2013

The Effect of Whole Body Low Frequency Vibration on Absolute and Relative Peak-Z Forces in Vertical Jump Performance

Morgan Shields Hilton

THE EFFECT OF WHOLE BODY LOW FREQUENCY VIBRATION ON ABSOLUTE AND RELATIVE PEAK-Z FORCES IN VERTICAL JUMP PERFORMANCE

by

Morgan Shields Hilton

A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

Oxford

March 2013

Approved by

____
Advisor: Dr. John C. Garner

____
Reader: Dr. Martha Bass

____
Reader: Dr. Mark Loftin

ABSTRACT

MORGAN SHIELDS HILTON: The Effect of Whole Body Low Frequency Vibration on Absolute and Relative Peak-z Forces in Vertical Jump Performance

Coaches, trainers, and performers depend on sports conditioning to take an athletes performance to the next level. Because the mechanisms used during conditioning are so important for sports, research has been collected over many years to determine the best way to efficiently progress towards a better performance. A recently studied performance enhancing technique is whole body low frequency vibration (WBLFV). The purpose of this study was to show whether whole body vibration enhanced athletic performance with an increase in the absolute and relative peak-z forces and to determine an optimal rest interval between vibration and performance. Sixteen healthy female adults completed the study. WBLFV was given through a vertical platform at a frequency of 30 Hz, amplitude of 2-4mm, and duration of 4 bouts of 30s for a total of 2 minutes with a 1:1 rest ratio. The participant preformed a quarter squat every 5 seconds on the vibration platform. After WBLFV, the participant followed with 3-countermovement vertical jumps (CMVJ) on the force platform with 5 different rest intervals (immediate, 30 seconds, 1 minute, 2 minutes, or 4 minutes). The control condition required participants to perform quarter squats with no vibration exposure and then immediately perform 3 CMVJs. The results showed a significant (<0.05) difference between the control and vibration groups, vibration with greater force results in both absolute (p=0.009) and relative (p=0.003) peak-z forces. No significant (>0.05) difference was found between the rest intervals for both absolute and relative peak-z forces. This study supports that vibration does lead to a greater force development and potentially better overall performance, yet the parameters within the vibration technique need more review to show

vibration's full effectiveness. With further research, vibration may develop as a primary technique in certain athletic training regimes.

TABLE OF CONTENTS

Chapter I

INTRODUCTION

Vibration is a technique that prepares the body for action. Understanding the effects and parameters of vibration is necessary in order to evaluate the role vibration training plays in performance and function. Treatment, prevention, and physiotherapeutic settings have recently utilized vibration to help individuals overcome diseases such as osteoporosis (15, 26, 44, 67, 69). Vibration is also employed in strength and power training. Many studies investigate the affects vibration has on strength, power, body composition, and flexibility of an individual (13,22,67,73,82). Vibration has an impact on the total body and permits a large scale for application in sports, therapy, and exercise; however this study is mainly concerned with the sports benefits from vibration training. Many coaches, trainers, and athletes are searching for more efficient and effective ways to improve athletic performance. In recent years, vibration has become a popular interest in sport performance programs. Strength and explosive force is necessary in many athletic settings, and those areas need to be trained in order to improve overall performance. In sport and conditioning literature, whole body vibration has been shown to increase the forces that facilitate a greater power output (13,22,67,73,82).

The underlying mechanism of whole-body vibration is post-activation potentiation (PAP). There are many different forms for inducing potentiation such as: half-squats with varying loads, isometric maximal voluntary contractions (5 seconds), electrical muscle stimulation, and plyometric (2). PAP includes a series of twitches, tetanic contractions, and sustained maximal voluntary contractions (MVC). It is unclear the exact cause of potentiation, but the possible theories are either phosphorylation of myosin or increased motor neuron excitability assessed in the Hoffmann reflex (2,42). Potentiation shows an increase in range of motion (ROM), muscle temperature, and muscle force output at the single-muscle-fiber level (2). Potentiation also shows an enhancement in peak twitch force, and increases in the rate of twitch force development with less time to reach peak twitch forces (42). The twitch potentiation has shown to increase the rate of force development of isometric contraction during high frequency stimulation (42). As the force development increases, it is also postulated to increase peak velocity and power during dynamic muscle contraction performances (42). If potentiation exists, then the time frame of usage is small with a required plan to ensure that the effects are not undetectable because of fatigue (2).

Potentiation caused by vibration may lead to an increase in the explosive vertical forces (peak-z forces) necessary for enhancing vertical jump performance (41). Because of this, research for this study focuses on the magnitude of absolute and relative peak-z forces developed during the vertical jump test after vibration stimulation. The countermovement vertical jump is an easy and effective method to use for this study because it allows for peak-z (absolute and relative) forces to be collected. The sports that vibration most applies to also involve the vertical jump as the main movement action (i.e.: long-jump, high-jump, volleyball). The results after data collection showed peak-z forces are an important link between vibration exposure and sports performance enhancement. Absolute and relative peak-z forces can vary according to certain parameters defined during testing. Eliminating or manipulating any extra variables leads to a more definite result. The parameters of this study are frequency, amplitude, and duration of exposure, and rest intervals. Both frequency and amplitude have been manipulated in previous studies and a safe range has been defined for both variables (28,45,65). The amount of time allowed for vibration exposure has also been tested in previous studies, with a defined time frame to ensure activation without fatigue (4). Although there is research to support the possible strength benefits derived from vibration, there is a lack in evidence pertaining to the optimal rest interval at which vibration would produce the most performance benefits. Therefore, the purpose of this study was to test the effects of vibration on absolute and relative peak-z forces and to define the most optimal rest interval for enhancing the forces that lead to strength gains for better performance.

Definitions:

Antagonist: a muscle acting to slow or stop movement (36)

Concurrent Activation Potentiation (CAP): occurs during the activation of muscles that are the target of training (31)

Ground reaction forces (GRFs): The forces that act on the body as a result of interaction with the ground. Newton's third law implies that ground reaction forces are equal and opposite to those that the body is applying to the ground. (71)

Kinematics: the form, pattern, or sequencing of movement with respect to time (36)

Kinetics: study of the action of forces (36)

Post-activation potentiation (PAP): occurs after stimulation of the muscle nerve (40)

Quarter squat: knee extension not exceeding and angle of 135 degrees

Range of Motion (ROM): angle through which a joint moves from anatomical position to the extreme limit of segment motion in a particular direction (36)

Stretch reflex: monosynaptic reflex initiated by stretching of muscle spindles and resulting in immediate development of muscle tension (36)

Stretch-shortening cycle (SSC): eccentric contraction followed immediately by concentric contraction (36)

Warm-up effect: friction between the vibrating tissues causing a raise in muscle temperature and an increase in blood flow (13)

Hypotheses:

Vibration:

H_{0A}: Absolute and relative peak-z force will not be affected by whole body low frequency vibration.

H_{1A}: Participants will produce a significantly greater absolute and relative peak-z force after vibration exposure compared to the control condition with no vibration exposure.

A study conducted by De Hoyo Lora et al. used 12 participants that participated in recreational physical activity to test whole body vibration as a method for improving explosive strength. The participants performed 5 sets of 60s of WBLFV exposure while maintaining a static squat position on the vibratory platform (Galileo Fitness®; Novotech, Germany). The results showed an increase in squat jump and countermovement jump performance after vibration. In another study by Cormie et al., participants performed a vibration and no vibration treatment condition (20). A 30-second bout of whole body vibration was given for vibration conditions. Subjects were tested with the vertical jump after various rest intervals (immediately, 5 minutes, 15 minutes, and 30 minutes). The results showed a significantly higher jump height immediately following vibration intervention. Based on the increase in strength and jump height seen with vibration stimulation in previous studies, an increase in absolute and relative peak-z forces is expected.

Rest intervals:

H_{0B}: There will be no difference in the absolute and relative peak-z forces between all rest intervals with vibration.

H_{1B}: The absolute and relative peak-z forces will not show a significant difference between the rest interval conditions with vibration.

A study conducted by Dabbs et. al evaluated the effect of different rest intervals after whole body vibration (24). Thirty recreationally trained subjects received 4 bouts of vibration for 30 seconds with 30 seconds of rest between bouts. Participants performed countermovement vertical jumps after a variety of rest conditions (immediate, 30 s, 1 min, 2 min, or 4 min) and the control condition involved no vibration with no rest interval. Although vertical jump height was greater with vibration compared to no vibration, no significant differences were found on absolute or relative ground reaction force after whole body vibration conditions. In another study by De Hoyo Lora et al., the countermovement jump and squat jump were tested after vibration exposure. The study provided a 30-minute rest interval after vibration intervention. The values of the post-test performed 30-minute after squat jump remained above the pretest ones and just below the immediate post-test ones. However, the countermovement jump dropped below the pre-test results. Based on the previous research, the author expected to find no difference in absolute and relative peak-z forces across all rest intervals.

Chapter II

REVIEW OF LITERATURE

Vertical Jump

The purpose of this study was to examine whether vibration affected absolute and relative peak-z forces for improving athletic performance, and also to determine an optimal rest interval after vibration intervention. The vertical jump (VJ) is a key element in this study because it is a frequent predictor of sports performance outcomes. The VJ is performed after vibration and the rest interval, and provides important information for assessing the benefits that can be derived from vibration. Many areas of the sports world utilize the vertical jump. The vertical jump is composed of many mechanical concepts including, but not limited to jump phases, kinetics, and kinematics; as well as having a physiological aspect. The vertical jump contains components such as coordination, the contribution of body segments towards the vertical jump, and the performance mechanisms. When performing a vertical jump, the countermovement vertical jump (CMJ) and the squat jump (SJ) are two types that are often assessed for performance measures (33,59,81).

The vertical jump requires different phases in order to complete the rise and fall in the vertical plane that defines a vertical jump. The VJ is broken into three different phases: preparatory (down) phase, propulsive (up) phase, and a flight phase (56). During the preparatory phase the ankles dorsiflex, the knees flex, the hips flex, and the shoulders are hyperextended (56). During the propulsive phase, the ankles plantar flex, the knees extend, and the hips extend, with flexed shoulders (56). Joints experience positive acceleration at the end of the preparatory phase to the beginning of the propulsion phase (56). Take off is the beginning portion of the propulsive phase. Take off phase begins at the moment the take off foot has contact with the ground until maximum flexion in the knee of the take off leg occurs (56). Horizontal velocity transfers into vertical velocity at this phase due to the ground reaction forces (GRF) acting in backward and upward directions (18). The knee extensors undergo eccentric muscle activation during the start of this phase (18). The second part of take off involves concentric muscle contraction and ends when the take off foot leaves ground contact (18). In the initial take off portion during eccentric muscle action, the horizontal velocity decreases and the strongest GRF develops as a consequence to increased vertical velocity, which defines the flight height of the subject (18). Ultimately, the velocity transfer is due to the actual torque (or moment: the tendency of a force to rotate an object about its axis) produced by the countermovement revolving around the take off point, which serves as the center of rotation (18). The distance between the countermovement and the foot defines the "lever arm" and this causes the overall velocity transformation (18). In one study, a deeper CMJ before take off provided increased performance (81). The third phase is the acceleration, or flight phase. The final portion of the vertical jump is the landing. The landing begins when the velocity of the center of mass becomes zero and ends when the balls and heels of the feet touch the ground. Joints are stressed from absorbing the body weight during the landing phase and injury may occur (62). There are different types of landing. Landings made with the balls of the feet first and then with the heels produce smaller peak forces, compared to flat-footed landings (62). Making hard landings with high frequency can produce a large amount of stress in the joints of the lower body, which leads to injury (62). Landing technique can be improved by increasing the landing time to decrease the impact forces (62). Flexing the hip, knee, and ankles with proper coordination, can increase the landing time, but increased landing times may not be beneficial for sport goals (i.e. basketball rebounds) (62).

Leading up to take off, the ankle extends approximately 10 cm, but the ankle extensors are not able to produce the total work output for a maximal VJ (18). The VJ has three distinct phases according to muscle excitations. The first portion involves a plantar movement of the foot to accelerate the body in the vertical direction (77). The gastrocnemius and the soleus produce this action (77). During vertical acceleration, extension of the trunk is produced by simultaneous action of the rectus femoris and the vastus group (77). The gluteus group and the hamstrings may produce extension in the thigh (77). The hamstrings and the biceps femoris counteract the required motion of the trunk, meaning they are not controlled during the entire jump movement (77). The second phase, known as the flight phase, shows little muscle activation (77). Landing phase begins with the largest torque in the knee joint area, thus major activation of the rectus femoris and vastus muscle group for negative acceleration of the body after the landing (77). Pre-activation can be observed in the plantar flexors immediately before landing and is functionally necessary to stiffen joint complexes before mechanical loading (77). During eccentric muscle actions, muscles are able to develop high forces (77). The eccentric phase of the movement was identified from the displacement of the center of mass (COM) when the subject was in contact with the force platform (33). The concentric phase of the movement was identified from the displacement of the COM when the subject was in contact with the force platform (77). During a deep squat in the CMJ, high peak knee flexion occurs with a natural increase in peak hip flexion (11). The peak hip flexion keeps the COM balanced and the GRF vector in front of the COM for optimal forward rotations of the lower limbs during the propulsion phase (11).

A CMJ begins with the subject in an upright standing position, moves into a preliminary downward movement by knee and hip flexion, followed by immediately extension of the knees and hips again to jump up vertically from the ground (50). CMJ benefits from the stretch–shorten cycle (SSC) (50). The countermovement jump is a much more natural jumping movement and most people can jump several centimeters higher in a CMJ than in a SJ (50). When performing a maximum height VJ, most subjects execute a countermovement that results in a coordinated flexion of the hips, knees and ankles and a following of rapid extension of these same articulations before take off (50). The CMJ has kinetic energy build up between the initial stance and take off phases of the jump (81). A SJ begins in a stationary semi-squatted position, then rapid extension of the knees and hips to jump vertically up off the ground occurs (50). There is no preliminary downward phase, thus the jump does not involve pre-stretching of the muscles (50).

The superiority of the CMJ over the SJ becomes apparent when comparing the force–displacement curves (50). Studies suggest that one advantage of a CMJ involves the leg muscles attaining a higher level of activation and force before they start to shorten (50). In the squat jump, the force at the start of the upward phase of the jump is equal to the jumper's body weight (50). By moving upwards, activation of the leg muscles is greatly increased, but it takes time and distance for the GRF to build up to a high level (50). In contrast, the GRF at the start of the upward phase in the CMJ is already much greater than body weight; and the activation and force in the leg muscles are high because the jumper has to slow and then reverse the initial downward motion, thus performing more work early in the upward phase of the jump (50). The jumper achieves a higher takeoff velocity and a greater flight height in the CMJ (50).

There are a variety of possible mechanisms responsible for the enhancement of force in the CMJ. Some argue that pre-stretching of the muscles allows the muscles to develop a higher level of active state and force before starting to shorten (50). Others argue that the extra work in the CMJ is from a release of elastic energy that has been stored in the muscles and tendons during the pre-stretch (50). Another mechanism explains that the enhancement through 'potentiation' of the contractile proteins in the muscle, or through the contribution of the spinal reflexes causes greater force in the CMJ (50). The speed of a CMJ can be manipulated by the more vigorous a preliminary downward phase of the CMJ leading to a higher jump because of the greater force at the beginning of the upward phase (50). A run-up to the jump produces more work and allows greater height achievement due to kinetic energy (KE) conversion into potential energy (PE) (50). The difference in jump height between the CMJ and the SJ is related to the amount of joint work, especially the joint work of the hips (80). CMJ causes a higher jump height because of a greater time for force development, more storage and reutilization of elastic energy; potentiation of contractile machinery, and the contribution of the reflexes (80). The role of elastic elements in series with contractile elements cause pre-stretched active muscles to absorb energy and temporarily store the energy in series elastic elements that are later utilized during concentric muscle activity (80). This mechanism is referred to as "elastic potentiation" and is said to enhance the maximum work produced during the concentric phase (80). The eccentric phase in the countermovement vertical jump sequence is always immediately followed by the concentric phase. The eccentric phase is termed an active pre-stretch mechanism that is beneficial to the overall jump. When performing the concentric phase, it is greater with an increase in the eccentric loading because the range of stretch of the muscles and joints are enhanced (59). WBLFV exposure elicits both concentric and eccentric muscle actions, as does the multi-segmented VJ (13). Pre-stretching within the CMJ or WBV enhances the concentric muscular contraction and excitatory responses of the muscle spindle must exceed the inhibitory effects of the Golgi tendon organ (GTO) (13).

The SSC enhances the performance of the concentric action (47). It is discussed as a mechanism for potentiation and the CMJ serves as a basic model for the SSC (47). The SSC involves muscle actions in which the concentric phase is immediately followed by an eccentric phase, referred to as the pre-stretch (80). It is suggested that a pre-stretch enhances the maximum work output that muscles can produce during the concentric phase (80). Some believe that the extra work is from release of elastic energy that has been stored in elastic components of the muscle-tendon complex during the pre-stretch (80). The SSC requires a well-timed pre-activation of the muscle before the eccentric phase, a short and fast eccentric phase, and immediate transition between stretch (eccentric) and shortening (concentric) phases (47). Movements like running, jumping, and throwing involve muscle actions in which the desired motion is led by a movement in the opposite direction (50). Muscles are supposedly 'pre-stretched' before shortening in the desired direction (50). Many studies have shown that pre-stretch enhances the force production and work output of the muscles in the successive movements (50).

The stretch reflex may make a contribution during the eccentric phase of SSC by regulating muscle stiffness (47). Muscle length from origin-to-insertion and muscle fiber length were both measured and showed high stretch velocities in the early contact phase, meaning the muscle spindles were activated (47). Motor output efficacy is determined by powerful force output (47). In the SSC, force output is accomplished by immediate transition from the pre-activated and eccentrically stretched muscle-tendon complex to the concentric push off (47). High stretch reflex may be expected after a powerful stretch of an activated muscular system (47). Tension during the stretch reflex is built by activity sent to the muscles before contact and the forceful hesitation of the cross-links of the actomyosin complexes with a loss of potential energy that was stored in the lengthened cross-bridges (47). The stretch-reflex system generating muscle activation is shown by the latencies of the EMG peaks in the stretched muscles after ground contact that match well with the stretch responses observed after mechanical stimulation (47). The instantaneous force-length and EMG-length curves show muscles in an isometric state after contact and the stretch reflex system provides high linearity in muscular stiffness meaning that the stretch reflex leads to activation (47). Elastic storage existence favors the reflex activation by the muscles providing tension in the tendon-muscle complex that leads to tendon length changes (47). All supporting evidence suggests that the stretch reflex does contribute to force generation during touchdown in the SSC VJ activity (47). Storage and reutilization of elastic energy in repetitive SSCs improve the economy of movements by lowering metabolic costs when a required increase occurs in the mechanical energy of the concentric actions of the contractile elements in the involved muscle (80). The SSC has positive and negative work phases (80). Work done during the concentric phase of the SSC is a portion of the contractile machinery and only part of the positive work can be related to metabolic energy according to efficiency in thermodynamics (80). In the negative work efficiency approach, negative work is assumed to perform at metabolic costs (80). In most studies, it is shown that the negative work absorbed by the muscles during pre-stretch is considerable larger than the amount of positive work done by the muscles during the concentric phase (80). In eccentric actions, mechanical energy is taken from the system and converted to heat (80). Sport action is determined by the mechanical output produced during the concentric phase (59). Research suggest that the magnitude of enhancement in mechanical output of the concentric phase is greater with increased eccentric loading, a greater range of stretch (with a fixed shortening range), and a decreases in in the shortening range (59). However, in many complex multi-joint movements, it is not possible to increase the joint range of stretching without also increasing the range of shortening (59).

The calculation time of the jump movement depends on the initial conditions as well as the biomechanical parameters (77). The kinematic variables calculated during the vertical force include: time in the air , which is the period between takeoff and contact after flight; vertical velocity at takeoff that is the net vertical force trace that used body mass to calculate the vertical velocity of the COM at takeoff, which began at the start of the jump and ended at takeoff; and total vertical displacement of the COM, being the total vertical displacement of the COM from the starting stance to the highest displacement achieved during flight (58). The kinematics of the VJ requires calculation of total positive vertical displacement of the COM from the subject's starting position to the maximum vertical projection during flight (58). Kinematics also includes: countermovement depth, which is the negative displacement of the COM when the subject was in contact with the force platform and is calculated through the double-integration of the net vertical force trace once the trace had been normalized to body mass; positive vertical impulse, the integration of the vertical force trace above body weight provided the positive vertical impulse during propulsion; negative vertical impulse, the integration of the vertical force trace below body weight provided the negative vertical impulse during propulsion (58). Vertical stiffness during the contact phase of the jump was calculated as the ratio of the vertical force to for VJ kinematic measures (58). Peak rate of force development during the concentric phase means the greatest value of the vertical force with respect to time that occurred during the concentric phase of the movement (58). Peak rate of force development during the eccentric phase is measured like the concentric phase, but is calculated during the eccentric phase of the movement (58). Average rate of force development during the concentric phase and the average rate of force development during the eccentric phase is calculated (58). Angular orientation, velocity and acceleration of the foot, lower leg, thigh and trunk, were computed as kinematics variables of the VJ (33).

Joint kinetics involves the proximal resultant joint force and torque exerted at the ankle, knee, hip and shoulder (33). The foot was subjected to proximal resultant joint torque; and the ground reaction force applied at the center of pressure, weight at its COM, and a proximal resultant joint force (33). The lower leg and thigh were subjected to a proximal resultant joint torque at the knee or hip and a distal resultant joint torque (33). The three forces of weight at its COM, a proximal resultant joint force at the knee or hip, and a distal resultant joint force acted on the lower leg and thigh. The forearm and hand segment was exposed to weight acting at its COM and a proximal resultant joint force and resultant joint torque. A proximal resultant joint torque at the shoulder and a distal resultant joint torque acted on the upper arm segment (33). The moment of inertia values can also be extrapolated for kinetic VJ data (33).

Linthorne provides a detailed explanation of the kinetics and kinematics involved during the VJ with a countermovement (50). The jump begins with the subject standing in the upright position (50). The leg and hip muscles are relaxed, allowing the knees and hips to undergo flexion due to gravity. The resultant force on the subject becomes negative and the COM accelerates downwards. As the subject reaches the maximum downward acceleration, the subject begins to increase the leg muscle activity and decrease the downward speed. The GRFs are equal to the body weight at this point, and the resulting force and the COM of the subject are both zero, marking downward velocity. This entire phase is referred to as the "unweighting" phase because the GRF is less than the body weight. The subject begins upward acceleration and the resultant force is now positive as the leg muscles are strongly activated and the GRF is close to maximum. This phase is referred to as the "push off" phase where the subject moves up by extension of the knees and hips and the velocity becomes positive. Usually, the maximum GRF occurs early in the push off phase. Although the subject is still moving upwards before the flight phase, the velocity has stated to slow due to gravity right before take off. When take off occurs, the GRF becomes zero. The COM is higher at take off then at the start of the jump due to extended ankle joints. The COM moves up as the subject ascends into the flight phase, then the peak of the jump is reached and the COM is temporarily at rest. The decent of the flight phase begins where the COM is moving downwards, the velocity is negative, and the speed is increasing. An impact peak is shown by the GRF that eventually becomes equal to the body weight when the jumper is again stationary and in the upright starting position on the force platform.

The VJ measures human power by the peak force and jump height produced during the jump that results from the net muscles moments created by the knee and hip extensors and ankle plantar-flexors during the propulsion phase (19). It is suggested that peak vertical GRF is a good indicator of lower extremity muscle strength and strongly predicts functional performance (19). The force exerted on the human body by the platform or surface is called the ground reaction force (GRF) and it follows Newton's third law of motion (50). GRFs signify the intensity and duration of stress (force) loaded on the body during contact with the ground (55). GRF allow identification of which movements have high peak component forces and impulses (55). These forces also determine the rate at which these peak forces occur after ground impact (55). The less time to reach peak force implies greater stress for the body and greater impulses translate into larger velocity changes, which mean greater strain is possible to the musculoskeletal system (55). During the McClay et. al study, the COP pattern for the subjects indicated that the toe and forefoot made initial contact with the peak GRF being approximately 1.5 times the body weight (55). The next phase landing pattern moved the center of pressure to a position directly beneath the calcaneus with GRF being 4 times body weight (55). A more flat-footed landing pattern was indicated by the COP patterns remaining in the mid-foot region and resulted in GRF nearly 6 times body weight (55). In one study, the GRF in the vertical direction exceeded the subject's body weight by 5.6 times and in the concentric take off phase the maximum GRF was 9% lower than the eccentric phase (3).

During a VJ, the subject must overcome body weight, and the resultant force acting on the jumper's COM is the GRF acting on the subject (50). Curves of force–time, acceleration–time, velocity–time, displacement–time, and force–displacement are calculated from the GRF obtained from the force platform (50). The flight height is calculated from the force platform data by the flight time method, impulse-momentum method, and the work-energy method (50). All three methods calculate the flight height by the velocity of the COM at the moment of take off (50). The law of conservation of mechanical energy is applied to the flight phase of the jump when relating flight height and take off velocity (50). Changes in KE and gravitational PE is considered between the point of takeoff to the instant the subject reaches the peak of the jump (50). During the flight time method, the initial time is at the instant of takeoff and the final time is at the instant of landing (50). The impulse-momentum method involves the integral of a force over time (i.e., impulse) that produces a change in the momentum of a body (50). The impulse–momentum theory is applied to the ground contact phase of the jump, starting from when the jumper is stationary to takeoff (50). The work-energy method is the integral of a force over displacement (i.e., work) that produces a change in the kinetic energy of a body (50). The work–energy theorem is applied at the ground contact phase of the jump, starting from when the subject is stationary through to take off (50).

The impulse-momentum relationship exists in the VJ because the product of the applied force and time, which is impulse, determines the change of momentum an object has (19). Momentum is the product of a mass and its velocity (19). In the force-time curve, impulse is the area under the curve and can easily be calculated by multiplying the magnitude of force by the duration of time at each point in the curve (19). Vertical impulse is a function of force and time, and represents the interaction between force generated and time during the jump; thus change in vertical impulse is dependent on changes in either force or time (19). In the VJ, the body pushes into the ground and GRF push back on the body to cause an increase in velocity of the body and a maximized time in which the applied force is acting (19). For VJ activity, a compromise between the development of maximal force and maximal time of force production needs to exist (19). When more time is provided for the force to accelerate the body during the jump, there is a greater applied force for greater take off velocity (19). One study found that subjects who acquired the greatest jump height achieved the greatest vertical velocity at take off, which results from a greater vertical impulse (19).

Coordination principles are defined by the CMJ by increasing the lower limb joint angle ROM for a more effective position in jumping (11). Coordination is the pattern of body and limb motions that relate to the pattern of environmental objects and events (38). Coordination involves limb movement in specific time and space patterns with the muscles working together to produce a movement pattern that meets task demands (38). Inter-limb coordination of the human system in shown with the strong relationship between knee and hip joint ROM allowing for optimal muscle contractile conditions (11). It is shown that subjects with a more skilled jumping action use a knee-hip coordination pattern involving greater knee flexion while maintaining less hip flexion in the jump (38). Coordination is important when studying the VJ and GRF applied to the body (10). A factor that impacts GRF is joint stiffness. The stiffness accounts for the rigidity in the ankle to protect the joint during landings that are made stressful by the GRF that act upon the joints (10).

Different muscles and body segments impact the vertical jump through coordinated and independent movements. Lower and upper body portions affect vertical jump height. In the lower body, the hip, knee, and ankles all contribute to jumping either through independent sectional extension and flexion, or multi-segment coordination. In one study, the strengthening of mono-articular hip extensors with mono-articular knee extensors produced an increase in vertical jump height (33). The upper body impacts on vertical jump height are due to the presence or absence of arm-swing in a CMJ. Adding arm motions into the VJ may affect the magnitude of the vertical components of the GRF and enhance the propulsive and net impulses exerted on the subject (33). Larger net impulse results in increased vertical velocity of the COM of the body at take off and flight height (33). Some suggest that arm motion reduces the magnitude of the maxima values, but increases the magnitude of the local minimum to have an overall effect of increasing jump height (33). As the lower body musculature proved an advantage in exerting GRF, the upward acceleration of the arms was seen to create a downward force on the body at the shoulders that slowed the rate of the shortening of the quadriceps and the gluteal muscles (33). In accordance with the force-velocity relationship for muscular contraction, slower concentric actions of the leg muscles lead to enhanced muscle tension and larger vertical GRF (33). Arm swing used during the VJ shows an increase in peak force (19). Arm swing in the CMJ proves a natural tendency because it is shown to require less practice than a CMJ with no arm swing (13).

The components of a vertical jump help to define the movement as a necessity in sport and recreational performance. Each phase of the vertical jump sequence is created by specific muscle actions, contractions, and coordination. The mechanical principles of muscle activation, recruitment, the SSC, the stretch reflex, joint motions, force production, and elastic energy are paired with the vertical jump. Coordination of the upper and lower body segments play a major role in the performance aspect of the vertical jump. All the elements presented work together in producing the upward movement of an individual's center of mass in the vertical plane.

Vibration and Force

Vibration is defined as a wave that is transmitted from the distal to proximal segment of muscle groups and usually involves a contraction (i.e. squat) produced by the participant during vibration exposure (45). Vibration is also termed a mechanical stimulus characterized by oscillatory motion (7). The intensity of vibration can vary according to the amplitude and frequency of the oscillatory movements. The waveform of vibration may be of a deterministic or random form. Random form is shown in more sport-type activity, while deterministic waveforms are produced by commercially available vibration platforms (45). Acute vibration training ensues a rapid and repetitive eccentric-concentric action that causes muscular work and increases the metabolic rate of the subject (15,16). Vibration training is performed by applying vibration to an isolated extremity by using specially designed pulley machines, or by the more common approach of whole-body vibration training (45).

There are certain advantages and disadvantages associated with vibration. The advantages of vibration on the body are shown through rehabilitation and prevention benefits, as well as performance enhancement. Vibration is used to help clear the lungs of patients with respiratory problems, to enhance movement and muscle function in athletes, and to help those suffering from diseases such as arthritis and osteoporosis (15). Vibration is also used to treat the stumps of amputated limbs, and to improve muscle function in spastic and uncoordinated individuals (45). Overall, vibration provides the additive affect of relief to muscular and skeletal structures in therapeutic situations and a performance enhancement for most populations (15). The negative effects of vibration are often associated with chronic exposure to large loads of vibration. During long-term vibration exposure, this technique may cause damage to several structures including peripheral nerves, blood vessels, joints, and perceptual function (45). The body's response to vibration depends on the frequency, magnitude, duration, and type of vibration applied to the subject. Depending on the specific amplitude and frequencies, vibration can be dangerous. Vibrations are delivered to the whole body by platforms in low, safe ranges of frequencies between 15 and 60 Hz and displacements 1 mm to 10 mm (82). The impacts of vibration are also dependent on an individual's genetics, gender, mass, and muscular/skeletal structure (82).

Application style plays a major role in determining the impacts from vibration. Vibration can be applied directly or indirectly. Direct application of vibration is brief (2-15 s). It is set at a high frequency (100-150 Hz), and given in small amplitudes (1-2mm); whereas, indirect vibration is applied to the whole body at lower vibration frequency (5-45 Hz) with a higher amplitude (2-10 mm), and a longer duration of either continuous (3-5 min) or intermittent (30-60 s) exposure (16). Direct application can be used on smaller segments of the body such as specific muscles or tendons.

Vibration platforms and an electric powered vibrating dumbbell are two commercial vibration products on the market. There are two types of vibrating platforms.

The first vibration platform transmits vibration through the body by vertical sinusoidal vibrations (VV), and the second type utilizes a side-alternation motion (SV) (16). The first platform produces vertical synchronous vibration where both legs vibrate as the platform moves in the vertical direction resulting in simultaneous and symmetrical motion of both sides of the body during exposure (16). The second type of platform oscillates around a central axis, while a crankshaft on both sides of the platform produces a rotational motion of the electro-motor and translates into a vertical displacement, evoking a seesaw motion. The amplitude is smaller when closer to the central axis and larger at the edge of the platform (0-10 mm) (16). The vibration dumbbell produces VV vibrations and targets the upper body as the central handle of the dumbbell rotates to produce oscillatory movements to the body (16). Vibration platforms allow for the subject to perform standing dynamic or static exercises while on the platform. In a previous study, SV and VV platforms were compared and provided that in SV vibration the pelvis hinders vibration energy more so than in VV vibration. Vibration transmitted to the upper-body and head was greater during VV than SV (16). Another study was performed investigating the muscle activity shown in SV and VV at a frequency of 30 Hz and an amplitude of 4 mm. Results show that during dynamic (from 10° to 35° of knee flexion, at a tempo of 4 s up and 4 s down) and static squatting at 18.5° knee flexion, the vastus lateralis and gastrocnemius as lower limb extensors were activated significantly more in SV than in VV; yet, activation of the tibialis anterior was significantly greater during VV than SV (16). There are three different vibration platform devices available. A study measured 3-dimensional platform accelerations of three different WBV devices with and without three volunteers of different weight (62, 81 and 100 kg) in the squat position (150° knee flexion) (64). They also measured the transmission of vertical platform accelerations of each device to the lower limbs tested on eight healthy volunteers in the squat position (100° knee flexion). The devices tested were two professional devices, the PowerPlate and the Galileo-Fitness, and one home-use device, the PowerMaxx. The first series showed that the platforms of two professional devices vibrated in an almost perfect vertical sine wave at frequencies between 25–50 and 5–40 Hz, and platform accelerations were slightly influenced by body weight (64). The PowerMaxx platform mainly vibrated in the horizontal plane at frequencies between 22 and 32 Hz, with minimal accelerations in the vertical direction. The weight of the volunteers reduced the platform accelerations in the horizontal plane but amplified those in the vertical direction about eight times (64). The vertical accelerations were highest in the Galileo (~15 units of g) and the PowerPlate (~8 units of g) and lowest in the PowerMaxx (~2 units of g). The second series produced the transmission of vertical accelerations at a common pre-set vibration frequency of 25 Hz were largest in the ankle and that transmission of acceleration reduced ~10 times at the knee and hip (64).

During vibration of the body, skeletal muscles undergo small changes in muscle length (4). Five factors dictate the human skeletal system's response to WBLFV platform exposure: vibration direction (vertical vs. oscillatory alternating), vibration frequency (Hz), vibration amplitude (displacement, in mm), acceleration (in gravitational units), duration of WBLFV application, and body position/posture on the platform (26). Unfortunately, there is a lack of definite guidelines that can be prescribed for determining the optimal amount of vibration variables to use in experimentation. Research aids in narrowing the determined range of each variable's amount used for experiments. Matthews et al. reported that in de-cerebrated cats, increasing vibration amplitude caused an increase in tonic vibration reflex (TVR) (53). TVR activated a larger number of muscle-spindle endings, causing more alpha (α) motor neurons to be activated; however, the range of amplitude that caused the increase occurred between 25-150 μm (82). In determining optimal amplitude, Moran et al. argued that higher vibration amplitudes may only benefit submaximal contractions and suggested that in maximal voluntary contractions the Ia afferent release may reach a threshold of saturation where vibration is unable to cause further increases in Ia-afferent inflow. Supporting evidence states that vibration can only increase maximal isometric contraction force and EMG activity when fatigue is present in the intrafusal fibers or when α-fibers are blocked (16, 45). Frequency strength in vibration is determined by testing a spectrum of different frequencies on the body. Vibration ranging from 1-20 Hz causes blurry vision, whereas vibration at frequencies between 20-70 Hz results in resonance of the eye (45). Vibration between 2-20 Hz may elicit a cardiovascular response similar to that of moderate exercise, and vibration at 120 Hz results in an increase in fetal heart rate (45). In one study, the individual frequency used during whole-body vibration for each participant was estimated on the basis of EMG activity and found that the optimum frequency selected for WBLFV varied between the participants (28). The individualized frequency produced greater responses from the muscular system in Di Giminiani et al. study and proved more beneficial than fixed pre-selected frequencies (28). A study by Petit et al. showed that high frequency/high peak-to-peak displacement was the most effective vibration setting in enhancing knee extensor muscle strength and jump performance during a 6-week

WBLFV training program and that these improvements were not mediated by central neural adaptations (65). A study by Mathieu et al. investigates whether a WBLFV training program gives results in an enhancement in strength and postural control. Isokinetic plantar and dorsiflexion peak torque, isokinetic knee flexion and extension peak torque, explosive strength (high box test), and postural control were assessed before and after the training period. In the results, both training programs significantly improved isokinetic ankle and knee muscle strength and explosive strength. The increases in explosive strength and in plantar-flexor strength at low speed were significantly higher in the WBLFV group than in the equally resistant control group (ER) after 6 weeks. However, neither WBLFV training nor ER training seemed to have an effect on postural control (52). WBLFV claims some significant benefits, but WBLFV may not induce more significant benefits in relation to other training regimes.

There is not enough evidence in current vibration studies to suggest one exact mechanism by which it causes strength and power gains. One theory provides that mechanical stimuli causes muscles fibers to stretch, inducing the stretch reflex, which increases neuromuscular function through neuron excitability and recruitment of muscular components (17). EMG activity and the enhancement of the H-wave to M-wave ratio of the Hoffman reflex support the vibration theory (17). Usually, neural adaptations are responsible for strength increases after short-term training programs and most assume the strength and power gains after WBLFV programs are due to neural adaptations as well (46, 65). The TVR response from direct vibration of the muscle belly or tendon strengthened the evidence for strength gain via neural adaptations causing muscle activation. It was assumed that WBLFV would cause the same response in the muscle as direct vibration application (65). Muscle spindle primary endings are the proposed cause for TVR because of their great response to vibration, so most studies focus on understanding the neuromuscular response to WBV (7).

TVR is a proposed mechanism to explain the enhancements vibration causes on muscle force, power, flexibility, proprioception, and balance. TVR involves spinal reflexes that enhance muscle contraction, thus increasing muscle activation (16). TVR results when vibration is applied directly for a short amount of time at a high frequency to promote a temporary increase in muscle activation (61). When vibration is applied to the whole body for a TVR response, the frequency and amplitude is low and the source of vibration is under the feet (61). According to Bishop, four factors affect the TVR response: the location of vibration, the excitability state of the central nervous system, the initial length of muscle (i.e.) pre-stretch, and the amount of vibration frequency and amplitude. Research suggests that the initial muscle length affects the strength of the TVR, where a larger lengthening of a muscle will induce a stronger TVR (4,15,16,45,82). The amplitude of vibration determines the amount of stretch available to the muscle. This mechanism is said to serve as the main evidence for neurogenic potentiation by using the vibration stimulus to augment muscle spindle activity, leading to an excitatory response in the primary endings of non-contracting muscles. As a result of the direct vibration, muscle contraction occurs with reciprocal inhibition of the antagonist muscles that elicit an excitatory response of the Ia fibers that are mediated by the synaptic and polysynaptic pathways (16,45).

Reciprocal inhibition depresses the excitability of the motor neurons innervating the antagonist muscles, while the monosynaptic stretch reflexes of the vibrated muscle are suppressed during the exposure (16). As the vibratory stimulus is applied to an agonist muscle, reciprocal inhibition of the antagonist motor neurons occurs. However, when vibration is applied at the same time to both the agonist and antagonist muscles the facilitator effect of each muscle group is repressed (16). De Gail et al. and Marsden et al. found that vibration also causes suppression of the muscle's phasic stretch reflexes. Arcangel et al. observed that during vibration of the Achilles tendon reflex, the tendon reflex and the Hoffmann response (H-reflex) were suppressed; yet, in the post-vibration period the reflexes were activated, showing that pre-synaptic inhibition of the Ia afferent terminals occurred in the study (16,45,49). More recent experiments on direct vibration application with more than 30s of exposure show a decrease in voluntary muscle activation (61). The exposure time qualifies for WBLFV, meaning that TVR may not be the cause for muscle activation stimulated by vibration.

Muscle tuning is an alternative neuro-mechanical based mechanism. It involves the muscular system inhibiting the vibration stimuli to promote muscle activity, therefore increasing muscle function (16). In muscle tuning, forces of impact create vibrations that travel through the musculature of the body. Soft tissues of the body stop vibrations to prevent resonance, which cause sensory organs to send impulses to the central nervous system to increase muscle activity and adjust joint stiffness (16,82). The muscle tuning mechanism relies on input force, vibration response of the tissue, and the level of muscle activity (16). Motor unit recruitment, synchronization, and co-contraction may be neuromuscular elements that are factors in force and power increases following acute vibration application (16).

A mechanism named the warm-up effect is defined as the friction between the vibrating tissues causing a raise in muscle temperature and an increase in blood flow. This effect may contribute to the explanation of vibration causing muscular performance enhancements (13,15,16). The stimulation of the Ia neural drive and proprioceptive loop by vibration is thought to replicate the warm-up effect due to an increase in pain tolerance, blood flow, and muscle elasticity (15). Some studies have cited the correlation due to findings of thixotropism production reducing blood viscosity and vasodilation that suggest an increase in mean blood flow after acute WBLFV (13). Vasodilation caused by WBLFV results in an increase of cutaneous and deep vessel blood flows and muscle temperature that may increase muscle elasticity (35). Pain sensation is reduced after vibration to increase the pain threshold and promote greater range of motion (ROM), which is linked to the warm-up effect (15, 35). Flexibility is enhanced by the stimulation of the central nervous system, hormones, and proprioceptor adjustments (35). Sensitivity of the stretch reflex is greatly affected by vibration and inhibits activation of the antagonist muscles by the Ia-inhibitory neurons that ultimately increase coordination (17,35). Muscle stiffness is altered by the firing of alpha and gamma motor-neurons that are triggered by fast changes in muscle length and joint rotation during vibration; and the Ib pathway produced by the vibrations excite the GTOs to inhibit muscle contraction and promote muscle relaxation (35). One study supported the increase in blood flow following vibration and explained the outcome may have resulted from "a reduction in the release of the vasoconstrictor endothelin from smooth muscle into the vessel cavity during vibration leads to vasodilatation" (46). EMG studies reveal that vibration stimulates muscle activation, thus prompting muscle training (46).

Potentiation can be described by its mechanism of action, such as the reflex potentiation (H-reflex) and twitch potentiation, or by a time element, which includes short-term potentiation, long-term potentiation, post-activation potentiation (PAP) and concurrent activation potentiation (CAP) (31). The twitch potentiation (TP) effect enhances peak twitch force after CC, increases the RFD, and decreases the response time of the twitch (41). A twitch is a brief muscle contraction following a presynaptic action potential, or single, synchronized volley of action potentials (41). The magnitude of potentiation is dependent on the intensity and duration of the induced voluntary contraction, as well as the muscle fiber type (41). It was found that maximal voluntary contractions (MVC) lasting 10 seconds produced the greatest TP and appeared most in fast (Type II) muscle fibers due to greater phosphorylation (41). Neuromuscular potentiation is also measured by the H-reflex. The H-reflex is a monosynaptic reflex induced by an electrical stimulation of Ia-afferents of the muscle nerve. The H-reflex occurs because of sensory fiber stimulation exciting the motor neuron pool (31). When the potential threshold is overcome, the action potential is generated and the muscle fibers innervated by that neuron become activated (31). Following volitional activation, post-activation depression (PAD) and post-activation potentiation (PAP) are found (41). PAD is caused by mechanisms at a presynaptic level related to a reduced transmitter release from previously activated fibers (41). PAD develops at muscle relaxation and can last 10-60 seconds or can persist for several minutes (41). After stimulation of the muscle nerve occurs, PAP develops after several seconds and can last from 1-16 minutes depending on the subject and parameters of the stimulation (41). Potentiation can occur to enhance muscle power through the neuromuscular system by stimulation of Ia-afferents (muscle spindles) leading to motor neuron activation with increased spatial recruitment (13). The stretch-reflex pathway is enhanced and causes an increase in sensitivity of the primary endings of the motor neurons (13).

Concurrent activation potentiation (CAP) occurs during the activation of muscles that are the target of training (31). CAP is commonly explained through the Jendrassik maneuver, remote voluntary contractions, and cortical motor overflow. The mechanisms of CAP must consider the potential effects of motor overflow, along with the theoretical explanations of Jendrassik maneuver with the H-reflex (31). Other possible explanations of CAP include increased activity of the alpha motor neuron activity, gamma loop, muscle spindle, and descending cortical input, and stimulus invoked afferent input resulting in inhibition of the presynaptic inhibition and postsynaptic changes in membrane potential (31).

Potentiation can also occur after the warm-up activity. PAP is evoked through voluntary conditioning contraction activities that include, but are not limited to, a series of isometric twitches, an isometric tetanic contraction (sustained contraction without relaxation), continuous isometric maximal voluntary contraction (MVC), and a series of dynamic contractions (75, 78). PAP potentially increases peak force and rate of force development (78). The mechanism of PAP is dependent on activity that causes muscle contraction and the PAP stimulus has been found to last between two-to-thirty minutes (43). The PAP phenomenon occurs when acute muscle force output is enhanced by contraction (17,70). Loading the neuromuscular system prior to explosive movements (i.e. vertical jump) allows for the system to reach an "excited" state that supposedly enhances performance with increased force output from PAP (70).

There are two theories behind the PAP phenomenon. Electrically induced contractions demonstrate PAP through both phosphorylation regulation and alpha-motor neuron excitability changes in the H-reflex (41). The first theory claims enhanced muscle force production at the structural level. Increased phosphorylation (ATP production) of myosin proteins during MVC causes actin, another muscle contraction protein, and the myosin-binding site to be more sensitive to Ca^{2+} released from the sarcoplasmic reticulum (17, 41, 43, 75, 78). Increased muscle activation leads to a greater duration of Ca^{2+} in the sarcoplasm of the muscle; thus, faster contraction rates and faster tension development (43,75). The second theory is coupled with the Hoffmann Reflex (H-reflex). The H-reflex occurs with excitation of the spinal reflex by Ia-afferent muscle nerves. The theory proposes that PAP enhances the H-reflex, which increases the efficiency and rate of nerve impulses to the muscle (43,70,78).

PAP operates as a net potentiated response with a number of possible underlying mechanisms (70). PAP works by applying a load to the body to stimulate the central nervous system to increase motor unit recruitment and force development before the actual performance (70). A balance relationship exists in PAP between enhanced mechanical power output and fatigue (26). This balance determines the net effect PAP can provide on enhancing the performance of explosive activity. The PAP-fatigue relationship is affected by several variables including conditioning contraction volume and intensity, recovery time after the conditioning contraction, type of contraction, type of successive activity, and the subject (26). Optimal performance occurs when fatigue has subsided but the potentiated effect still exists (41).

Studies show that PAP may enhance performances that include fast shortening contractions (i.e. jumping) by increasing the isometric rate at which force is developed (13,75). Fast twitch (Type II) muscle fibers have a shorter twitch contraction time. A study that tested muscle twitch response and muscle fiber distribution showed that PAP is most effective when there is a greater amount of Type II fibers in the contracting muscle (43). Other research has shown that PAP has a great impact on performances where motor units fire at relatively low frequencies and use more slow twitch (Type I) fibers, such as in endurance training (41,75). Hamada et. al concluded that because endurance athletes have a greater resistance to fatigue, the PAP effect can delay the onset of fatigue to enhance performance (43). PAP indirectly causes a delay of fatigue onset by a decrease in motor unit firing rate by reducing the number of nerve impulses and muscle action potentials. Also, PAP increases the force output for a given motor-unit firing rate, which relieves the motor neurons from maintaining a high level of excitation (75).

PAP does not affect the force of high frequency tetanic contractions due to saturation and reduced sensitivity of Ca^{2+} concentration during these contractions (75). However, PAP increases the force of shortening (concentric) contractions (75). Because strength and speed performance usually requires motor units to discharge at very high rates, and PAP cannot increase high frequency force, PAP seems to show little benefit during these activities (75). Although studies have suggested minor benefits through PAP, complex training is derived from its principles. Complex training is a strategy that uses PAP by loading with a heavy resistance exercise (HRE), then preforming an explosive movement (i.e. plyometric) with similar biomechanical characteristics (41). The HRE with the explosive movement is called a complex pair (41). Complex training is performed over a long period with many sets that will eventually produce changes in the muscle and enhance power performance (41).

WBLFV is a current prescription in training and exercise programs because it may provide a neurogenic potentiation to the muscle that other traditional exercises do not offer (14). The vibration waves in WBLFV are not specific to one muscle or muscle group, but instead, it should affect the whole body. The lack of specificity and consequences of reciprocal inhibition lead to a focus on the agonist and antagonist muscle groups affected during WBLFV for an increase in coordination to increase strength (61). WBLFV would need to cause a continual increase in maximally activating the agonist muscles or a decrease in any unnecessary antagonist activation to have a long-term affect on muscle strength performance (61). Another theory involves an increased activation causing an increased load on the agonist muscles during WBLFV (61). Localized muscle components would adapt through muscle fiber recruitment with eventual hypertrophy to increase force production. This theory is unlikely mostly because of the relatively low load imposed on the muscle-tendon unit during WBLFV (61). One study performed by De Ruiter et al. used the twitch-technique to compare the maximal voluntary torque output with the attainable by superimposed electrical stimulation, but no WBLFV effects were found (61). It is unclear from current research which mechanism(s) are responsible for enhancing muscular performance, and possible could be determined that multiple mechanisms are involved in enhancement.

The outcome measures of vibration are potentially influenced by, but are not limited to, the type of vibration equipment used, amplitudes and durations, and exercises and participant types (16). Indirect and direct application methods also cause the existence of differing results. In the post-vibration period, the H-reflex displays a gradual recovery to normal values over a period of about 100 seconds, while the stretch reflex does not (45). The depression of the H-reflex during exposure to vibration is greater as the amplitude of the vibration increases at a constant frequency, but the depression remains unchanged if the amplitude is constant as the frequency of vibration increases (45). Research proves that vibration compensates for the reduction shown in motor output while in a fatigued state when the exposure is preceded by a prolonged maximal voluntary contraction (i.e., 4 minutes) (45). It has been hypothesized that, in a fatigued state, vibration compensates for the decreased gamma motor neuron drive by exciting the la afferents, resulting in the reflexive excitation of the motor neurons and greater force output (4,45). The mechanical behavior of skeletal muscle is affected separately from the neural factors that can affect muscle response after vibration exposure. In a study by Bosco et al., trained athletes were tested to show the affects of WBLFV on the mechanical behavior of human skeletal muscle with minimized contribution of learning effects as a factor in producing performance enhancements (4). A maximal dynamic leg press exercise on a slide machine with extra loads of 70, 90, 110 and 130 kg were utilized. After testing one leg was randomly assigned to the control and the other to the experimental treatment with vibration. Results showed statistically significant enhancement of the experimental treatment in average velocity, average force, and average power. The velocity-force and power-force relationship curve shifted to the right after the vibration treatment (4). The conclusion shows that WBLFV has a direct affect on skeletal muscle.

Structural adaptations in the muscle from WBLFV may positively affect functional performance (25,76). Structural adaptation in muscle tissue is either cross-sectional or longitudinal (76). Cross-sectional adaptations result in changes in maximal isometric force and longitudinal adaptation, the length in which the muscle generates maximal force, will be affected (76). Joint movement depends on the force that muscles produce and on the distance over which this force is applied in relation to the rotation axis of the joint, known as the moment arm (25). Force production depends on: force-speed relationship, force-length relationship, and temporal and spatial summations of motor neurons (25). In joints with three degrees of freedom, different movements result in changes to muscle moment arm behavior and muscle lengths, and to force production capacity that alters in the force–length relationship (25). Thus, torque production capacity for the same movement can be altered, when movements take place on a different joint plane (25). The length of a muscle varies with the angle the joint spans, and muscle length during WBLFV can be manipulated by changing the joint angles (76). In a WBLFV training study, the maximal extending knee joint moment of subjects improved, which confirms that WBLFV increases force production (76).

WBLFV is used as an attempt to produce training effects with improved strength and power in sports situations. WBLFV has also been recommended to avoid sarcopenia and osteoporosis in elderly people, especially in women. There are also suggestions to use WBLFV as means to speed up the recovery processes after training sessions in athletes (26,44,82). Vibration is employed in exercise routines in many different forms. Custom-built vibratory devices have been developed specifically for flexibility training, while other devices apply vibration units to resistance training equipment (16). Cardiovascular and metabolic responses observed with squatting exercise on vibrating plates suggest that WBLFV could serve as a mild form of exercise for the cardiovascular system (8). A decrease in bone density and a change in the architecture of the bone occur mainly because of the reduction or cessation of physical activity. The reduction of mechanical strain on bone changes the bones architecture and predisposes the individuals to osteoporosis. WBLFV is introduced as a technique in helping individuals to maintain or improve low bone mineral density by providing mechanical strains on the skeletal and muscular system of the body (26). The Daily Stress Stimulus Theory proposes that if the daily stress stimulus is greater than some target stimulus, a net bone gain will occur and that if the daily stress stimulus is less than some target stimulus, a net bone loss will occur (26). In a study by Roelants (73) et al., they investigated the effects of a 24-week WBLFV training on knee-extension strength and speed of movement and on counter-movement jump performance in older women. Speed of movement of knee extension significantly increased at low resistance (1% or 20% of isometric maximum) in the WBLFV group only (7.4 ± 1.8% and 6.3 ± 2.0%) after 24 weeks of training, with no significant differences in training effect between the WBV and the RES groups (P=.391; P=.142). Counter-movement jump height enhanced significantly (P<.001) in the WBLFV group (19.4 ± 2.8%) and the RES group (12.9 ± 2.9%) after 24 weeks of training. Most of the gain in knee-extension strength and speed of movement and in counter-movement jump performance had been realized after 12 weeks of training (73). WBLFV proves to be a suitable method for increasing speed of movement and strength gain in older women due to vibration exposure as a stimulus. Aside from the benefits of WBV shown on the elderly or diseased population, there is little evidence that suggests significant performance enhancements on the athletic population based on WBLFV training. There is no current consensus on the effectiveness of vibration exercise (7). It is very important to note that most studies conducted on WBLFV investigate the benefits shown in noncompetitive athletes, sports science students, and/or injured and aged individuals (7). In compiling studies specifically concerned with the athletic population, Cardinale focuses on an experiment with vibrating dumbbells showing an increase in power output acutely due to a large increase in EMG activity in elite boxers (Galileo, Novotec, Pforzheim, Germany) and also performing stretching on vibrating devices has shown to increase flexibility in gymnasts more than conventional stretching and increase flexibility without affecting explosive abilities when combined with stretching (7). The WBLFV technique alone does not provide significant enhancements on performance for athletes. The added benefit for sport situations is produced when WBLFV is used in conjunction with regular resistance and aerobic exercise routines that already provide a certain level of muscle activation.

Chapter III

METHODS

Participants

A total of 16 participants completed this study. Recreationally trained participants must have had at least one year of jumping experience and a year of lower body strength and explosive training. Minors were not included in this study to avoid developmental factors, and any persons over 30 years of age were excluded due to this studies focus on the college age population. If the prospective subject took any medications that altered balance, musculoskeletal system, or central nervous system functions that relate to motor and posture control, the subject was excluded from the study. Individuals with lower body orthopedic injury or lower body musculoskeletal injury were also be excluded from the study. Participant anthropometric measures are shown on Table 1.

	n	age (yrs)	height (cm)	mass (kg)
Participants	16	21.5 ± 1.7	165.5 ± 6.2	62.9 ± 7.5

Table 1: Participant Demographics

Experiment Design

This study was conducted to determine the effects of vibration on the body to ultimately enhance athletic performance. This study experimented with different rest intervals between vibration stimulation and vertical jump (VJ) performance to establish the optimal amount of rest.

Visit 1:

The first session served as a familiarization visit where the participant read and signed the Informed Consent and was given verbal instructions and demonstrations of the procedure. The participant was screened in determining eligibility to participate in the study. Anthropometric measures (height, mass, and age) were taken. The participants were asked to perform countermovement vertical jumps (CMVJ) until the scores did not exceed one inch of each other to gain consistency in the data. If jumps remained inconsistent, then the participant was excluded from the study. Each participant's reach height on the Vertec was recorded before the vibration and 3 CMVJ performed for each condition. Participants were instructed to perform the countermovement of the VJ with self-selected knee depth and arm swing. The participants were encouraged to jump as fast and high as possible with 15-second rest between each jump. Familiarization with the vibration protocol was also required. The participants became accustomed to the oscillatory waves provided by the vibration plate, and practiced the quarter squat tempo during vibration. Participants were encouraged to keep a relaxed jaw and slightly bent knees during the vibration protocol in order to relieve any discomfort or blurred vision.

Visit 2-4:

The next 3 sessions (visits 2-4) contained 2 randomized rest interval conditions per session with 10 minutes between each condition to eliminate any overlapping effects. Previous research deemed WBV ineffective after 10 minutes of rest from exposure (12). After completing the first condition of the session, the participants sat in a chair with no additional movement for 10 minutes and then followed with the second condition to complete the session. The order of the conditions performed was randomized. The participant preformed a quarter squat every 5 seconds on the vibration plate to stimulate the CMVJ with knee extension not exceeding and angle of 135 degrees. After WBLFV, the participant immediately performed 3 CMVJ on a force platform with 5 different rest intervals (immediate, 30 seconds, 1 minute, 2 minutes, or 4 minutes). The control condition required participants to perform quarter squats, but with no vibration exposure and then immediately perform 3 CMVJs.

Equipment

a. Power Plate:

The AIRdaptive (Power Plate, Inc.) vibration platform was used during the study. It is a 33''x33'' flat platform with a stable handle attached. Multi-planar accelerations are produced with focus on the vertical z-plane. The frequency of vibration ranges from minimum 30 Hz to maximum 50 Hz, and the amplitude ranges from 2-4 mm (low) to 4-6mm (high). Whole-body low frequency vibration (WBLFV) was given through a vertical platform with a frequency of 30 Hz, amplitude of 2-4mm, and duration of 4 bouts of 30s for a total of 2 minutes with a 1:1 rest ratio.

b. Force Plate:

The Bertec® Force (Bertec Corp. Columbus, OH, USA) platform sampling at 1,080 Hz was used in the CMVJ data collection. Data was sampled at 1,080 Hz and maximum peak vertical ground reaction force (GRFvmax) was analyzed for each condition.

Measurements

The force platform was used to measure ground reaction force (GRF). Peak vertical force (Peak-z) was also measured. Relative GRFs were determined by dividing peak GRFz by the body weight of the subject in Newton (N).

Statistical Analysis

Individual paired-sample t-tests compared the control group and vibration group to test the group differences for absolute peak-z forces and relative peak-z forces. A 2 x 6 (group x time) mixed factor ANOVA showed differences in rest intervals. If interaction occurred they would be followed up with simple ANOVA's and main effects were followed up with a least significant difference post-hoc analysis for pairwise differences.

Chapter IV

RESULTS

There was a significant ($p = 0.009$) difference between the control and vibration groups for absolute peak-z force. Absolute peak-z forces showed control (1618.7 ± 416.6 N) and vibration (1710.5 ± 118.5 N). A significant ($p = 0.003$) difference was found between control and vibration groups for relative peak-z forces. Relative peak-z forces resulted in control (249.0 ± 47.4 N) and vibration (263.9 ± 49.0 N). No significant (>0.05) interactions or main effects were found for rest intervals.

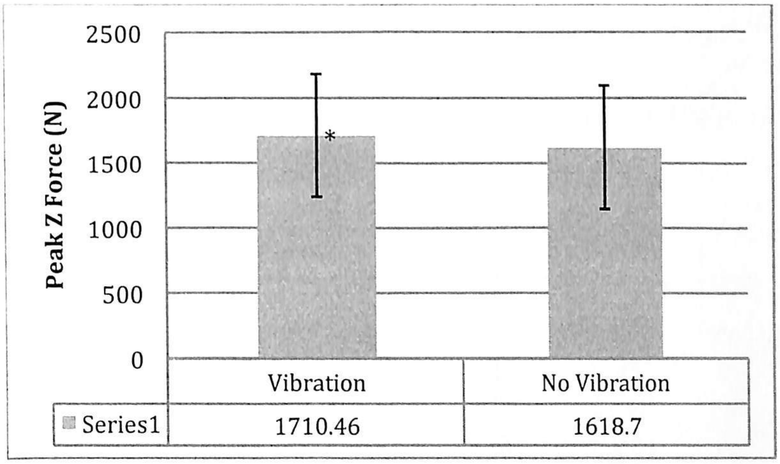

Figure 1. Absolute Peak Z Force (Vibration vs. Control conditions) * Indicates significant difference between the two conditions, with standard error bars

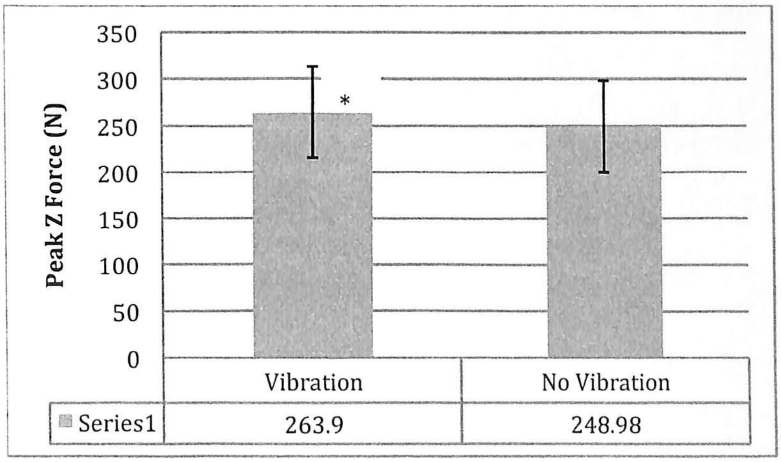

Figure 2. Relative Peak Z Force (Vibration vs. Control conditions) * Indicates significant difference between the two conditions, with standard error bars

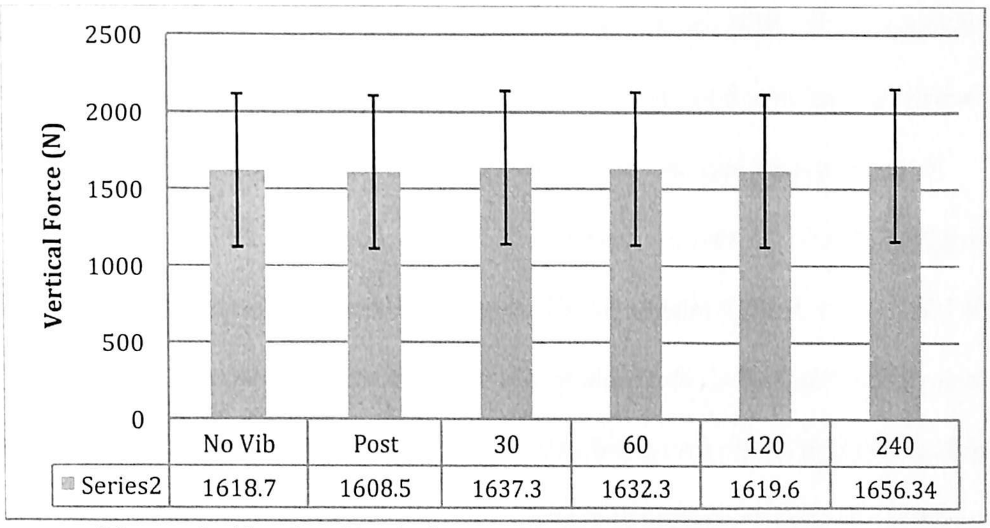

Figure 3. Absolute Vertical Force Between All Rest Intervals

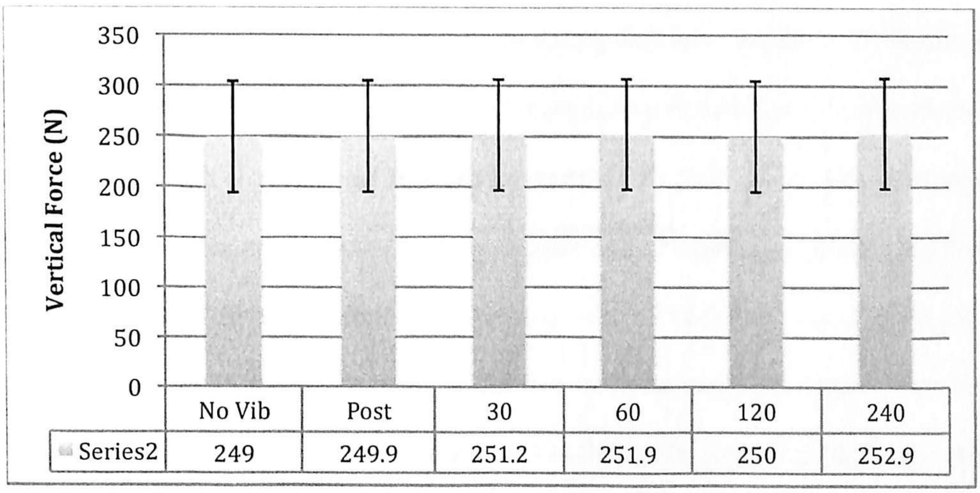

Figure 4. Relative Vertical Force Between All Rest Intervals

Chapter V

DISCUSSION

The purpose of this study was to investigate whether WBLFV caused an increase in absolute and relative peak-z forces in the vertical jump and to define the optimal rest interval between vibration and action that allows for enhanced peak-z forces. A significant ($p = 0.009$) difference was found between the control and vibration group for both absolute and relative peak-z measures. The significant difference for WBLFV is shown when all conditions are excluded except the condition that contains the maximum peak-z force for that participant. In only referencing the maximum peak-z condition for comparison, this provides evidence for a strong individual preference of which rest interval most benefits their performance. Due to increased peak-z forces found within the WBLFV group, muscle potentiation before testing may have occurred. Previous research has shown that an increase in gravitational load during vibration is similar to the load experienced with conventional resistance exercise (7,8). Post-activation potentiation is a popular mechanism referenced by many experiments to explain increases in both peak force and rate of force development following WBLFV (2,42). It is unclear the exact cause of potentiation, but the possible theories are either phosphorylation of myosin or increased motor neuron excitability assessed in the Hoffmann reflex (2,42). In previous research, an increase in range of motion, muscle temperature, and muscle force output at the single-muscle-fiber level was attributed to potentiation (2). Potentiation also shows an enhancement in peak twitch force, and increases in the rate of twitch force development with less time to reach peak twitch forces (42). The twitch potentiation has shown to increase the rate of force development of isometric contraction during high frequency stimulation (42). As the force development increases, it is also postulated to increase peak velocity and power during dynamic muscle contraction performances (42). When vibration is brief and does not produce fatigue, there is an increase of nervous system signals that facilitate strength generation (2,27). The net effect on performance in an activity can be attributed to the balance between PAP and fatigue. It has been demonstrated that tendon vibration that exceeds 30-seconds of stimulation results in decreased muscle activation due to reduced Ia input to the motor neuron pool as a results of neurotransmitter depletion or increased pre-synaptic inhibition (9). Previous research has stated that 30-second bouts of WBLFV immediately followed by testing resulted in an increase of performance variables, which correlates with the findings of this study (20). PAP is highly individualized in that some participants may have a greater PAP or fatigue effect for the same rest interval (24). Also, Dabbs et al. found that WBLFV given within 0-4 minutes before performance increased VJ height, which parallels with the rest intervals tested within this study (24). Because the rest intervals were tested within a small range of time, we can suspect PAP to be one of the mechanisms that attributed to the results of this study. Fatigue was not induced due to the conservative protocol.

Another major finding of the study was a non-significant difference between rest conditions. The rest interval that elicited an increase in absolute and relative peak-z forces varied across participants; thus, indicating a strong individual preference in optimal rest intervals. Although the duration of exposure was the same, the frequency differed in other studies. In a study by Di Giminaiani et al., the goal was to assess the effects of 8 weeks of WBLFV on explosive and reactive leg strength (28). The study included an individualized-vibration group that had frequency determined by participant's EMGrms activity. Our study did not utilize EMG activity to set individualized parameters, but only used fixed-vibration protocol. The lack of peak-z increase between rest intervals may be due to a fixed protocol. This suggests that in order to produce a greater neuromuscular response, individualized variables may be more beneficial than a pre-selected set of conditions.

WBLFV may provoke gravitational changes in the body that promote neuromuscular facilitation. Neuromuscular facilitation is suggested as the driving force behind the explanation of increases in muscular performance. Theoretically, if one can enhance the neural component, then the overall performances of the individual are enhanced. The WBLFV is used because it is thought to produce the needed explosive strength to enhance performance. Yet, because this is a fairly recent topic of discussion, the improvements due to neuro-myogenic components remain unclear. The current investigation provides that WBLFV given in 4 sets of 30-second bouts before performance may increase absolute and relative peak-z to increase overall explosive strength of the participant, but at individually referenced rest intervals. The author recommends that rest intervals between WBLFV and performance be determined before competition in order to provide the most ideal results. After determining optimal rest times, individuals could incorporate WBLFV into their training and warm-up routines. WBLFV is most appropriate for maximizing performance in athletic competitions that involve single explosive movements (i.e.: high jump and long jump). The effects shown in this study may apply to athletes, trainers, and coaches involved with sports performance. Performance benefits with long-term vibration exposure should be explored in future research.

BIBLIOGRAPHY

1. Aminian-Far, A. Whole-body vibration and the prevention and treatment of delayed-onset muscle soreness. *Journal of athletic training* 46: 43, 2011.

2. Bazett-Jones, DM. Effect of potentiation and stretching on maximal force, rate of force development, and range of motion. *Journal of Strength and Conditioning Research* 19: 421, 2005.

3. Bongiovanni, LG. Tonic vibration reflexes elicited during fatigue from maximal voluntary contractions in man. *Journal of Physiology. (London)* 423: 1, 1990.

4. Bosco, C. Adaptive responses of human skeletal muscle to vibration exposure. *Clinical physiology (Oxford)* 19: 183-187, 1999.

5. Burke, D. The responses of human muscle spindle endings to vibration during isometric contraction. *Journal of Physiology. (London)* 261: 695, 1976.

6. Burke, D. The responses of human muscle spindle endings to vibration of non-contracting muscles. *Journal of Physiology (London)* 261: 673, 1976.

7. Cardinale, M. Vibration training in elite sport: effective training solution or just another fad? *International Journal of Sports Physiology and Performance* 3: 232, 2008.

8. Cardinale, MM. The acute effects of different whole body vibration amplitudes on the endocrine system of young healthy men: a preliminary study. *Clinical Physiology and Functional Imaging* 26: 380-384, 2006.

9. Carson, RG, Popple, AE, Verschueren, SMP, and Riek, S. Superimposed vibration confers no additional benefit compared with resistance training alone Carson et al. Vibration superimposed on resistance training. *Scandinavian Journal Medical Science Sports* 20: 827-833, 2010.

10. Chockley, C. Ground Reaction Force Comparison Between Jumps Landing on the Full Foot and Jumps Landing en Pointe in Ballet Dancers. *Journal of Dance Medicine & Science* 12: 5-8, 2008.

11. Clansey, A, and Lees, A. Changes in Lower Limb Joint Range of Motion on Countermovement Vertical Jumping. *International Symposium on Biomechanics in Sports: Conference Proceedings Archive* 28: 1-2, 2010.

12. Clark, RA, Bryant, AL, and Reaburn, P. The Acute Effects of a Single Set of Contrast Preloading on a Loaded Countermovement Jump Training Session. *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 20: 162-166, 2006.

13. Cochrane, DDJ. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. *British Journal of Sports Medicine.* 39: 860-865, 2005.

14. Cochrane, DJ. Comparing muscle temperature during static and dynamic squatting with and without whole-body vibration. *Clinical physiology and functional imaging* 30: 223, 2010.

15. Cochrane, DJ. Vibration exercise: the potential benefits. *International Journal of Sports Medicine* 32: 75, 2011.

16. Cochrane, DJ. The potential neural mechanisms of acute indirect vibration. *Journal of Sports Science & Medicine* 10: 19, 2011.

17. Cochrane, DJDJ. The acute effect of vibration exercise on concentric muscular characteristics. *Journal of Science and Medicine in Sport* 11: 527-534, 2008.

18. Čoh, M. Biomechanical Characteristics of Take Off Action in High Jump -- a Case Study. *Serbian Journal of Sports Sciences* 4: 127-135, 2010.

19. Cordova. Reliability of ground reaction forces during a vertical jump: implications for functional strength assessment. *Journal of Athletic Training* 31: 342-345, 1996.

20. Cormie, P, Deane, RS, Triplett, T, and McBride, JM. Acute Effects of Whole-Body Vibration on Muscle Activity, Strength, and Power. *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 20: 257-261, 2006.

21. Crewther, B. Gravitational forces and whole body vibration: implications for prescription of vibratory stimulation. *Physical therapy in sport* 5: 37, 2004.

22. Cronin, J. The acute effects of hamstring stretching and vibration on dynamic knee joint range of motion and jump performance. *Physical therapy in sport* 9: 89, 2008.

23. Cronin, JB. Muscle stiffness and injury effects of whole body vibration. *Physical therapy in sport* 5: 68, 2004.

24. Dabbs, NC, Muñoz, CX, Tran, TT, Brown, LE, and Bottaro, M. Effect of Different Rest Intervals After Whole-Body Vibration on Vertical Jump Performance. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins)* 25: 662-667, 2011.

25. De Toledo, JM, Krug, RC, Castro, MP, Ribeiro, DC, and Loss, JF. Torque and Force Production During Shoulder External Rotation: Differences Between Transverse and Sagittal Planes. *Journal of Applied Biomechanics* 24: 51-57, 2008.

26. de Zepetnek, JOT. Whole-body vibration as potential intervention for people with low bone mineral density and osteoporosis: a review. *Journal of rehabilitation research and development* 46: 529, 2009.

27. de, HL, Granados, SR, Corrales, BS, and Páez, LC. Whole Body Vibration: Acute and Residual Effect on the Explosive Strength. *Journal of Human Sport & Exercise* 5: 188-195, 2010.

28. Di Giminiani, R, Tihanyi, J, Safar, S, and Scrimaglio, R. The effects of vibration on explosive and reactive strength when applying individualized vibration frequencies. *Journal of Sports Science* 27: 169-177, 2009.

29. Di Giminiani, R, Tihanyi, J, Safar, S, and Scrimaglio, R. The effects of vibration on explosive and reactive strength when applying individualized vibration frequencies. *Journal of Sports Science* 27: 169-177, 2009.

30. Domire, ZJ, and Challis, JH. The influence of squat depth on maximal vertical jump performance. *Journal of Sports Science* 25: 193-200, 2007.

31. Ebben, WP. A Brief Review of Concurrent Activation Potentiation: Theoretical and Practical Constructs. *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 20: 985-991, 2006.

32. Erskine, J, Smillie, I, Leiper, J, Ball, D, and Cardinale, M. Neuromuscular and hormonal responses to a single session of whole body vibration exercise in healthy young men. *Clinical Physiology & Functional Imaging* 27: 242-248, 2007.

33. Feltner, ME, Fraschetti, DJ, and Crisp, RJ. Upper extremity augmentation of lower extremity kinetics during countermovement vertical jumps. *Journal of Sports Science.* 17: 449-466, 1999.

34. Fratini, A. Muscle motion and EMG activity in vibration treatment. *Medical English Physiology.* 31: 1166, 2009.

35. Gerodimos, VV. The acute effects of different whole-body vibration amplitudes and frequencies on flexibility and vertical jumping performance. *Journal of Science and Medicine in Sport* 13: 438-443, 2010.

36. Hall, Susan Jean. *Basic biomechanics*. 6th Ed. McGraw-Hill Companies 2012.

37. Hand, J. A comparison of whole-body vibration and resistance training on total work in the rotator cuff. *Journal of athletic training* 44: 469, 2009.

38. Harrison, AJ, Ryan, W, and Hayes, K. Functional data analysis of joint coordination in the development of vertical jump performance. *Sports Biomechanics* 6: 199-214, 2007.

39. Hazell, TJ, Jakobi, JM, and Kenno, KA. The effects of whole-body vibration on upper- and lower-body EMG during static and dynamic contractions. *Applied Physiology, Nutrition & Metabolism* 32: 1156-1163, 2007.

40. Herrero, AJ. Whole-body vibration alters blood flow velocity and neuromuscular activity in Friedreich's ataxia. *Clinical physiology and functional imaging* 31: 139, 2011.

41. Hodgson, M, Docherty, D, and Robbins, D. Post-Activation Potentiation. *Sports Medicine* 35: 585-595, 2005.

42. Hodgson, MJ, Docherty, D, and Zehr, EP. Postactivation Potentiation of Force Is Independent of H-Reflex Excitability. *International Journal of Sports Physiology & Performance* 3: 219-231, 2008.

43. Horwath, R, and Kravitz, L. Postactivation Potentiation: A Brief Review. *IDEA Fitness Journal* 5: 21-23, 2008.

44. Humphries, B. Whole-body vibration effects on bone mineral density in women with or without resistance training. *Aviation Space Environmental Medicine* 80: 1025, 2009.

45. Jordan, MJ. Vibration training: an overview of the area, training consequences, and future considerations. *Journal of strength and conditioning research* 19: 459, 2005.

46. Kerschan-Schindl, KK. Whole-body vibration exercise leads to alterations in muscle blood volume. *Clinical physiology (Oxford)* 21: 377-382, 2001.

47. Komi, PV. Stretch reflexes can have an important role in force enhancement during SSC exercise. *Journal of applied biomechanics* 13: 451, 1997.

48. Komi, PPV. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *Journal of Biomechanics* 33: 1197-1206, 2000.

49. Lapole, TT. Effects of repeated Achilles tendon vibration on triceps surae force production. *Journal of Electromyography and Kinesiology* 20: 648-654, 2010.

50. Linthorne, Nicholas P. "Analysis of standing vertical jumps using a force platform." *American Journal of Physics*. 69.11 (2001):1198-1204

51. Madou, KH. The effects of whole body vibration on physical and physiological capability in special populations. *Hong Kong physiotherapy journal* 26: 24, 2008.

52. Mahieu, NN. Improving strength and postural control in young skiers: whole-body vibration versus equivalent resistance training. *Journal of athletic training* 41: 286, 2006.

53. Matthews, PB, and Muir, RB. Reflex action of amplitude-modulated vibration in man [proceedings. *Journal of Physiology* 296: 5P-6P, 1979.

54. Maulder. Horizontal and vertical jump assessment: reliability, symmetry, discriminative and predictive ability. *Physical therapy in Sport* 6: 74-82, 2005.

55. McClay, IR, Robinson, JR, Andriacchi, TP, Frederick, EC, Gross, T, Martin, P, Valiant, G, Williams, KR, and Cavanagh, PR. A profile of ground reaction forces in professional basketball. / Un profil des forces de reaction du sol en basketball professionnel. *Journal of Applied Biomechanics* 10: 222-236, 1994.

56.McGinnis, Peter Merton. *Biomechanics of Sport and Exercise*. Human Kinetics Publishers, 2005.

57. Mester, JJ. Biological reaction to vibration - implications for sport. *Journal of Science and Medicine in Sport* 2: 211-226, 1999.

58. Moir, GL, Garcia, A, and Dwyer, GB. Intersession Reliability of Kinematic and Kinetic Variables During Vertical Jumps in Men and Women. *International Journal of Sports Physiology & Performance* 4: 317-330, 2009.

59. Moran, KA, and Wallace, ES. Eccentric loading and range of knee joint motion effects on performance enhancement in vertical jumping. *Human Movement Science* 26: 824-840, 2007.

60. Nicol, C. The stretch-shortening cycle: a model to study naturally occurring neuromuscular fatigue. *Sports medicine (Auckland)* 36: 977, 2006.

61. Nordlund, MM, and Thorstensson, A. Strength training effects of whole-body vibration? *Scandinavian Journal of Medical Science. Sports* 17: 12-17, 2007.

62. Ortega, DR, Rodríguez Bíes, EC, and Berral de, IR. Analysis of the vertical ground reaction forces and temporal factors in the landing phase of a countermovement jump. *Journal of Sports Science & Medicine* 9: 282-287, 2010.

63. Osawa, Y, and Oguma, Y. Effects of whole-body vibration on resistance training for untrained adults. *Journal of Sports Science & Medicine* 10: 328-337, 2011.

64. Pel, JJMJJM. Platform accelerations of three different whole-body vibration devices and the transmission of vertical vibrations to the lower limbs. *Medical English Physiology* 31: 937-944, 2009.

65. Petit, PD. Optimal whole-body vibration settings for muscle strength and power enhancement in human knee extensors. *Journal of electromyography and kinesiology* 20: 1186, 2010.

66. Pollock, RD. Muscle activity and acceleration during whole body vibration: effect of frequency and amplitude. *Clinical biomechanics (Bristol)* 25: 840, 2010.

67. Rees, S. Effects of vibration exercise on muscle performance and mobility in an older population. *Journal of Aging Physiology Actions.* 15: 367, 2007.

68. Ribot-Ciscar, EE. Muscle spindle activity following muscle tendon vibration in man. *Neuroscience Letter.* 258: 147-150, 1998.

69. Rietschel, E. Whole body vibration: a new therapeutic approach to improve muscle function in cystic fibrosis? *International journal of rehabilitation research* 31: 253, 2008.

70. Robbins, DW. Postactivation Potentiation and its Practical Applicability: a Brief Review. *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 19: 453-458, 2005.

71. Rodgers, Mary M., and Peter R. Cavanagh. "Glossary of biomechanical terms, concepts, and units." *Physical Therapy* 64.12 (1984): 1886-1902.

72. Roelants, M. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. *Journal of strength and conditioning research* 20: 124, 2006.

73. Roelants, MM. Whole-Body-Vibration Training Increases Knee-Extension Strength and Speed of Movement in Older Women STRENGTH GAIN FOLLOWING WHOLE-BODY VIBRATION. *Journal of the American Geriatrics Society (JAGS)* 52: 901-908, 2004.

74. Rønnestad, BR. Comparing the Performance-Enhancing Effects of Squats on a Vibration Platform with Conventional Squats in Recreationally Resistance-Trained Men. *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 18: 839-845, 2004.

75. Sale, DD. Postactivation potentiation: role in performance. *British Journal of Sports Medicine.* 38: 386-387, 2004.

76. Savelberg, HHCM, Keizer, HA, and Meijer, K. Whole-Body Vibration Induced Adaptation in Knee Extensors; Consequences of Initial Strength, Vibration Frequency, and Joint Angle. *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 21: 589-593, 2007.

77. Spägele, T, Kistner, A, and Gollhofer, A. Modelling, simulation and optimisation of a human vertical jump. *Journal of Biomechanics* 32: 521-530, 1999.

78. Tillin, NA, and Bishop, D. Factors Modulating Post-Activation Potentiation and its Effect on Performance of Subsequent Explosive Activities. *Sports Medicine* 39: 147-166, 2009.

79. Umberger, BR. Mechanics of the vertical jump and two-joint muscles: implications for training. *Strength & Conditioning* 20: 70-74, 1998.

80. van, IS, Bobbert, MF, and de Haan, A. Does elastic energy enhance work and efficiency in the stretch-shortening cycle? / L ' energie elastique ameliore-t-elle le travail et le rendement du cycle etirement-raccourcissement. *Journal of Applied Biomechanics* 13: 389-415, 1997.

81. Vanrenterghem. Performing the vertical jump: movement adaptations for submaximal jumping. *Human movement science* 22: 713-727, 2004.

82. Viru, M, and Viru, A. Whole Body Vibration (Wbv) as a Training Means. *Acta Academiae Olympiquae Estoniae* 13: 5-10, 2005.

83. Wunderer, K. The effect of whole body vibration in common neurological conditions–a systematic review. *Physical therapy reviews* 13: 434, 2008.