WHOLE BODY VIBRATION AND DROP LANDING MECHANICS

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE

MASTER OF SCIENCE

BY

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Declaration

The work presented in this thesis document, is to the best of my knowledge to be true and original, unless cited otherwise, and that this document has not been submitted to another institution for the requirements of a different degree.

X

_______________________
Ryan P. Hubble, Primary Investigator
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ABSTRACT

THESIS: Whole Body Vibration and Drop Landing Mechanics

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Whole body vibration (WBV) is a training modality that involves an individual standing on a plate that provides vibrations at multiple frequencies and amplitudes. Improvements in muscular concentric force production such as power and strength have been extensively studied, however little work has been conducted looking at the effects of WBV on eccentric actions. The landing phase of a jump is an eccentric mechanism to decelerate the body as it prepares to stop or initiate another movement. This study sought to identify the effects of WBV on ground reaction forces, loading rates, valgus knee angles, frontal plane knee moment and jump height, as well as a higher order interaction between gender and time as a result of the vibration. An individualized frequency WBV protocol was utilized as 10 female and 9 male subjects completed drop jumps pre-vibration, post vibration and at 10 and 20 minutes post vibration. Baseline valgus knee angle increased 0.857 degrees post vibration, while remaining increased by 0.917 and 1.189 degrees at the 10 and 20 minute post vibration time intervals, respectively. Repeated measure ANOVA’s revealed that valgus knee angle significantly (p=0.011) increased post vibration. Gender comparisons revealed that females had a significantly greater knee moment (p=0.038) and males significantly jumped higher than females (p<0.001). As an end result following WBV, the subjects landed in significantly greater knee valgus, regardless of sex. Since it has been
demonstrated that a knee in a valgus position increases the potential risk for anterior cruciate ligament injury, caution should be taken when combining WBV and jump training protocols.
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Chapter 1

Introduction

Whole body vibration (WBV) involves an individual standing on a platform that oscillates in a horizontal, vertical, or even a see-saw fashion. Most common vibration platforms involve near vertical vibrations that initiate a vertical displacement of an individuals’ center of mass, which increases gravitational forces on the individual (Furness & Maschette, 2009). Whole body vibration has been shown to improve power output (Bosco et al., 1999; Cochrane, Stannard, Firth, & Rittweger, 2010; Di Giminiani, Manno, Scrimaglio, Sementilli, & Tihanyi, 2010; Di Giminiani, Tihanyi, Safar, & Scrimaglio, 2009), strength (de Ruiter, van der Linden, van der Zijden, Hollander, & de Haan, 2003; Savelberg, Keizer, & Meijer, 2007), balance (Torvinen, Kannu, et al., 2002), and flexibility (Di Giminiani, et al., 2010).

Multiple WBV studies have measured the effects of the vibration stimulus on isometric strength (minimal change in muscle length) (de Ruiter, et al., 2003; Savelberg, et al., 2007) and concentric (muscle shortening) power (Bosco, et al., 1999; Cochrane, et al., 2010; Di Geminian, et al., 2010; Di Geminian, et al., 2009). At present, however, there are no published studies of the effects of WBV on the deceleration phase of a landing, which involves the muscles undergoing an eccentric (muscle lengthening) load.
As individual’s land, they have to eccentrically absorb the negative acceleration of the body in order to halt its movement, or halt the movement in order to produce another movement (e.g., jump, change in direction). During a landing, there is a reactive force from the ground that is an equal and opposite force to that produced by individuals as they land and these forces are referred to as ground reaction forces (GRF). Given the abundance of studies looking at jump height following vibration (Di Giminiani, et al., 2010; Di Giminiani, et al., 2009; Lamont et al., 2010; Ronnestad, Holden, Samnoy, & Paulsen, 2012; Torvinen, Sievanen, et al., 2002; Wyon, Guinan, & Hawkey, 2010), there is general trends indicating that WBV acutely improves jump height. However, it is unknown if WBV influences an individual’s lower extremity control during the landing from a jump. Exposure to WBV may affect the forces produced by the legs as well as the kinematic control of the lower extremities during a landing. These are important areas of investigation that need to be addressed.

During the landing phase of a jump individuals may be susceptible to injury, and these landings potentially pose an increased risk of anterior cruciate ligament (ACL) injury, in particular (Pappas, Hagins, Sheikhzadeh, Nordin, & Rose, 2007). This landing can be further defined as a noncontact landing, which consists of the individual making contact with only the floor or landing surface. As stated earlier, during a landing a GRF is created equaling the force of an individual, or object, as they negatively accelerate towards the ground. The value of this force is a function of the mass of the individual and the acceleration due to gravity. Having larger GRFs has been associated with ACL risk (Hewett, Stroupe, Nance, & Noyes, 1996; Irmischer et al., 2004).

During the landing, certain lower extremity orientations or positions have been shown to also increase the potential risk for ACL injury. When an individual lands in what is called the “point of no return,” which includes increased hip adduction and internal rotation with an associated increase in valgus knee angles and external tibial rotation, it poses an increased ACL
injury risk (Ireland, 1999). One of the factors noted in the “point of no return” that has often been cited as a significant contributor to increased ACL injury risk during landing is valgus knee angle (Hewett, 2000; Ireland, 1999). In women, this valgus knee angle is consistently larger than that of males (Ford, Myer, & Hewett, 2003; Hewett et al., 2005; Russell, Palmieri, Zinder, & Ingersoll, 2006), which may help to explain why females are at a higher risk for ACL injury. On a positive note however, it has been shown than individuals can improve the control of the body’s limbs during a landing, and limit such risk factors as valgus knee angle (Hewett, Ford, Hoogenboom, & Myer, 2010).

**Purpose**

The purpose of this study was to assess the effects of individualized frequency WBV on GRF during the eccentric portion of a landing. This study sought to determine if WBV has an effect on knee valgus angle, frontal plane knee moment during the landing and subsequent jump height. Additionally all variables were investigated to determine if a gender comparison existed or was differentially impacted by the vibration stimulus.

**Hypothesis**

It was hypothesized that due to the theorized improved efficiency of the stretch reflex loop and the improved concentric power production that comes with it, GRFs would be reduced after WBV. It was also hypothesized that valgus knee angle would decrease following WBV. Lastly, it was also hypothesized that jump height would improve.
Chapter 2-Literature Review

Whole Body Vibration

Whole Body Vibration Characteristics and Theory

Whole body vibration has been used as a tool to induce short term adaptations to muscle tissue. Whole body vibration involves an individual standing on a platform that oscillates vertically to produce a vertical displacement of the subjects’ center of gravity and alters gravitational forces on the subject (Furness and Maschette 2009). The nature of the vibrations can occur across a range of amplitudes ranging from 2-10mm, with the addition of the vibrations being at different frequencies ranging from 20-50 Hz. This vibration induces one of two proposed adaptation mechanisms in muscle fibers (Cardinale & Bosco, 2003). Through a tonic reflex, the repeated elongation of the muscle fibers has been suggested to stimulate Ia afferent activity, leading to reflexive muscle reactions (Savelberg, et al., 2007), or the muscles are put under an increased load during WBV (Savelberg, et al., 2007) which induces a post potentiation activation (PPA) effect.

The rationale behind the involvement of the tonic vibration reflex and improved muscular performance following WBV is that it stretches the soft muscular tissue and this has the potential to activate muscle spindles which can lead to an enhancement of the stretch reflex loop.
(Cardinale & Bosco, 2003). This enhancement is due to excitation of alpha motor neurons, which illicit contractions of homonymous motor units and as an end result causes a tonic contraction of the muscle, or tonic vibration reflex (Jordan, Norris, Smith, & Herzog, 2005). In other words, after this series of tonic reflex twitches that have been induced by WBV, this tonic reflex is somewhat primed and becomes more sensitive and more efficient at activating to a stretch of the muscle spindle. In addition, the stretch reflex is depressed during vibration, but shows a potentiated effect immediately following (Jordan, et al., 2005). This “potentiation” is another possible reason to explain improvements in muscular power and strength following a WBV treatment.

The term potentiation has been expanded into what is known as post potentiation activation (PPA) which occurs when there is work done prior to a performance task (Cochrane, et al., 2010). As stated earlier WBV can produce increased forces on the body, as high as 15 times gravity (Savelberg, et al., 2007). Post potentiation activation is said to improve the strength of muscular contraction following contractile activity such as a series of evoked twitches or any maximal voluntary contraction (Sale, 2002). This same improvement of muscular strength has been shown following WBV (Cochrane, et al., 2010), which involves a series of evoked twitches. As a result of the vibration, it is theorized that the phosphorylation of myosin regulatory light chains makes actin and myosin more sensitive to the intracellular Ca^{2+} signal (Sweeney, Bowman, & Stull, 1993; Zhi et al., 2005). This increased sensitivity of Ca^{2+} signals means there is a faster and greater rate of cross bridge attachment and twitch tension (Metzger, Greaser, & Moss, 1989). Improved sensitivity of the actin and myosin chains coupled with an increased rate of attachment resulting in a more vigorous contraction could lead to strength and power improvements. These proposed improvements now are being reassessed, due to new discoveries on the degree of the frequency of vibration.
Fixed Frequency Whole Body Vibration

Typical studies utilizing WBV have incorporated fixed frequency protocols (i.e. one frequency across all individuals) typically ranging in frequency from 20 to 40 Hz (Adams et al., 2009). In response to the different frequencies the findings have been largely equivocal in terms of the effects on performance. Bosco and colleagues (Bosco, et al., 1999) utilized a 60 second long vibration at 26 Hz and recorded a significant increase in jump height post vibration. Other successful protocols have utilized varying frequencies in a range from 25-40 Hz (Bosco, et al., 1999; de Ruiter, et al., 2003; Rittweger, Beller, & Felsenberg, 2000) with times ranging from 60-120 seconds (Savelberg, et al., 2007), and as high as four minutes or greater of continuous vibration (Cochrane, et al., 2010; Torvinen, Sievanen, et al., 2002). These protocols reported improvements in power output primarily through jump height and post potentiation activation, and are key elements to this research project. Recently however, the emergence of individualized frequency protocols has led to a new area of study involving WBV.

Individualized Frequency Whole Body Vibration

A newer method is emerging for determining the frequency for WBV protocols, because recent research has shown that the vastus lateralis muscle will have different levels of activation during different vibration frequencies (Cardinale & Lim, 2003), and that individuals will respond differently to different frequencies (Bongiovanni, Hagbarth, & Stjernberg, 1990; Cardinale & Bosco, 2003). To determine the optimal frequency for each individual, subjects were assessed while standing on a vibration platform across a range of frequencies (i.e., 20 Hz to 55 Hz at 5 Hz intervals) with four minutes rest provided in between each trial (Di Giminiani, et al., 2010). Electromyographic (EMG) data were collected during the trials, and later analyzed to determine which frequency evoked the greatest neuromuscular response and the frequency that elicited the greatest neuromuscular response was used for all data collections during the study. During recent research individuals were either in a no vibration, a fixed-frequency, or an individualized
frequency group. Although both vibration groups experienced a significant improvement in jump height for squat jumps and reactive rebound jumps, the individualized frequency group had a greater response compared to the fixed-frequency group (Di Giminiani, et al., 2009). Additional studies support the use of WBV at an individualized frequency through improvements of power during a drop jump over an eight week training period (Di Giminiani, et al., 2010). It is important to note that the improvements seen have either been associated with isometric strength or concentric power production.

**Areas of WBV Study**

Whole body vibration has been shown to improve power output (Bosco, et al., 1999; Cochrane, et al., 2010; Di Giminiani, et al., 2010; Di Giminiani, et al., 2009), strength (de Ruiter, et al., 2003; Savelberg, et al., 2007), balance (Torvinen, Kannu, et al., 2002), and flexibility (Di Giminiani, et al., 2010). These are great areas of performance, but after examining the studies, they involve muscular strength through isometric or concentric actions and muscular power through concentric actions. Multiple WBV studies have measured the effects of a vibration stimulus on the isometric (minimal change in muscle length) strength (de Ruiter, et al., 2003; Savelberg, et al., 2007) and concentric (muscle shortening) actions that produce power output (Bosco, et al., 1999; Cochrane, et al., 2010; Di Giminiani, et al., 2010; Di Giminiani, et al., 2009). To the investigators knowledge, no studies have looked at the effects of WBV on muscles undergoing an eccentric (muscle lengthening) load.

**Potential Risks**

Whole body vibration does have associated potential risks although they typically result from long-term exposure to WBV and can result in neurological damage. One such long-term exposure injury includes hand-arm vibration syndrome (Jordan, et al., 2005). Miners who operate drills (jackhammers included) are at a higher risk of hand-arm disease and show increased incidence rates in the hands(Wasserman & Taylor, 1991) and spine, respectively. In terms of
short term injury, the transmission of the vibrations to an individuals’ head may give them headaches (Mester, Kleinoder, & Yue, 2006). There are a few guidelines that can help reduce the risks from exposure to WBV which include adopting a half squat stance while receiving WBV training (Abercromby et al., 2007). Maintaining vibration frequencies above 20 Hz can help to avoid matching the resonance frequency of the body (Mester, et al., 2006), as well as keeping the intervals of vibration less than 60 seconds (Mester, et al., 2006). Following these guidelines will help to reduce the risks of WBV.

**Electromyography**

Earlier, individualized frequency WBV protocols were discussed. In order to obtain an individualized WBV frequency, the EMG must be collected to ascertain an activation level of the muscle. Action potentials are produced by chemical reactions, and this reaction is conducted by muscular tissue, and as this action potential travels along muscular tissue, the signals can be read and analyzed. These signals can be collected via bipolar surface electrodes placed on the skin above the bellies of the muscle to be measured. The electrodes record a raw EMG signal that is a representation of the activation of the muscle. When the individual is vibrated, the EMG sensors pick up the chemical changes in the muscles as they contract in reaction to the vibration stimulus. The frequency of vibration can then be altered by adjusting the control settings of the vibration plate. The theory behind the individualized frequency is that one of the frequencies should produce a higher muscular activation than the others. As the amount of force to be produced by the muscle increases more motor units will be activated and the sensor will pick up the increase of myoelectric output, producing a greater EMG signal. The initial signal is raw, with both positive and negative values. Taking an absolute value of the signal will convert all values to positive values. Next, a root mean square of the signal is calculated and examined to determine the overall greatest activation level. This overall highest activation level can then be selected for use for in the vibration protocol (Di Giminiani, et al., 2010; Di Giminiani, et al., 2009).
Summary

In summation, WBV has been shown to improve performance parameters such as balance, flexibility, strength and power. Upon taking a closer look at the studies in these areas, WBV has extensively looked at improvements in muscular strength through isometric and concentric actions and looked at power improvement through concentric actions. When investigating concentric power output, a common measurement seen is the improvement in jump height through various jumping protocols. Even though looking at jump height is an important measurement, the individual still has to land and since the jump height has the potential to change, the landing from an improved jump height may have the potential to change, and should be examined.

Examining Landings

The Landing

A landing is when an individual loses contact with a support surface and then returns to that surface or another surface of different height. When an individual initiates contact with a surface, they have to decelerate their bodies’ negative acceleration to return to a state of equilibrium. There are two major strategies used while landing, toe to heel (forefoot) or heel to toe (rear foot) (Cortes et al., 2007). Athletes have unique landing strategies depending on their personal preference and task demands (Cortes, et al., 2007). It has been suggested that the forefoot landing strategy has the greatest potential to reduce peak ground reaction forces (GRF) at impact (Butler, Crowell, & Davis, 2003; Dufek & Bates, 1990). As landing height increases, and consequently movement velocity increases, individuals are encouraged to land with greater initial knee and hip flexion to reduce peak impact forces on the lower extremities (Oggero, Pagnacco, Morr, Barnes, & Berme, 1997). These data show that a forefoot landing strategy coupled with increased knee and hip flexion has the potential to reduce ground reaction forces on the lower
extremities. Each individual has their own preferred landing strategy however, which is commonly used in multiple landings protocols that have been completed successfully and safely.

**Landing Protocols**

Through review of current literature there are common drop jump, or drop landing with a countermovement jump, protocols that have been completed and established to be safe for subjects. As a result of these investigations there has also been a range of drop jump heights established and utilized in various populations ranging from 0.32m to 0.61m (James, Scheuermann, & Smith, 2010; Medina, Valovich McLeod, Howell, & Kingma, 2008; Shultz & Schmitz, 2009; Shultz, Schmitz, Nguyen, & Levine, 2010). Investigators examining the effect of landing height on GRF reported that peak vertical GRF were substantially elevated at a 0.60 m landing height compared to a 0.30 m landing height (Yeow, Lee, & Goh, 2009). The results should be focused on just the performance of the lower extremities, so having the arms elevated reduces the effect of the arms on the countermovement jump (Pappas, et al., 2007), thus helping to isolate the lower extremities. Controlling the hands could involve stepping directly off of an elevated platform with hands at ear level and landing with both feet on the force plate(s) at the same time (Shultz, Nguyen, Leonard, & Schmitz, 2009; Shultz & Schmitz, 2009; Shultz, et al., 2010), or even just having the subjects cross their hands over their chest (Pappas, et al., 2007). These protocols, with the exception of hand and arm placement, had the subjects land using their own preferred landing strategy, so they are experiencing a familiar movement and can help to reduce any injury risks associated with landings.

**Risk Factors for Landings**

During the deceleration phase of landings, there is a potential risk of ACL injury, which can significantly alter the individuals performance and is associated with potentially severe costs (Flynn et al., 2005). As the jump height of the individual increases, the GRF that the individual will experience while landing increases (Yeow, et al., 2009). This increase in GRF as a result of
the increased jump height must be absorbed. Having higher GRF has been associated with ACL injury risk (Hewett, et al., 1996; Irmischer, et al., 2004). This establishes a need for studies to discover preventative methods to try to prevent ACL injuries from occurring or reduce the chance of them occurring or reoccurring. Research has identified lower extremity positions that have a greater potential to influence ACL injury, and has been described as the “point of no return” (Ireland, 1999). The point of no return is characterized by increased adduction and internal rotation of the hip with an associated increase in valgus knee angles and external tibial rotation. Of these joint positions, landing with a knee valgus alignment puts the knee in an unstable position (Hewett, 2000). Multiple sources cite knee valgus as a major contributing factor to ACL rupture (Cowley, Ford, Myer, Kernozek, & Hewett, 2006; Griffin et al., 2006; Olsen, Myklebust, Engebretsen, & Bahr, 2004). Data also suggests increased tibial external rotation (Cowley, et al., 2006; Olsen, et al., 2004) associated with valgus forces adds to the increased ACL injury risk. Since valgus angles are already an elevated risk factor, it is unfortunate that this angle poses an additional risk for females.

**Females and Valgus Knee Angle**

It is unfortunate that females are already as much as four to eight times more likely to sustain an ACL injury (Hewett, 2000) when compared to males. Likely associated with increased ACL risk, females have been shown to display greater knee joint valgus angles than men (Ford, et al., 2003; Hewett, et al., 2005; Russell, et al., 2006). This landing predisposition could pose a problem for females. As stated earlier, as jump height increases, the GRF will increase as well (Yeow, et al., 2009). As valgus knee angle increases, so does the knee adductor moment (Markolf, Graff-Radford, & Amstutz, 1978), and this moment is influenced by GRF’s. With that being said, as GRF increases, the potential of having a higher knee adductor moment increases based on the valgus angle of the knee. This poses a risk because higher knee adductor moments have been positively correlated with predicting ACL injury risk in a larger percentage of females.
As stated earlier, females tend to land with higher knee valgus angles, which can potentially further increase knee adduction moments and put females at an even higher risk for ACL injury. The ACL risk for females is an important topic that is compounded by multiple risk factors.

The Menstrual Cycle and ACL Injury Incidence

When using female subjects, the menstrual cycle should not be forgotten as a topic of discussion. During the menstrual cycle, hormonal production of estrogen increases dramatically (Hewett, 2000) and estrogen has been shown through an in vitro study to significantly decrease ligament strength (Booth & Tipton, 1970). If the strength of a ligament is decreased, its ability to perform its task of restraining joint motions may be compromised. This could ultimately lead to increased joint laxity which has been shown as a factor that can contribute to putting the knee into an at risk position (greater knee valgus and hip adduction and internal rotation) of ACL injuries (Shultz & Schmitz, 2009). It has been suggested that the higher rates of ACL injuries in females may be affected by the menstrual cycle, yet the research has been largely equivocal. Some self-reported data has suggested that females are more susceptible to injury during the pre-ovulatory phase of the menstrual cycle (Slauterbeck et al., 2002; Wojtys, Huston, Lindenfeld, Hewett, & Greenfield, 1998) however, another study showed that ACL injuries in females were higher not only in the pre-ovulation phase, but also in the post-ovulation phase (Myklebust, Maehlum, Holm, & Bahr, 1998). Though hormonal fluctuations may pose a factor of increased joint laxity, recent research has shown no correlation between menstrual cycle and joint laxity (Beynnon et al., 2005; Eiling, Bryant, Petersen, Murphy, & Hohmann, 2007). This study focused on frontal plane kinematics, and research shows that there is no significant difference in frontal plane kinematics during a drop jump over the course of the menstrual cycle (Dedrick et al., 2008). As depressing as ACL injuries sound, there is hope through training to reduce the likelihood of the occurrence or reoccurrence of such injuries.
Training to Prevent ACL Injuries

There are multiple training methods that can be used, but can be categorized into four areas of focus: landing technique training, strengthening of the posterior chain muscles, side to side strength and power symmetry, and core/perturbation training (Hewett, et al., 2010). Plyometric training can involve jumping, so proper landing technique, such as the toe to heel method described earlier, should be taught for these exercises. Plyometric exercises have been found to decrease landing forces, varus and valgus forces, as well as improve muscle activation (Griffin, Albohm et al. 2006). Plyometric training helps to increase power production by attempting to reduce the time it takes to reach peak torque and tries to improve voluntary contraction in anticipation of a movement (Wojtys, Wylie et al. 1996). Exercises such as Romanian dead lifts focus on strengthening the hamstrings and gluteal muscles, which are a part of the posterior chain of muscles used in jumping and landing. Isolation of each leg with exercises such as pistol or single leg squats can help to focus on trying to create symmetry between each leg. Balance training, however, seems to be one of the best methods for reducing ACL injuries (Griffin, Albohm et al. 2006). All of this training brings the focus of this study back to WBV. Whole body vibration is a training method that has been shown to improve power output (Bosco, et al., 1999; Cochrane, et al., 2010; Di Giminiani, et al., 2010; Di Giminiani, et al., 2009), strength (de Ruiter, et al., 2003; Savelberg, et al., 2007), balance (Torvinen, Kannu, et al., 2002), and flexibility (Di Giminiani, et al., 2010). The potential of WBV to improve various performance parameters can help to answer the questions proposed by this study.

Summary

In summation, WBV has been used to improve performance parameters. These performance parameters involve isometric and concentric strength and concentric power production. There lacks data on the effects of WBV on eccentric muscular actions. Multiple WBV studies look at improved power output through jump height, yet to the investigators
knowledge, there have been no studies investigating the landing phase of a jump, which requires eccentric muscle actions to perform. As referenced earlier, certain positions while landing, such as the degree of valgus knee angle, pose a potentially greater risk for ACL injury. If WBV has the potential to improve power output and increase jump height, does this new jump height affect how the individual lands and absorbs the energy? This topic has not been investigated, and research should be conducted to investigate the effects, if any, of WBV on how the lower extremities absorb energy eccentrically and the landing mechanics associated with the landing.
Introduction

Whole body vibration (WBV) has been used as a tool to induce short term adaptations to muscular tissue. Whole body vibration involves standing on a vertically oscillating platform that causes a displacement of the individuals center of gravity altering the gravitational forces on the body (Furness & Maschette, 2009). The vibrations imposed can occur across a range of amplitudes and over a wide range of frequencies and have been shown to improve power output (Bosco, et al., 1999; Cochrane, et al., 2010; Di Giminiani, et al., 2010; Di Giminiani, et al., 2009), strength (de Ruiter, et al., 2003; Savelberg, et al., 2007), balance (Torvinen, Sievanen, et al., 2002), and flexibility (Di Giminiani, et al., 2010). Two ways in which WBV is theorized to improve muscular performance are through post potentiation activation (Cochrane, et al., 2010) and the improvement of the stretch reflex loop or tonic reflex (Cardinale & Bosco, 2003).

Multiple WBV studies have measured the effects of the vibration stimulus on maximal isometric strength (minimal change in muscle length) (de Ruiter, et al., 2003; Savelberg, et al., 2007) and concentric power (muscle shortening) (Bosco, et al., 1999; Cochrane, et al., 2010; Di Giminiani, et al., 2010; Di Giminiani, et al., 2009). However there appears to be a dearth of literature looking at the effects of WBV on muscles undergoing an eccentric (muscle lengthening) load and the ability to control energy absorption.
The effects of WBV on both post potentiation activation and the stretch reflex loop may contribute to the increased ability to generate power. Although studies have demonstrated that WBV can increase jump performance (Wyon, et al., 2010) the results have been somewhat equivocal. More recently the use of an individualized frequency of WBV has produced significant results (Di Giminiani, et al., 2010) even eliciting more highly significant results than that of a fixed frequency vibration protocol (Di Giminiani, et al., 2009). Regardless of the type of vibration used however, these studies have focused on the upward power generating portion of the jump. While generating higher levels of force and power are important for many aspects of sport performance, successfully landing from the improved jump height has not received attention in terms of the adaptations that occurs following WBV. The landing is important because the individual has to decelerate the body in order maintain stability, absorb the kinetic energy and ultimately produce the power necessary for a subsequent jump or movement. If an individual has improved jump height following WBV, then it is possible that the WBV may affect the landing as well. Whole body vibration may add additional control of the lower extremities by increasing the sensitivity of the muscle spindle or through post potentiation activation, and this could translate into decreased GRFs and less deviation from a normal landing, keeping the knees closer in line between the ankles and hips to reduce valgus knee angle.

Research has demonstrated that most non-contact ACL injuries occur during the landing phase of a jump (Jacobs, Uhl, Mattacola, Shapiro, & Rayens, 2007; Medina, et al., 2008; Russell, et al., 2006). Women are four to eight times more likely to sustain an ACL injury (Cowley, et al., 2006; Hewett, 2000; Hewett, et al., 2010; Nagano, Ida, Akai, & Fukubayashi, 2007) when compared to males. Given the high incidence rates and the severity and cost associated with ACL injuries (Flynn, et al., 2005) there is a need for studies to identify risk factors and ultimately to try to prevent ACL injuries from occurring or reduce the chance of them reoccurring. When an individual lands, they often times assume a position in which the knees move into an unstable
valgus position (Hewett, 2000). This valgus position is part of the “point of no return“ that has been shown to increase the risk for ACL injuries (Ireland, 1999), which consists of the hips adducting and internally rotating with valgus knee angles and an associated external tibia rotation. This position places a considerable amount of strain on the ACL and increases the risk of injury. If WBV can improve the muscles capacity to produce force the active contraction of the knee musculature may help to facilitate an improvement in the contribution to joint stability of the passive structures of the knee (i.e. ACL) and consequently reduce the risk of ACL injury.

One population that consistently demonstrates greater valgus knee angles are women when compared to men (Ford, et al., 2003; Hewett, et al., 2005; Russell, et al., 2006) which has been suggested to be one of the causes for the higher incidence rates of ACL injury in women. As the jump height of the individual increases, the ground reaction force (GRF) that the individual will experience while landing also increases (Yeow, et al., 2009). Having higher ground reaction forces (GRF) has been associated with ACL injury risk (Hewett, et al., 1996; Irmischer, et al., 2004). Having higher GRFs can be detrimental because adductor moments of the knee can help to predict ACL injury (Markolf, Graff-Radford et al. 1978). With high incidence rates research still needs to be conducted looking into the mechanism of these injuries. As such, it was the purpose of this study to identify if the changes associated with WBV of the muscles of the lower extremity are, through improved control, able to help absorb the negative acceleration of the body, alter landing forces, and alter landing mechanics.

Methods

Methods of Data Collection

Twenty college aged subjects (10 male, 10 females) were recruited for this study, prior to the second visit, one male dropped out due to a knee injury sustained during an activity unrelated to this study, bringing the total to 19 subjects (9 males, 21.40±2.87years, 78.68±13.89kg, 1.75±0.09m; 10 females, 21.40±3.13years, 63.48±12.21kg, 1.66±0.06m) who were without lower
extremity neuropathies, recent injuries, or a history of concussions. Subjects were required to be recreationally active based on American Society of Sports Medicine guidelines (Thompson, 2010). This study was approved by the Ball State University institutional review board.

Subjects were asked to participate in two separate visits with the initial visit consisting of the subjects receiving an explanation of the study, along with the associated risks and asked to sign a university approved consent form. During the initial visit each subjects’ individualized frequency was determined. To determine the individualized frequency for the subject, electromyographic (EMG) electrodes (Bagnoli DE 2.1) were applied over the muscle bellies of the tibialis anterior, medial gastrocnemius, vastus lateralis, and bicep femoris. Prior to electrode placement the area was shaved, abraded and cleansed with alcohol to remove hair and oils from the skin (Ritzmann, Kramer, Gruber, Gollhofer, & Taube, 2010). The longitudinal axis of the electrode was placed on the skin directly above the muscle in line with the direction of the underlying muscle fibers (Ritzmann, et al., 2010). Once all electrodes were attached, the subject stood with their knees bent in a semi-squat position (Cardinale & Bosco, 2003) to approximately 15 degrees on a vibration plate (Pneu-VibePro, Sandpoint, ID) with EMG activity being monitored by a Bagnoli-16 system (Delsys, Boston, MA).

For the individualized frequency protocol, subjects completed baseline (no vibration) trials immediately followed by a random vibration frequency of 20, 25, 30, 35, 40, 45, 50 or 55 Hz. Each vibration trial lasted 10 seconds, resulting in a total of 80 seconds of vibration during the individualized frequency protocol. Between each vibration exposure four minutes of rest was provided to limit the effects of fatigue or crossover from the previous vibration exposure. Following the first visit a root mean square value was computed to determine the muscle activation levels at the various vibration frequencies. Baseline (no vibration) levels were compared to activation levels during WBV, and the individualized frequency was that which produced the largest difference between the vibration frequency activation and the baseline
activation level. After the individualized frequency, the subject performed 10-20 practice drop jumps from a box at a height of 0.60 m (James, et al., 2010) and to help lessen potential learning effects. The subject was instructed to land with each foot completely on 0.46 m x 0.51 m force plates (AMTI OR6-7-1000, Watertown,MA), and to jump as high as possible after the landing. The subject held onto a harness that they wore to control arm movement and to maintain the same upper body orientation for every trial. At the end of the first visit the subject was asked to return 48 hours to ten days after the first visit and to refrain from exercise 24 hours prior to their second scheduled visit.

For the second visit, the subjects were prepped with motion capture reflective markers and EMG electrodes. The EMG preparation was the same as the first visit and reflective markers were secured to anatomical landmarks on both the upper and lower body with double sided tape to the skin. A cluster set of markers was used for the thigh and shank, with additional markers on the lateral malleolus of the ankle, lateral knee, anterior superior iliac crest, posterior superior iliac crest, on the acromion process of each shoulder, a marker at the base of the clavicles and additional markers on the 7th cervical and 12th thoracic vertebrae. Next the subjects completed a warm-up of five minutes of walking on a treadmill as a self selected pace followed by 5-10 drop jumps, such that five successful landings were recorded. A successful landing consisted of all reflective markers being recorded while the subject landed with each foot completely on their assigned force plate. Unsuccessful trials were discarded, which included falls, landing off of the force plates, loss of balance, a non-maximal jump and markers falling off of the subject. To help offset the potential effects of fatigue, 30 seconds of rest was provided between trials. The subject then completed a vibration protocol that consisted of ten, one minute vibration sessions with a one minute rest in between each trial, and a four minute rest period after the fifth trial (Di Giminiani, et al., 2010; Di Giminiani, et al., 2009). For the vibration sessions, the individual maintained a semi-squat position with approximately 15 degrees of knee flexion to maximize the
effects of the vibration and reduce residual vibrations to the head (Abercromby, et al., 2007). The subject performed 5-10 additional drop jumps following the final vibration trial, and then completed an additional 5-10 drop jumps 10 and 20 minutes after the cessation of vibration. The additional trials performed 10 and 20 minutes post vibration were performed to assess for any changes associated with recovery or improved performance from the WBV protocol.

**Data Analysis**

Data for this study was assessed from initial contact to peak knee flexion, as measured in other drop landing studies (Howard, Fazio, Mattacola, Uhl, & Jacobs, 2011; Shultz, et al., 2009; Shultz & Schmitz, 2009; Shultz, et al., 2010). The subject landed with each leg on a separate force plate at the same instant, yet only the dominant right leg was used for data analysis. This study looked at peak GRFs and the loading rate of the GRFs as measured from initial impact to peak knee flexion during the drop landing. Peak frontal plane knee varus/valgus angles and knee moment were analyzed during the landing as well as jump height. Pre and post values of all measures were compared to baseline values. Ultimately, the data was assessed for four time points, pre-vibration, post vibration, and 10 and 20 minutes post vibration. In addition, potential changes as a function of gender were assessed.

**Statistical Analysis**

To assess for changes between pre and post WBV exposure as well as for differences between males and females, separate two x four (sex x time) Repeated Measure Analysis of Variance (RM-ANOVA’s) contrasts were performed on GRF, loading rate, knee valgus angle, frontal plane knee moment and jump height. In the event that significant main effects were found across the effects of time and sex, follow-up pairwise comparisons were performed. Sphericity was also assessed, and if violated, Huyn-Feldt corrections were used for data comparisons. For all comparisons the alpha level was set at p ≤ 0.05.
Results

All 19 subjects completed the study safely and with no reported discomfort. Summary data for all dependent measures across all testing periods are presented in Table 1. After processing the individualized frequency of all subjects, the average vibration frequency used consisted of 33.68±7.42 Hz with a range from 20-50 Hz.

Ground Reaction Forces

For the measures of peak GRF across the pre, post and 10 and 20 minute post assessment, there were no significant differences across any of the simple main effects of time (p=0.158) or sex (p=0.408) or for the higher order interaction of time by sex (p=0.623). For the measures of peak loading rate across the pre, post and 10 and 20 minute post assessment, there were no significant differences across any of the simple main effects of time (p=0.155) or sex (p=0.565) or for the higher order interaction of time by sex (p=0.153).

Knee Angle

Assessing the measure of valgus knee angle revealed a significant main effect for time (F=4.78(2.303, 36.884), p=0.011 η0.230 power=0.801). Further pairwise comparisons revealed that valgus knee angle increased significantly during the post vibration (p=0.008), ten minutes post vibration (p=0.031) and 20 minutes post vibration (p=0.020) conditions. These findings indicate that following WBV, during the initial contact to peak knee flexion phase, when collapsed across sex, subjects landed with significantly greater knee valgus angle. The effects for sex and the interaction between sex and time were not significant, however these data show that females likely had a greater valgus knee angle due to a large effect size (0.81)

Jump Comparison

Jump height was assessed to determine if vibration improved jump height as referenced in previous studies. Jump height was not significantly (p=0.675) affected across all three time
intervals following WBV or for the higher order interaction of time by sex (p=0.465). However, sex comparisons revealed that the males jumped significantly higher than females (F=21.71(1,16), p<.001 η=.576 power=.992)(Table 1).

**Knee Moment**

Frontal plane knee moment did not significantly (p=0.859) change during all three time intervals following WBV or for the higher order interaction of time by sex (p=0.756). Females did, however, show a significantly (F=29.415(1,16) p=.038 η=.241 power=.563) greater frontal plane knee moment than males (Table 1).

**Discussion**

For this study there were three or four main purposes investigated WBV utilizing an individualized frequency on the mechanics of a drop landing. The results of this study revealed that following a WBV protocol individuals, regardless of sex, experienced an increased valgus knee angle during the landing phase of a drop landing. The effects of WBV have been shown to last up to 60 minutes following vibration (Cardinale & Bosco, 2003) which is supported by the valgus knee angles recorded in the current study. These data also showed that females had a larger knee adductor moment than males, and males jump higher than females, which were expected outcomes (Komi & Bosco, 1978; Sigward & Powers, 2006) When individuals land from a height they are required to decelerate the body to come to a halt or prepare for the next movement. During a landing an individual’s knees can travel outwards and away from each other creating a varus knee angle, inwards and towards each other creating a valgus knee angle, or in what can be observed as a stacked or vertical alignment of the knees between the hips and ankles. Previous studies have indicated that valgus knee angles are a potential risk factor for ACL injury (Cowley, et al., 2006; Griffin, et al., 2006; Olsen, et al., 2004). In addition, females are known to generally have a greater valgus knee angle (Ford, et al., 2003; Hewett, et al., 2005; Russell, et al., 2006) when compared to males. With WBV showing
an increased valgus knee angle regardless of the sex of the individual, caution should be taken when applying WBV before performing plyometric movements that involves jumping. Even though WBV has been shown to improve power output, when performing movements such as depth jumps that require a landing, the WBV could increase valgus knee angles, potentially putting the individual at a greater risk for an ACL injury. Although there was an increase in valgus knee angle following WBV, recent research (Reyes, Dickin, Dolny, & Crusat, 2010) demonstrated that when participants were given time to rest, a beneficial effect of vibration was seen and performance improved. As such it might be the case that using the current protocol the subjects could have benefitted from a longer rest period or that the vibration exposure was too long. Ten minutes of vibration could have been too much and the subjects may have experienced some degree of fatigue. To combat this future studies could either reduce the time the subjects experience vibration during the vibration protocol, or increase the rest time the subjects after the vibration protocol is completed.

The use of a plyometric drop jump protocol for this study differs considerably from most WBV studies in that the task required the use of eccentric muscle action as opposed to the more common concentric actions such as jumping, squatting and isokinetic testing. The landing task utilized in the current study analyzed the eccentric actions required to decelerate the body. It was recently indicated that that the eccentric phase of a drop jump creates a negative energy balance through comparison between a squat jump, countermovement jump and a drop jump. The countermovement jump displayed significantly higher concentric force and jump height compared to a squat jump, however, even though the drop jump showed a significant increase in concentric force compared to the countermovement jump, a significantly greater jump height was not seen (McBride, McCaulley, & Cormie, 2008). It was concluded that the eccentric load was excessive and even though a greater concentric force was produced, this negative energy balance resulted in no significant increase in jump height. That study based their drop height off of each
subjects maximal jump height during the countermovement jump, and the average drop height was around 0.40 m. This could explain why no significant increase was seen for jump height in this study. If a 0.40 m drop height created too much of a negative energy balance to improve jump height, then it is possible that the drop height of 0.60 m platform used in this study was too high for the subjects and created a significant negative energy balance, resulting in no significant change in jump height. Additionally, if the 0.60 m box height was higher than their maximal jump height, then decelerating the body could be considered an even more challenging task and may have impaired the individual from controlling joint angles and in effect collapsing during the landing, as well as not showing a significant improvement in jump height. It is important to note that the current study is one of the first to examine an eccentric action of the musculature used to perform a movement following WBV exposure. Given the significant changes in valgus knee angle during landing in the current study future investigation is warranted addressing the effects of vibration on eccentric actions of muscles. Although significant changes in valgus knee angle were found, future studies should assess different box heights to determine if the effects of WBV could alter landing mechanics.

A significantly higher knee adductor moment was seen for females when compared to males. As stated earlier, females tend to have a higher valgus knee angle when compared to males, and this valgus angle influences the knee adductor moment. Recent research has shown a positive correlation of having a higher knee adductor moment with ACL injury risk (Podraza & White, 2010). With this being said, all individuals may want to use caution when performing plyometric movements following a WBV session. These data show that valgus angle increased for up to 20 minutes following vibration, which as an end result can potentially increase the knee adductor moment and put individuals at a higher risk for ACL injury.

The current stance used in multiple research protocols requires the individual to stand with feet shoulder width apart with toes straight in a semi-squat position (Cardinale & Bosco,
2003; Marin & Rhea, 2010). Although not assessed this shoulder width stance produced an observable slight valgus knee angle. Consequently, one could speculate that the stance used during vibration may have elicited the increase in knee valgus angle instead of the vibration. Melnyk et al. (Melnyk, Kofler, Faist, Hodapp, & Gollhofer, 2008) utilized a stance where the subjects outwardly rotated their feet approximately five degrees, and displayed improved knee stability following a whole body vibration protocol. The mechanism used in their study utilized a pulley system that pulled on and measured tibial translation using a potentiometer attached at the kneecap. Although not reported the figures included in the article suggest that the subjects may have been in a hip width stance rather than the shoulder width stance, as used in this and other studies. Future research should investigate the effects of different stance widths including inward and outward rotated hips to manipulate varus and valgus knee angle during vibration.

**Conclusion**

Whole body vibration utilizing an individualized frequency was shown to increase valgus knee angle for up to 20 minutes following a vibration training protocol. Even though this study focused on discovering if WBV had an effect on peak GRF and loading rates, no significant differences were found. It should be noted however that the drop height used may have diminished the ability of the individuals to actively control the landing by not being able to stop the movement of the center of gravity quick enough to perform the subsequent jumping action. Despite this the information obtained may still be useful to know when creating training protocols. If the training protocols include vibration and any kind of plyometric or jump training of the lower extremities, then caution should be used. Individuals who already have valgus knee angles during landings could potentially be at a higher risk for ACL injury for up to 20 minutes following a vibration session. Only subjects trained with proper landing mechanics should potentially use vibration platforms to supplement their training program. Future research should
investigate the effects of an individualized vibration protocol by manipulating the vibration to rest ratio and different stances.
Figure 1.  The average peak valgus knee angle across five drop landings at four time points are illustrated. *= indicates a significant difference from baseline values.
Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gender</th>
<th>Pre-vibration</th>
<th>Post Vibration</th>
<th>10 Mins Post Vibration</th>
<th>20 Mins Post Vibration</th>
<th>P Values</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Time</td>
<td>Sex</td>
<td>Time x Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRF (BW)</td>
<td>Male</td>
<td>2.78±0.63</td>
<td>2.64±0.54</td>
<td>2.63±0.57</td>
<td>2.61±0.69</td>
<td>0.158</td>
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<tr>
<td></td>
<td>Female</td>
<td>2.92±0.49</td>
<td>2.94±0.56</td>
<td>2.87±0.52</td>
<td>2.82±0.70</td>
<td>0.155</td>
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<tr>
<td>Loading Rate (BW/s)</td>
<td>Male</td>
<td>215.63±79.40</td>
<td>207.27±66.80</td>
<td>204.86±57.54</td>
<td>190.82±53.77</td>
<td>0.155</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>217.67±81.59</td>
<td>231.07±82.35</td>
<td>226.31±74.47</td>
<td>220.40±80.06</td>
<td>0.153</td>
</tr>
<tr>
<td>Knee Angle</td>
<td>Male</td>
<td>-6.79±6.87</td>
<td>-7.27±6.63†</td>
<td>-7.46±6.23†</td>
<td>-7.69±6.87†</td>
<td>0.011</td>
</tr>
<tr>
<td>(degrees)</td>
<td>Female</td>
<td>-11.56±5.93</td>
<td>-12.79±5.65†</td>
<td>-12.84±6.14†</td>
<td>-13.03±6.69†</td>
<td>0.091</td>
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<tr>
<td>Knee Moment</td>
<td>Male</td>
<td>-0.316±0.264</td>
<td>-0.316±0.227</td>
<td>-0.309±0.225</td>
<td>-0.355±0.231</td>
<td>0.859</td>
</tr>
<tr>
<td>(Nm/kg)</td>
<td>Female††</td>
<td>-0.805±0.497</td>
<td>-0.786±0.640</td>
<td>-0.772±0.512</td>
<td>-0.777±0.525</td>
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<tr>
<td>Jump Height</td>
<td>Male††</td>
<td>0.410±0.047</td>
<td>0.416±0.041</td>
<td>0.406±0.039</td>
<td>0.413±0.034</td>
<td>0.557</td>
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<tr>
<td>(m)</td>
<td>Female</td>
<td>0.293±0.071</td>
<td>0.286±0.719</td>
<td>0.287±0.066</td>
<td>0.286±0.058</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

†Indicates a significant difference from baseline values, BW = bodyweight

††Indicates a significant difference between gender
Chapter 4- Summary and Conclusions

Summary

Whole body vibration is a training tool that has been shown to improve balance, flexibility, strength and power. In regards to strength and power, isometric strength and concentric power have been studied; however, little research has been conducted looking at the effects of WBV on eccentric loading activities during movements. Various jumps such as a countermovement jump and a drop landing with a subsequent jump (Cochrane & Stannard, 2005; Di Giminiani, et al., 2010; Di Giminiani, et al., 2009; Torvinen, Sievanen, et al., 2002) have been used to test power output through jump height following a vibration protocol. Integral to this study are results indicating that the landing phase following a jump has been identified as a high risk factor for ACL injuries. During a landing, factors such as hip and knee extension at initial contact, knee valgus angle, and tibial rotation can contribute to ACL injury risk. Valgus knee angle has been cited multiple times as a leading contributor to ACL injuries. Interestingly enough, females tend to have greater valgus knee angles which could potentially put them at a higher ACL injury risk. This study sought to investigate multiple questions: does WBV affect GRF during the landing phase, do the neuromuscular effects resulting from WBV alter the kinematics of the landing, does WBV improve jump height and are there any gender differences in general and as a result of the WBV?
The study consisted of an individualized frequency visit and a second visit that included drop jumps and a vibration protocol. The vibration used consisted of a frequency that elicited the greatest neuromuscular response from the subject. Following vibration, there was a significant increase in valgus knee angle that persisted up to 20 minutes following the vibration exposure with no concomitant changes in peak ground reaction forces, peak loading rate, jump height, or knee moment following vibration. Not surprisingly, males jumped significantly higher than females, and females had a significantly greater knee adductor moment compared to males.

**Limitations**

There are multiple protocols that have been used for WBV and as such a defined volume of vibration required to produce significant results has not yet been established. It is possible that the volume of vibration, the number of drop jumps or both used for this study produced fatigue and impacted the results. Another possible limitation was the stance used during vibration. Most studies have utilized a shoulder width stance with the individual standing in a semi-squat stance with toes pointed forward. This stance has the potential to produce a slight valgus knee angle, which may affect lower extremity kinematics during activities such as jumping and landing. Future studies should continue to manipulate drop jump platform height, the volume of vibration time and stances used during vibration protocols.

**Conclusion**

Based on the findings of this study, it can be concluded that valgus knee angle significantly increased following an individualized frequency vibration protocol. The study also confirmed that females had a greater knee adductor moment with a possible difference in valgus knee angle due to a large effect size. An increased valgus knee angle as a result of WBV can put individuals at a higher risk for ACL injury, and an even higher risk for females who start with a larger valgus knee angle. For women, when an increased valgus knee angle as a result of WBV is coupled with an already high degree of initial knee valgus and knee adductor moment their risk...
for ACL injury is elevated even further. From a training standpoint, individuals should use caution when using a vibration platform and plyometric training that includes jumping or stepping off of a box and landing (depth jumps) until additional data is provided on WBV and its effects on landing mechanics.

**Future Recommendations**

There was no apparent recovery following the 20 minute rest period for knee valgus angle. A possibility is that the rest period was not sufficient enough for the subjects, and that some low levels of fatigue could have been affecting the data. To this end, future research should examine the effects of vibration on drop jumps at longer time intervals following vibration, such as 30 and 60 minutes post vibration, or reduce the duration of the vibration protocol. The possibility of muscular fatigue could potentially have occurred due to the number of drop jumps performed as well as the height of the box. Future studies should manipulate the height of the box for a population such as the one used in this study. In terms of the increased knee valgus there is a possibility that the individuals’ stance on the vibration plate may have caused the increase and not the vibration alone. A slight valgus knee angle was observed for multiple subjects while standing in a shoulder width stance. Future studies should change the distance between the feet and an inward or outward rotation of the feet to manipulate the angle of the knees between valgus and varus stances. Given the overall finding from this study and the number of iterations of potential research questions that have been uncovered as a result of this study, future research is recommended in the area of WBV and landing mechanics.
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