, 25, 31, 36). Caffeine inhibits adenosine, an endogenous

physiological CNS depressant. Adenosine inhibition by caffeine may result in an increase in noradrenaline and epinephrine release (5), thereby lowering the rating of perceived exertion (25, 31). Either of these effects could dull the perception of effort and extend exercise time to exhaustion. Finally, some have proposed that caffeine's ergogenic effect may be caused primarily by a direct impact on skeletal muscle tissue; caffeine appears to alter the release of sarcoplasmic calcium, which could increase muscular power output during strenuous activities (34).

Little is known regarding the effect of caffeine-intake on agility and quickness. While Jacobson and Edgley (22) found that a caffeine dose of 300 mg improved reaction time and movement time this notion that caffeine may enhance performance in athletic events which require quick and rapid movement warrants further study (36). The purpose of this study was to determine whether an acute caffeine dose enhances performance in the pro-agility run test. It was hypothesized that the caffeine dose will enhance performance in this activity.

CHAPTER II

MATERIALS & METHODS

Approach to the Problem

To determine whether an acute dose of caffeine enhances athletic agility, male college students performed the pro-agility run and the Wingate anaerobic power test on separate occasions: a) after ingesting a caffeine (Caf) treatment (6 mg kg^{-1}); and b) after ingesting a placebo (Pl) treatment (dextrose). The caffeine used in this study was pure caffeine anhydrous powder (Spectrum Chemicals), dispensed into gelatin capsules. Mean values for the pro-agility run (s) as well as peak power output (J), mean power output (J), and % power decrease observed during the Wingate anaerobic power test were calculated, and paired t-tests were used to determine whether the caffeine dose enhanced pro-agility run times, anaerobic power, or power decrease.

Subjects

Subjects consisted of 16 males, ages 21-28 years old who were recruited from Physical Fitness & Wellness classes at a university. This study was limited to male subjects to rule out a potential complication if women were used. Abernathy and Todd (1) reported that the use of oral contraceptives by women slows the breakdown of caffeine into paraxanthine, thereby extending the plasma half-life of caffeine (1). This process could result in an increased accumulation of caffeine in women who are

regular caffeine users and who take oestrogen-containing oral contraceptives, potentially confounding the results.

All subjects submitted written informed consent following an explanation of testing protocol, including potential risks involved. Approval by the university's Committee of the Protection of Human Subjects was obtained prior to the commencement of testing.

Testing Procedures

During week 1 of testing, all subjects completed a health history questionnaire. Height and weight were measured with subjects wearing exercise clothes but no shoes. Body composition was assessed using a three-site (chest, abdomen, and thigh) sum of skinfold protocol (2). All body size and composition measures were taken by an experienced test administrator, who was previously trained according to the American College of Sports Medicine (ACSM) standards for body composition assessment (2).

Each subject completed a questionnaire to assess routine caffeine use. Bell and McLellan (5) considered caffeine "users" to be individuals whose daily caffeine consumption exceeds 300 mg. In the present study, only one subject consumed more than 300 mg per day on average, while the remaining 15 subjects consumed <300 mg per day.

Following preliminary measurements, subjects practiced the pro-agility run (15) and the Wingate anaerobic power test (27) during week 1. At the end of week 1, each subject performed the agility test and the power test without any

supplementation. During week 2, subjects performed these tests after ingesting either 6 mg kg^{-1} of Caf or Pl following a 2 to 3-hr fast and a 48-hr abstinence from caffeine. This dosage has shown to be effective in enhancing exercise performance (13, 31, 34), and a 48-hr caffeine abstinence prior to acute caffeine ingestion appears to be a sufficient time period to eliminate caffeine from the body (11). Subjects performed the agility test first, then performed the power test 2 to 3 days later.

During week 3, the subjects repeated each test 2 to 3 days apart. The subjects were again asked to fast for 2 to 3-hr prior to testing and to abstain from caffeine for 48 hours prior to testing. Subjects that received a Caf treatment for the pro-agility run during week 2 received a Pl treatment prior to the pro-agility run during week 3. Likewise, subjects that received a Caf treatment prior to performing the Wingate test during week 2 received Pl treatment prior to Wingate testing during week 3. In a given week, no subject received Caf treatment for both tests.

Instrumentation

A calibrated physician scale (Detecto Scale Co., Jericho, NY) was used to obtain height and weight, and Lange calipers (Cambridge, MD) were used to measure skinfold thickness. Timing gates (Brower Timing Systems Speedtrap 2, Draper, UT) and electronic stop-watches (Accusplit 601X, Cranston, RI) were used to measure speed and agility. Anaerobic power was tested using the Monark cycle ergometer (Quinton Instrument, Bothwell, WA) and computerized power calculations were made with the POWER program (Sports Medicine Industries, Inc., St. Cloud, MN).

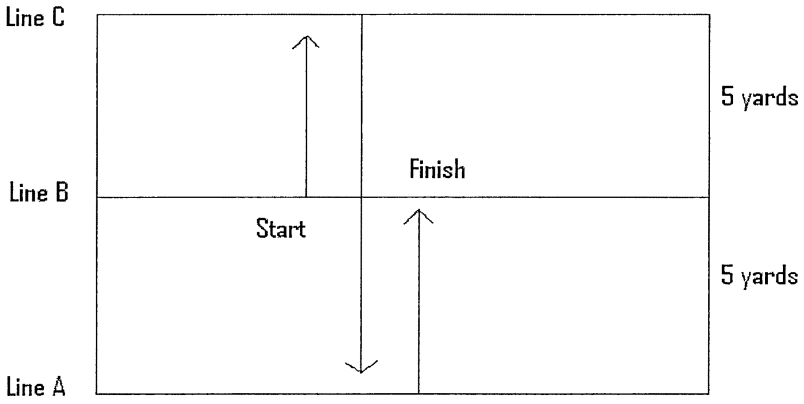
All test administrators were trained on how to use the equipment prior to assessment of subjects.

Tests

Agility. The pro-agility run, also known as the 20-yd shuttle run, was used to assess agility (see Figure 1). The pro-agility run was performed on a parquet surface. Starting position was a 2-point stance straddling line B, where the electronic timer was placed to mark the starting and finishing point. Once a subject was ready to begin the test, he placed one foot on the starting pad of the electronic timer and was asked to pause for at least 2-s in order for the timer to set. After the electronic timer was set (confirmed by a constant beep), the subject pivoted and sprinted as fast as possible toward line C. The subject touched the line with one foot then reversed direction and ran to line A, touching the line with one foot. Finally, the subject completed the test by sprinting back through the electronic timing gate set up at line B.

Three test administrators using stopwatches and one electronic timer recorded the time to the nearest .01 s. The stopwatches were started at the subject's first movement and were stopped as the subject's torso crossed the finish line. Hand-timers were asked to begin and stop the hand-help stopwatches with their index fingers. The best electronic time and the best average hand time of three trials was used for data analysis.

Figure 1. Pro-agility shuttle run.



Anaerobic Power. The Wingate anaerobic power test was used to measure each subject's anaerobic power output. This test was performed on a Monark cycle ergometer with a load set at 7.5% of body weight. The subjects were asked to pedal as fast as possible at the onset of the test and to maintain maximal effort throughout the 20-second testing period. Test assessments were recorded automatically in revolutions per minute. Test results were given in terms of peak power, mean power, and % power decrease. The POWER program takes into account the resistance of the flywheel and the ribbon on the cycle ergometer to factor into corrected power figures.

Data Analysis

For this study, data analysis was performed using paired t-tests to compare each subject's Caf and Pl performances. The dependent variables for agility analysis were the pro-agility run times, while the independent variables were the treatments

(Caf vs. Pl). The dependent variables for the Wingate anerobic power test were peak power, mean power, and % power decrease.

CHAPTER III

RESULTS

After data screening, the final sample included 16 of the 17 original subjects. One subject was not used when it was determined that he used the prescription drug, Adderall. Table 2 reports the subjects' descriptive characteristics. Although the subjects were not collegiate athletes, they were Exercise and Sports Science students, and met or exceeded the U.S. Surgeon General's recommendation for physical activity (14).

Table 2. Subject characteristics.

	Mean ± SD	Range
Age	23.7 ± 2.02	21-28
Weight (kg)	87.56 ± 17.23	62.27-129.09
Height (cm)	179.94 ± 7.78	167.64-193.04
% Body Fat	13.33 ± 5.51	5.78-25.38

Table 3 reports the responses (mean ± SD and range) for each dependent variable measured during each test. Paired t-tests comparing Pl and Caf trials revealed no significant difference in: (a) pro-agility run times ($t(1,15) = -.069$, $p > .05$); (b)

peak power output (t (1, 14)= -0.07, $p > .05$); (c) mean power output (t (1, 14)= 0.95, $p > .05$); or (d) % power decrease (t (1,14) = -0.7, $p > .05$).

Table 3. Pro-agility Run Times, Peak Power Output, Mean Power Output, and Percent Power Output Decrease.

	Placebo		Caffeine	
	Mean ± SD	Range	Mean ± SD	Range
Pro-Agility Run (s)	4.78 ± .26	4.41– 5.29	4.75 ±.29	4.33 – 5.32
Peak Power (W)	1053.33 ± 262.66	642 – 1446	1050.07 ± 243.58	628 – 1460
Mean Power (W)	829.67 ± 196.01	5220 – 1245	858.33 ± 194.11	575 – 1170
% Power Decrease (W)	37.19 ± 9.40	16.6 – 50.0	35.07 ± 7.48	21.1 – 44.4

Note: No significant differences between placebo and caffeine trials were observed in any of these tests.

CHAPTER IV

DISCUSSION

Caffeine's effect on anaerobic exercise performance remains unclear. Caffeine intake is associated with increased epinephrine levels about one hour after ingestion (20), which has led researchers to speculate that caffeine may modify anaerobic metabolism due to increased motor activity (10). Some studies have found that an acute caffeine dose enhanced power (23) and time-trial (7) rowing, while other studies have found no significant effect of caffeine on anaerobic cycling power (10, 20) or on repeated sprints (30).

Caffeine has been associated with improved reactions and reflexes. Jacobson and Edgley (22) found that caffeine doses of 300 mg (4.12 mg kg^{-1}) improved reaction time and movement time. Improved reaction time could lead to improvement in athletic events requiring quick reflexes, such as agility drills (36).

In this study, no significant ($p > .05$) improvement was observed in peak power output, mean power output, and % power output decrease during Wingate test performance following caffeine ingestion. This is consistent with studies that have examined caffeine's effects on cycle ergometer power testing (10, 20, 36). It is possible that subject training status factors into these results. Studies that have found significant anaerobic performance improvements have often examined highly-trained

subjects (7, 23), while many studies that have found no effect of caffeine on anaerobic exercise performance have examined recreational athletes (10, 20). Subjects in the present study fall into the recreational category.

The caffeine dosage is an important factor when examining caffeine's effect on reaction time. Jacobson and Edgley (22) found improved reaction time and movement time untrained subjects at caffeine doses of 300 mg (4.12 $mg\,kg^{-1}$), but they found no enhancement when subjects took 600 mg (8.24 $mg\,kg^{-1}$) before the reaction test. The authors speculated that at a caffeine dose somewhere between 300-600 mg, the initial boost in the neuromuscular response time which occurs at moderate doses may become attenuated. In the present study, subjects received a caffeine dose of 6 $mg\,kg^{-1}$, with the mean caffeine dose of 525.34 mg. It is possible that this amount of high enough to attenuate the neuromuscular response time, thereby mitigating any anticipated ergogenic effects.

In summary, a caffeine dose of 6 $mg\,kg^{-1}$ does not appear to enhance agility as measured by the pro-agility run test. It remains possible that caffeine may improve agility under different circumstances. For instance, a smaller caffeine dose may prove to be more effective, as others have suggested that caffeine improves reaction time only up to a certain dosage (22). Future studies should perhaps test-subjects using manual reaction time tests in addition to agility tests in order to fine-tune the process of ascertaining the ergogenic effect of caffeine on agility. Furthermore, while the pro-agility run is often used as a standard agility test, other agility tests requiring more direction-changing movements may yield different results. Agility tests that include a

stimulus that dictates movement patterns, rather than a set pattern, may more accurately reflect the types of enhancement that caffeine could provide.

Practical Applications

Although the results of this study suggest that an acute caffeine dose may be ineffective in improving agility as measured by the pro-agility shuttle run, caffeine's potential as an anaerobic ergogenic aid should not be dismissed. As with other dietary supplements, caffeine can affect people differently depending on habituation, diet, training status, and other factors. Agility during competition may be enhanced if caffeine is able to improve reaction time. In the present study, subjects were not forced to react to a stimulus. Athletes participating in sports such as football, baseball, basketball and tennis must react to a stimulus without foreknowledge of movement patterns. It remains possible that caffeine may enhance agility in this regard.

APPENDIX A

REVIEW OF LITERATURE

Trimethylxanthine, or more commonly referred to as caffeine, is a CNS stimulant that is found in such consumables as coffee, tea, soft drinks, chocolate, and prescription medications (e.g., asthma and chronic obstructive pulmonary disease), as well as over-the-counter weight-loss products, nutritional supplements, and ergogenic aids (24, 36). Recent reports indicate that more than 80% of the world's population consumes caffeine on a daily basis (24). Consumption of caffeine in coffee, tea, and soft drinks accounts for more than 90% of total caffeine intake (24). Table 1 includes the most common beverages and their corresponding caffeine contents (8).

Table 1. Caffeine Content in Common Beverages.

Beverage	Volume	Caffeine Content
Coffee, brewed	8 oz	135 mg
Coffee, instant	8 oz.	95 mg
Tea, leaf or bag	8 oz.	50 mg
Tea, green	8 oz.	30 mg
Coca-Cola	8 oz.	23 mg
Cocoa or Hot Chocolate	8 oz.	5 mg

People often mention improved alertness and reduced mental and physical fatigue as the primary purpose for regular caffeine consumption (36). Although excessive caffeine consumption is associated with such side effects as anxiety, restlessness and sleeplessness (36), the benefits associated with caffeine intake appear to outweigh the costs for many. Currently, more than 80% of the world's population consumes caffeine on a daily basis (24).

In addition to caffeine's utilization as a stimulant for alertness, it is often consumed by dieters as a weight loss aid and by athletes to enhance athletic performance. In particular, caffeine is routinely added to over-the-counter weight loss products as it is believed to stimulate lipolysis and act as a CNS stimulant (36). Although caffeine's impact on high-intensity, short-duration exercise is unclear (4, 10, 20, 36), it has consistently been shown to enhance performance of low-to-moderate intensity exercise of long duration (5, 11, 12, 17, 33). Despite the discordance, caffeine, a legal substance in limited amounts in virtually all sport associations, is a popular ergogenic aid used by many athletes in many different sports. Because of its popularity, coupled with the lack of understanding regarding its effectiveness on performances requiring maximal or near-maximal effort, there is a need to identify the types of athletic performances that are proven to be enhanced by caffeine consumption. The purposes of this literature review are to: (1) delineate caffeine's purported effects on human performance; (2) determine whether caffeine supplementation impacts exercise performance of varying intensity and duration; and (3) identify areas of study that require further examination. This information could assist athletes and coaches in determining caffeine's ergonenic potential by

identifying the modes of exercise enhanced by caffeine ingestion and the optimal dosage for yielding these effects.

Physiological Effects of Caffeine during Exercise

Research has suggested that caffeine may enhance performance by increasing fat metabolism (3, 12, 33), stimulating the CNS (9, 25, 31), and/or augmenting muscular contractility (28, 34, 32, 36). This section discusses each theory and applies these theories to explain how specific modes of exercise may be enhanced by caffeine intake.

Effects of Caffeine on Metabolism during Exercise. Caffeine consumption stimulates an increase in epinephrine secretion by the adrenal medulla (3, 10). An increase in plasma levels of epinephrine augments lipolysis of triglycerides stored within both adipose and muscle tissue (3, 10). By increasing lipolysis, use of fatty acids for energy may attenuate muscle glycogenolysis (16), thereby conserving glycogen reserves (29, 33).

Conservation of glycogen stores can lead to enhanced exercise duration. For example, in a study by Spriet et al. (33), eight recreational cyclists cycled to exhaustion at 80% VO_2 max 60 minutes after ingesting 9 mg kg^{-1} of body weight of a placebo (dextrose). Subjects in this study had a mean body weight of 74.5 kg, so the average caffeine dose was 670.5 mg. One week later, the cyclists repeated the exercise 60 minutes following the ingestion of 9 mg kg^{-1} of body weight of caffeine. During the 60 minutes after caffeine ingestion, plasma FFA concentrations did not

increase for the placebo trial, but increased by 92% above baseline (0.24 vs. 0.46 mM) for the caffeine trial. Compared to the placebo trial, the caffeine trial free fatty acid (FFA) levels were significantly higher during the first 15 minutes of exercise. During the initial 15 minutes, the rate of glycogen utilization was 55% lower in the caffeine group than the placebo group (4.7 vs. 10.6 mmol kg dry muscle^{-1} min^{-1}). Cycling time to exhaustion for the caffeine trial was 27% longer than the placebo trial (75.8 vs. 96.2 min). The authors concluded that reducing glycogenolysis, thereby conserving muscle glycogen during the first 15 minutes of exercise appeared to have a significant impact on exercise to exhaustion. According to these results, caffeine intake will increase a person's ability to sustain a greater submaximal exercise duration.

Bangsbo et al. drew similar conclusions when they studied 12 long-distance runners who exhibited a notable decrease in respiratory exchange ratio (RER) during running bouts at about 80% VO_2 max 30 minutes after an acute caffeine ingestion (500 mg) (3). RER refers to the ratio of carbon dioxide produced to oxygen consumed during a given period (29). A decrease in RER indicates an increase in fat metabolism (3). While the subjects' plasma FFA levels were not concurrently elevated, the authors noted that plasma FFA levels may not necessarily reflect FFA turnover because muscle triglycerides can be the primary source of increased fat metabolism. The oxidation of intramuscular triglycerides would not be detectable in the plasma (3).

Other studies have been less supportive of the notion that enhanced performance associated with caffeine ingestion is attributable to a glycogen sparing

effect (33). For example, Graham et al. (18) recorded measurements of glucose and FFA levels in 10 male subjects (mean body weight = 84.9 kg) during one hour of cycling at 70% VO_2 max following a caffeine dose of 6 mg kg^{-1} (mean caffeine dose = 509.4 mg). At 0, 10 and 60 minutes, a needle biopsy of the vastus lateralis muscle was taken along with blood samples. While they found that caffeine ingestion was associated with increased mobilization of FFA into the plasma at rest (prior to exercise), they found no change in RER during exercise. Additionally, they observed little change in muscle substrate use, indicating that the caffeine-related responses were not directly associated with the working muscles. They concluded that carbohydrate and fat metabolism in working muscles were unaffected by caffeine ingestion, while other tissues accounted for the caffeine-related responses. Thus, the authors propose that caffeine's ergogenic effects are likely not due to metabolic changes of active muscles, as glycogen-sparing would not occur in working muscles.

Cox et al. also failed to find evidence to support the notion that metabolic alterations lead to performance enhancement (13). While caffeine ingestion (6 mg kg^{-1}) was associated with an increase in plasma FFA in 20 highly-trained cyclists (mean body weight = 76.7 kg, mean caffeine dose = 460.2 mg), there were no corresponding variations in the rates of substrate utilization according to RER measurements during a steady-state cycling bout at ~70% VO_2 max. The authors noted that RER measurement may not be a sensitive indication of muscle metabolism.

There is no consensus explanation regarding the inconsistency in studies involving caffeine and its effect on fat metabolism. Graham et al. state that it does not appear that differences in exercise intensity, level of subject training, or caffeine dose

in discordant studies account for the different findings (18). Clearly, more research is necessary to directly measure factors involved in this metabolic explanation before firm conclusions can be drawn.

Stimulation of Central Nervous System. It is generally accepted that caffeine stimulates CNS activity, leading some to believe that enhanced performance associated with caffeine is attributable only to increased alertness and improved mood (32). However, it appears that caffeine's CNS-stimulating effects dull the perception of effort and enhance motor unit recruitment, which could also contribute to its ergogenic effect (32).

Caffeine has been found to increase levels of several brain neurotransmitters, including serotonin, dopamine, acetylcholine, norepinephrine and glutamate, due to adenosine receptor antagonism (32). Adenosine is a neuromodulator that causes decreased motor activity, decreased alertness, vasodilation and slowed heart rate. Caffeine blocks adenosine receptors, thus preventing adenosine from binding to them. As a result, adenosine is unable to exert its effect, resulting in an increase in neurotransmitter release and a lowering of the threshold for neuronal activation (36). This results in greater motor unit recruitment and/or a decrease in the time required for motor unit recruitment. Aspects of performance, such as reaction time, could potentially be enhanced if motor units are recruited more quickly (36).

It is believed that consistent use of caffeine could lead to changes in the body's response to caffeine. Bell and McLellan (5) compared the effects of caffeine in 13 "caffeine users" (consume >300 mg/day) and 8 "non-users" (consume <50 mg/day). The subjects performed cycling bouts at 80% VO_2 max to exhaustion once

per week, either one, three or six hours after caffeine (5 mg kg^{-1}) and placebo ingestion. In the non-user group, exercise times one, three and six hours following caffeine ingestion were 32.7, 32.1, and 32.7 min., respectively. The placebo group recorded exercise times of 24.2, 25.8, and 23.2 min. one, three, and six hours after placebo consumption. Each subject's scores were significantly greater in the caffeine trial than the placebo trial. In the user group, exercise times one, three and six hours after caffeine consumption produced exercise times of 27.4, 28.1, and 24.5 min., respectively, while the user placebo group recorded scores of 23.3, 23.2, and 23.5 minutes to exhaustion. Only the cycling trials one and three hours after caffeine consumption resulted in significant improvements in exercise time in the user-caffeine group compared to the user-placebo group.

The authors suggest that caffeine's ergogenic effect on the aerobic exercise in this study is due to its role as an adenosine receptor antagonist (5). As an antagonist, caffeine blocks adenosine from binding to adenosine receptors, creating a blockade. Such a blockade results in increased dopamine and noradrenaline release, which could enhance exercise performance. Additionally, Bell and McLellan found that exercise time to exhaustion was greater and longer-lasting in the non-user group. Habitual caffeine use is associated with an increase of the number of adenosine receptors. Theoretically then, non-users would be more sensitive to the effects of caffeine because the ingestion of a common caffeine dose would block a greater percentage of total adenosine receptors in non-users than in users (5).

Ratings of perceived exertion (RPE) provide a quantifiable indication of caffeine's effects on the CNS during exercise (32). RPE refers to the subject's

perception of the level of intensity during a bout of exercise. Caffeine ingestion has been associated with a reduction in RPE or force sensation during exercise (25, 31). The reduction in RPE during exercise may be attributable to an increase in excitatory neurotransmitters, which leads to a decrease in the firing threshold of motorneurons (9). This threshold decrease would lead to greater motor unit recruitment for a given exercise bout, which would result in lowered afferent feedback from the working muscle and a lowered RPE (32).

Caffeine may also inhibit pain sensation associated with sustained isometric contraction (25). Plaskett and Cafarelli (31) examined caffeine's effect on 15 male subjects' ability to perform repeated submaximal isometric quadriceps contractions, 60 minutes after a caffeine dose of 6 mg kg^{-1} (mean body weight = 77.1 kg, mean caffeine dose = 462.6 mg). Subjects performed repeated submaximal (50% maximal voluntary contraction) isometric contractions of the right quadriceps to the limit of endurance. They observed a mean increase of 17% in endurance time after caffeine ingestion using electromyography (EMG). The investigators also performed a separate experiment with the same subjects to determine whether or not caffeine affected force sensation during a 100-second isometric contraction of the quadriceps. They found that caffeine reduced force sensation during the first 10-20 seconds of muscle contraction. In addition, they found that the activation of motor units was maintained at near-maximal levels for a longer period with caffeine, indicating a willingness to prolong endurance.

Augmentation of Muscle Contractility. Another proposed explanation of caffeine's ergogenic effect deals with muscle contractility and ion handling in muscle

cells. Increased calcium release by the sarcoplasmic reticulum during later stage of exercise and increased Na-K^+ ATPase activity may account for the observed effects caffeine has on muscle contractility (28, 32). This section will examine the bases for these explanations.

Caffeine's direct effect on muscle tissue may be attributed to three factors: 1) a more rapid release of calcium ions from the sarcoplasmic reticulum; 2) enhancement of troponin/myosin calcium sensitivity; and 3) a decrease in the rate of calcium ion uptake in the sarcoplasmic reticulum (32).

In one study, Tarnopolsky and Cupido (34) found that caffeine caused a potentiation of contraction force during low frequency (20 Hz) muscle stimulation following a caffeine dose of 6 mg kg^{-1}. They administered a 2 minute tetanic stimulation of the common peroneal nerve on 12 male subjects in order to measure voluntary contraction strength and peak twitch torque. A higher tetanic torque was measured in the caffeine group at 60, 90, and 120 seconds during a 20 Hz tetanic contraction. The authors asserted that the ergogenic effect of caffeine was at least partially attributable to a direct effect on skeletal muscle.

A change in the release of sarcoplasmic calcium following caffeine ingestion appears to be the main factor involved in the increased contractility of skeletal muscle (36). After caffeine is consumed, it rapidly reaches muscle fibers and causes the release of calcium into the muscle myoplasm. With high caffeine doses, the release of sarcoplasmic calcium is sufficient to directly initiate a mechanical response (36). Thus, high concentrations of caffeine can cause a spontaneous muscle contraction and tension in the muscle develops without membrane depolarization (36).

Caffeine may aid in the regulation of plasma and intracellular potassium (K^+) by stimulating the Na-K^+ pump activity in skeletal muscle and other tissues. Lindinger et al. (28) found that increased levels of epinephrine found in the plasma following caffeine ingestion could provide stimulation of the Na-K^+ pump activity. Caffeine increases the rate of K^+ uptake, thus the rise in plasma K^+ levels during exercise is attenuated.

Evidence has supported each of these explanations regarding the ergogenic effect of caffeine. Graham (17) purposed that it is likely that caffeine acts through several mechanisms and that the different responses may come into play in different situations.

Caffeine and Exercise

Aerobic Studies. Costill et al. (12) performed early studies on caffeine's effect on cycling endurance in the 1970s, finding that caffeine improved cycling time to exhaustion considerably at 80% VO_2 max. Since then, numerous studies have found that caffeine ingestion prior to (3, 6, 13, 17, 29) and during (11) low-intensity, long duration exercise enhances performance and time to exhaustion. Results of the studies investigating caffeine's effect on aerobic performance have been more consistent than those investigating caffeine's effect on anaerobic or high-intensity exercise.

Since caffeine is most commonly consumed in the form of coffee, Graham et al. (19) compared the effects of coffee and pure caffeine ingestion on endurance exercise performance. They administered five treatments to 9 subjects: 1.) placebo

capsule with water; 2.) caffeine capsules (4.45 mg kg^{-1}) with water; 3.) regular coffee (4.45 mg kg^{-1}); 4.) decaffeinated coffee; or 5.) decaffeinated coffee plus caffeine (4.45 mg kg^{-1}). The subjects (mean body weight = 73.1 kg, mean caffeine dose = 325.3 mg) then ran on a treadmill at a speed and slope calculated to require 85% VO_2 max until exhaustion. Caffeine capsule ingestion resulted in a significant increase in endurance time of 7.5-10 min. compared to the other trials. There was no difference in time to exhaustion among the three coffee groups or the placebo group. It appears that an endurance enhancement occurred only when caffeine was ingested independent of coffee. The authors suggest that some component(s) in coffee may interfere with the normal ergogenic response of caffeine.

To examine the ideal timing of caffeine consumption for performance-enhancing purposes, Cox et al. (13) designed a study that considered the impact of the timing of caffeine consumption on exercise. They measured 20 highly-trained cyclists (mean body weight = 76.7 kg) in a time trial (7 kJ kg^{-1}) at the end of a 120-minute cycling bout. Subjects received one of the following treatments: 1.) a caffeine dose (6 mg kg^{-1}, mean caffeine dose = 460.2 mg) 1 hour prior to exercise, and placebo every 20 minutes during exercise (precaf); 2.) placebo prior to exercise and six caffeine doses (1 mg kg^{-1}) every 20 minutes during exercise (durcaf); or 3.) placebo prior to exercise and placebo every 20 minutes during exercise (placebo). The precaf group recorded a 3.4% enhancement compared to the placebo group during the time trial (28:18 vs. 29:18). The durcaf group recorded a 3.1% enhancement compared to the placebo group (28:24 vs. 29:18). Thus, ingestion of a single caffeine dose prior to

exercise appeared to have a similar effect as ingesting the same amount of caffeine in divided doses throughout exercise.

Conway et al. (11) performed a similar study on 9 well-trained cyclists (mean body weight = 76.4 kg), giving one group a single caffeine dose (6 mg kg^{-1}, mean caffeine dose = 458.4 mg), one group two divided caffeine doses (3 mg kg^{-1} each, mean divided dose = 229.2 mg), and one group a placebo. Each subject received a placebo or caffeine dose both 60 minutes prior to exercise and 45 minutes into exercise. The subjects cycled for 90 minutes at 70% VO_2 max, then performed a time trial in which they completed a specified amount of work as quickly as possible. There was no significant difference between the single-dose and divided-dose caffeine groups, and both of the caffeine groups recorded faster times in the time trial than the placebo group (23.8 min. for the caffeine group, 28.3 min. for the placebo group).

In addition, Conway et al. (11) also examined the caffeine concentration in the subjects' urine after the completion of the exercise bouts. Urinary caffeine level was nearly twice as high in the single-dose group (6.89 ug ml^{-1}) as it was in the divided-dose group (3.82 ug ml^{-1}). This effect could present a "loophole" in the accurate determination of an athlete's caffeine intake if an athlete participates in an event that restricts caffeine concentrations in the body. Conway et al. suggest that larger caffeine doses that may ordinarily exceed limitations may fail to exceed these limitations if the dose was divided.

Anaerobic Studies. Epinephrine levels are increased significantly about one hour after caffeine consumption (20). Collomp et al. (10) noted that higher levels of blood catecholamines and lactates were found after caffeine ingestion. These caffeine-induced changes, they postulated, may modify anaerobic metabolism, leading to increased maximal power production. Collomp et al. (10) studied caffeine's effects on all-out 30-sec sprints on a cycle ergometer using 6 active adult subjects (mean body weight = 61.3 kg). The subjects performed the sprints on a Monark cycle ergometer with a load of .08 kg/kg body weight. The exercise was performed 1 hour after ingestion of a caffeine capsule (5 mg kg^{-1}, mean caffeine dose = 306.5 mg) or placebo capsule. Each subject performed the Wingate Test twice: once with caffeine, once with placebo. During the test, the subjects pedaled as fast as possible to maintain maximal speed throughout the 30-sec time period. During the cycling bouts, each subject's performance was measured by 3 indices of work: anaerobic power (the peak power performed during any 5-sec period); anaerobic capacity (the total work performed during the entire 30-sec cycling period); and power decrease (the difference between peak power and the lowest 5-sec power divided by the elapsed time). Collomp et al. found that caffeine failed to significantly improve physical performance during the Wingate cycling test for anaerobic power (615 W vs. 625 W, placebo vs. caffeine), anaerobic capacity (13,100 J vs. 13,390 J), or power decrease (13.8 W/s vs. 14.65 W/s). They found that caffeine consumption led to an increase in catecholamine secretion and blood lactate concentration.

Collomp et al. offered possible explanations for the lack of performance enhancement despite the increase in catecholamine secretion. They postulated that

caffeine ingestion may increase hydrogen ion (H^+) and inorganic phosphate (P_i) accumulation, which could cancel the positive effects of the metabolic chain reaction induced by caffeine. They also stated that the subjects involved in this study lacked specific training for this particular activity, which could have mitigated the effects of caffeine.

In a similar study, Greer et al. (20) examined caffeine's effect on anaerobic power using four consecutive Wingate tests. In this study, nine healthy men (mean body weight = 82.2 kg) ingested either placebo (dextrose) or caffeine (6 mg kg^{-1}, mean caffeine dose = 493.2 mg) about 60 minutes prior to exercise. The subjects then performed four 30-second Wingate sprints with a load of .09 kg/kg body weight and with four minutes of rest between each bout. In a randomized, double-blind manner, they measured each subject's performance in three categories: average power, calculated as the average of six 5-second power outputs; peak power, or the highest 5-second power output during the 30-second test; and rate of power loss, calculated as (maximum power – minimum power)/30. They found that caffeine ingestion had no significant effect on peak power, average power, or the rate of power loss for any of the Wingate tests. The authors suggested that results may have varied had they used a higher caffeine dosage than the 6 mg kg^{-1} body mass that was used. In addition, they state cite subject training status as a possible contributing factor for their findings. The subjects involved in this study were recreationally active, but were not anaerobically trained athletes. Bell et al. (4) also examined the effect of caffeine on Wingate power production and found that their results were consistent with others (10, 20) that found no effect of caffeine on power production in untrained subjects.

Since running speed is an important aspect of many team sports, Paton et al. (30) studied caffeine's effect on repeated 20-meter sprints in 16 male team-sport athletes (mean body weight = 79 kg). The test consisted of 10 consecutive sprints, each performed within 10 seconds of each other. The authors found a statistically insignificant increase in sprint speed with caffeine ingestion (6 mg kg^{-1}, mean caffeine dose = 474 mg). They postulated that the true effect of caffeine on short-term, high-intensity exercise is a small enhancement which falls within the confidence intervals of the effect in their study (about 0.5%).

To help explain caffeine's apparent lack of effect on anaerobic exercise, Vergauwen (34) found that caffeine affected the carbohydrate metabolism of only slow-twitch muscle fibers during electrical muscle stimulation. Some researchers believe that adenosine receptors may exist only in slow-twitch muscle fibers; therefore, improvements in high-intensity exercise performance would not be expected with caffeine ingestion, as fast-twitch muscle fibers are responsible for the performance of anaerobic activities.

Other studies have found that caffeine exerts an ergogenic effect on anaerobic activities. In these studies, the training status of the subjects seems to be a key variable. To determine caffeine's effects on anaerobically trained athletes, Jacobson et al. (23) examined caffeine's effect on maximal strength and power in 20 male American football players at the Division I collegiate level (mean body weight = 101 kg). The subjects were tested on the Cybex II Dynamometer for knee extension and flexion peak torque (Joules) and power (Watts) before and after ingestion of caffeine (7 mg kg^{-1}, mean caffeine dose = 707 mg) or placebo. The authors found a significant

increase in knee extension torque in the post-caffeine trial over the pre-caffeine trial (325.4 vs. 292.4 J) at an angular velocity of $30^{o}s^{-1}$. In addition, they found a significant increase in knee extension power with caffeine over placebo (633.6 vs. 597 W) at an angular velocity of $300^{o}s^{-1}$. Jacobson et al. offered subject training status as a possible explanation for their findings. Since the subjects were experienced anaerobic athletes, Jacobson et al. suggested that the subjects' acquaintance with resistance training could have enhanced the ability to exert maximal effort in each trial. Also, the subjects involved were made to abstain from caffeine for one week leading up to the test, which represents a greater abstinence period than subjects in other studies.

Also using experienced athletes, Bruce et al. (7) investigated caffeine's role in the performance of 2000-meter rowing in eight well-trained male rowers. Each subject completed a random order of three experimental trials of a 2000-m rowing test on an air-braked ergometer one hour following ingestion of a low-caffeine dose ($6\ mg\,kg^{-1}$), a high-caffeine dose ($9\ mg\,kg^{-1}$), or placebo. Compared to placebo, the lower dose of caffeine resulted in a 1.3% improvement in time to complete the 2000-m time trial, while the higher dose resulted in a 1% improvement over the placebo trials. These improvements are likely to be worthwhile to competitive rowers. Like Jacobson, the authors of this study attributed these results to the training status of the subjects. They suggested that well-trained subjects are likely to perform the exercise bouts more reliably than untrained subjects participating in a new type of activity. Additionally, the authors noted that highly trained athletes have genetic endowment

and training history that could yield different effects on performance with caffeine supplementation when compared to untrained or moderately-trained individuals.

More research in the area of caffeine's effect on anaerobic activity is warranted due to the inconsistencies of previous studies. It appears to be likely that subject training status is an important factor involved in caffeine's role in anaerobic performance. This suggests that athletes may find that caffeine could provide a performance enhancement when performing movements or exercises with which they are familiar.

Caffeine's Impact on Agility

Little research exists regarding caffeine's effects on the performance of athletic activities that require quick reactions and rapid movements. Evidence suggests that caffeine could enhance reaction time and movement time (22), but little is known about caffeine's impact on these types of factors from an athletic standpoint, such as agility.

In most team sports, movement patterns that require agility and change-of-direction abilities are essential. An athlete's quickness is often evaluated as an indicator of overall ability in a given sport. The National Football League (NFL), for example, holds a prospect combine prior to its amateur draft each year, where prospective players gather and perform a series of athletic tests. Among these tests is a pro shuttle run, which is used as a tool to measure an athlete's agility. This is

considered one of the most important tests the prospects perform, as quick reactions and fluid direction-changing abilities are vital to success in a game situation.

A basic component of agility is the ability to react and move quickly. Jacobson and Edgley (22) examined the effects of caffeine on reaction time and movement time in 30 subjects (19 male, 11 female). They randomly assigned subjects to three groups: two experimental groups, one receiving 300 mg of caffeine and the other receiving 600 mg, and a placebo group. Pre- and post-tests for reaction time and movement time were measured using a specially designed chair with a mounted breaker switch. The subject began the test with the right hand in contact with this breaker switch. When a visual cue, which was a bright light placed directly in front of him/her, was given, the subject was to abduct his/her shoulder until the hand crossed a photoelectric beam. The reaction time component of this test was measured as the time interval from the initiation of the light stimulus to the initial movement of the hand off the switch. Movement time was calculated by measuring the interval between the hand's movement off of the breaker switch to the hand crossing the photoelectric beam. They found a significant improvement in reaction time in the 300 mg group (273.2 ms vs. 240.2 ms, pre-test vs. post-test), while the 600 mg group and placebo group resulted in no significant changes. Additionally, the 300 mg group also showed significant movement time improvement (225.3 ms vs. 209.9 ms, pre-test vs. post-test), while the other groups showed no significant differences between pre- and post-test trials. The authors concluded that somewhere between the 300-600 mg range of consumed caffeine, the neuromuscular response time is attenuated.

Williams stated that it is widely accepted that caffeine dosages between 100-300 mg have positive impacts on reaction time and movement time (36). This suggests that caffeine could improve performance in activities that require agility and quick reactions. Such activities are essential in team sports such as football, basketball, baseball, soccer and volleyball. More research in this area is necessary before conclusions can be drawn about caffeine's impact on agility and quickness.

Activities such as a pro shuttle run are short-duration, high-intensity movements. Some research suggests that anaerobic activities may be enhanced by the use of caffeine (7, 23). Other studies suggest that reaction time and movement time, key factors in the measure of a subject's agility, may be improved with the supplementation of caffeine (36). Research on caffeine's effect on agility sprinting is therefore warranted, as the current literature lacks sufficient data in this arena.

Conclusion

Caffeine is a rare substance in that it is believed to exert an ergogenic effect and it remains legal according to every major sports organization. Due to its availability, popularity, and potential performance-enhancement qualities, caffeine is a substance that should be studied thoroughly. As athletics have become such an important part of our society from a social and economic standpoint, substances that are believed to enhance athletic performance will be highly sought-after and widely used. While many previous caffeine studies have provided a good deal of information

about this substance, questions remain as to the full extent of caffeine's ergogenic potential.

APPENDIX B

Informed Consent for Participating in a Research Study

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1. **Testing Objectives and Purpose**. I have been invited to participate in a study investigating the effects of caffeine on athletic agility. The purpose of this investigation is to determine whether an acute caffeine dose enhances performance in a shuttle run, which is a sprint that involves quickly changing directions. The study is being conducted by, Andrew Lorino, a graduate student at Texas State University-San Marcos, in the Health, Physical Education, and Recreation Department. He is performing this study to fulfill his master's thesis requirement. I have been selected as a possible participant in this study because my physical fitness and wellness (PFW) class was chosen to be the experimental class. I will be one of 17 students chosen to participate in this study.

2. **Explanation of Procedures.** If I decide to participate, I will complete the following on the first day of testing: a) a health history questionnaire; and b) body size and composition measurements. For one week prior to testing, I will practice the pro-agility test and the Wingate cycle ergometer test during my PE class. After practicing this activity, I will be required to perform the agility tests without any supplementation. Within the next 7 days, I will repeat the agility tests after ingesting either caffeine (6 $mg\,kg^{-1}$) or placebo.

3. **Description of Potential Risks**. I understand that caffeine is associated with certain side effects and risks. Side effects include restlessness, anxiety, and sleeplessness. Although caffeine can be lethal to humans in doses of 10g or more; I understand that I will receive a much lower dose, a dose similar to consumption of 3 - 6 cups of coffee. Every effort will be made to minimize these risks by evaluation and preliminary information relating to my health and fitness and by careful observations during and after testing. In addition, emergency equipment is located nearby in the athletic training offices and is available at all times.

4. **Benefits to be Expected.** Although there will be no direct benefit from the research, I understand that the results will aid in determining my weight status, as well as in determining whether I am at risk for a chronic disease (such as cardiovascular disease, diabetes type II, and/or osteoporosis).

5. **Responsibilities of the Participant.** I understand that I am responsible for fully disclosing my current health status and medical history, including any medications that I have taken today or recently. Any information that I possess about my health status or any previous experiences of heart-related symptoms (such as shortness of breath with low-level activity, pain, pressure, tightness, heaviness in the chest, neck, jaw, back and/or arms) with physical effort might affect the safety of my exercise test. In addition, I understand that I should report immediately any unusual feelings that I may experience during the exercise tests. Finally, I understand that I MUST ABSTAIN from caffeine intake for 48 hours prior to all testing.

6. **Confidentiality.** It is my understanding that any information that is obtained in connection with this study and that can be identified with me will remain confidential and will be disclosed only with my permission. However, I am in agreement, that the information from these tests not identifiable to me can be used for research purposes. The data collected for this research will be kept for approximately one year in a file cabinet located in a locked closet in the Human Performance Lab accessible only by the primary investigator and the lab coordinator.

If I have any additional questions later, I may contact Andrew Lorino, (512) 470-7372, or the chair of my thesis, Dr. Lisa Lloyd, (512) 245-8358. I also understand that I am free to deny answering any questions during the evaluation process or to withdraw consent and discontinue participating in any procedures. Finally, my decision whether or not to participate in this study will not prejudice my future relations with Texas State University or with Andrew Lorino.

I have read this form, and I understand the test procedures, risks, and benefits of the study that I am about to participate in. Knowing these risks and having had an opportunity to ask questions that have been answered to my satisfaction, my signature indicates my consent to participate in this study.

_____ _____

Signature of Participant Date

_____ _____

Signature of Witness Date

_____ _____

Signature of Investigator Date

APPENDIX C

CAFFEINE QUESTIONNAIRE

Name _____

1.) On average, how much coffee/tea do you consume?

a.) more than 3 cups per day
b.) 1-2 cups per day
c.) 2-4 cups per week
d.) don't drink coffee/tea

2.) On average, how much caffeinated soda do you drink per wee?

a.) more than 4 11.5-oz. cans per day
b.) 1-3 cans per day
c.) 2-4 cans per week
d.) don't drink caffeinated soda

3.) Do you use supplements that contain caffeine?

a.) Yes
b.) No
c.) Don't know

If so, how often? _____

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VITA

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