The Effects of Whole Body Vibration on the Wingate Test for Anaerobic Power When Applying Individualized Frequencies

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By

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DECLARATION

The work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text, and the material has not been submitted, either in whole or in part, for a degree at this or any other university.

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Nomenclature

I-Freq- Individualized Frequency

PP- Peak Power

AP- Average Power

RF- Rate of Fatigue

WBV- Whole Body Vibration

EMG- Electromyography

EMG_{rms}- Electromyography Root-Mean-Squared

CHAPTER 1- Development of the Problem

Introduction

The ability to generate high force in the shortest time possible, also referred to as the rate of force development or power, is a quality possessed and optimized by elite athletes. Power development has become a primary focus of athletic performance enhancement training programs [1]. Power is also an important component of general health and fitness. Traditional overload techniques require considerable time, intensity and volume of training to improve power in an individual. Several training modalities have been used to accentuate power including plyometrics (the pre-stretching of active muscles prior to contraction), resistance training, and electrical stimulation [2]. More recently, whole-body vibration (WBV) has been proposed as a potential alternative, or adjuvant to exercise for power development [3-6]. Additionally, WBV is potentially a less time-consuming method for increasing power output than traditional training [7]. Vibration training or WBV constitutes a mechanical stimulus that typically enters the human body by way of the feet when standing on a vibration platform in a semi-crouched position [8, 9]. It is assumed that the vibration frequency induced by the motor platform may induce non-voluntary muscular contraction termed the tonic vibration reflex (TVR) [10].

Current research has focused expansively on both the acute and chronic effects of vibrations using different types of vibratory methods [11-16]. Acute vibration, consisting of a single bout of vibratory stimulus used to elicit a response in the individual, has been seen to improve dynamic muscle performance such as during the counter movement jump[14], one repetition max test[17], vertical jump height [18] and squat endurance until exhaustion [19]. Additionally Bosco et al. concluded that a single bout of vibration resulted in significant temporary increase in muscular strength in the lower extremities. One particular study focusing on maximal power in participants in elite and amateur athletes (sports including judo, wrestling, weighlifting, gymnastics, track and field, basketball and volleyball), concluded that an acute bout of vibration to the arm muscle during a bilateral biceps curl induced a significantly larger increase in maximal power during the active phase of the biceps curl for the elite athletes (10.4%) than for the amateur club participants (7.9% increase)[4]. These results suggest that higher trained individuals may still elicit a training effect following vibration and in this case, even more so than their lesser trained counterparts. Acute WBV may improve anaerobic power in athletes however, there has yet to be a study to examine the effects of acute WBV on anaerobic exercise performance using the glycolytic system (e.g., exercise lasting up to approximately 30 seconds).

Several factors have been shown to influence the acute, residual, and chronic effects of vibration exposure and training. Vibration application (i.e., applied directly to the tendon or applied to the feet), amplitude, frequency, and exercise protocols are the vibration characteristics that influence the neuromuscular system [20]. Many previous studies have utilized vibrations frequencies between 20 and 40 Hz with the most commonly used frequency being approximately 30 Hz, with an amplitude between 1 - 5 mm [8, 9]. The findings of these studies, however, have been equivocal in terms of how individuals have responded to the applied frequencies. Recent studies have stated that each individual may in fact have different optimal frequencies of vibration that will elicit the greatest reflex response during WBV [21-23].

Using EMG recordings of the concerned muscle during vibration exposure may allow researchers to determine an individual's optimal frequency as a neurological index [21-23]. In a seminal study using individualized frequency during whole-body vibration, Di Giminaini et al. (2009) reported a significant increase in vertical jump height during the squat jump and also an increase in power and height during continuous rebound jumping. In the same study it was also determined that in a comparable group of participants, the day-to-day reliability of the individual vibration frequency was 0.92 demonstrating the reproducibility of the measure.

Physical fitness can be accessed through five major components including cardiorespiratory endurance, muscular power/strength, muscular endurance, flexibility and body composition. An anaerobic activity is defined as energy expenditure that utilizes anaerobic metabolism that is 90-seconds or less in duration and uses an exhaustive effort [24]. Several tests have been developed to assess an athlete's peak power, anaerobic capacity, or both. These tests include the vertical jump test, standing long jump test, Bosco repeated jumps, and the Wingate test for anaerobic power [24]. The Wingate test is a 30-second all-out exhaustive ergometry test where the athlete pedals against a resistance that is set at a certain percentage of their body weight. Power is measured throughout the test by the number of revolutions the athlete can achieve during the 30-seconds of the test [24]. Two major energy sources are required of the athlete during the Wingate test including the adenosine triphosphate-phosphocreatine (ATP-PCr) system lasing for 3 to 15 seconds during maximal effort [25], and through anaerobic glycolysis which can be sustained the remainder of the 30-second test[26] . The Wingate test becomes a good measurement of the athlete's ability to work using both the ATP-PCr and glycolytic systems. Despite the Wingate test being a well documented, reliable laboratory test to determine anaerobic power, the literature regarding WBV using individualized frequency has had a propensity to focus on the vertical jump test and the Bosco repeated jumps as anaerobic power measurements [13-15, 22, 27-29].

When training to increase power, it becomes important to measure it in ways that relate to athletic performance. The Wingate test for anaerobic power is a cycling specific test where anaerobic power, anaerobic fatigue and total anaerobic capacity (rate of fatigue) are measured [30, 31]. The Wingate was developed in the 1970s and has been accepted in laboratories around the world to assess muscle power, muscle endurance, and fatigability and has been proven as a reliable assessment of physiological responses to supramaximal exercise [32]. The Wingate provides the tester with information regarding Peak Power (PP), Average Power (AP) and Rate of Fatigue. Because of the cycling specific nature of the test, it provides a good measurement of cycling power production following an acute bout of WBV when using individualized frequency.

Purpose

It was hypothesized that an individualized vibratory treatment would lead to greater anaerobic power production than a fixed vibration treatment in trained participants (cyclists) and would be beneficial during a Wingate performance test. As such, the aims of the present study were twofold: first to examine the effects of acute vertical whole-body vibration treatment on anaerobic power in trained male participants using a sport-specific test. Secondly, to determine if an individualized frequency is superior to the common frequency of 30 Hz that has been repeatedly observed in the whole-body vibration literature.

Significance

Findings from this study will help to advance the knowledge base regarding the use of acute WBV on cycling power production. Additionally, the effects of individualized frequency are rather new and have not been extensively researched to date. As such, furthering our understanding of WBV through the use of individualized frequency is desired. Furthermore, results from this study will also help to advance our understanding of strength and conditioning research and enhance our understanding of WBV as a viable training method.

Limitations

The recruited cycling participants were told to give their best effort for the three Wingate anaerobic tests. The importance of this was explained as it is the cornerstone of the test and they were verbally encouraged during their performance in an attempt to encourage them to perform at their best. Despite these procedures, the investigators had no control over whether or not the highest level of effort was given by the participant thus potentially skewing data and results. Exercise was accounted for the day of testing however the prior week's activity level and the activity level between test days were not accounted for. The participants were allowed to adjust the Monark cycling ergometer to their specifications and were told to "mimic" their current bike set-up as closely as possible. Although the cyclists were able to adjust the ergometer, they were not permitted to change the pedals of the ergometer and therefore were not allowed to "clip-in". Some subjects verbalized that this hindered their performance as it was not what they were accustomed to. Recommendations for vibration intensity, including amplitude and vibration frequency, are still vague. This being so, parameters chosen for this population, such as the amplitude, were done to the best of our ability through a thorough review of the WBV literature.

Delimitations

Recruited participants for the study were male cyclists between the ages of 18-45. To meet inclusion criteria, participants had to be considered highly-trained male cyclists. Highly-trained was defined as riding in excess of 100 miles per week during the normal competitive cycling season. The cyclists also had to have competed in at least 6 road races in the past calendar year and/or currently hold a Category 4 USA Cycling Association License or higher. Cyclists who may have been equally as elite in ability may have been excluded from the recruitment process due to the inclusion/exclusion criteria. Due to the high training status of the cohorts, eliciting an acute training effect may have been difficult and lesser trained individuals may be used in the future. Subjects were given guidelines to follow for the day of testing; however, there is no certainty that the guidelines were followed. Pre-testing energy consumption may have been different because of the guidelines set for the research protocol than what subjects would normally do before cycling and/or competing. The study also investigated performance during a 30-second time frame; therefore results cannot be extrapolated to longer performance durations etc.

Summary

Repeatedly studies utilizing whole-body vibrations have assessed vibration frequencies between 20 and 40 Hz with 30 Hz being the most common. Results have been equivocal as it has been acknowledged that each individual may have a different optimal vibration frequencies or an "individualized frequency". These individualized frequencies may elicit a greater reflex response in the individual. This project combined the few studies that have initiated the use of individualized frequency [21-23, 33] with those that have traditionally used a 30 Hz protocol. Additionally, by using the Wingate test to find peak anaerobic power following an acute bout of whole-body vibration, we utilized a sport-specific test to gauge performance and measure power. Because of the cycling specific nature of the test, it can become a good measurement of cycling power production following an acute bout of WBV when using individualized frequency. Findings will help to advance the knowledge base regarding the use of an acute bout of WBV utilizing individualized frequencies and their effects on cycling power production. Results from this study will also help to further our understanding of strength and conditioning research and increase our understanding of WBV as a viable training method.

CHAPTER 2- Review of Literature

Whole Body Vibration

Introduction

Vibration training or whole-body vibration (WBV) constitutes a mechanical stimulus that typically enters the human body by way of the feet when standing on a vibration platform in a semi-crouched position [8, 9]. It is assumed that the vibration frequency induced by the motor platform may induce non-voluntary muscular contraction termed the tonic vibration reflex (TVR) [10].

WBV has been proposed as a potential alternative, or adjuvant, to exercise. In the last decade several studies have demonstrated the positive effects of WBV in increased power development [1, 4-6, 34], increased flexibility [27, 35], improved balance [3, 16], and increased muscular strength [2, 34]. Other findings included an acute decrease in arterial stiffness [36] and an increase in energy metabolism through an increase in oxygen uptake comparable to walking [37, 38]. However, other studies have not found significant improvements in power [13], balance [3, 16], or strength[39]

Current research has focused expansively on the acute and chronic effects of vibrations using different types of vibratory methods [11-16]. Several factors have been shown to influence the acute, residual, and chronic effects of vibration exposure and training. When quantifying a vibration application the variables of duration, amplitude, frequency, and exercise protocols can be manipulated to influence the neuromuscular system with the intensity of the exposure being determined by vibration frequency and amplitude[20]. Many previous studies have utilized vibrations between 20 and 40 Hz with a higher prevalence in the 30 Hz range, and amplitude setting between 1 and 5 mm [8, 9]. In these studies, however, individuals have responded differently to the applied frequencies. Recent studies have stated that each individual may have different optimal frequencies of vibration that will elicit the greatest reflex response during WBV [21-23]. Using electromyography (EMG) recordings of the concerned muscle and taking the RMS of the activity during vibration exposure appears to be appropriate for identifying an individual's optimal frequency when used as a neurological index [21-23]. In one of the primary studies using individualized frequency during whole-body vibration, Di Giminaini et al., (2009) reported a significant increase in vertical jump height during the squat jump and also an increase in power and height during continuous rebound jumping.

Biomechanical Parameters of WBV

The biomechanical parameters determining the intensity of WBV are the amplitude, frequency, and magnitude of the oscillations. The extent of the oscillatory motion determines the amplitude, or the peak to peak displacement of the vibration measured in millimeters (mm) [29]. The repetition rate of the cycles of oscillation during the vibration is the frequency measured in hertz (Hz) [37], while the acceleration indicates the magnitude of vibration. The frequencies used for vibration exercise range from 15 to 44 Hz while displacements or amplitude values range from 3 to 10 mm [29]. The literature also supports values of acceleration ranging from 3.5 to 15 g where g is the Earth's gravitational field. Thus, vibration provides a perturbation of the gravitational field during the time of vibration intervention [9].

As mentioned previously, vibration is a mechanical force which can be explained by a periodic alteration of force, acceleration, and displacement over time. Vibratory exercise is then a forced sinusoidal oscillation where energy is transferred from an actuator to a resonator [40, 41]. WBV exercise is typically practiced while standing on an oscillating platform, as it was performed in the current study. There are, however, two main types of vibrating platforms. The first transfers the vibration to both feet synchronously while the second type of platform oscillates in a side-to-side alternating way where the right and left foot switch from high to low. The present study used a platform that vibrated the feet simultaneously as to avoid the additional degrees of freedom with the side-to-side alternating platform where rotation around the hip and lumbo-sacral joint is introduced [9, 20]. Vibration devices also differ by way of energy generation. It is common for some vibration devices to operate by direct mechanical transmission while others rely on electromagnetic transmission. The most common method of energy transmission is from vibration platforms that are based on oscillating mass springs [38, 40].

Tonic Vibration Reflex

Mechanical vibration may induce non-voluntary muscular contraction [42]. The phenomenon of vibratory induced non-voluntary contraction has been coined tonic vibration reflex (TVR) [10]. It has been shown that mechanical vibrations applied to the muscle or tendons have the ability to stimulate sensory receptors, especially length detecting muscle spindles [42]. The activation of these muscle spindles facilitates the activation of alpha motoneurons leading to a reflexive muscle contraction, or the tonic vibration reflex [43]. This response is mediated by monosynaptic and polysynaptic pathways and results in increased motor unit activation [44]. Therefore, whole-body vibration assumes that the vibration frequency induced by the motor platform elicits a tonic vibration reflex response in the individual.

Risks and Dangers

The notion that vibration can be beneficial is relatively new. Literature into the effects of WBV in humans has covered a broad range of topics and different responses have been reported ranging from beneficial to dangerous. Much research has been conducted in occupational medicine and ergonomics where it has been stated that long term vibration exposure should mainly be avoided [23]. Generalizations have been made that vibrations are negative especially when experienced in the workforce [9]. Therefore the notion that vibrations can be beneficial to humans is relatively new. Whole-body vibration training is the intentional exposure to vibrations for both proposed therapeutic and training benefits[40]. When using WBV as an intervention, the risk of adverse health effects can be lowered with a few modifications. When using a vertical vibration platform, it has been determined that vibrations may be less harmful during a half-squat position rather than full-squats or an upright stance [45]. It has also been noted that single leg vertical vibration as opposed to both feet being vibrated simultaneously may be less harmful when vibrating one leg at a time is applicable [45]. To avoid high transmission factors to the head, the resonance frequency range should be avoided. Thus the frequencies below 20 Hz should be avoided [41]. Vibration training can elicit minor discomforts in the form of muscular soreness as well as some minor pooling of blood in the extremities. Despite all of the potential risk factors purported to be linked to WBV, previous literature in vibration therapy has been conducted in a variety of populations (e.g., older adults, untrained, and highly trained individuals) and reported minor to no discomfort as a function of vibration [5, 14, 34, 45].

WBV and Power Production

Explosive strength, or the ability to develop force within a short time to receive a power output, is of primary importance in many sports. Typically, exercises for explosive strength training are characterized by fast muscular contractions with an external load of about 50-70% of maximal strength [4]. The instantaneous effect of explosive strength exercises can be assessed by the power which an athlete can generate in a movement. Several training techniques have been used to accentuate power training including plyometrics (the pre-stretching of active muscles prior to contraction), resistance training, and electrical stimulation [2]. More recently, whole-body vibration (WBV) has been proposed as a potential alternative, or adjuvant to exercise for power development [3-6]. Since the introduction of WBV as a means to improve muscular power, WBV has been shown to elicit improvements in dynamic performances related to vertical jump height and jump ability, lower-limb strength, and flexibility [1, 2, 5, 6, 27, 34, 35, 46]. To determine increases in power production, several tests are able to assess an athlete's peak power, anaerobic capacity, or both. These tests include the vertical jump test, standing long jump test, Bosco repeated jumps, and the Wingate test for anaerobic power [24].

Individualized Frequencies

In previous literature, the effect of vibration training was conducted without individualizing the applied vibration frequency to each subject [5, 6, 11, 13, 43]. Given the equivalence of research findings and the vast array of WBV methods used it is apparent that some standardization needs to be implemented to help focus the research in this area. This notion is especially apparent with the lack of information on the effectiveness of different vibration frequencies on neuromuscular performance [21]. It has recently become important to identify how muscles behave during WBV in various exercise positions and at different vibration frequencies [33].

It has been determined that different vibration frequencies elicit different EMG responses in the stimulated muscle [21-23]. A way to monitor these responses is to inspect EMG amplitude and density and is referred to as the root mean square($_{RMS}$) of the EMG (EMG_{RMS}) [47]. Several studies have shown that WBV treatment leads to an increase in EMG_{RMS} activity of the vastus lateralis muscle as compared with baseline values collected in no-vibration, or controlled conditions [21-23, 44]. Increasing muscular activity during WBV is likely a result of increased neuromuscular activation. By applying a vibratory stimuli, the tonic vibration reflex is induced (as explained previously) [33]. The increased or different muscular activation levels during different frequencies may be explained by the level of muscular contraction and neuromuscular responses during the WBV bout. The different responses may be modulated by the intensity of muscle co-activation and the varying vibration frequencies [33].

A study performed by Cardinale et al. determined that when viewing the EMG_{RMS} recording of the vastus lateralis, the highest EMG_{RMS} was found at 30 Hz suggesting this frequency as the one eliciting the highest reflex response or "individualized frequency" in the vastus lateralis [21]. Interestingly, the frequency of 30 Hz, when chosen as a fixed frequency, is commonly seen in the literature when trying to demonstrate the effects of whole-body vibration [27, 33, 39, 45, 48, 49]. So few studies have been done to find individualized frequency and for that reason, the methods to do so are still being fine-tuned. The premiere study in individualized frequency used a methodology similar to what will be used in the present study. In the study, the frequency of vibration was determined for each member by monitoring the EMG_{RMS} activity of the vastus lateralis muscle during trials performed at different frequencies; no vibration (i.e. 0 Hz), and at 20, 25, 30, 35, 40, 45, 50, and 55 Hz. These were administered in random order with a 4-minute pause between trials with each subject experiencing vibration for 20-seconds. The highest neuromuscular response (EMG_{RMS} activity) recorded during the trials was used for the vibration training [22].

Electromyography (EMG)

The electrical signal associated with the contraction of a muscle is called an electromyogram and the area of study is termed electromyography (EMG). Muscular tissue conducts electrical potentials and, once the motor unit is recruited, the signal generated in the muscle fibers is termed a 'motor unit action potential'. Electrodes placed on the surface of the muscle records the sum of all motor unit action potentials being transmitted along the muscle fibers under the electrode at a given time providing a numerical value output. Surface electrodes, as with indwelling electrodes, can both detect the average activity of superficial muscles although surface electrodes have been shown to produce more reproducible results than indwelling electrodes [50]. Surface EMG is currently considered a more acceptable way to record EMG as it is practical and requires a less intricate and invasive set up [51]. Surface electrodes are influenced by the electrical signal or waves within a few millimeters of the conductor and reasonable approximation has been found more than 1 mm from the electrode surface [52]. However, surface EMGs are not as useful when recording the activities of small muscles or when the muscle is not situated directly below the skin [51].

Interpretation of EMG Signals

There are many variables that influence the EMG signal at a given time. Velocity of shortening or lengthening of the muscle, the rate of tension buildup, fatigue, and reflex activity are common factors that can manipulate the EMG signal, creating well documented patterns as shown in the literature [47, 52-55].

When viewing a recording of un-processed EMG data, the question of its relationship to muscle force is common. It is inferred that when there is no EMG signal, there is no active muscle force. In turn, although the relationship is not always perfect, the more muscle fibers active, and the more frequently the firing rate, the higher the force and the EMG. There is a quantitative relationship between EMG and force, yet a quantitative prediction of muscle force from EMG is not as evident [51]. However, the relationship is demonstrated when during voluntary muscular activity, the EMG increases in magnitude as tension or force increases [53]. Looking at a force-velocity curve or relationship, it is shown that EMG recordings during concentric movements are larger than those measured at isometric actions showing that when the force is greater, the EMG recording is larger [47]. Magnitude differences in the EMG signal are also demonstrated by the positioning of the electrode. Motor units positioned far away from the surface electrode site will result in smaller numerical values than those of similar size nearer to the electrode [50].

When looking at an EMG signal, mean absolute values for amplitude and median frequency are influenced by both the level of muscular force (as mentioned above) and also by fatigue [55, 56]. It is commonly accepted in the literature that fatigue can be seen in EMG signal changes only when there is also a drop in mean frequency and an increase in signal amplitude. This can visibly be seen when force produced by a muscle is unchanged with time, fatigue will result in a downward shift of the frequency spectrum of the signal and an increase of signal amplitude.

This is why if fatigue is being monitored, it is assessed by simultaneously monitoring the frequency and the amplitude, not just frequency alone [55]

Amplification, Noise, and Artifacts

A biological amplifier of certain specifications is required for the recording of EMG. The specifications can deal with the considerable dilemma of getting a "clean" EMG signal. A "clean" EMG signal is one that is undistorted and free of noise or artifacts. An undistorted signal is one that has been amplified linearly over the range of the amplifier and recording system; the larger signals have been amplified as much as the smaller signals [47]. All EMG devices allow for an adjustable gain setting which affects the basic sensitivity of the machine when it is recording a signal. When the machine is on a low gain setting, it will require a greater signal from the muscle before the output changes, it is less sensitive. On a high gain setting, small muscle signals will produce a large response, it is more sensitive. By adjusting the gain settings it is possible for the output to display to respond to varying magnitudes of muscular activity [57].

Noise in the EMG signal is introduced from sources other than muscles. The origin of noise can be biological or man-made where biological noise might be heart rhythm being picked up by the electrodes and man-made noise can come from machinery or is potentially generated within the components of the amplifier [53].

Artifacts in the EMG recording are referred to as false signals. Artifacts are typically generated by the cabling system or the electrodes themselves [58]. It is at times important to secure all cables and make sure electrodes are properly adhered to the subject to prevent artifacts. This is especially imperative with ballistic movements or those movements performed at high speeds.

Full Wave Rectification, Filtering

When surface EMG is recorded, the signal is “raw” and resembles white noise with both positive and negative components. To handle the “raw” EMG, the signal is rectified meaning that all negative parts of the signal are made positive [47]. This full-wave rectification generates the absolute value of the EMG, usually with a positive polarity [53]. A full-wave rectification alone is only semi-quantitative in EMG assessment; other processing schemes need to be applied.

Following rectification of the EMG signal, a “smoothing” process is applied. A low-pass filter is put into effect and results in a signal that follows the amplitude of the EMG with some delay and the signal now has rounded edges. If temporal resolution is an issue, the filtering procedure needs to incorporate a time constant that is selected for the smoothing algorithm. With a small time constant, the magnitude fluctuates considerably while sudden changes in EMG amplitude are followed with a small delay. With a long time constant the fluctuations are small and the time delay between sudden changes in the raw and smoothed EMG signal is long [53]

EMG Activity During Whole-Body Vibration

An increase in EMG activity is typically observed during whole-body vibration (WBV) treatment with values higher than the values observed during voluntary muscular activity [9]. Increasing muscular activity during WBV may result from increased neuromuscular activation. By applying a vibration stimulus, the tonic vibration reflex is induced (which will be addressed in the WBV section). Studies in which varying frequencies are utilized have demonstrated increased muscular activation during the vibration stimulus which may be determined by level of muscular contraction and the neuromuscular responses. The neuromuscular response during WBV may then be modulated by the intensity of muscle co-activation and vibration frequencies [33].

EMG_{RMS}

It has been determined that different vibration frequencies elicit different EMG responses in the stimulated muscle [21-23]. A way to monitor these responses is to inspect EMG root mean square (RMS), which is a measure of EMG amplitude and density [47]. The RMS represents the square root of the average power of the EMG signal for a given period of time. It is known as a time domain variable because the amplitude of the signal is measured as a function of time [47]. Muscular activity while exposed to vibration can be recorded to determine the optimal frequency setting that elicits the highest level of muscular activity, as measured by the EMG_{RMS} [23].

Wingate Test for Anaerobic Power

Introduction

Physical fitness can be accessed through five major components. These components include cardio-respiratory endurance, muscular power and strength, muscular endurance, flexibility, and body composition. Anaerobic activity is defined as energy expenditure that uses anaerobic metabolism that lasts less than 90 seconds, utilizing an exhaustive effort. Anaerobic metabolism is defined as metabolism without the use of oxygen [24]. The 30 second Wingate test is used to measure anaerobic power for short duration, high power output during cycling [32],requiring primarily two major energy sources. The first energy source is adenosine triphosphate-phosphocreatine (ATP-PCr) system, which lasts using stored ATP for a duration of 10-15 seconds during maximal exertion and effort. Once depleted, the second system, anaerobic glycolysis, can be sustained for the remainder of the maximal effort [25]. Anaerobic metabolism is used extensively during competition in sports such as football, cycling, sprinting, soccer, and baseball.

The Wingate test for anaerobic power is an important measurement of one of the key components of physical fitness.

It must be noted that it is incorrect to assume that a certain task or test can be performed using exclusively aerobic or anaerobic energy systems. This notion has been accepted for all-out maximal aerobic power protocols that are also known to tax the anaerobic energy sources. Likewise, one can anticipate some of the energy used for performing the Wingate to be derived from aerobic pathways. However, the anaerobic contribution must be predominant for the Wingate to be considered an “anaerobic” test [24, 25, 59].

The Wingate anaerobic test was developed at the Wingate Institute for Physical Education and Sport, Israel, during the mid and late 1970s. Since the introduction of its prototype in 1974, the Wingate anaerobic test has been used in various laboratories not only as an assessment of anaerobic performance, but also as a standardized test that can help analyze responses to supramaximal exercise [30]. The Wingate anaerobic test is considered the gold standard for anaerobic testing and was designed with accessibility in mind. The test was designed to be simple to administer without the need for particularly skilled personnel. The Wingate test is inexpensive as it is usually administered on commonly available equipment such as the Monark cycle ergometers [30]. The test is safe and non-invasive, able to measure muscular performance rather than indirect variables such as using age (yr) and body mass (kg) along with weight lifted (kg) to make indirect estimates about muscular performance [59]. The Wingate also has the ability to be objective, reliable, valid, and sensitive to the improvement or deterioration in anaerobic performance [30].

To adequately test anaerobic ability, a test must be very high in intensity and last anywhere between a fraction of a second to 90 seconds in length [60]. The Wingate test is a 30 second protocol in which the individual pedals at a maximal speed against a constant force, where the force is a; predetermined value to yield supramaximal mechanical power. A warm-up can be used and is helpful. One study systematically assessed the effects of warming up on performance in the Wingate test and found that a warm-up improved mean power by 7% but did not have an effect on peak power [61]. The testing procedure begins with the start command and the subjects must pedal as fast as possible against light resistance to overcome the inertial and frictional resistance and to shorten the acceleration phase. The investigator should make sure that the subject reaches a point to where they cannot speed up anymore. The rationale behind this procedure is that once the predetermined load has been applied, the subject will not be able to speed up anymore. This phase normally lasts 3-4 seconds. The full load is then applied to start the 30 second test. Verbal encouragement should be given to the subjects [59].

Force

Choosing a force setting that will elicit the highest possible peak power and mean power for each subject during testing is important. The force chosen should elicit a noticeable development of fatigue within the first few seconds [32]. The force originally suggested for use during the Wingate was 0.075 kp/kg body mass where kp stands for kilopond which is a unit of force. The kilopond is the force equivalent of 1 kg multiplied by 9.81 $m.s^{-2}$ [28]. The force is equivalent to a mechanical workload of 4.41 Joule per pedal revolution per kg body mass, yet appears to be too low to elicit a maximal effort in most adults [59]. When using active male adults, the optimal force that yielded the highest mean power was 0.087 kp/kg [30], noting that the workload used is dependent on the level of training in the subjects. Using this reasoning and previous studies as a guide, 0.085 kp/kg will be utilized for the current study [30, 62-64]. Subjects that are athletes will need a higher load or force setting for the Wingate than that of adults and children. It is noted that administering a force that is equivalent to 0.5 Joule/rev/kg higher or lower than the true optimum force underestimated the mean power by only 3% in males who performed on a cycle ergometer [65].

What the Wingate Test Can Measure

The Wingate looks at pedal revolutions against a constant resistance as its measure of mechanical power. The Wingate test uses the average of 3-5 second segments. The choice of analyzing 3 or 5 second segments during the 30 second test has shown to have little or no effect on the results [30]. Three indices can be measured and include; peak power, mean power, and rate of fatigue. Peak power is the highest mechanical power elicited during the test [59]. This typically occurs in the first few seconds of the test. To obtain peak power, the mean power over any 3-5 seconds periods is taken. Mean power is the average, or mean, power sustained throughout the 30 second period. This value is obtained by averaging the values obtained during the ten 3 second or six 5 second segments. The rate of fatigue is the degree of power drop-off during the Wingate test. It is the difference in power output from the highest to the lowest power output recorded and is calculated as a percentage of peak power. This can also be calculated as the slope of the straight line by finding the peak power (highest power obtained during either 3 or 5 second interval) and the lowest power recorded during the test. The lowest power is then subtracted from the peak power, divided by the peak power, then multiplied by 100 thus making the rate of fatigue a percentage of peak power [61]. By providing various measures of power as well as the ability to sustain power over a period of time, these measurements make the Wingate a valuable test for coaches, athletes, and research scientists [24]. The information obtained from the Wingate test allows for subjects to be compared among other people with similar backgrounds and can be used as an index to gauge performance and training improvements. Researchers are able to test new training methods and use quantitative values such as peak power as an indicator to locate change.

Repeatability of the Wingate

The performance level of most young adult males has been shown to recover fully within 10 min after the completion of the Wingate test for anaerobic power [31]. To guarantee a complete recovery before repeating a Wingate test, a rest interval of at least 10 minutes is recommended when retesting the same muscle groups [59].

Dangers and Safety Considerations

The Wingate test for anaerobic power is a relatively safe test, one that can be administered to elderly, children, and subjects with respiratory or coronary disease, although special precautions such as blood pressure monitoring and electrocardiogram monitoring should be taken for special populations [59]. Additionally, as with any cycling activity, there is a small risk of injury associated with cycling according to this protocol. The Wingate test is a maximal exercise test that is considered a low risk exercise test. The American College of Sports Medicine reports in adults, that the following generalizations can be made regarding the safety of graded exercise testing: "The risk of death during or immediately after an exercise test is less than or equal to 0.01%. The risk of acute heart attack during or immediately after an exercise test is less than or equal to 0.04%. The risk of complication requiring hospitalization (including heart attack and/or serious arrhythmias) is less than or equal to 0.2%". These risks are remote and are lowered when reasonable precautions to prevent injury are taken [66].

Another side effect from the Wingate test is nausea and vomiting which occurs in approximately 5% of adults tested. A study by Inbar et al. (1975) looked at four conditions and physiological indices before and after the test to see the responses to the before mentioned side effects. The conditions were: 1) a standard active warm-up and cool down; 2) no warm-up but a cool down; 3) no warm-up and no cool down; and 4) warm-up but no cool down. The physiological indices tested were blood pressure, ECG, pH, blood lactate, lactate dehydrogenase (LDH), and creatine phosphokinase (CPK). When tests were performed without a cool down the subjects experienced a sharp decrease in blood pH, a sharp drop in blood pressure, and an increase in concentrations of LDH and CPK. A significant positive correlation was found between those changes and the subject's subjective feeling at the end of the Wingate test [59, 61]. Thus it has been suggested that performing a warm-up and cool down for the Wingate can help to alleviate nausea and vomiting in the subject during such a high intensity test.

Optimization of the Wingate

Pedal Crank Length

The typical length of the pedal crank in ergometers is 17.5 cm. In previous studies, this length is used as it is the conventional length set in most ergometers used during testing [59, 65]. Although not widely shown in the Wingate literature, optimal crank length should vary with the leg length of the individual. The lack of proper crank length can have an effect on several biomechanical variables; angle of application, torque, kinetic energy of moving the leg, and muscle tension and force-velocity relationships [59]. According to a study performed by Inbar et al. (1983), using crank lengths of 12.5, 15.0, 17.5, 20.0, and 22.5 cm, and a best-fit parabolic curve, it was found that optimal lengths for finding the mean power and the peak power were 16.4 cm and 16.6 cm respectively. The investigators further found that the optimal crank length depended on the length of the subject's lower limb. It was noted that deviation from the subject's optimal crank length by as much as 5 cm had an effect on mean power by 0.77% and peak power by 1.24% [67]. The practical implications of using a subject's crank length that they train with on their own cycle can become optimal noting the difference in the variables of peak power and mean power in the Wingate test.

Clips, Toe Stirrups, and Their Use

The utilization of toe stirrups on the pedals constitutes a methodological sophistication during the Wingate test. Toe stirrups have been found to increase the peak power and mean power by 5-12% during the Wingate as compared to using just the pedals with no added equipment [68]. The reasoning for this is that a push and pull force can be exerted on the pedal throughout the full cycle [59]. It has been found that maximal power output is significantly higher during cycling with toe clips (782 W vs. 668 W) in a study using 6 male cyclists [69]. This can also be explained due to the pulling and pushing force that can be exerted onto the pedal throughout the full cycle. When looking at the effects of pedal type during the pull-up action during cycling when using elite cyclists, it was established that there was a significant difference in using clipless pedals and pedals with clips. It was found that there was a significant increase in pedaling efficiency during the upstroke using pedals with clips [70]. Although this study did not assess the difference between toe straps and pedals with clips, it was shown that just as toe straps can increase the pulling and pushing forces throughout the whole cycle, the pedals with clips are also able to demonstrate the same increases. Therefore, the use of any system that allows the application of force throughout the cycle is recommended with all subjects for the Wingate test [59].

The Wingate Protocol as Described by Bar-Or and Our Load

In terms of the load applied on a Monark cycle ergometer, a typical Wingate's force is set to 0.075kp per kilogram of bodyweight. Therefore we defined the modified Wingate as using a Monark cycle ergometer with the load of 0.085 kp per kilogram of bodyweight for the present study. The reasoning behind the load value of 0.085kp per kilogram of bodyweight was that when using active male adults, optimal force that yielded the highest mean power was 0.087 kp/kg [30], noting that the workload used is dependent on the level of training in the subjects. Using this reasoning and previous studies as a guide, 0.085 kp/kg will be utilized for the current study [30, 62-64].

CHAPTER 3- Manuscript

THE EFFECTS OF WHOLE BODY VIBRATION ON THE WINGATE TEST FOR ANAEROBIC POWER WHEN APPLYING INDIVIDUALIZED FREQUENCIES

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Abstract

Background: Whole-body vibration (WBV) has been proposed as a viable alternative, or adjuvant to exercise for power development in athletes. More recently individualized frequency (I-Freq) has been introduced with the notion that individuals may elicit a greater reflex response to different levels (Hz) of vibration. ***Purpose***: The aim of the study was to evaluate acute WBV as a feasible intervention to increase power in trained cyclists. Additionally, to evaluate the efficacy of utilizing I-Freq as an alternative to 30Hz, a common frequency seen in the literature.

Methods: Twelve highly-trained, competitive male cyclists (age= 29.9 yrs ± SD 10.0; body height=175.4 cm ± SD 7.8; body mass= 77.3 kg ± SD 13.9) free of musculoskeletal injury or pathology participated in the study. The Wingate test for anaerobic power was administered on three occasions following either a control of no vibration, 30 Hz, or I-freq. Measures of peak power (PP), average power (AP) and rate of fatigue were recorded and compared to the vibratory conditions using separate RM-ANOVAS. ***Results:*** PP, AP, and rate of fatigue were not significantly impacted by 30 Hz and I-Freq vibration interventions ($p > 0.05$). ***Conclusion:*** Acute WBV using the parameters of the present study may not have been practical to elicit an increase in power as potential changes in the highly trained population may have been muted as a function of training status.

Introduction

The ability to generate high force in the shortest time possible, also referred to as the rate of force development or power, is a quality possessed and optimized by elite athletes. Power development has become a primary focus of athletic performance enhancement training programs [1]. Several training techniques have been used to accentuate power training including plyometrics (the pre-stretching of active muscles prior to contraction), resistance training, and electrical stimulation [2]. More recently, whole-body vibration (WBV) has been proposed as a potential alternative, or adjuvant to exercise for power development [3-6]. Vibration training or WBV constitutes a mechanical stimulus that typically enters the human body by way of the feet when standing on a vibration platform in a semi-crouched position [7, 8]. It is assumed that the vibration frequency induced by the motor platform may induce non-voluntary muscular contraction termed the tonic vibration reflex (TVR) [9].

Current research has focused expansively on the acute and chronic effects of vibrations using different types of vibratory methods (e.g. direct vibration of the tendon, vibration platforms) [10-15]. Several factors have been shown to influence the acute, residual, and chronic effects of vibration exposure and training such as vibration application (e.g., applied directly to the tendon or applied to the feet), amplitude, frequency, and exercise protocols are the vibration characteristics that can have an influence on the neuromuscular system [16]. Many previous studies have utilized vibration frequencies between 20 and 40 Hz with the most commonly used frequency being approximately 30 Hz, using an amplitude between 1 - 5 mm [7, 8]. The findings of these studies, however, have been equivocal in terms of how individuals have responded to the applied frequencies. Recent studies have stated that each individual may in fact have different optimal frequencies of vibration that will elicit the greatest reflex response during WBV

[17-19]. Using EMG recordings of the concerned muscle during vibration exposure may allow researchers to determine an individual's optimal frequency as a neurological index [17-19]. In a seminal study using individualized frequency during WBV, Di Giminiani et al. (2009) reported a significant increase in vertical jump height during the squat jump and also an increase in power and height during continuous rebound jumping. In the same work by Giminiani et al. (2009) it was also determined that in a comparable group of participants, the day-to-day reliability of the individual vibration frequency was 0.92, demonstrating the reproducibility of the measure.

Several tests have been developed to assess an athlete's peak power, anaerobic capacity, or both. These tests include the vertical jump test, standing long jump test, Bosco repeated jumps, and the Wingate test for anaerobic power [20]. Despite the different methods of assessing anaerobic power, the literature regarding WBV using individualized frequency has had a propensity to focus on the vertical jump test and the Bosco repeated jumps as anaerobic power measurements [12-14, 18, 21-23]. When training to increase power, it becomes important to measure it in ways that relate to athletic performance. The Wingate test for anaerobic power is a cycling specific test where anaerobic power, anaerobic fatigue and total anaerobic capacity are measured [24, 25]. The Wingate test for anaerobic power has proven to be a reliable test in a laboratory setting regardless of population and days of administration with some correlations as high as r=0.98 [24]. Because of the cycling specific nature of the test, it provides a good measurement of cycling power production following an acute bout of WBV when using individualized frequency.

It was hypothesized that an individualized vibratory treatment would lead to greater anaerobic power production than a fixed vibration treatment in trained participants (cyclists) and would be beneficial during a Wingate performance test. Additionally, it was thought that acute WBV may be a beneficial to anaerobic power production prior to performance. As such, the aims of the present study were twofold: first to examine the effects of acute vertical WBV treatment on anaerobic power in trained male participants using a sport-specific test, and secondly, to determine if an individual's individualized frequency is superior to the common frequency of 30 Hz. Findings from this study will help to advance the knowledge base regarding the use of an acute bout of WBV on cycling power production. Furthermore, results from this study will also help to further our understanding of strength and conditioning research and increase our understanding of WBV as a viable training method.

Methods

Participants and Study Design

Twelve highly trained, competitive male cyclists (age= 29.9 yrs ± SD 10.0; body height=175.4 cm ± SD 7.8; body mass= 77.3 kg ± SD 13.9) participated in the study. To ensure a competitive, highly trained status, all subjects held at minimum a Category 4 (CAT) USA Cycling Association license (2 subjects held a CAT 1, 1 held a CAT 2, 3 held a CAT 3 and 5 held a CAT 4), competed in at least 6 races in the past year prior to the study and had been riding in excess of 100 miles per week as part of their training protocol. One subject had to be excluded from statistical analysis due to adherence to the Wingate protocol. A health history questionnaire was completed to ensure subjects with chronic medical conditions and musculoskeletal injury or pathology were excluded. Additionally, each participant completed an informed consent document outlining the experiment that was approved by the Ball State University Institutional Review Board.

All data collections took place in the Ball State University Biomechanics laboratory on two separate occasions. These visits were 2-7 days apart with the first session lasting approximately 60 minutes and the second session lasting approximately 90 minutes.

Prior to testing, anthropometric data (height, body mass) was recorded. The first visit included a short exposure of vibration (1 minute 20 second total vibration time) to determine each participant's individualized frequency (described in detail below) and was subsequently used on day two of the study. After the individualized frequency procedure, a 10-minute seated rest period was given to the participant followed by a 5-minute warm-up on a Monark Cycle Ergometer. One 30-second Wingate test (control) was administered followed by 2-5 minutes of an active recovery phase on the cycle ergometer.

The second visit began with a 5-minute warm-up on the Monark Cycle Ergometer. Next, WVB was administered using one of the frequencies presented in random order: individualized frequency as determined on day one or the 30 Hz frequency. Immediately following vibration a 30-second Wingate test was administered followed by 2-5 minutes of active recovery on the cycle ergometer. There was a 20-minute passive rest period given and the procedure was repeated once more with the remaining frequency.

Wingate Testing Procedure

Each participant was fitted comfortably onto a Monark Peak Bike Ergomedic 894E Cycle Ergometer (Monark Exercise AB, Vansbro, Sweden) with friction-loaded flywheel and factory-calibrated weight set. The participant was allowed to self-adjust seat height, seat fore/aft position, and handlebar height and angle to comfort. All fit measurements were recorded to ensure reproducibility on day two of the study.

Once the ergometer was set, the subject's individualized frequency was established. To determine the individualized frequency of vibration, EMG_{rms} activity of the vastus lateralis muscle was monitored during trials performed at different vibration frequencies on a 0.82 * 1.02 m Pneu-Vibe Pro vibrating platform (Pneumex Inc, Sandpoint, Idaho). The individualized frequency for each participant was that which resulted in the maximum activity of the vastus lateralis on the dominant leg. A 16 channel Delsys EMG system (Delsys Bagnoli Desktop EMG System, Boston, Massachusetts) using EMGworks 3.7 Acquisition software (DelSys, Boston, Massachusetts) was used to record muscular activity. The sites for the electrodes were shaved, lightly abraded, and cleansed with alcohol. The reference, in the form of a dispersive pad, was placed over the patella of the right knee.

To determine muscle activation levels during vibration participants stood with knees flexed at approximately 15 degrees on the vibrating platform and were exposed to vibrations ranging from 20-55 Hz randomly in 5 Hz increments with a peak-to-peak vibration amplitude of approximately 2 mm. For each vibration frequency, muscle activity was recorded for both a 10-second period of no vibration followed by a 10-second exposure at the randomly set frequency with a 4-minute pause between trials [18]. Following the data collection, EMG data were filtered with a band-stop filter set at ± 2 Hz of the frequency of interest and processed using DelSys analyzer software (DelSys, Boston, Massachusetts) to obtain root mean square (RMS) measures for each frequency. The frequency resulting in the highest neuromuscular response (EMG_{rms} activity) was then used as the individualized vibration frequency for the vibration intervention on day two (Figure 1).

Insert Figure 1 here

Following the determination of the individualized frequency, 10-minutes of seated rest were given to the subject to allow for the effects of the vibration to dissipate [26, 27]. The rest period was then followed by a 5-minute warm-up at 100 Watts on the Monark Cycle Ergometer. A Wingate test protocol similar to that described by Inbar et al. [28] was utilized. The flywheel force was kept constant at 0.085 kp/kg body mass within a 0.1-kg resolution of resistance range [24, 29, 30]. Weights were loaded by the test administrator onto the pan and suspended so that the subject began pedaling with only the resistance of the flywheel. At the signal “Go”, the subject began to pedal maximally. When the subject’s cadence reached their highest rpm at no resistance, the electromagnet released the weight pan and the 30-second test began. Verbal encouragement was provided to promote the participant to pedal at a maximal effort throughout the duration of the test. Computer software (Monark Anaerobic Test Software version 2.2) calculated Peak Power (W/kg), Average Power (W/kg), and Rate of Fatigue (%) throughout the 30-second test. Following the completion of the Wingate test participants cycled at a low aerobic workload (25-100 W) for 2-5 minutes as an active recovery phase.

Whole-Body Vibration Intervention

For the second data collection session, participants performed two separate vibration exposures each of which was followed by a Wingate test. The two tasks included a vibration exposure at their individualized frequency (determined on day one) and a vibration exposure at a fixed frequency of 30 Hz. The participant was asked to remove their shoes and stand with knees flexed at approximately 15 degrees on the vibrating platform. The vibration exposure consisted of five, two-minute vibrations separated by one minute of rest for a total vibration exposure time of 10-minutes [17]. Immediately following the vibration exposure, participants put on their shoes and performed a Wingate test. Following each Wingate test, the participant cycled at a low aerobic workload (25-100 W) for 2-5 minutes as an active recovery phase. In addition, the participant was allowed to passively rest seated or supine for 20 minutes following the first Wingate Test as to recover prior to the next vibration intervention and Wingate [25].

Statistics

Data from each of the three different dependent measures (peak power, average power, and rate of fatigue) were analyzed using separate RM-ANOVAs to determine the effects of the three vibration conditions (individualized frequency, set frequency of 30 Hz, and a control no vibration condition). Where appropriate, follow-up pairwise comparisons were performed to determine the location of the differences. For all tests the significance level was set at $p \leq 0.05$. All statistics were performed using SPSS v16 statistical software (SPSS Inc. Chicago, Illinois).

Results

All subjects were able to complete all vibration treatments and Wingate trials. One subject had to be excluded from statistical analysis due to lack of adherence to the Wingate protocol. The means and standard deviations of all test variables (PP, AP, and rate of fatigue) are displayed in Table 1.

Insert Table 1 Here

From Figure 2A and Figure 2B it can be seen that the test variables from the Wingate test for anaerobic power (i.e., PP, AP, and rate of fatigue) were not impacted differently by the three interventions (control, 30 Hz, and individualized frequency). For the measure of PP, no significant effect of vibration (F=2.54, p=0.104, partial eta^2 =0.202, observed power=0.358) was observed which indicates that no significant differences between the control of no vibration, 30 Hz, and the individualized frequency. Similarly, in response to the vibration treatments, no significant effect was observed for the measure of AP (F=0.534, p=0.589, partial eta^2 =0.052, observed power= 0.127). Likewise, as a result of vibration, there was no significant effect in the rate of fatigue (F=1.966, p=0.166, partial eta^2 =0.164, observed power= 0.358) as the subjects did not fatigue differently across the three testing conditions regardless of vibration intervention.

Insert Figure 2A and Figure 2B here

Discussion

Based on the results of the present study, acute WBV did not significantly increase PP, AP or improve rate of fatigue in the trained cyclists. It was also noted that the individualized frequency was not superior to 30 Hz in that neither vibration intervention was able to elicit an effect on power in the athletes. The literature regarding WBV has been equivocal thus the findings support previous acute WBV data suggesting that WBV may not increase power in highly trained individuals[31]. Up until now vibration studies, specifically ones using individualized frequency, have not been tested with a sport specific power measurement such as the Wingate test.

The capacity for improvement for elite athletes in laboratory or field tests is typically small [32]. The participants in the current study were elite cyclists who have obtained rankings and train and race vigorously most months. No significant effects were observed between the various vibration interventions and measures of PP, AP and rate of fatigue from the Wingate Test for anaerobic power. Although previous vibration studies have elicited a significant increase in power in elite and amateur athletes in other sports (typically measured by the vertical jump) [13, 23, 33, 34], the combination of elite athlete and the sport specific nature of the Wingate test in the current study proved to show no significance. The lack of power increase could be in part due to the stimulus used in the present study as the vibration stimuli may not have been sufficient in terms of length and intensity for these elite cycling athletes. The amount of vibration to be prescribed to an athlete remains ambiguous in the literature. Similar findings were reported by Ronnestad et al. where acute bouts of various WBV frequencies were tested on measures of power using the squat jump and countermovement jump in trained and un-trained individuals. Ronnestad et al. reported that untrained subjects significantly increased peak average power during both measures using a 50 Hz frequency whereas the trained individuals were only able to exhibit significant increases during the squat jump. It is important to note that in the Ronnestad and colleagues study, the trained group included recreationally strength trained subjects, not power athletes as with our study. The results however, support our recommendations of utilizing a lesser trained subject population in future testing. It has been suggested that on the basis of the assumed increase in motor unit recruitment due to vibration, it may be assumed that a larger effect of vibration may be observed in untrained subjects due to their presumed lack of ability to recruit high-threshold motor units [4]. Prospective research endeavors may choose to look at this protocol using a population of lesser-trained cyclists or untrained individuals in the event that training status may be a limiting factor for eliciting increases in power following acute WBV. Additionally, for the case of elite athletes, the vibration length and intensity should be altered based on the results of the present study to evaluate various vibration parameters and their ability to elicit an effect on acute power development.

Using a fixed vibration frequency and physically active participants, De Ruiter et al. were unable to observe significant improvements in power. The introduction of individualized frequency in the study by Di Giminiani et al. using similarly physically active individuals was able to show an increase in power for the individualized frequency group, and like De Ruiter et al. not for the fixed vibration group thus indicating that individualized frequency may be superior especially in active individuals. The study utilized physically active individuals involved in systemic activities such as swimming and track and field at least three days a week where our current study evaluated elite cyclists. Although a similar vibration protocol was used in our study as Di Giminiani et al, we were unable to elicit an acute response in the individualized frequency group. Our study evaluated the acute effect of WBV on power whereas Di Giminiani evaluated the training effects of WBV longitudinally. It may still be considered that longitudinally, individualized frequency may be superior to a fixed frequency however; in the current study acute effects of individualized frequency were not shown to be superior to a fixed frequency as appropriate parameters may not have been utilized for the subject population. When implementing Individualized frequency, factors such as amplitude, the muscle used to determine the individual's optimal frequency, and duration of vibration may prove to be important variables in properly determining the subject's individualized frequency. Furthermore, the longitudinal response of elite athletes using individualized frequency as part of a training protocol should be evaluated.

It should be noted that the vibration intervention did not significantly hinder Wingate performance in all variables tested in the present study. There was however a slight trend for a decrease in PP and AP when vibration at 30 Hz and the Individualized frequency was added prior to the administration of the Wingate test, however, a decreasing trend for rate of fatigue was not noted in either vibration case.

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Tables

Table 1. Wingate test results.

	PP (W)	PP (W/kg^{-1})	AP (W)	AP (W/kg^{-1})	RF (%)
Subjects (n=11)					
Control	945.8 ± 173.8	12.8 ± 2.1	674.7 ± 125.5	9.1 ± 1.2	52.5 ± 6.4
30HZ	907.6 ± 214.9	12.1 ± 1.5	661.8 ± 105.6	8.9 ± 0.7	49.8 ± 5.4
I-Freq	891.2 ± 206.7	11.9 ± 1.5	660.8 ± 117.2	8.8 ± 0.5	49.3 ± 5.2

PP= peak power; AV= average power; RF= rate of fatigue; I-Freq= individualized frequency

Figures

Figure 1-

Figure 1 A

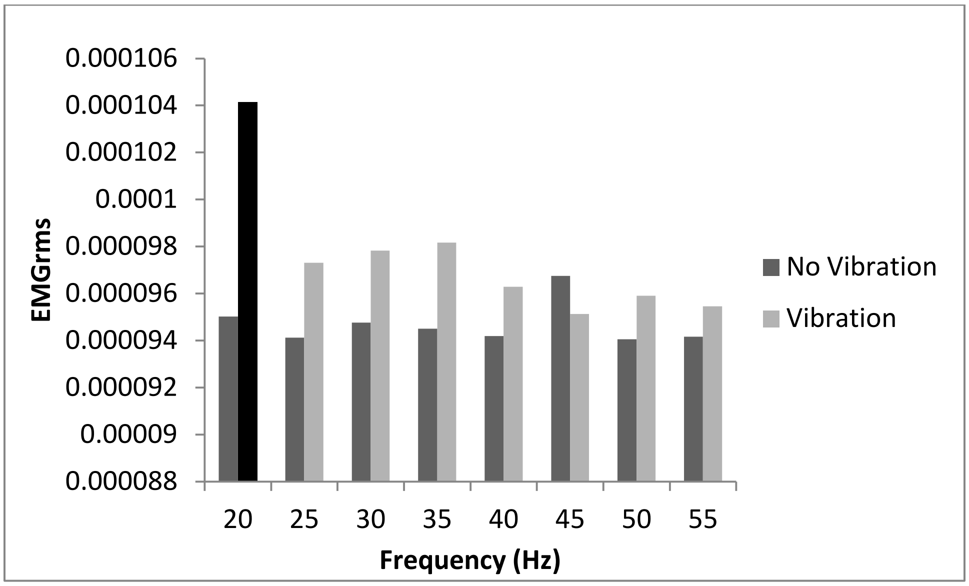

Figure 1 B

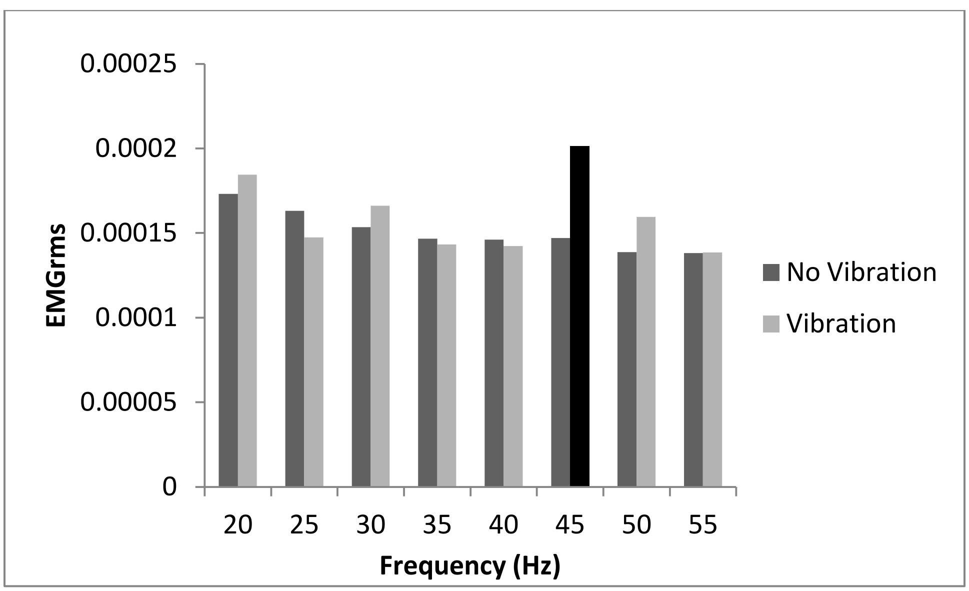

Figure 2-

Figure 2 A. Mean Wingate measurements of peak power and average power.

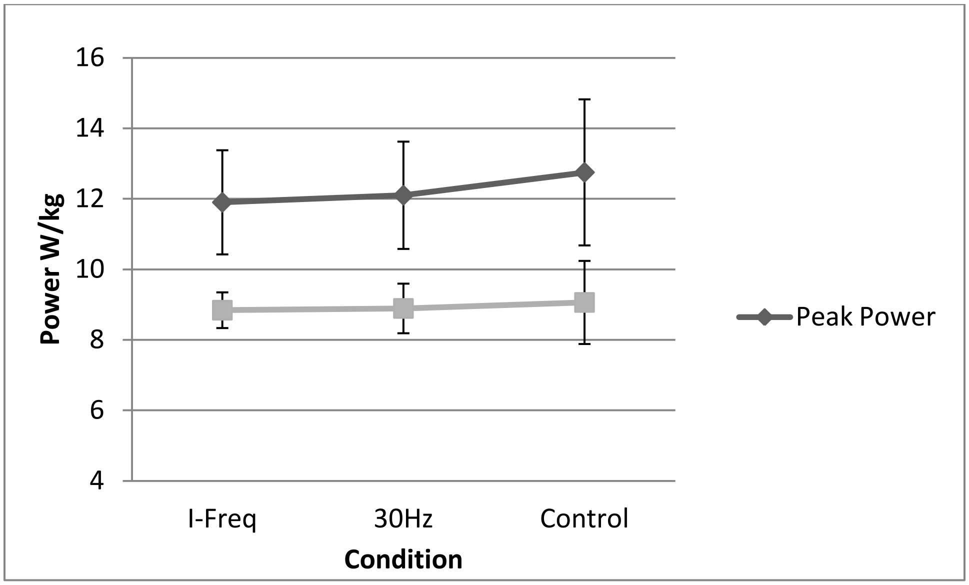

Figure 2 B. Mean measurement of rate of fatigue from the Wingate.

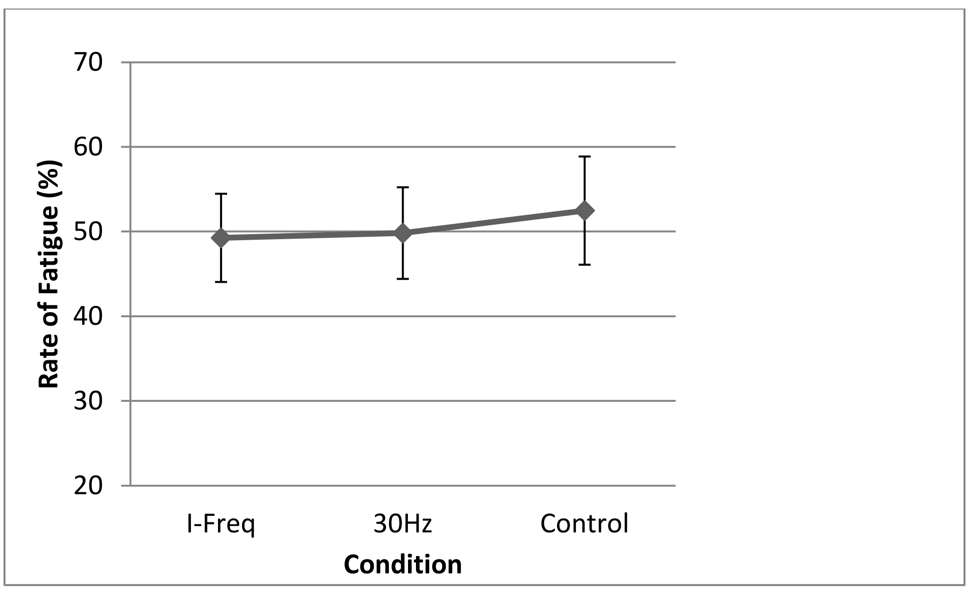

Figure Legends

Figure 1

The EMG_{rms} of the vastus lateralis of the dominant leg recorded during different vibration frequencies. The black bars indicate the highest neuromuscular responses recorded indicating the participants' individualized frequency. Example for participant A and for participant B located in Figure 1 A and Figure 1 B, respectively.

Figure 2 A

Figure 2 A depicts the mean values from the 11 subjects of average power and peak power from the three interventions of the Wingate test: I-Freq (individualized frequency), 30 Hz, and Control. No significance was noted, however the trend for a slight decrease in power for the vibration conditions (I-Freq and 30 Hz) was observed.

Figure 2 B

Figure 2 B the mean rate of fatigue (%) value from the 11 subjects from the three interventions of the Wingate test: I-Freq (individualized frequency), 30 Hz and Control. There is a slight trend for a decrease in the rate of fatigue for the vibration conditions (I-Freq and 30 Hz) although no significance was observed.

Tables Legends

Table 1-

Mean Wingate test results for the eleven subjects are represented in Table 1. Measures of PP and AP are expressed in Watts (W) and normalized to bodyweight (W/kg^{-1}). Rate of fatigue is expressed as a percent

CHAPTER 4- References

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