The Report committee for Michael Travis Brenneman certifies that this is the approved version of the following report:

# TRAINING FOR MUSCULAR POWER ADAPTATIONS: THE ROLE OF CONTRACTION TYPE AND VELOCITY

**APPROVED BY**

**SUPERVISING COMMITTEE:**

Supervisor: ________________________________

Edward F. Coyle

________________________________

Roger P. Farrar

# TRAINING FOR MUSCULAR POWER ADAPTATIONS: THE ROLE OF CONTRACTION TYPE AND VELOCITY

by

Michael Travis Brenneman, B.S.

Report

Presented to the Faculty of the Graduate School of
The University of Texas at Austin
in Partial Fulfillment
of the Requirements
for the Degree of

**Master of Science in Kinesiology**

The University of Texas at Austin

May 2016

# ACKNOWLEDGMENTS

I would like to thank Dr. Edward Coyle for his mentorship, guidance, and support during my time in the Human Performance Lab. His reputation is beyond reproach and the fact he believed in me enough to allow me to work under him is a great honor. I would also like to thank Dr. Roger Farrar for taking the time to offer his expertise, feedback, and advice. I would especially like to thank Dr. Donovan Fogt for planting the initial seeds of interest and desire in studying physiology. Additionally, I'd like to thank the members of the Human Performance Lab: Brian, Ting, and Dongwoo as senior members for their leadership and assistance in teaching the techniques and skills necessary to perform competently in the lab as well as broadening my knowledge in physiology; Jake, Luke, and Heath for their support and camaraderie as we all went through this experience together; John and Kiki for their support and always being willing to help when needed.

# ABSTRACT

# TRAINING FOR MUSCULAR POWER ADAPTATIONS: THE ROLE OF CONTRACTION TYPE AND VELOCITY

by

Michael Travis Brenneman, M.S.Kin

The University of Texas at Austin, 2016

SUPERVISOR: Edward F. Coyle

Muscular power, an integral component in most sport, is the product of force and velocity. Power is often viewed synonymously, yet incorrectly, with strength. Where power has an inherent speed component, strength is independent of movement velocity, and is a measure of a muscle's ability to produce a maximal force. In a majority of athletic events power is requisite to success, and is often more decisive in performance outcomes than strength alone. Currently, results from existing research examining the effectiveness of differing velocities of contraction in improving maximal power are mixed. Common methodologies used in research settings to study muscular power changes are isotonic training, isokinetic training, isometric training, and plyometric training. However, little research has been done examining the potential efficacy of training using inertial loading. This report examines existing research on movement velocities and loads, compares the effects of training velocities for increasing maximal power, identifies shortfalls and information gaps, and recommends future research in training for muscular power adaptations and improved athletic performance. This report also provides a detailed description of inertial load training and establishes a theoretical study design, hypothesis, and reasoning outlining why and how inertial load training may elicit muscular power increases and improved athletic performance.

## TABLE OF CONTENTS

# INTRODUCTION

## Background

Power is a product of force and velocity, and is highest at approximately 1/3 of maximal contraction velocity [22]. Power plays an important role in many sports and recreational activities. While the type of power required may be different, of course, depending on the sport or activity performed, and the physical demands therein, training for muscular power is an important aspect in virtually all athletic disciplines. Therefore it is no surprise that power has been studied using several different methodologies including varied velocities of contraction and varied percentages of a participant's one repetition maximum.

Power is often associated with strength. While the two variables can be interconnected they are independent performance measures. Often, and incorrectly, used interchangeably it is important to establish an understanding of the delineation between strength and power. From a performance perspective power can be viewed as the explosive nature of force production and carries with it a fundamental relationship with speed of movement [23]. Conversely, strength is a measure of force output and is associated with the ability of a muscle or muscle group to exert force to overcome a resistance independent of speed of contraction [55]. Upon further examination of the practical implications of these definitions one can understand that power is directly related to speed of movement or velocity of contraction and the resultant force. Thus, training for power is not synonymous with training for strength.

In most athletic events power is more decisive in performance than static strength or even instantaneous force such as seen during isokinetic contraction [32]. In other words, in a majority of athletic events it may be more important to examine how much power an athlete can exert over a given time, and at a performance dictated velocity, vice how much strength can be generated, with some exception. Since power is related to velocity, and due to the fact most sports do not simply require one constant velocity, it stands to reason that velocity of contraction and speed of movement are of great importance to athletes, coaches, trainers, and researchers examining human performance.

The goal of most training programs is improving performance whether for competition, personal fulfillment, or health and wellness. This includes, among other variables, increases in power at different velocities, and encompasses muscle fiber-type morphology, neural adaptations such as enhanced motor unit recruitment, and increased proficiency in technique execution. A driving principle in improving athletic performance is the principle of specificity of training which dictates that greater improvements are obtained when training patterns mimic performance patterns. As it relates to velocity, and when there exists a need for high power output, this principle further indicates velocity specific adaptations (and subsequent transference) may best be attained when training at velocities similar to the performance task. This should not be mistakenly inferred as solely "fast" training. When focusing on performance specificity it may seem intuitive to an athletic population to train at fast velocities, but consider a rehabilitative setting, where muscular imbalance in speed and inter-limb power exist, or an elderly population in which a desired result is related to health and quality of life, and it is clear fast velocities may not be essential for performance.

There are three major modes of strength training: isometric, isokinetic, and isotonic [12]. More recently research on plyometric training has also examined muscular power adaptations. Numerous studies have examined training at various velocities and the resultant impact on, among other variables, power generation. The majority of these studies involve the use of isokinetic dynamometry with set contraction speeds using maximal voluntary contraction (MVC). Other studies have examined and compared isokinetic training to isotonic training, plyometric training, and isometric training.

The results thus far have been mixed and remain somewhat unclear. Earlier findings have shown training at a higher velocity using isokinetic contractions can lead to power improvements at higher velocities as well as lower velocities. [13, 19] However, training at lower velocities has been shown to improve power only at lower velocity movements [36, 13]. Previous studies have utilized various methods to measure maximal power output as well as to conduct training in an effort to identify the ideal methods by which to improve maximal power output. Some studies have examined both slow and fast isokinetic contractions independent of each other, as well as mixed (slow and fast) isokinetic contractions during the same training protocol [13]. Studies have also varied the duration of training in regards to sets, repetitions, and overall lengths of training protocols [45]. However, these studies have not investigated the use of inertial load training, which consists of mixed velocity and mixed force during single bouts of short-burst exercise conducted at maximal effort.

## Purpose

The purpose of this report is to examine the existing literature reviewing the methods and results of training studies meant to induce muscular power changes. Common protocols used in research settings for analyzing muscular power include isotonic, isometric, isokinetic, and, to a lesser extent, plyometric training. The majority of research has examined isokinetic contractions using various speeds of movement. However, there is limited research examining muscular power adaptations in response to inertial loading. Inertial loading is accomplished by acceleration of an unloaded, unbraked flywheel. As force is applied and the flywheel accelerates, the amount of force necessary to maintain velocity is decreased until such time as maximal velocity is reached under minimal force. Using the inertial loading method, power output can be calculated by measuring the relationships between angular acceleration, angular velocity and torque production when inertia of the flywheel is known [39].

This report will identify shortfalls and information gaps in the existing literature and suggest and describe potential methods to be used in examining the potential efficacy of using inertial load training to increase muscular power output and improve athletic performance, while describing the possible physiological mechanisms supporting the veracity of the recommendations.

Examining the effect of inertial load training on muscular power changes is important due to the fact it is the only method which utilizes mixed force / mixed velocity contractions in a single four second bout at maximal effort. Inertial loading is reliable in eliciting, and accurate in measuring, maximal power [39]. Improvements in power output can result from both physiological as well as neurological adaptations to the various training stimuli. To date no studies have been done on muscular power changes using this type of training. It is theorized this form of training may provide the most robust stimulation of the nervous system as well as the muscle itself. Therefore, another purpose of this report is to describe a theoretical study which would be suitable in investigating the effectiveness of inertial load training for increasing maximal power using only an inertial loaded cycle ergometer.

## Hypothesis and Reasoning

We hypothesize the use of inertial load training that would be utilized in this theoretical study design would improve maximal power output, as well as athletic performance markers, over a theoretical eight week study protocol more than previous training methods reported in the literature. Additionally we hypothesize there would be a an attenuation in percent of leg power imbalances over the course of the protocol. This hypothesis is supported by a number of physiological factors. First, inertial load training uniquely allows for the development of high force output under low velocity contractions in the first one to two seconds and an automatic transfer to low force output under high velocity contractions in the final two to three seconds. This transition is fluid and occurs naturally as a participant overcomes the inertia of the unloaded flywheel until traction can no longer be maintained under a free-spin condition. This potentially allows for a more robust pattern of motor unit recruitment encompassing both fast and slow twitch muscle fibers. Additionally, inertial load training allows for simultaneous and alternating use of each leg during each repetition which may possibly have an impact on muscular power imbalances between right and left legs over the duration of the study.

Inertial load training allows for dynamic recruitment and transition during one singular repetition at a naturally selected rate of speed and RPM; not one directed or imposed by outside factors such as would be seen in isokinetic training where the rate of movement is manipulated. However, inertial load training does have important similarities to isokinetic training in that each bout of inertial load training can be performed at maximal effort. In this way it is similar to isokinetic training, yet has the unique characteristic of allowing for these maximal efforts to be conducted at natural, self-selected velocities and corresponding RPM, which research indicates is indicative of muscle fiber type predominance [24]. This may potentially further the benefit in athletic performance as most athletic endeavors are also executed at self-selected velocities.

Additionally, a novel capability of a theoretical study such as this would be its ability to identify and measure musculoskeletal imbalances using the inertial loaded cycle ergometer. The ergometer has the unique ability to measure and record instantaneous power for individual legs and to instantly display any differences in muscle power output as a percent difference between the right and left leg. These data can be examined to identify any trends and/or changes over the course of the proposed study in percent difference between individual leg power, possibly indicating any potential efficacy of inertial load training in a rehabilitation setting or its use to minimize and/or correct muscular power changes between legs. We hypothesize a decrease in percent difference between inter-leg power would occur over the course of the theoretical study.

# REVIEW OF LITERATURE

## Isotonic Training: Overview, Methods, and Results

Isotonic training is movement conducted at a constant external tension during shortening or lengthening [49]. Examples of isotonic contractions include lifting weights, and a great percentage of isotonic contractions occur in the sagittal plane of motion. Isotonic contractions consist of both concentric and eccentric components, and is typically the most popular type of training for strength and power in the athletic “real-world” training environment., although it is not as commonly studied in research lab environments. The three most common types of stimuli associated with isotonic contractions, and thus the most commonly investigated, as related to power include: high force, low velocity such as seen in power lifters; high force, high velocity, such as seen in Olympic lifters; and low force, high velocity such as seen in sprinters [41]. Research indicates of these three variants, contractions utilizing high force with high velocity typically produce greater gains in strength and power [20, 49]. This is understandable when applying the principle of specificity of training and remembering that power is in inherently related to speed of movement, and also why research suggests Olympic weightlifters possess more peak power than their powerlifting counterparts [49].

It is important to note there is a point at which high velocity seems to have a diminishing return effect on improvements in muscular power. Fenn (1935) found a muscle produces less force as speed of shortening is increased during concentric contraction. This corroborates the force-velocity relationship established by Hill, (1922) which showed peak power occurs at ~33% maximum contraction velocity. Above and below this speed, power declines to a rate of zero at 100% and 0% of maximum velocity in a parabolic curve. This of course is due to power being a product of force and velocity. This is specifically a key factor when utilizing isotonic training due to the fact the resistant load is held constant and only the speed of movement may be altered, depending on the performance task and the goal of the training itself.

Improvements in performance resulting from isotonic training summate from a combination of: early phase neural adaptations in motor unit recruitment [51]; early to mid-phase learning patterns regarding technique [34]; and late phase morphological changes such as hypertrophy [29]. Studies show improvements in strength, power, and torque in as little as two days with no changes in muscle morphology further substantiating that initial adaptations are indeed neural [18, 51]. Corroborating research suggests changes in muscle morphology occur later in a training program [29]. Most studies examining training protocols lasting fewer than six to eight weeks have noticed minimal, if any, fiber phenotype changes or increases in fiber size [49, 36, 56, 34, 2). Conversely, studies lasting longer than eight weeks have been shown to elicit these changes [13, 57, 29]. When compared to training at maximum velocity with no load, isotonic training has been shown to elicit greater gains in strength and muscle power [59]. These results have been corroborated when examining velocity specific training with constant loads as is commonly the case during resistance training [16].

## Isometric Training: Overview, Methods, and Results

Isometric training is defined as increased tension of the muscle without actual shortening (or lengthening) of the muscle fiber(s) as seen in typical eccentric and/or concentric contractions [57]. There is some argument as to the validity of this terminology of whether or not an isometric contraction is indeed an actual “contraction” in terms of physiology, since there is no change in the length of the sarcomere. There is, however, the activation of tension-generating mechanisms within the muscle fibers. Due to this tension being produced without sarcomere shortening, and since the term “isometric contraction” is a commonly accepted label, the terminology is used in this report.

Isometric contractions are commonly utilized as the predominant method of muscle contraction in research settings concerning pathophysiology and conditions including hypertension, cardiovascular disease (CVD), and diabetes among other acute and chronic pathologic conditions [50]. In cases such as these, isometric contractions are commonly paired with occlusion or post-exercise muscle ischemia (PEMI) and are thus used to examine autonomic responses such as the exercise pressor reflex [62] or other responses potentially impacting blood flow, blood pressure, or cardiac response. In these types of studies, isometric contractions are graded depending on percentage of MVC and/or time of contraction. Typically, the longer the contraction will be sustained the lower the percent MVC.

When examined in athletic situations, and/or used as measures of performance, isometric contractions are rarely used alone but in conjunction with (and in comparison to) isotonic contractions [42, 59]. Studies examining the combination of isotonic and isometric contractions have utilized high load / high velocity movements combined with low load / low velocity movements in isotonic contractions and compared these to percentages of MVC in isometric contractions. Understandably, percentages of MVC are typically significantly higher when utilizing isometric training for athletic purposes than those utilizing in rehabilitation studies [16]. It is commonly accepted that training modalities utilizing solely isometric contractions are inferior to isotonic as well as isokinetic contractions in eliciting maximal improvements in performance and maximal improvements in overall muscular power [25, 27, 49, 34, 45]

Some results of studies comparing isotonic, isometric, and isokinetic contractions suggest isometric training at maximum strength (100% $F_{max}$) may be a more effective form of training to increase power than training with zero load at maximum velocity [59] This adheres to the theory presented by Hill (1925) regarding the force-velocity relationship, and the resultant disappearance of power (and force) as velocity reaches maximum. At maximum velocity there can be no power generated because at maximum velocity there is no generated force Conversely, and because of this, in order to attain maximum velocity there can be no resistance (mass). This makes sense when understanding the relationship between power, force, and velocity, and between force, mass, and acceleration [47]. This also indirectly corroborates the theory that isokinetic training is superior to isometric training when it concerns athletic performance. Isometric training at 100% $F_{max}$ is, for the sake of practicality, little more than an isokinetic contraction at zero velocity. Since velocity plays such an important role in the nature and mechanisms of muscular power improvement it only makes sense to vary velocity during different training movements, ideally dependent upon the nature of the desired outcome(s), versus producing static contractions with no speed of movement, even if said contractions are at or near MVC over a long time domain.

## Isokinetic Training: Overview, Methods, and Results

Isokinetic training is defined as contraction(s), either eccentric, concentric, or both, conducted at a fixed and constant velocity [49]. These components are studied together or isolated and analyzed individually. Isokinetic training in research settings is typically done using "slow" (~24 to ~96 degrees per second) and/or "fast" (~240 to ~300 degrees per second) velocities of contraction during knee extension. Therefore, most studies divide participants into two groups: a slow group; and a fast group. A few studies have examined groups using a combination of slow and fast contractions but at different time points and not mixed together during singular bouts of exercise. Additionally, some studies have included and analyzed responses in groups who train at what is deemed an "intermediate" velocity (~180 degrees per second) and the resultant effects [13, 32, 19, 35]. In the cases of mixed training and intermediate contractions, workload is typically normalized such that overall amount of work is the same.

The purpose of studies such as these is to examine the effects of isokinetic training at one velocity on performance measures at a different velocity. For instance, in a simplified approach, will sprinting make an athlete better at jogging during a prolonged even such as a marathon, in terms movement patterns? Perhaps in a more tangible example, will slow deliberate front squats make an Olympic weightlifter better at executing a very quick, explosive clean? Isokinetic training has, in some cases, been shown to be superior to both isotonic and isometric training in producing gains in strength, power, torque, and force [57, 49]. This makes sense when considering velocity of movement is directly influenced by the load to be moved, coupled with the stretch / shorten cycle found in eccentric / concentric coupling, and the subsequent absence of this velocity in isometric contractions. In one study, isokinetic training has also been shown to have a greater enhancement on strength, anthropomorphic measurements, and motor performance compared to isotonic training [49].

There is a significant amount of research involving the use of isokinetic contractions and the resultant effects on performance. It may be the preferred method of training in research settings due to the nature of control of velocity of contraction coupled with the fact that practically all isokinetic training is conducted at 100% MVC and maximal effort. This allows for a perfect analysis of the independent variables of percent contraction and range of motion and the dependent variable of contraction speed.

Due to the large amount of studies examining isokinetic training, it is understandable there are contradicting findings regarding how various contraction velocities affect performance improvements, and transference between training velocities and testing velocities. Some studies indicate training at fast velocities allows for gains at both fast and slow testing velocities [44,10, 36, 13, 58]. Conversely, other studies show training at specific velocities only allow for gains at that specific velocity [10, 57, 21, 19].

Isokinetic training effects have been examined from both short, medium, and long term adaptations. Short term and medium duration studies include those examining training adaptations in as little as two days [34, 51], up to two weeks [2], and six weeks [36]. These studies showed varied ranges of increases in peak torque and peak power as well as reduced fatigability in the case of Lesmes (1978). One study consisting of two weeks of training showed an increase in strength, power, and force with no change in muscle size or enzymatic activity [2]. These results indicate the changes may be due to muscle contractility and neural adaptations. Prevost (1999) looked at two days of training and found the initial improvements were only present in the fast-velocity training group, further indicating the results are neural  adaptations, specific to a fast training velocity. This is further corroborated by the lack of hypertrophy and other morphological and enzymatic responses. Had muscle morphology been a factor one would expect to see a performance increase at all testing speeds (slow and fast). Studies examining long term adaptations (eight weeks and above) showed changes in muscle morphology including type II fiber hypertrophy in addition to the supposed neural adaptations [49, 13, 56].

In addition to examining the differences in duration, several studies have compared contraction speed. In one study the combined effects of duration and speed were in line with previous results suggesting fast contraction speeds showed enhanced power only at the faster, but not at the slower, velocities [32]. In this same study the slow only training group showed performance increases at all test speeds. This study was in contrast to an earlier study examining high power and low power isokinetic training. The low power (low speed, low load) group produced increases in muscular force only at the low speed. The high power (high speed, low load) group produced increases in muscular force at all speeds of contraction [44]. Differences in what constituted “fast” in these studies may have been a factor in the disputed results.

Confounding the issue even more, some studies have found increasing the overall speed at which work was performed was as effective at improving performance as was altering the load or resistance [25]. This gives rise to the notion that as long as overall work rates remain the same improvement should be seen at different rates of contractions. Another study related to work rate and constant speed of contraction examined short duration / high intensity training using different time intervals [36]. This study ensured overall work rate was the same by altering the number of contractions. The results, including increases in peak torque and peak power, indicated velocity (intensity) may have more to do with improvements than how long the contraction takes (volume). This gives credence to the ideas regarding training principles and the principle of overload, which includes both volume and intensity, whereby you can alter volume (in this case contraction time), as long as intensity (in this case velocity) remains high, you will still show improvements. This is part of the basis of the theory of periodized training, altering volume and intensity at certain time points in a training cycle [40].

In an effort to delineate the speed issue and the resultant improvements of “fast” and “slow” contraction group, Coyle (1981) looked at a mixed velocity training program. For three sets the group conducted fast (~300 degrees per second) contractions and for a subsequent three sets the group conducted slow (~60 degrees per second) contractions. This was one of the first studies to utilize a mixed group in conjunction with a fast only and slow only group. Furthermore, this study also utilized an “intermediate” (~180 degrees per second) training group to examine possible effects. Results indicated the fast training group had the largest margin of overall improvement at all velocities. However, results also suggested the fast group was the only group to show significant muscle morphology with type II fiber hypertrophy. This may have been a causative factor, leaving the neurological component unanswered. One later study, which contradicted the former, showed a slow contraction group had the greatest improvements at different testing speeds [19]. One difference between the studies was the fast group in the latter study exercised at over 400 degrees per second compared with 300 degrees per second in the former.

Regardless of the potential differences and discrepancies in cross-over enhancement between various speeds, the overriding principle of specificity holds true. In all the referenced studies utilizing isokinetic contractions, participants had the greatest improvements at the specific training velocities. The groups who trained at “fast” velocities improved more at the higher testing velocity than did the “slow” contraction group. The reciprocal is also true with the participants training at “slow” velocities improving performance more at slow testing velocities than the fast-trained. One thing which should not be overlooked in isokinetic training is recovery. While fast contraction velocities may bring about greater improvements in strength and power, they have also been shown to require more recovery time, and that when adequate recovery is not attained, there is a subsequent decrease in performance [30].

## Plyometric Training: Overview, Methods, and Results

More recently, research has examined plyometric training and its effects on muscular power and strength adaptations. Plyometric training, while not as heavily studied as isokinetic or isometric training, has been in use in athletic training for several years and was initially created by Russian Scientist Yuri Verkhoshansky and has become synonymous with jump training [61,11]. Although not inherently dangerous, due to the explosive and intense nature of the ballistic and dynamic style jumps, plyometric training is more apt to be studied in athletic vice clinical populations such that you may see in isotonic, isometric, and isokinetic training.

Plyometric training, as mentioned is centered around jumping. This can include box jumps, depth jumps, squat hops, maximal vertical jumps, or any other jumping movement. However, plyometric training does involve more than just jumping as well [63, 64]. One of the more common and popular types of plyometric training is the depth jump. Plyometric training is unique in that it contains an eccentric, isometric, and concentric component within a singular repetition. Additionally, plyometric training relies heavily on time of execution for success in improved power and performance [43]. The landing portion places a heavy eccentric load on hips, knees, and ankles, while isometric contractions occur at the landing to stop and stabilize the involved muscles to prepare for the concentric return jump. Time of execution is crucial for plyometric training success similar to other training methods, because, of the relationship of force, mass, and acceleration, already established. The less time it takes to transition from eccentric landing to the concentric jumping, the greater the amount of force produced. In other words, athletes should focusing on hitting the ground and returning to the air as quickly as possible, taking full advantage of the stretch-shortening cycle of contraction.

Most studies examining the effects of plyometric training due so on acute markers of performance, reaction forces, fatigue, and muscle soreness and damage. Fewer studies have examined the potential chronic effects of plyometric training on peak power and other muscular adaptations. Some of these former studies suggest that an acute bout of intense plyometric exercise induce time-dependent changes in performance [6]. Additionally, other studies indicate that plyometric training, in accordance with the principle of specificity of training, has its greatest effects in vertical jump height and power with less impact on overall peak power and other improved athletic performance markers [15, 28].

Thus it seems that plyometric training may indeed improve power and performance, but these improvements appear to be limited to those movement patterns and time domains that closely mimic training patterns. This leads credence to the theories that jumping is a specific skill and as such will have little transference to other movement patterns that require power, force, and variances in times of execution.

# METHODS

## Proposed Participants

The target participants for a proposed study of this nature examining the effect of inertial load training on muscular power changes would consist of a sample size of at least eight healthy, untrained college-aged males and females. The target participants would likely be aged 18-34, who will be nominally classified as active, but who are not currently participating in any prescribed or programmed exercise regimen(s). In a study of this design, exclusion criteria would likely be based on ages older than 34 and younger than 18, and individuals who are currently involved in a programmed or prescribed exercise regimen, as well as individuals currently under the care of a physician who advises against participation or participants currently undergoing any treatment(s) or rehabilitation for musculoskeletal injuries for which a study of this design would be contraindicated.

## Theoretical Study Design

This theoretical study would consist of an eight week training protocol in which participants would be asked to report to the lab three times per week for the inertial load training. At the initial visit, and upon completion of consent, health questionnaire, and descriptions of the protocol, participant height and weight would be obtained, and initial fitting of the seat height, pedals, handlebar positioning would occur along with familiarization and two "practice" sessions on the inertial load cycle ergometer.

Proposed initial baseline measurements of accepted peak and anaerobic power tests would include a standard Wingate Anaerobic Power Test, the Margaria-Kalamen Power Test, and the vertical jump power test. In addition to the proposed measures of power, athletic performance measures would also be taken and would consist of a timed 20-yd dash and a measured distance of horizontal standing broad jump. All baseline measurements would occur during the initial visit.

The actual inertial load training would theoretically have participants perform five sets of inertial load cycling per visit, all of which would be conducted at maximal effort. Upon each arrival to the laboratory, participants weight will be collected to normalize power per kilogram. Each "set" will consist of four bouts of maximal acceleration lasting approximately four seconds. Each "bout" will be separated by 90 seconds of resting recovery and each subsequent "set" will be separated by two minutes resting recovery, which is in accordance to accepted timelines of adenosine triphosphate (ATP) replenishment [4]. Each visit would thus consist of 20 overall maximal effort bouts on the inertial load cycle ergometer.

During the fourth (midpoint) and eighth (final) week of testing, proposed participants would again undergo the initial measurements of power and athletic performance as mentioned above. During these weeks there will be two training sessions instead of three with the third allotted session to be used for the performance markers. Each proposed training session would subsequently take approximately 30 minutes, with the initial, midpoint, and end of study assessments taking approximately 60 minutes.

## Proposed Measurements

The independent variables for this theoretical research study would be the participants themselves, as well as the training protocol as described above. That is to say, the proposed participants would act as their own controls, measuring the changes between the initial, midpoint, and endpoint power and performance markers, as well as the changes in peak power from session to session over the duration of the eight week study. These measurements would be analyzed collectively as percent changes within the group.

The dependent variables then would be the initial, midpoint, and endpoint measurements themselves of maximal power from the Wingate, Margaria-Kalamen, and vertical jump test, as well the athletic performance markers as reflected by the standing broad jump and 20 yard dash.

## Proposed Statistical Analysis

Proposed analysis for this theoretical study would include determining the collective percent changes in mean peak power from session to session over the course of the proposed eight week protocol. Mean peak power output from the first session to the last session would be analyzed using a one-tailed, paired, student's t-test, with an established significance of $p<0.05$. Values would be reported as mean +/- standard error of the mean (SEM) and reporting standard deviation.

Due to the fact that a directional change would be expected, and the possibility of results in a negative direction would be minimal in this theoretical study, a one tailed t-test is justified over a two-tailed test. Additionally, since each participant would train each session over the duration of the theoretical study a pairwise comparison would also be examined.

# CONCLUSION

In addition to the aforementioned training modalities discussed herein, one topic not directly discussed in this report, but which is becoming of more interest as of late, is intention and motivation. A few studies have examined a participant's intention as it relates to movement patterns. One such study presented data suggesting the principle for stimuli for high-velocity responses (neural) are the repeated attempts to perform these high-velocity contractions [5]. This has been corroborated by other research suggesting intentions to move rapidly may come into play even more than movements against heavy loads [53, 52, 14]. This is based on the premise that whenever maximum effort is used, independent of the load, motor unit activation patterns have been shown to be similar regardless of the external speed environment [53, 52, 14].. In other words, attempting, or intending to attempt, a high velocity contraction was enough to elicit gains in power compared to contractions when high velocity was actually attained.

Even less research has been done on inertial load training, which more uniquely and closely mimics an athlete's competitive training and competition environment. Inertial load training is similar to isokinetic training in that both modalities require maximal effort of contraction; however, the speed at this maximal effort may be very different between the two modalities, and inertial load training allows for more dynamic velocities of contraction over a given period of time. As mentioned, isokinetic training is often viewed as the preferred method of studying movement velocity and speed of muscular contraction due to the very nature velocity is held constant even during MVC.

However, isokinetic training still has its limitations. One such limitation is “machine based” isokinetic training usually involves only single-joint actions and thus fails to involve complex movements. Failure to examine the relationship between training velocity and performance velocity during athletic events is an evident downside of isokinetic training. As noted, typical velocities of isokinetic training range from “slow” to “intermediate” to “fast”. Even studies claiming to examine “fast” training velocities of up to 400 degrees per second are conducted at well below normal movement velocities seen in athletics [37]. This further corroborated by studies showing that un-resisted movement velocities of knee flexors reach up to 1000 degrees per second and hip angular velocities up to 500 degrees per second [38]. This was corroborated by a study examining the biomechanics of drop jumping in which researchers found contraction velocities of 880 degrees per second [8]. Compounding this is the fact that recorded RPM values at peak power output range from 600 degrees per second to well over 900 degrees per second and the necessity to study higher contraction velocities is apparent.

Given that angular velocities seen in sport are generally much higher than those utilized in current research training, it stands to reason a program utilizing these higher velocities may lead to performance increases not seen in traditional training modalities as it relates to the principle of specificity of training. Particularly if one adheres to the viewpoint which postulates fast velocity training will improve performance at not only fast velocities but over a range of velocities.

Another argument against isokinetic training is the categorical assignment of velocities. Speed may be better analyzed when dictated by the athletic demands and not by the machine. Even studies examining multiple stimuli, (whether isotonic involving varied forces and velocities, isometric involving varied relative contraction intensities, or isokinetic involving varied velocities) are still unable to pinpoint any possible discrete, intricate links between improvements in performance and training stimuli. The multiple contradictory findings contained herein support this point.

Considering power is dependent upon torque and revolutions per minute (RPM) [45], it stands to reason training for maximal power increases should be done not at static velocities against static resistance from repetition to repetition, but across a range of velocities, resistances, and forces over a given singular repetition, such as in inertial load training.

This report highlights the need for further research in inertial load training. The inertial load training methodology is well warranted and would be beneficial in providing insight into the potential mechanisms behind performance increases still unanswered by the existing literature. Inertial load training has the potential not only to increase peak power output but also to improve athletic performance, and possibly minimize imbalances in lower limb power output.

# REFERENCES

1. Adeyanju, K., Crews, T. R., & Meadors, W. J. (1983). Effects of two speeds of isokinetic training on muscular strength, power and endurance. The Journal of Sports Medicine and Physical Fitness, 23(3): 352.

2. Akima, H., Takahashi, H., Kuno, S.Y., Masuda, K. Masuda, T. Shimojo, H., Anno, I., Itai, Y. Katsuta, S. (1999). Early phase adaptations of muscle use and strength to isokinetic training. Med. and Sci. in Sport and Exer. 31(4), 588-594.

3. American College of Sports Medicine Position Stand. (2009). Progression models in resistance training for healthy adults. Med Sci Sports Exerc 41: 687–708.

4. Baechle, T. R., Earle, R. W., & National Strength & Conditioning Association (U.S.). (2000). Essentials of strength training and conditioning. Champaign, Ill: Human Kinetics.

5. Behm, D. G., & Sale, D. G. (1993). Intended rather than actual movement velocity determines velocity-specific training response. Journal of Applied Physiology, 74(1), 359-368.

6. Beneka, A., Malliou, P., Missailidou, V., Chatzinikolaou, A., Fatouros, I., Gourgoulis, V., & Georgiadis, E. (2013). Muscle performance following an acute bout of plyometric training combined with low or high intensity weight exercise. Journal of Sports Sciences, 31(3): 335-343.

7. Blattner, S. E., & Noble, L. (1979). Relative effects of isokinetic and plyometric training on vertical jumping performance. Research Quarterly. American Alliance for Health, Physical Education, Recreation and Dance, 50(4), 583-588.

8. Bobbert, M.F, Huijing, P.A, and Van Ingen Schenau, G.J. (1987). The influence of dropping height on the biomechanics of drop jumping. Med. Sci. Sports Exerc. 19, 339-346.

9. Bobbert, M. F., Huijing, P. A., & Van Ingen Schenau, G. J. (1987). Drop jumping. II. The influence of dropping height on the biomechanics of drop jumping. Med Sci Sports Exerc, 19(4), 339-46.

10. Caiozzo, V. J., Perrine, J. J., & Edgerton, V. R. (1981). Training-induced alterations of the in vivo force-velocity relationship of human muscle. Journal of Applied Physiology, 51(3), 750-754.

11. Chu, D. (1998). Jumping Into Plyometrics. Champaign, IL: Human Kinetics.

12. Clarke, D. H. (1973). Adaptations in strength and muscular endurance resulting from exercise. Exercise and sport sciences reviews, 1(1), 73-107.

13. Coyle, E.F., Feiring, D.C., Rotkis, T.C., Cote, R.W., Roby, F.B., Lee, W., Wilmore, J.H. (1981). Specificity of power improvements through slow and fast isokinetic training. J. Appl. Physiol. 51(6), 1437-1442.

14. Cronin, J. B., McNair, P. J., & Marshall, R. N. (2002). Is velocity-specific strength training important in improving functional performance?. The Journal of sports medicine and physical fitness, 42(3), 267-273.

15. De Villarreal, ESS, Kellis, E, Kraemer, WJ, and Izquierdo, M. (2009). Determining variables of plyometric training for improving vertical jump height performance: A meta-analysis. J Strength Cond Res 23:495–506.

16. Doherty, T. J., & Campagna, P. D. (1993). The effects of periodized velocity-specific resistance training on maximal and sustained force production in women. Journal of sports sciences, 11(1), 77-82.

17. Ebben, W. P., Fauth, M. L., Garceau, L. R., & Petushek, E. J. (2011). Kinetic quantification of plyometric exercise intensity. Journal of Strength and Conditioning Research, 25(12): 3288-3298.

18. Enoka, R.M. (1988). Muscle strength and its development: New perspectives. Int'l Journal of Applied Medicine and Science in Sport and Exercise. 6:146-159.

19. Ewing, J.L., Wolfe, D.R., Rogers, M.A., Amundson, M.L., Stull, G.A. (1990). Effects of velocity of isokinetic training on strength, power, and quadriceps muscle fibre characteristics. Eur. J. Appl. Physiol. 61, 159-162.

20. Fenn, W. O., & Marsh, B. S. (1935). Muscular force at different speeds of shortening. The Journal of Physiology, 85(3), 277-297.

21. Garnica, R. A. (1986). Muscular Power in Young Women After Slow and Fast Isokinetic Training. Journal of Orthopaedic & Sports Physical Therapy, 8(1): 1-9.

22. Gasser H. S., Hill A. V. (1924). The dynamics of muscular contraction. Proc. R. Soc. Lond. B Biol. Sci. 96, 398–437

23. Hakkinen, K., Komi, P. V., & Alen, M. (1985). Effect of explosive type strength training on isometric force-and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. Acta Physiological Scandinavica, 125(4), 587-600.

24. Hansen, E., Andersen, J., Nielsen, J., & Sjogaard, G. (2002). Muscle fibre type, efficiency, and mechanical optima affect freely chosen pedal rate during cycling. Acta Physiologica Scandinavica, 176(3), 185-194.

25. Hellebrandt, F.A. (1958) Methods of muscle training: Influence of pacing. Phys. Ther. Rev. 2:319-326.

26. Hill, A. V. (1922). The maximum work and mechanical efficiency of human muscles, and their most economical speed. The Journal of physiology, 56(1-2), 19-41.

27. Hoffman, B. 1964. Functional isometric contraction: system of static contraction: exercise without movement. 2nd Edition. Revised.

28. Hori, N, Newton, RU, Kawamori, N, McGuigan, MR, Kraemer, WJ, and Nosaka, K. (2009). Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. J Strength Cond Res 22: 874–882.

29. Housh, D.J., Housh, T.J., Johnson, G.O., Chu, W.K. (1992) Hypertrophic respsonse to unilateral concentric isokinetic resistance training. JAP 73(1), 65-70.

30. Ide, B. N., Leme, T. C., Lopes, C. R., Moreira, A., Dechechi, C. J., Sarraipa, M. F., Macedo, D. V. (2011). Time course of strength and power recovery after resistance training with different movement velocities. The Journal of Strength & Conditioning Research, 25(7), 2025-2033.

31. Inbar, O., 1943, Bar-Or, O., & Skinner, J. S., 1936. (1996). The wingate anaerobic test. Champaign, IL: Human Kinetics.

32. Kanehisa, H., Miyashita, M. (1983). Specificity of velocity in strength training. Eur. J. Appl. Physiol. 52, 104-106.

33. Kaneko, M., et al. "Training effect of different loads on the force-velocity relationship and mechanical power output in human muscle." Scand J Sports Sci 5.2 (1983), 50-55.

34. Kraemer, W. J., Fleck, S. J., & Evans, W. J. (1995). Strength and power training: physiological mechanisms of adaptation. Exercise and sport sciences reviews, 24, 363-397.

35. Kristensen, G. O., Van den Tillaar, R., & Ettema, G. J. (2006). Velocity specificity in early-phase sprint training. The Journal of Strength & Conditioning Research, 20(4), 833-837.

36. Lesmes, G.R, Costill, D.L, Coyle, E.F., Fink, W.J. (1978). Muscle strength and power changes during maximal isokinetic exercise. Med Sci Sports 10(4), 266-269.

37. MacDougall, J. D., Wenger, H. A., & Green, H. J. (Eds.). (1991). Physiological testing of the high-performance athlete. Champaign, Ill.: Human Kinetics Books.

38. Mann, R.V., Sprague, P.G. (1980). A kinetic analysis of the ground leg during sprint running. Research Quarterly for Exercise and Sport, 51:334-348.

39. Martin, J.C., Wagner, B.M., Coyle, E.F. (1997). Inertial-load method determines maximal cycling power in a single exercise bout. Med. Sci. Sports Exerc. 29(11), 1505-1512.

40. Matveyev, L. (1977). Fundamentals of Sports Training. Fizkultura Sports Publishers. English Translation- 1981 Progress Publishers.

41. McBride, J. M., Triplett, T., Davie, A., Newton, R. U. (1999). A comparison of strength and power characteristics between power lifters, Olympic lifters, and sprinters. Journal of Strength & Conditioning Research, 13(1), 58-66.

42. McKethan, J. F., & Mayhew, J. L. (1974). Effects of isometrics, isotonics, and combined isometrics-isotonics on quadriceps strength and vertical jump. The Journal of sports medicine and physical fitness, 14(3), 224.

43. Medvedev, V.V. Marchenko, S.V. Fomichenko (1983). Speed-strength structure of vertical jumps by qualified weightlifters in different take-off conditions. Soviet Sports Review International (19):164–167.

44. Moffroid, M. T., & Whipple, R. H. (1970). Specificity of speed of exercise. Physical Therapy, 50(12), 1692-1700.

45. Murray, D.P., Brown, L.E., Zinder, S.M., Noffal, G.J., Bera, S.G., Garrett, N.M. (2007). Effects of velocity-specific training on rate of velocity development, peak torque, and performance. J. Strength and Cond. Research. 21(3), 870-874.

46. Narici, M. V., Roi, G. S., Landoni, L., Minetti, A. E., & Cerretelli, P. (1989). Changes in force, cross-sectional area and neural activation during strength training and detraining of the human quadriceps. European Journal of Applied Physiology and Occupational Physiology, 59(4), 310-319.

47. Newton, I. (1686). Principia Mathematica Philosophiae Naturalis. Revised.

48. Petersen, S. R., Bagnall, K. M., Wenger, H. A., Reid, D. C., Castor, W. R., & Quinney, H. A. (1989). The Influence of Velocity-Specific Resistance Training on the In Vivo Torque-Velocity Relationship and the Cross-Sectional Area of Quadriceps Femoris. Journal of Orthopaedic & Sports Physical Therapy, 10(11), 456-462.

49. Pipes, T. V., & Wilmore, J. H. (1974). Isokinetic vs. isotonic strength training in adult men. Medicine and science in sports, 7(4), 262-274.

50. Pollock, M. L., Franklin, B. A., Balady, G. J., Chaitman, B. L., Fleg, J. L., Fletcher, B., Bazzarre, T. (2000). Resistance exercise in individuals with and without cardiovascular disease benefits, rationale, safety, and prescription an advisory from the committee on exercise, rehabilitation, and prevention, council on clinical cardiology, American Heart Association. *Circulation*, *101*(7), 828-833.

51. Prevost, M.C., Nelson, A.G., and Maraj, B.K.V. (1999) The effect of two days of velocity-specific isokinetic training on torque production. J. Strength Cond. Res. 13, 35-39.

52. Proteau, L., Marteniuk, R. G., & Lévesque, L. (1992). A sensorimotor basis for motor learning: Evidence indicating specificity of practice. The Quarterly Journal of Experimental Psychology, 44(3), 557-575.

53. Sale, D. G. (1986). Influence of exercise and training on motor unit activation. Exercise and sport sciences reviews, 15, 95-151.

54. Sargent DA. The physical test of a man. American Physical Education Review 26: 188-194. 1921.

55. Sapega, A.A., Drillings, G. (1983). The definition and assessment of muscular power. J. Orth and Sports Phys. Therapy. 5(1), 83-86.

56. Sidossis, L.S., Horowitz, J.F., Coyle, E.F. (1992). Load and velocity of contraction influence gross and delta mechanical efficiency. Int'l Journ. Sports Med. 5(13), 407-411.

57. Smith, M. J., & Melton, P. (1981). Isokinetic versus isotonic variable-resistance training. American Journal of Sports Medicine, 9(4), 275-279.

58. Timm, K. E. (1987). Investigation of the physiological overflow effect from speed-specific isokinetic activity. Journal of Orthopaedic & Sports Physical Therapy, 9(3), 106-110.

59. Toji, H., Suei, K., & Kaneko, M. (1997). Effects of combined training loads on relations among force, velocity, and power development. Canadian Journal of Applied Physiology, 22(4), 328-336.

60. Twist, C., Gleeson, N., Eston, R. (2008) The effects of plyometric exercise on unilateral balance performance, Journal of Sports Sciences, 26(10):1073-1080.

61. Verkhoshansky, Y. (1966). Perspectives in the improvement of speed-strength preparation of jumpers. Legkaya Atletika (Track and Field) (9):11–12.

62. Victor, R. G., Seals, D. R. (1989). Reflex stimulation of sympathetic outflow during rhythmic exercise in humans. American Journal of Physiology-Heart and Circulatory Physiology, 257(6), H2017-H2024.

63. Yessis, M. (2000). Explosive Running. McGraw-Hill Companies, Inc.

64. Yessis, M (2009). Explosive Plyometrics. Ultimate Athlete Concepts.

# VITA

Michael Travis Brenneman was born in Webster, Texas. After graduating high school he entered the United States Military and served on active duty for over eight years. While stationed in San Antonio he enrolled in The University of Texas at San Antonio, earning a Bachelor of Science degree specializing in Athletic Medicine in 2012. During this time his research focused on anaerobic threshold and heart rate variability, with work published in The International Journal of Exercise Science. He entered the Graduate School at The University of Texas at Austin in August, 2014.

This report was typed by the author

Permanent Method Of Contact: michael.t.brenneman@gmail.com