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The Effect of Whole Body Vibration on Rate of Force Development and Vertical Jump Performence In College Aged Females

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THE EFFECTS OF WHOLE-BODY VIBRATION ON RATE OF FORCE DEVELOPMENT AND VERTICAL JUMP PERFORMANCE IN COLLEGE AGED FEMALES

by
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ABSTRACT

MARCO ITALIA: The Effect of Whole-Body Vibration on Rate of Force Development and Vertical Jump Performance in College Aged Females (Under the direction of Dr. John Garner)

Whole-body vibration (WBV) may potentiate vertical jump (VJ) performance via augmented muscular strength and motor function. The purpose of this study was to evaluate the effect of different rest intervals after WBV on VJ performance. Eight collegiately trained athletes (age 20.75 ± 1.16yr, mass 61.35 ±9.68kg, height 168.19±7.73cm) and eight recreationally active (age 22.25 ±1.83yr, mass 64.35 ±4.64kg, height 162.53 ± 2.6cm) individuals volunteered to participate in 4 testing visits separated by 24 hours. Visit 1 acted as a familiarization visit where subjects were introduced to the VJ and WBV protocols. Visits 2–4 contained 2 randomized conditions per visit with a 10-minute rest period between conditions. The WBV was administered on a multi-planar platform with a frequency of 30 Hz and an amplitude of 2-4 mm in 4 bouts of 30 seconds for a total of 2 minutes with 30 seconds of rest between bouts. During WBV, subjects performed a quarter squat every 5 seconds, simulating a countermovement jump (CMJ). Whole-body vibration was followed by 3 CMJs with 5 different rest intervals: immediate, 30 seconds, 1 minute, 2 minutes, or 4 minutes. For a control condition, subjects performed squats with no WBV. There were no significant ($p > 0.05$) differences in rate of force development after WBV rest intervals. However, results of VJ height revealed that maximum values, regardless of rest interval (19.250 $\pm$ 2.852 in), were significantly ($p < 0.05$) greater than the control condition (18.219 $\pm$ 2.938 in). Therefore, subjects' VJ height potentiated at different times after WBV suggesting strong individual differences in optimal rest interval. Coaches may

use WBV to enhance acute VJ performance but should first identify each individual's optimal rest time to maximize the potentiating effects.

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CHAPTER 1

INTRODUCTION

Many sports require the ability of athletes to produce high amounts of force in a short amount of time. The ability for an athlete to produce high rate of force development is often related to an athlete's overall strength levels (65). Stone, et al. suggested that the ability to express high rates of force development and high power outputs are critical performance characteristics important to success in most sporting events (65). These characteristics are especially important in jumping, sprinting, or changing direction (33, 52, 65).

In order to understand why power is important for athletic performance, we must first understand what power is. Power is calculated by multiplying force by velocity (55). Based on the equation we see that an athlete's ability to generate high power output is based on the athlete's ability to produce a high amount of force with a high velocity. There is an inverse relationship between force and velocity. Force and velocity are interdependent, and maximal power output occurs at compromised levels of maximal force and velocity (44, 63). When attempting to increase the power output of an athlete there are three elements to consider. The first one is that overall muscular strength is maximized. Two, it is important to express high forces as the velocity of shortening decreases. Third, it is important to develop the ability to express high amounts of force in short periods of time.

Rate of force development (RFD) is also defined as "explosive muscle strength". Rate of force development describes the rate at which force is expressed during a sporting movement (4, 52). RFD is determined from the slope of the force-time curve between 0 and 200 milliseconds

(33). Rate of force development exhibits a significant functional importance in fast and forceful muscle contractions (4). There have been various methods used to increase the rate of force development (48, 49).

Generally there are three main schools of thought that are used when attempting to maximize power output. The first suggests that lowering the intensity (> 50% of 1 repetition maximum) for the development of power generating capacity. The second school of thought suggests that higher loads of one repetition maximum (50%-70% of 1 RM) are required to increase power capacity. The final school of thought takes a mixed approach. It suggests a way in which a variety of loads and exercise types are used in a periodized fashion to optimize power output (10, 20, 44). Typically results have shown that heavy resistance exercises result in an increase in isometric peak force and rate of force development. The theory behind this school of thought lies in the theory of potentiation.

When discussing potentiation there are two types of potentiation: Concurrent Activation Potentiation (CAP) and Post Activation Potentiation (PAP). CAP is a simultaneous ergogenic advantage associated with muscle activations remote to the activation of the prime mover (24). Most of CAP research has been done on mandibular orthopedic repositioning appliances and dental research (24). PAP describes the immediate muscle force output of explosive movements typically following heavy resistance exercises (59). However, heavy resistance training is not the only modality used to induce the PAP response. With the improvement of technology, the use vibration as a method for inducing the PAP response has become a topic of interest for many strength professionals (14). Research on vibration has revealed an importance on the frequency of vibration and amount of exposure time (8, 49, 51). The purpose of this study was to examine if vertical jump performance increased after WBV.

Purpose

The purpose of this study was to examine the effect of whole-body vibration over different rest intervals and the effect on rate of force development and vertical jump performance.

Hypotheses

Rate of Force Development

H_{0A}: There will be no difference after whole-body vibration in the rate of force development.

H_{A1}: There will be significant increase in rate of force development after whole-body vibration.

From previous literature on whole-body vibration, results have indicated an increase in rate of force development. Rate of force development is important in determining how powerful an athlete is. Power is the amount of work done divided by the amount of time, which can be derived to be the amount of force multiplied by the velocity of the movement. So when discussing power we must look at the amount of force applied, the velocity of the movement, and the amount of time it takes to complete the movement. Rate of force development applies to how quickly and individual can create an amount of force. An increase in rate of force development will shorten the amount of time it takes to create maximal force output. From previous literature vibration has been shown to increase RFD, therefore we expect to see the same results (21, 49, 53).

Vertical Jump Height

H_{oB}: There will be no difference in vertical jump height after whole-body vibration

H_{B1}: There will be a significant increase in vertical jump height after whole-body vibration

A vertical jump is the act of raising one's center of gravity (5). When performing a vertical jump test there are many different ways, we used the countermovement jump method (5). Vertical jump height has been used as an applied measurement of power (11). The previous research on the effects of whole-body vibration on vertical jump indicated that there will be an increase in vertical jump height following whole-body vibration. We expect to see similar results, which will have an increase in vertical jump height.

Definitions

Ground Reaction Force (GRF): Useful in evaluation power is the ground reaction force. The ground reaction is equal, in magnitude, to the force exerted on the supporting surface through the foot, but is opposite in direction (31, 70). The ground reaction forces can be broken down in two components: the horizontal (anterior-posterior), and vertical components (41)

Rate of Force Development (RFD): The rate of rise in contractile force at the onset of contraction. In order to calculate the rate of force development, it is the slope of a joint moment-time curve; which is the change in moment over the change in time (3)

Impulse: The effect of force acting over time. Impulse is calculated as the product of force and time (J= F x t) (45)

Concentric: A concentric muscle action means the length of the muscle is shortening in order to produce tension. The joint movement is in the same direction as the net torque created by the muscles (34)

Eccentric: An eccentric muscle action is one in which the length of the muscle increases. In this type of movement the direction of the joint movement is opposite the net torque (34)

Counter-movement Vertical Jump (CMVJ): A jump that is proceeded by a countermovement, which is a quick bend of the knees during which the center of mass drops somewhat before jumping upwards (18)

Whole-Body Vibration (WBV): Whole-body vibration is a mechanical stimulus characterize by an oscillatory motion. The biomechanical parameters in determining the intensity of the vibration are the amplitude, frequency, and magnitude of the oscillations. Amplitude is determined by the peak to peak displacement of the oscillations. The rate at which the oscillations cycle determines the frequency of the vibration measured in Hertz (Hz). The acceleration of the vibration indicates the magnitude (14)

Potentiation: A phenomenon that offers a proposition to optimize power and force production (59).

Concurrent Activation Potentiation (CAP): CAP is a simultaneous ergogenic advantage associated with muscle activations remote to the activation of the prime mover (24)

Post-Activation Potentiation (PAP): PAP describes the immediate muscle force output of explosive movements typically following heavy resistance exercises (59).

CHAPTER II

REVIEW OF LITERATURE

Sports athletes around the world require explosive movements to create the power needed to be successful in their respective sport. Vertical jump provides an effective measurement of power and is used by coaches, strength professionals, and researchers, as an indirect, applied measurement of performance. The development of explosive power in the legs is especially important when testing an athlete's vertical jump height. When doing a vertical jump, an athlete uses major muscle groups to generate the power needed to jump to maximum height. In order to understand the principles behind the muscle mechanics we must first look at the composition of a muscle itself.

Skeletal muscle makes up 40% of our total body weight. These muscles enable humans to do all sorts of different body movements. Each muscle is made up of muscle fibers. Muscle fibers are arranged in a parallel fashion and are connected to the bone by tendons. Muscle fibers are cable-like structures, composed of myofibrils. Myofibrils contain the contractile structures that are responsible for actively shortening the muscle and generating a force. The myofibrils are made of filaments with different thicknesses that are arranged in a highly specific way. The thicker filament is myosin and the thinner filament is actin. Actin and myosin are anchored together at the z-disc. Myosin is a club-like structure composed of a long shaft with two globular heads at one end. Actin is a globular protein composed of troponin and tropomyosin. They are connected end to end to form a string that runs between the groves of the actin along the entire filament. Troponin is a protein binding complex that has a high affinity to calcium. Binding of calcium to troponin causes a structural change of the troponin-tropomyosin complex responsible for the activation of muscle contraction. The heads and part of the shaft extend from the rod to form what is called the myosin cross-bridges (25). During a muscle contraction the number of linkages between the myosin heads and the actin is proportional to the force production and energy expenditure (34).

Muscle fibers are organized into different functional groups. Muscle fibers are innervated by motor units, which begin the process for muscular contraction. A motor unit is a composition of a motor neuron which controls all the muscle fibers that it innervates. The motor neuron sends a nerve impulse to the motor unit, which is connected to the muscle fiber at the motor end plate, causing the muscle fibers to contract. Gross muscle functions, such as those that produce forceful movements, are a result of large motor unity activity. Motor units are composed of twitch-type cells that respond to a single stimulus developing tension in a twitch like fashion (34). The twitches are caused by nerve impulses. The way in which the muscle responds to the impulse determines which classification of muscle type it is categorized into.

Skeletal muscle fibers have different structural, histochemical, and behavioral characteristics (34). The main energy source for muscles comes from Adenosine Tri-phosphate (ATP). ATP is a nucleotide that comes from carbohydrates. ATP is required for all muscle actions.

Based on these different characteristics, fibers are divided into fast twitch and slow twitch. It takes a fast twitch muscle one-seventh of the time required by slow twitch fibers to reach peak tension (27). Fast twitch muscles are able to create more tension in the muscle in a shorter amount of time. Fast twitch fibers have a high concentration of ATPase, which breaks down ATP at a faster rate. Since fast twitch fibers break down ATP faster they fatigue more quickly. Fast twitch fibers are highly correlated to a performer's success in events that require a fast, powerful muscular contraction. These events are related with immediate rate of fatigue (7). Events that are more endurance based, such as distance running and swimming for example, require muscle to fatigue at a slower rate; athletes involved in this type of event have more slow-twitch fibers (46).

The activation of a muscle creates tension in the muscle. The amount of tension that the muscle produces is constant throughout the length of the muscle, and all of its inclusive parts. The tension created by muscle activation produces a shortening force that causes the tendons to pull on the attached bones and creates a torque across the joints crossed by the muscle. In order to overcome greater amounts of external forces the muscle must produce enough force. The central nervous system is the control center that enables the speed and magnitude of a muscle contraction. Slow-twitch fibers, because of the composition, tend to have lower thresholds of activation than fast-twitch (23). For movements that increase in speed, or force the motor units with higher thresholds become activated, such as type II fibers. The impulses generated by the central nervous system (CNS) control the muscles involved and determine the muscle action.

Muscle actions are described as concentric, eccentric, or isometric. A concentric muscle action means the length of the muscle is shortening in order to produce tension. The joint movement is in the same direction as the net torque created by the muscles (34). An eccentric muscle action is one in which the length of the muscle increases. In this type of movement the direction of the joint movement is opposite the net torque. In a downward phase of a squat the eccentric tension created by the leg extensors act as a breaking mechanism to control the movement (34). The third type of muscle action is isometric, meaning no change in the muscle length. In an isometric action the torque at the joint is equal to the torque of the muscle, resulting in a net torque of zero (34). Understanding the true nature of a muscle action is difficult, and in most laboratory settings is studied from a relaxed state or from an isometric contraction state (15). The reason for this to be carefully understood is because of the relationship that exists between force and velocity.

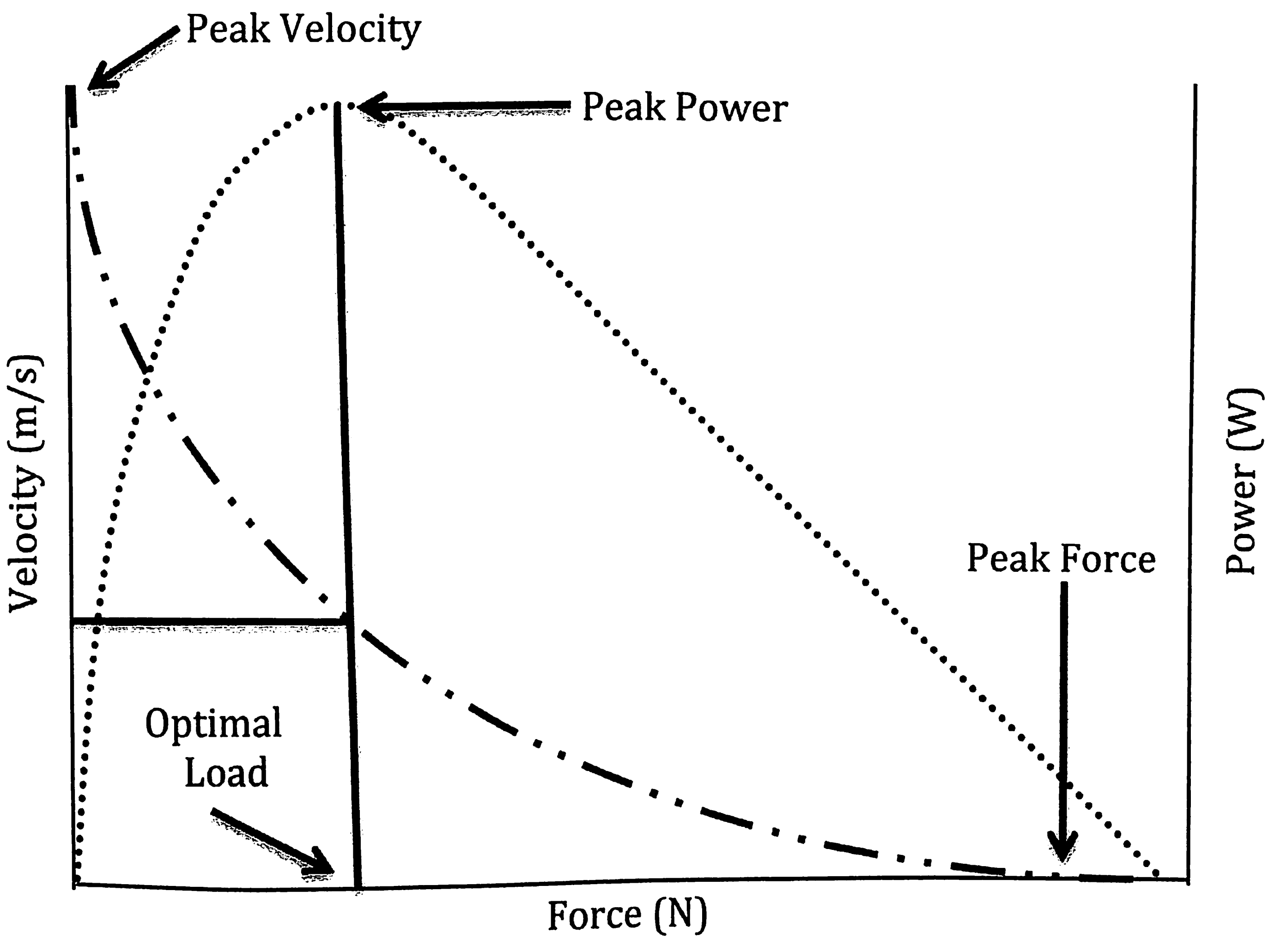

Figure 1.0 Force-velocity, force-power, velocity power, and optimal load relationship (56, 67)

The force-velocity curve above describes the relationship between force applied and velocity (56, 67). The graph shows that as the amount of the force produced increases, the velocity of that movement slowed down, and vice versa. The human body is consisted of lever systems, which are rigid or semi-rigid objects that are capable of rotating about fulcrum (54). Torque is the amount of outside force that causes an object to rotate (54). In order for there to be a torque the applied force has to be applied off of the fulcrum, because it is the axis of rotation (54). Figure 1.0 shows that the lower the torque the more velocity the knee extensors were able to produce. Similarly, the heavier torque requires a heavy force to rotate the object; therefore the velocity of the muscle action must decrease. As the force continues to increase it will eventually reach a point at which the muscle action shows no change in velocity. This is called an isometric muscle action. There is an inverse relationship between the force and velocity during a concentric muscle action. The opposite is true for an eccentric muscle action. As the load increases, the velocity of the eccentric muscle action increases. The relationship described in figure 1.0 has been tested in skeletal, smooth, and cardiac muscle in humans and shows that this general pattern holds true for all of them (39). How much force a muscle is able to produce is based on the relationship between the length and the tension of the muscle.

The maximum amount of tension produced in a muscle is dependent on the muscle length (34). Research shows that single muscle fibers in isolated muscle preparations, generates maximum force at its peak when the muscle is slightly stretched (57). This phenomenon is called the Stretch-Shortening Cycle. An actively stretched muscle can generate more force than in the absence of the pre-stretch, "An eccentric muscle action immediately followed by a concentric muscle action" (34). Research on frog muscles, has shown that stretching on the sartorius, semitendinosus, and gastrocnemius, prior to release showed that it created more force than the muscles beginning at resting length (15). The stretch-shortening cycle contributes to effective development of concentric muscle force in many sports activities (34). Olympic lifters, who compete competitively, use quick knee flexion in the transition phase of the snatch to invoke the stretch-shortening cycle and enhance their performance (30). The stretch-shortening cycle translates over into athletes developing muscular power.

Muscular power is an important contributor to sports that require both strength and speed. Muscular power is defined as the product of muscular force and velocity of muscle shortening (34). Fast-twitch fibers have the ability to generate tension more rapidly. Biopsies on athletes involved in events that require strength and power have found a high proportion of fast-twitch fibers in their muscles (7). In translation over to the vertical jump, athletes are required to develop the maximum amount of force in a short amount of time in order to maximize their vertical jump height.

Vertical jump performance has been widely studied, and they have found a strong correlation to a human's measure of power (11, 37, 62). Generation of peak force in the lower extremities results from the net muscle moments created by the knee and hip extensors and ankle plantarflexors during propulsion. Another variable that is useful in evaluation of power is the ground reaction force. The ground reaction is equal, in magnitude, to the force the person exerts on the supporting surface through the foot, but is opposite in direction (31, 70). The ground reaction forces can be broken down into two components: the horizontal (anterior-posterior), and vertical components (41). When studying the vertical jump it is important to look at the factors that are going to affect an athlete's vertical jump performance. There are two major factors that affect an athlete's vertical jump performance; the individual's body weight and the ground reaction force (41). In a study done by Cordova, he wanted to test the reliability and determine the relationship between peak vertical ground reaction force and vertical impulse during a one-legged vertical jump (17). Nineteen student volunteers participated in the study that consisted of performing a one-legged vertical jump using the right lower extremity. The subjects placed their right foot in the middle of the force plate, with their contralateral knee flexed at 90° to prevent the left foot from touching the force platform. They began each jump from an upright position and were allowed for countermovement; however their arm movement was restricted by having the subjects cross their arms against their chest (18). Subjects were instructed to go past 90° of knee flexion with the right extremity during this countermovement. The results of the study showed that the "coefficient of stability estimated peak vertical ground reaction force was high (rxx = .94)" (17). The high test-retest reliability of peak vertical ground reaction force obtained in the study showed that this type of measurement is stable over time.

One of the more recent modes to enhance athletic performance is whole-body vibration (WBV). Vibration is a mechanical stimulus characterize by an oscillatory motion. The biomechanical parameters in determining the intensity of the vibration are the amplitude, frequency, and magnitude of the oscillations. Amplitude is determined by the peak to peak displacement of the oscillations. The rate at which the oscillations cycle determines the frequency of the vibration measured in Hertz (Hz). The acceleration of the vibration indicates the magnitude (14).

Vibration has been widely documented for the use in medicine and physical therapy (9, 50). The physiotherapeutic approach involves applying the vibration locally to a selected muscle or tendon. The research show that vibration started out as pinpoint vibration. A vibration that is specific to treating a specific area. As technology has evolved, the treatment protocol has moved to the vibration platform. The vibration platform uses the same biomechanical principles as pinpoint vibration: that amplitude, the frequency, and the magnitude, and is now transferred over to a vibration platform. WBV protocols consist of subjects standing on the vibration platform and are subject to different protocols on the machine. This type of approach is applicable to the general populations. A study done by Mathe looked at the effects of vibration on different age ranges (51). Fifty total subjects were assigned to one of three groups depending solely on age. The 3 groups were young (n=20, 22.75 + 1.74 years), Middle-aged (n=15, 40.53 + 3.07 years) and old (n=15; 58.07 + 2.40 years). Subjects participated in a 2-hour testing session which consisted of pre- and post-trials for both CMVJ and maximal isometric leg extension, with a WBV intervention in between. The vibration protocol was 3 sets, 30-seconds in duration, at a frequency of 30 Hz on a low-amplitude. Tested peak power, peak rate of force development, rate of force development index, peak force, time to peak force, average time to peak, force and EMG amplitude values for both vastus lateralis and rectus femoris (51). The results of the study found that with an overall study of the data collect, the younger group had significant higher peak power values post-vibration (51).

The introduction of vibration as an intervention for exercise is a fairly recent idea. The first to approach working with well-trained subjects was the Russian scientist Issurin, and his colleagues. They looked at how vibration stimulation its effects on power and flexibility. They found that vibration was effective in enhancing strength in the subjects (42). Using vibration as an approach to exercise has produced interest on the effects of vibration on cardiovascular function (29), hormones (13), power output (22, 48, 51), balance (68), and vertical jump performance (8, 12, 49). In the literature, there have been studies done on different types of vibration platforms such as the, GALILEO 2000(12), NEMES 30 L (13), Power Plate® Next Generation WBV platform (8), Galileo Fitness® platform (22). Despite the different names each platform provides the same biomechanical basis. Each vibration machine showed an enhancement in performance on the different variables studied.

Vibration has been studied looking at the effects on the cardiovascular system. The purpose of Garatachea's study was to study how cycle time duration affects energy expenditure. Nine men were recruited from the university campus. All subjects, recreationally active, regularly practiced sports 1 to 3 times per week and had no prior experience in weight training in the squat or in WBV training. The subjects' mean SD age was 24.2 $\pm$3.5 years, height was 176.4 $\pm$ 4.5 cm, and body mass was 74.7 $\pm$ 9.8 kg (29). Squatting Protocol was almost maximal extension (170 degrees) to 90 degrees of knee flexion. Cycle time duration was defined as the time employed for completing 1 eccentric phase and the next concentric phase. Three squatting exercises in cycles of (a) 6, (b) 4, and (c) 2 seconds to90 knee flexion were performed, with vibration (Vb) and without vibration (Vb). A metronome was set at 1 Hz beats to control the movement velocity of the squatting exercise, and the subjects were instructed to move (a) 3, (b) 2, and (c) 1 second in both concentric and eccentric phases as evenly as they could. In all tests under vibration conditions, the frequency (number of vibrations per second) was set at 30 Hz, and the amplitude of vibration (extent of the vibratory movement) was 4 mm (29). Results found that oxygen uptake and energy expenditure were greater with the vibration (29).

Acute vibration has shown improvements in strength with isometric lower limb extension (69). The study done by Torvien had a protocol which consisted of vibration exposure for four minutes with the subjects standing erect. The vibration frequency increased in 1 min intervals: 15 Hz for the first minute, 20 Hz for the second minute, 25 Hz for the third minute and 30 Hz for the last minute. Two minutes after the vibration exposure there was a 2.0 kg increase in isometric lower limb extension (69).

A main variable that has been looked at when studying the effects of WBV is the amount of exposure to vibration. In one study subjects were exposed to vibration for 5 sets of 60 s with another 60 s rest between bouts with a frequency of 30 Hz and an amplitude of 2.5 mm (22). In another study WBV protocol consisted of 6 sets of static, body squats, 3 sets bilaterally for 30 s and 3 sets unilaterally. All squats held at 100 degrees (53). One study had participants stand upright on a vibration platform for a total of 6 minutes. Vibration frequency gradually increased during the first minute to a frequency of 26 Hz, which it maintained throughout the remaining 5 minutes (43). A study done by Cormie had a vibration treatment protocol which used the Power Plate body vibration platform at 30 Hz, held constant half-squat (100 deg.) for 30 seconds (19). In Ronnestad's study of the effects of the vibration platform, he had subjects perform weight squats with a bar on the vibration platform (60). Torvien did a randomized cross-over study designed to investigate the effects of a 4-min bout of vibration (69). During the vibration intervention, the vibration frequency increased in 1 min intervals: 15 Hz for the first minute, 20 Hz for the second minute, 25 Hz for the third minute and 30 Hz for the last minute (69). In a study done by Bosco subjects were exposed to vibration using the GALILEO 2000 device with a frequency of 26 Hz. Subjects were exposed to 5 series of vibration lasting 90 s each separated by 40 s of intermission (12). The treatment series consisted of different exposure to vibration on the platform: SERIES 1-toes on platform, SERIES 2-Half squat position. SERIES 3- feet externally rotated knee flexed at 90 deg. SERIES 4-One leg on right side of platform bent at 90 degrees, SERIES 5- other leg on left side of platform knee bent at 90 degrees (12).

Once the amount of exposure is determined researchers have to look at measuring different variables at different rest intervals to see the effects that the rest after the vibration has on the subjects. In one study, subjects performed three measured maximal CMJs immediately after vibration stimulus and again at five and 10 minutes post-vibration (8). The study found no significant results in the study; however they did find that women increased CMJ at 40 Hz and

50 Hz (8). Important for strength training and often the most un-recognized element is the rate of force development.

Rate of force development is extremely important for athletes who engage in sports that involve an explosive type of muscle action. Explosive muscle strength can be defined as "the rate of rise in contractile force at the onset of contraction" (3). In other words this is the rate of force development (RFD). Explosive muscle strength is the RFD exerted within the early phase of rising phase of muscle force (32, 61, 64, 66). In order to calculate the rate of force development, it is the slope of a joint moment-time curve; which is the change in moment over the change in time (3). RFD is very significant in explosive, forceful movements. An example of this is included in movements such as "sprint running, karate, or boxing typically involve contraction times of 50-250 ms" (3). Increases in RFD are highly important in the early phase of muscle contraction. RFD is a major determinant of the maximal force and velocity that can be achieved during fast limb movements (1, 2). RFD can be influenced by the level of neural activation (20), muscle size, and fiber type composition (38). One study took 15 males and put

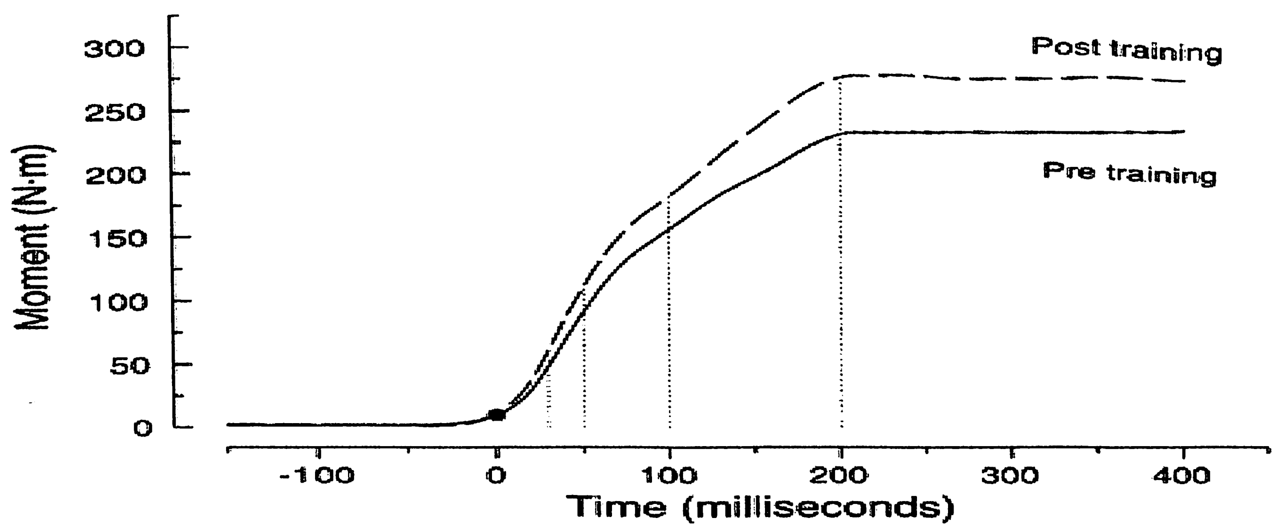

Figure 2.0 Moment-Time Graph of Quadriceps (3)

them through a progressive heavy-resistance strength training program for 14 weeks. Maximal quadriceps muscle strength was measured by maximal isometric knee extension moment exerted in an isokinetic dynamometer. The results of the study show that after the training the subjects' quadriceps contraction strength increased. It was observed that there was a steeper slope for the moment-time curve after training (3). Results also showed a 15% increase in normalized RFD in the initial phase of the fore rise (3). The results of this study show that heavy resistance training can increase the rate of force development, which is important when performing explosive movements. Explosive movements are required for most athletic areas. If an athlete can produce a greater amount of force over a shorter amount of time, it gives him an advantage. The purpose of every strength professional involved in competitive sports is to increase the amount of force an athlete can produce and do so in a short amount of time.

FPost-Activation Potentiation (PAP) is a phenomenon that offers a proposition to optimize power and force production above those training modalities without the use of PAP (59). PAP describes the immediate muscle force output of explosive movements following heavy resistance exercises (59). Over the last few years many of the mainstream strength and conditioning programs have used this through complex training (47). The main principle surrounding the studies of PAP is that prior heavy loading induces a high level of central nervous stimulation, which results in greater motor unit recruitment, leading to a higher force output (16, 58), also known as complex training. For example, a typical complex training protocol could consist of a maximum voluntary contraction, like a squat, and immediately followed by a plyometric movement, such as a box jump, in order to induce a higher PAP response (28). In order to understand how this phenomenon works we must look at the two theories used to describe the post activation potentiation principle.

The first theory involves an increase of phosphorylation of the myosin regulatory light chains, which are the proteins responsible for contraction, during a maximum voluntary contraction (35). The increase in phosphorylation allows the myosin-actin binding structure to be more responsive to the release of calcium ion released during the contraction cycle. The more responsive myosin-actin binding sites leads trigger events that lead to enhanced muscle force output at the structural level (35). The increased amount of muscle activation, leads to an increased amount of time the calcium ions remain in the muscle cell environment, leading to the increased phosphorylation of the myosin-light chain proteins (58). As a result of these events, it allows for faster contraction rates of the muscles and allows for faster rates of tension to develop in the muscle (16).

The second theory involves the Hoffman reflex (H-reflex) named after the scientist that first described the reflex, Paul Hoffmann. The H-reflex is an excitation of the spinal reflex elicited by the Ia afferent nerve fibers. The Ia afferent nerves are specialized nerves that conduct impulses to the muscle. With theory two, the PAP intervention increases the H-reflex, which increases the efficiency and rate at which the impulses travel to the muscle (40). By increasing the efficiency and rate of the impulses it can lead to a greater recruitment of motor neurons and leads to a quicker recruitment of the muscles. By having quicker recruitment of motor neurons, the athlete, or individual, is able to generate the maximum amount of muscles needed to perform the exercise at a faster rate.

It has been assumed that muscles with a predominance of fast-twitch fibers (Type II), have a shorter contraction rate and exhibit more force than slow-twitch fibers with a longer contraction time (Type I). In a study, researchers looked at muscle fiber type distribution and PAP in human knee extensors. The study was completed in two phases; the first phase tested a group of 20 males measuring muscle twitch response of a 10-secon MVC with a dynamometer and Electromyography (EMG). In the second phase, four subjects with the highest and lowest PAP scores underwent a needle biopsy of the vastus lateralis to determine the distribution of fiber type. The results showed that PAP is most effective when Type II fibers are at a greater percentage of the muscles being used (36). This phenomenon shows increased performance in athletes, and recreational athletes, who participate in explosive activities such as sprinting, jumping, and throwing. In another study researchers looked at the effects of warm-up protocol with and without a weighted vest. The study used 20 female subjects, which volunteered for the experiment that had three different protocols of stretching. Protocol SS consisted of static stretching of each of the major muscle groups for 10 minutes, protocol DY consisted of nine dynamic exercises that progressed from moderate to high intensity, and protocol DY2 consisted of the same dynamic exercise protocol as DY; however each subject wore a weighted vest, weighted with about 2% of body mass, during the dynamic warm-up protocol. Results of the study show significant increased performance on the vertical jump as the DY and DY2 protocols when compared to the SS protocol. DY2, weighted vest protocol, elicited the greatest improvement in performance during the tests (26).

CHAPTER III

METHODS

Experimental Approach to the Problem

The purpose of this study was to investigate acute performance potentiation after WBV exposure as might be used in a modified warm-up procedure. Therefore, this study used a repeated measures design by having subjects perform 5 different rest interval conditions and comparing VJ performance to a control condition without WBV. Rest intervals ranged from immediate post to 4 minutes post.

Subjects

Table 1: Participants Anthropometrics

Training Status	N	Age (years)	Height (cm)	Mass (kg)
Collegiate	8	20.75 ± 1.16	168.19 ± 7.73	61.35 ± 9.68
Recreational	8	22.25 ± 1.83	162.53 ± 2.6	64.35 ± 4.64

Eight collegiately trained and eight recreationally trained females volunteered to participate in 4 testing visits. Subjects' anthropometrics are listed in Table 1. The subjects were selected at random from responses to participate and by word of mouth to participate in the study. Subjects were excluded if they reported any lower body orthopedic injury or musculoskeletal injury within the past year. Each visit was within plus or minus 1 hour from initial to all proceeding visits, separated by at least 24 hours during the spring season in a controlled laboratory setting. Subjects were asked to wear comfortable clothing and the same shoes for each visit. Diet and hydration were not recorded, but subjects were asked to keep consistent throughout the duration of the study. Each subject read and signed a university Institutional Review Board approved informed consent form before participation.

Procedures

Visit 1 served as a familiarization session, which included completing the informed consent, anthropometric measurements, familiarization with the CMJ and WBV protocol. During the familiarization session, each subject completed 3 CMJs to assess variability; if the 3 CMJs exceeded 5% difference in jump height, they were ask to return to the laboratory on a subsequent day to complete another 3 jumps until the criterion was met. Subjects then performed 6 randomly assigned experimental conditions in 3 days with 2 conditions per day (2) separated by a 10-minute rest period. This rest period was deemed sufficient because previous literature has shown that WBV is ineffective after 10 minutes of exposure (1).

WBV sessions entailed 4 bouts of 30 seconds (2) for a total of 2 minutes of vibration with 30 seconds rest between bouts. During WBV, subjects performed quartersquats (2, 3) every 5 seconds while also simulating the arm swing used in a CMJ. Subjects were instructed to step off the plate during the rest time. After WBV exposure, subjects were instructed to walk quickly to the force plate (~15 ft) at which point they stood quietly until their rest interval for that condition was completed and then performed 3 CMJs. One condition served as a control during which the subjects stood on the vibration platform with no vibration, completed the squatting protocol then immediately performed 3 CMJs. The other 5 conditions used rest intervals of either immediately post, 30 seconds, 1 minute, 2 minutes, or 4 minutes followed by 3 CMJs (1).

Equipment

I. Vibration Plate

Whole-body vibration was performed on the AIRdaptive (Power Plate, Inc.) system. This system is composed of a 33" x 33" flat vibration platform fixed to a stable handle. It produces multi-planar accelerations with a primary emphasis on the z-plane (vertical). The vibration frequency ranges from a minimum of 30 Hz to a maximum of 50 Hz (cycles per second), with an amplitude setting from 2-4 mm (low) to 4-6 mm (high). Vibrations treatments can be manipulated by altering frequency and amplitude of movement, as well as exposure time.

Participants were instructed to perform quartersquats to a 60 degree angle of knee flexion, with their feet positioned shoulder width apart and their toes pointing slightly outward. WBV exposure was two bouts of a 1:1 work to rest ration of 30s with a total of 1 minute of vibration exposure. Frequency of the AIRdapative was set at 30 Hz, with amplitude of 2-4 mm.

II. Force Plate

A Bertec Force (BertecCorp. Columbus, OH, USA) platform sampling at 1080 Hz was used to record the GRF of the subject during the CMJ.

III. Vertec

A Vertec (Sports Imports, Columbus, OH, USA) free standing jump height measurement device was used to record vertical jump height.

IV. Performance Variables

Vertical jump performance was assessed on all visits to the laboratory. Participants were instructed to perform three maximal countermovement vertical jumps (CMVJ; 30 s rest), with arm swing and were instructed to jump as high as possible. The Vertec was used as a visual target where participants can hit tabs that indicate jump height. All jump data was stored for later analysis of ground reaction, rate of force development, peak velocity, and take off velocity, rate of velocity development, impulse, and peak power output. Rate of force development was determined from the slope of the force time curve (change in force/ change in time). The slope was determined between specified time bands between 0 and 200 milliseconds because between this time is often associated with fast movement (33).

Statistical Analyses

A paired-sample t-test compared control group and vibration group to test the group differences in RFD and VJH. A 2 x 6 (group x condition) mixed factor ANOVA was used to test for difference in rest intervals. If interaction occurs they were followed up with simple ANOVA's and main effects followed up with a least significant difference post-hoc analysis for pairwise differences.

CHAPTER IV

RESULTS

Paired Sample T-Tests revealed significant difference (p= .007) between the control (18 $\pm$ 2.9381) and vibration (19.250 $\pm$ 2.8519) groups for vertical jump height. No significant (p = .051) value between rate of force development between control and vibration groups was observed. No significant (p =0.75) interactions or main effects were found for all rest intervals on vertical jump height and rate of force development. There was no significant (p >0.05) group difference found between training status.

Vertical Jump Height

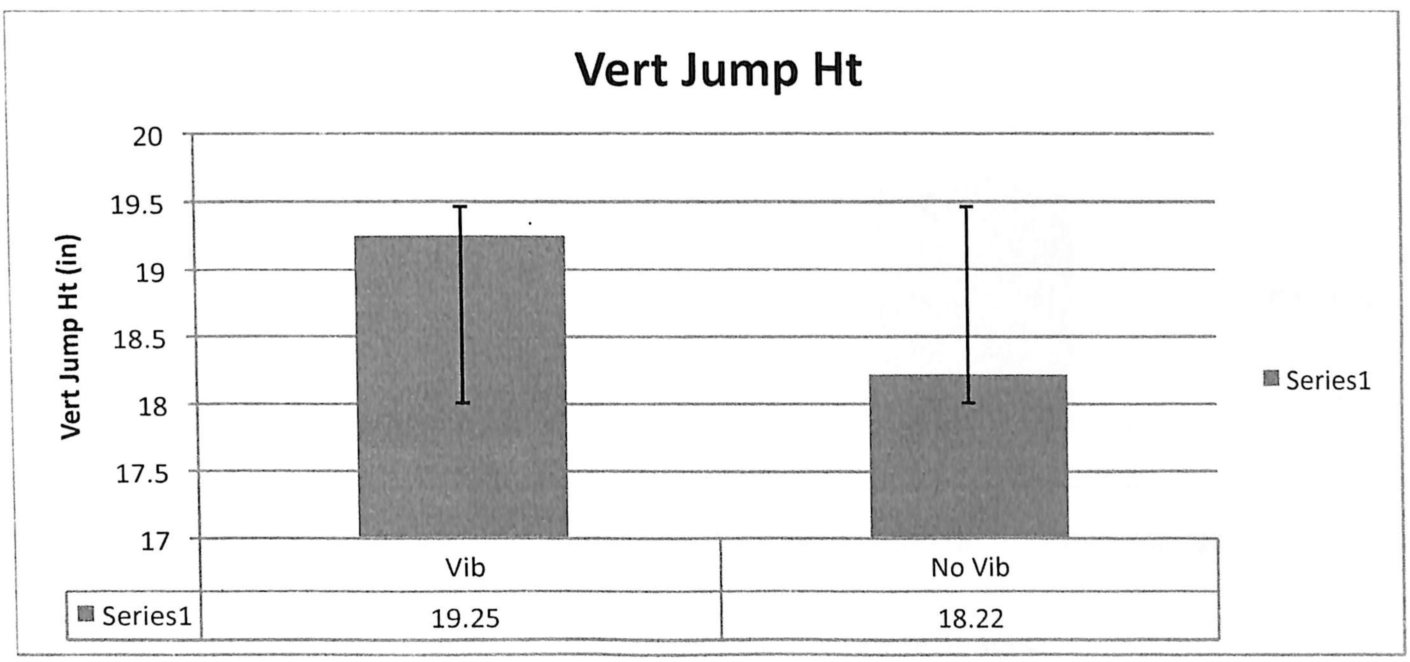

Figure 1. Vertical Jump Height Over Vibration or No Vibration. * Indicates significant difference between vibration and no vibration, with standard error bars

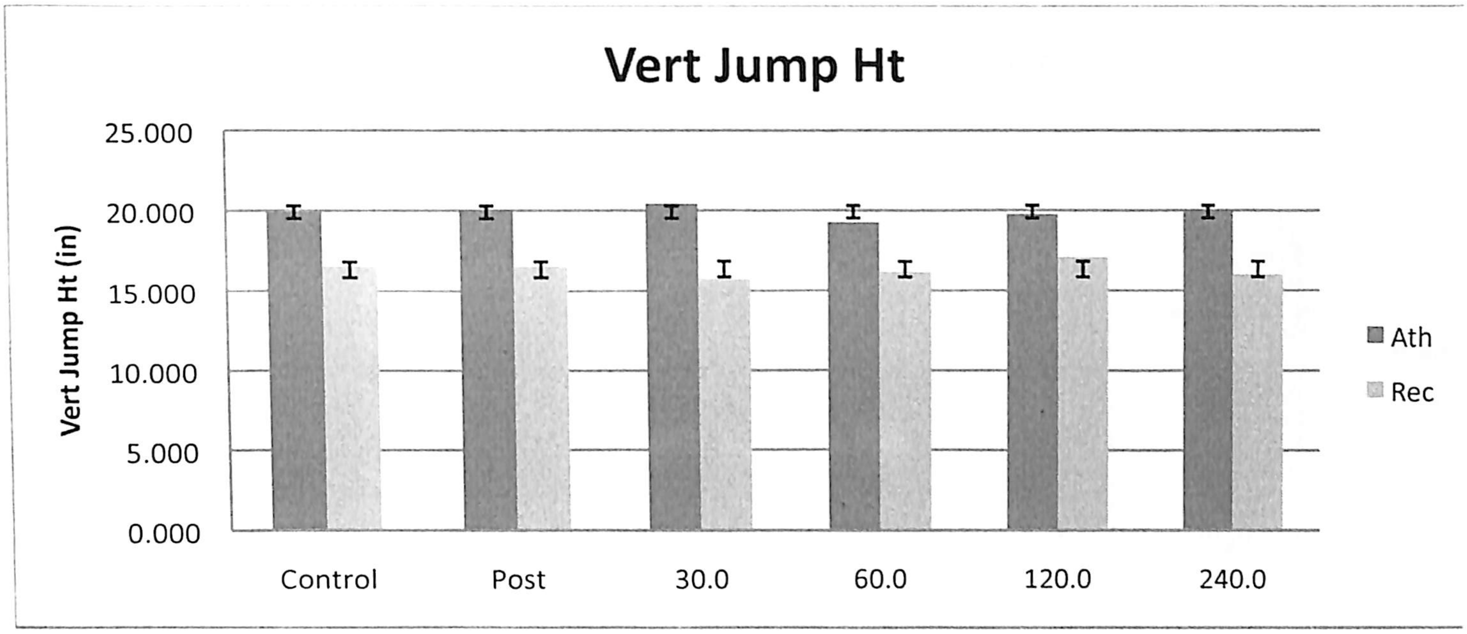

Figure 2. Vertical Jump Height Over the 6 Conditions With Time Points of Interest.

<u>RFD</u>

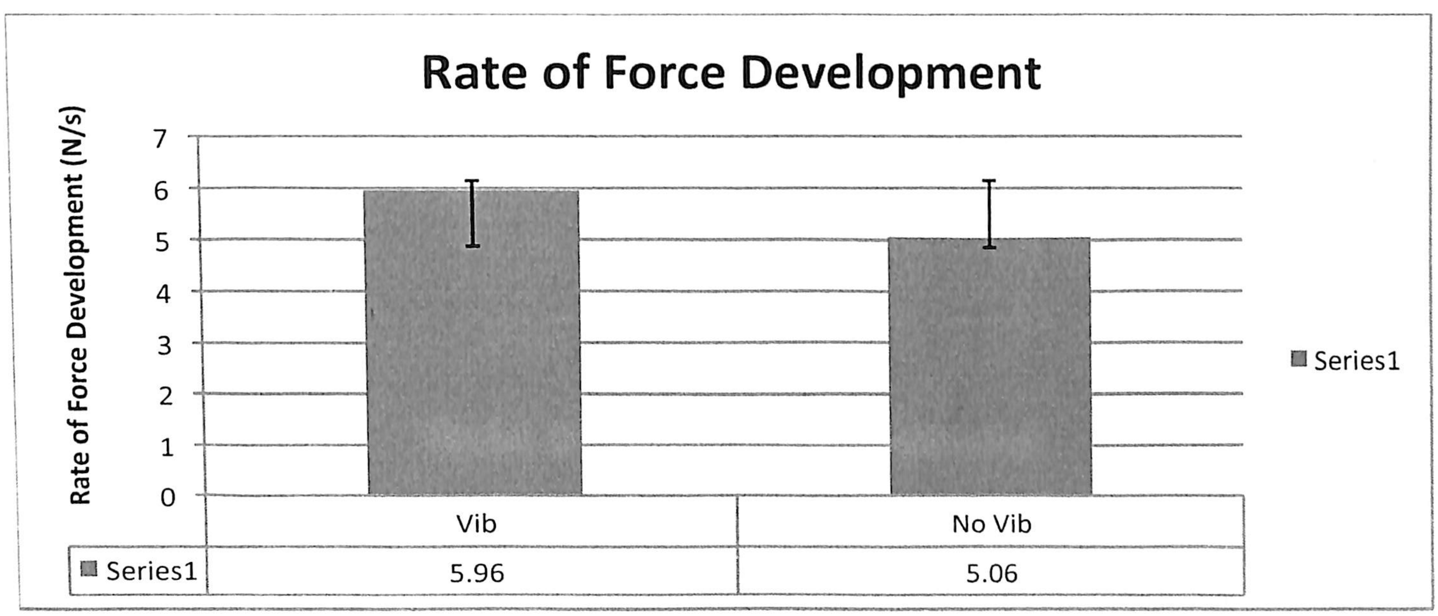

Figure 3. Rate of Force Development Over Vibration or No Vibration

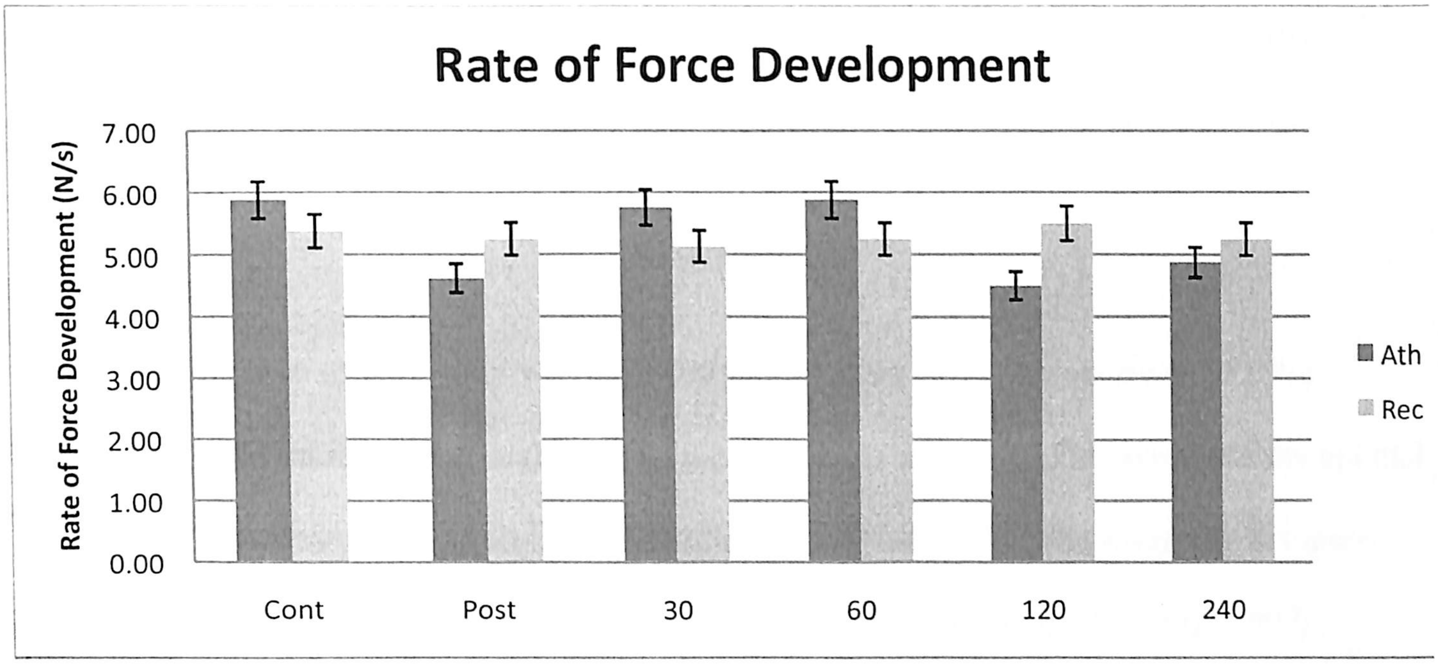

Figure 4. Rate of Force Development Over the 6 Conditions with Time Points of Interest

CHAPTER V

DISCUSSION

The purpose of this study was to investigate whether WBV increases rate of force development and increases vertical jump height. The study also looked to investigate the optimal rest interval between vibration and action to improve RFD and VJH. The study also compared these variables among training statuses (athletic vs. recreational). A significant ($p = .007$) difference was found in the control and vibration group for VJH. No significant ($p = .051$) differences were found in the control and vibration groups for RFD.

In a study done by Bosco and Cardinale found no significant results in a group that just performed tactical and technical training for handball and water polo (12). The group that received vibration showed significant ($p<0.05$) enhancement on the rise of center of gravity (12). Average height during continuous five seconds of jumping significantly improved ($p<0.01$) (12). Power developed during five seconds of continuous jumping did not change significantly (12). Mathe found no significant decrease in average peak power, average peak RFD, average peak fore, average time to peak force between pre- and post-vibration in young (n=20, 22.75 $\pm$ 1.74 years) vs. Middle-aged (n=15, 40.53 $\pm$ 3.07 years) vs. old (n=15; 58.07 $\pm$ 2.40 years) subjects (51). The young group showed significantly higher values for average peak power, average peak force and RF EMG amplitude when compared to the old across pre- and post-vibration (51). One study looked at four different conditions of vibration and found that jump height after intermittent vibration of 50 Hz was greater than after continuous vibration of 30 Hz ($p = .039$) (49). Differences were found among the four conditions and the four series for peak power (p =

.022 and p = .035), relative peak power (p = .028 and p =.036), FITRO dyne mean power (p = .012 and p = .003), and Lewis nomogram mean power (p = .014 and p= .018).The two-minute post-vibration trial had significantly higher mean power than all other trials (p < .05). Pre-vibration trial yielded lower FITRO dyne mean power values than trials post vibration (p = .035). The intermittent vibration at 50 Hz yielded greater mean power than the continuous bouts of vibration (p < .05) (49). McBride's study found a significant increase in peak force during MVC was observed IMM-Post (9.4%) and 8 min Post (10.4%) in the WBV group only (53). No significant changes in RFD were observed in either the WBV or S group (53). Jacobs, et al. found peak isokinetic force of knee flexion increased significantly (101.6 + 39.1 vs 109.8 + 40.2 Nm) as did knee extension (178.9 + 53.9 vs. 190.7 + 52 Nm (43). Cormie found peak force during slightly decreased from baseline, following both vibration and sham stimuli. Significant difference between treatments was observed in jump height from baseline immediately post treatment. Subjects jumped higher following exposure to WBV (19). Torvien, et al. found isometric lower limb extension strength increased 2.0 kg at 2 min after the vibration-intervention. Benefit of vibration diminished after 60 min. The vertical jump height increased 0.7 cm at 2 min after the vibration-intervention. The effect disappeared by 60 min after intervention. The mean power frequency of the soleus diminished systematically during the 4 min vibration (69). Our study found significant increases in VJH as many of the previous studies have found as well. The interesting result of our study was the significant increase in VJH, but that there was no significant increase in RFD post-vibration. Our data did not show a significant (p =.051) value for RFD, the trend of the data does suggest that vibration did have some effect on RFD. Statistically we cannot count this as a significant difference, however with it being so close to being significant there is a trend suggesting that it is moving toward being significant. If we could have had a larger subject population this value may have changed. Another effect on this value could be the training status of our subjects. The collegiately trained athletes overall had a higher vertical jump. Athletes that are more efficient in there movement can have a greater RFD. Athletes can create the force needed to jump higher in a shorter amount of time due to the training that is involved in there respectable sport. The mechanics involved in a vertical jump is important to providing the maximal height an individual can reach. There has to be proper timing of transfer of momentum in order to reach peak power output. Previous literature confirms that a counter-movement jump has a higher vertical jump height than a standing jump (18).

We have also seen from our study that not every subject responds to vibration the best at the same rest interval. How the subject responds to vibration exposure is on an individual basis. Every individual is made up of different muscle fiber compositions, and the makeup of the fiber composition can determine the amount of time that is effective for the individuals. Different individuals could respond to vibration at different exposure times and at different frequencies. Our study finds that vibration does increase VJH, but we still do not know the exact mechanism in which it does. Typically periodization methods of training are used to increase power output (6).

Conclusion

Athlete's today have even more pressure to perform on a high level than ever before. There is always someone waiting to get their chance to perform. When it comes time to perform the athlete wants to be at the peak of his game and be able to perform at that level day in and day out. And the truth is that level continues to rise year after year. Our study finds that whole-body vibration is a quick, effective modality to increase the power output of the athlete.

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