WHOLE BODY VIBRATION AS AN INNOVATIVE INTERVENTION TO IMPROVE PHYSICAL FUNCTION AND VASCULAR HEALTH WITHIN A LIFESPAN

by

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DISSERTATION

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ABSTRACT

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Over the past several decades, technological advances in computers, transportation devices, and other automated devices have decreased the need for human locomotion and physical activity in the workplace and at home. The need to be physically active in order to sustain and prosper in life has been almost fully eliminated by these technological advances. As a result, sedentary patterns of living have become more prevalent throughout all socioeconomic levels. Age related injuries and conditions including falls and osteoporosis can be debilitating or life ending and have been associated with sedentary behaviors as these can lead to decreased range of motion, muscular atrophy, impaired balance and motor control, reduced gait stability and speed, lower bone density, and subsequent falls. However, muscle weakness, dysfunction, and immobility do not have to consume an individual because the implementation of proper exercise interventions throughout the lifespan can delay or prevent age related injuries.

Unfortunately, once a body has entered a state of detraining and lowered function it is often very difficult to reestablish neuromuscular control and bone density by using traditional exercise movements. The types of movements that will densify bones and replace degenerating muscle tissues are often very aggressive and require extensive equipment and supervision.

Therefore, there is a need for a therapeutic intervention that can reinvigorate and reestablish neuromuscular control and bone density with little effort. The focus of the following studies is to investigate how the use of whole-body vibration as an exercise modality can improve physical function, as the study findings suggest this method of movement could be a solution to atrophy, weakness, and poor balance.

Chapter 2 of this work presents a review of literature on whole-body vibration published in the *Practical Pain Management* journal. It addresses the current literature on a myriad of factors including pain, flexibility, bone density, balance, strength, and pulmonary rehabilitation. This review presents the findings of 65 studies, all which incorporate the use of a whole-body vibration platform on different populations, all possessing the common goal of assessing the body's response to vibration. Every condition studied in the review showed improvement, including pulmonary conditions like chronic obstructive pulmonary disease. This review of literature established and enhanced the author's curiosity and drive to perform additional studies using whole-body vibration as an exercise modality.

Study 1 (Chapter 3) investigates the use of whole-body vibration on an active population with an average age of 53 years old and a max age of 69 years old. The subjects recruited were recreationally active golfers who did not partake it any specific fitness regimen or strength training program. The assessments administered to the study participants were chosen to reflect physical characteristics needed for golfing; however, these variables are also important in tracking and determining age related physical function. Subjects were tested for power using a kneeling medicine ball explosive chest pass, dynamic balance using the Y-Balance Test™, core muscle endurance using the timed plank, and contralateral movement efficiency using a kinetics tool called Fusionetics®. The study participants were separated into 3 groups, one which performed 4 simple body weight movements while standing on the whole-body vibration platform (VIB), one which completed the same movements while standing on stable group (GRD), and a control group who was asked to maintain their current regimen and not add additional exercise in (CON). There were significant improvements for VIB group ($p < 0.01$) for many of the assessments. Percent improvements from pre to posttest for the Kneeling Chest Launch were 10.3±7.3% (VIB), 2.7±4.2% (GRD), -9.5±16.3% (CON) and for Y-Balance Test™ (left) were 10.7±7.6%, 1.1±3.5%, 5.7±6.3%, respectively.

The first study completed by our research team addressed the question of whether whole-body vibration can improve human physical abilities in adults that participate in recreational activity. This opened our curiosity to address these same performance variables in an inactive population, and to determine if the physical improvements noted in the first study would be augmented because of the participant's sedentary lifestyle. Study 2 (Chapter 4) addresses the effects of whole-body vibration training and dosage on physical functioning in a sedentary population over the age of 40 (range 40-75; mean = 56.5 yrs). We investigated the effects of 2 different dosages (1X/week and 3X/week) on several physical function measures and quality of life after 4 and 8 weeks of training. There were no effects for dosage, but almost all of our physical function variables and quality of life measures improved significantly over the 8 weeks. For example, Y-Balance™ composite scores improved up to 31%, timed plank test duration improved up to 100%, and the power assessment from the kneeling chest launch increased up to 8%. We added an isolated strength measure to assess quadriceps strength using the 5-RM test and subjective quality of life assessments from the SF-36 health form. Our subjects improved approximately 40% in the 5-RM test and had significantly improved quality of life scores in physical functioning, physical limitations, energy, emotional well-being, and general health. The overall findings of this study strongly suggest that whole-body vibration significantly improves dynamic balance, core endurance, leg strength, core power, and quality of life in sedentary subjects regardless of the number of times they trained within a week.

In lieu of these findings, we suggest and encourage that whole-body vibration, specifically high amplitude oscillatory forms, be implemented into the medical, occupational, fitness, and home use arenas. The use of whole-body vibration platforms to maintain and improve physical function when sedentary behaviors are prevalent may delay or prevent age related injuries. The main strength of whole-body vibration training lies in its ease of use due to its simple equipment set-up and operation and to the fact that is can be easily used in the home or workplace without specialized clothing or shoes. Based on the information presented in the review of literature (Chapter 2), Study 1 (Chapter 3), and Study 2 (Chapter 4) it appears that whole-body vibration can result in the same positive bodily adaptations as weight training, aerobic equipment, and stretching apparatuses combined.

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DEDICATION

This work is dedicated to my wonderful wife Ashley and my two children, Grace Jean and Nolan Leroy Newhart. Without them I would not have the strength, focus and temperament to complete a project such as this. Also, to my parents, sport coaches and mentors who always taught me to push for a higher level and never give up.

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Chapter 1

Introduction

INTRODUCTION

The anatomy and physiology of the body from the muscular and nervous systems to the bioenergetic systems support the notion that the human body was created to move and not remain still (Cael, 2012; Coburn JW, 2012; Haff GG, 2016; Jacobs, 2018). The body is equipped with muscles across every joint that all have the purpose of moving the limbs and energy systems with massive storage capabilities to ensure energy will rarely be depleted (Rhees, R.W., & Palmer, 2013). The introduction of the information age has given us a brief look about what will happen to the human body if movement is stripped away (Proper, Singh, van Mechelen, & Chinapaw, 2011; van Uffelen et al., 2010; Wilmot et al., 2012, 2013). The result is disease, depression, sickness and early death which identifies that there is a vast need for a solution to offset these burdens to humanity (Grontved & Hu, 2011; Manson et al., 1991; Teychenne, Ball, & Salmon, 2008). Sedentary behaviors have been on the rise for the past three decades which has led to more disease, childhood obesity, and a declining state of the human race (Pate, O'Neill, & Lobelo, 2008).

Inactivity as a result of changing times

A time period which might be considered the most unnatural to human existence has been upon us within the past few decades and has turned humans away from the want and need to move and exercise (Barnes et al., 2013; Barnes et al., 2012; Pate et al., 2008). Automobiles and machines fulfil the majority of work humans used to perform, and the gratifying feelings we used to experience from accomplishing these tasks (serotonin and dopamine release) was replaced by other forms of stimulation such as food, television, social media, none of which involve the need for movement (Berridge, 1996; Blackwell, Leaman, Tramposch, Osborne, & Liss, 2017; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Hu et al., 2001). Therefore, the consequences of inactivity and a sedentary life are both physical and mental. Physically as we age and continue a sedentary lifestyle there will likely be muscular wasting, greater instance of injuries, obesity, pain, and dysfunction (Grontved & Hu, 2011; Manson et al., 1991; Proper et al., 2011; Teychenne, Ball, & Salmon, 2010; van Uffelen et al., 2010; Wilmot et al., 2012, 2013). These physiological changes are accompanied by changes in our biopsychosocial state and feelings of well-being controlled by the brain centers which can lead to depression because the main purpose of the body no longer exists (Harlow, Newcomb, & Bentler, 1986).

The exercise science and health fields have developed rapidly over the past 50 years and has been progressed by many great exercise scientists (Corbin, 2012; Haggerty, 1997; Knudson, 2016). Kenneth Cooper, one of the early innovators of health and fitness was one of the professionals that identified that moving the body in a manner in which it engaged in before automation, actually elongated the lifespan due to a better functioning cardiovascular system, stronger muscles, and lower body fat percentage (Blair et al., 1989; Willis, Morrow, & Jackson, 2010; Willis, Morrow, Jackson, Defina, & Cooper, 2011). It has been shown through many studies that structured exercise offered in a fitness center or conducted in natural environments are the best way to offset declines in the human mental and functional capacity, (Blair et al., 1995; Colcombe et al., 2006; Intlekofer & Cotman, 2013; I. M. Lee, Hsieh, & Paffenbarger, 1995; Paffenbarger et al., 1993; Paffenbarger et al., 1994). Purposefully activating the body in gravity-based exercise movements causes the muscles to experience adaptations including both neurological and morphological changes thereby reversing muscle mass loss associated with inactivity (Best, 1997; Friden & Lieber, 2001; Nikolaou, Macdonald, Glisson, Seaber, & Garrett, 1987). Exercise movements also result in an increase in heart strength and functional capacity which allows blood to be more forcefully and efficiently carried throughout the body

(Chrysohoou et al., 2015; Huonker, Schmidt-Trucksass, Heiss, & Keul, 2002). The improved vascular function allows for less plaque build-up in the arteries resulting in a decreased risk for arterial blockages and vessel disease (Coffman, 1983; Moser, Babin, Cotts, & Prandoni, 1954). Despite these facts humans do not engage regularly in physical activities even when they know that doing so will elongate their life and lead to a higher quality of life.

Reasons for inactivity of Americans are wide ranging (Auweele, 1997; Gomez-Lopez, Granero-Gallegos, Baena-Extremera, & Ruiz-Juan, 2011); however, among those reasons lies the perception that exercise is too difficult, and this factor is amplified by the additional fact that individuals also feel that once they have reached a certain point of deconditioning it is essentially pointless to try and change their state into a more healthy direction (Bassey, 1978; Rutten, Abu-Omar, Meierjurgen, Lutz, & Adlwarth, 2009; Tharrett, 2017). An example of declining human function and an increase in sedentary behavior is simply the action of washing a car. The most recent emergence of the drive through car wash locations often times only a few miles apart from one another (Zhong, Zhang, Chen, Zhao, & Guo, 2017) has occurred within the past 5 years. Before that time period an estimated 50% of people who wanted a clean car would wash it themselves. Washing your car counts as an hour of activity and keeps the body physically fit when performed weekly (Levine, 2002, 2004; Levine & Kotz, 2005; Pivarnik, Reeves, & Rafferty, 2003; Sallis et al., 1985). Now that there are inexpensive car washes only miles apart the percentage may have dropped to 10% of people who reap the fitness benefits of self-washing their car. This shows a stark picture of our progressing sedentary society in that 40% of people now do not likely benefit from an activity like car washing.

The purpose of this report is to fully investigate and address an emerging method of exercising and activating the body through the use of a technology called whole-body vibration.

This exercise method is unique in that the delivery system does not require much effort from the user yet has shown promise through research studies in producing elevations in physical function after its use (Chrysohoou et al., 2015; Iwamoto, Takeda, Sato, & Uzawa, 2005; Jones, Martin, Jagim, & Oliver, 2017; Newhart et al., 2019). Because difficulty in completing exercises that can overload and lead to adaptations is one of the reasons people remain largely sedentary, whole-body vibration appears ideal for the heavily deconditioned situation of some, where high levels of body motion are not a possibility (Kawanabe et al., 2007). It is interesting to note that technological devices led us into this sedentary human state and it appears we must turn to technology to return us to our natural state.

Background of whole-body vibration

Whole-body vibration has a body of literature backing its benefits starting around 1960 with a study by (Magid, Coermann, & Ziegenruecker, 1960) and has been slowly growing ever since. Speculation may suggest that the high cost of the platform and the lack of need for vibration training in the human fitness routine impeded a more rapid rate of research studies and findings. Bogaerts, Delecluse, Claessens, Troosters, Boonen, & Verschueren (2007 & 2009) conducted two longitudinal studies between 2007 and 2009 both which compared body weight whole-body vibration exercise to traditional means of cardiovascular and strength training over a years' time (A. Bogaerts et al., 2007; A. C. Bogaerts et al., 2009). The two studies compared vibration training to resistance training, while tracking improvements in muscle strength, muscle power and cardiovascular function. The results of these studies showed that physical function measures of strength, power and muscle mass with vibration training improved almost to the same degree as a traditional resistance training program. There were cardiovascular improvements with vibration training when compared to the control group; however, they were not as robust has a traditional cardiovascular program. Multiple studies, health professionals and aging specialists suggest that the hallmark of aging is muscular weakness, in which case resistance training would currently be the best way to combat this situation (Kirkendall & Garrett, 1998; Lamberts, van den Beld, & van der Lely, 1997; Young, 1997). The work by Bogaerts et al. suggests that whole-body vibration may be just as effective of a tool in the prevention of age-related muscular weakness as traditional resistance training.

Vibration training is very mild; therefore, the initial thought might be that it would not serve as an adequate exercise stimulus to actually improve the physical function (Russo 2003 and 2004). The literature previously discussed by Bogaerts et al. proved that vibration training can be used to adequately improve function in older adults, which would also likely improve function for sedentary and obese adults. Roelants, Delecluse, & Verschueren (2004) also showed equal improvements in muscle strength and contraction speed from vibration training when compared to traditional leg press and leg extension resistance training (Roelants, Delecluse, & Verschueren, 2004). Standing vibration platforms also may eliminate the notion that exercise has to be difficult and may serve as an easy, effective prescription to reintegrate fitness back into the body (Iwamoto et al., 2005).

Whole-body vibration as a solution to falls and aging

The effects of poor aging include factors such as increases in falls due to poor balance and motor control, decreased ability to locomote and move heavy objects as a result of inadequate strength, decreased core muscle strength and endurance which reduces the body's ability to function as a kinetic chain, decreased hip range of motion which leads to poor stride length and inability to properly walk, and decreased power and the ability to rapidly fire muscles (Daley & Spinks, 2000; Deschenes, 2004; Finlayson & Peterson, 2010; Matsuda, Verrall, Finlayson, Molton, & Jensen, 2015; Rogers & Evans, 1993; Springer et al., 2006; Tromp, Smit, Deeg, Bouter, & Lips, 1998).

The review of literature (Chapter 2) provides a comprehensive and wide arcing summary of the findings related to whole-body vibration and the effects it can have on health, sedentary bodies and diseased states. The first topic of discussion covered in the review covers chronic pain and the effects whole body vibration has on this condition. The articles discussed reveal that there is a higher adherence rate to whole-body vibration than to other therapies prescribed for chronic pain. Chronic pain is usually the result of a variety of reasons, those which include conditions resulting from muscle weakness, muscle tension/flexibility imbalance, poor posture (Burnham, May, Nelson, Steadward, & Reid, 1993; Greigelmorris, Larson, Muellerklaus, & Oatis, 1992; Hurley, 1999; J. H. Lee et al., 1999; Nadler et al., 2002; P. B. O'Sullivan, Mitchell, Bulich, Waller, & Holte, 2006). Five studies examined in the literature review outlined situations where whole-body vibration treatments alleviated chronic pain from a plethora of factors (Alentorn-Geli, Padilla, Moras, Lazaro Haro, & Fernandez-Sola, 2008; del Pozo-Cruz et al., 2011; Kessler & Hong, 2013; Pozo-Cruz, 2011; Yang & Seo, 2015).

Dynamic stretching are flexibility exercises done by the performance of repetitive bouts of a given movement-based technique that stimulates the neuromuscular control system and its regulation of muscle activity and relaxation (Behm & Chaouachi, 2011; K. O'Sullivan, Murray, & Sainsbury, 2009; Yamaguchi & Ishii, 2005), whole-body vibration has been shown in literature to be closely related to dynamic stretching (Houston, Hodson, Adams, & Hoch, 2015; Tseng et al., 2016). Research investigating the effects of whole-body vibration on flexibility of older adults and athletic populations demonstrates both the acute and long-term effects of improved flexibility during whole-body vibration sessions, and also presents suggestive literature that whole-body vibration can increase range of motion more effectively than land-based static stretching (Fagnani, Giombini, Di Cesare, Pigozzi, & Di Salvo, 2006).

The review of literature did not report any improvements in bone density (BMD) with low amplitude vibration training. Two studies showed improvements with higher amplitude vibration on sheep limbs (Gusi, Raimundo, & Leal, 2006; Rubin et al., 2002). Rubin et al. (2002) showed BMD increases in sheep hind legs after a 1-year vibration stimulus period (Rubin et al., 2002). Rubin et al. (2002) actually were able to dissect and observe the bone of the animals thereby giving a really accurate measure of BMD. Gusi, Raimundo, & Leal (2006) used a vibration apparatus with a 30 mm displacement and was delivered for 8 months (Gusi et al., 2006) to post-menopausal women. Gusi et al. observed a 4.3% increase in BMD at the femoral neck after the vibration intervention and this study holds more merit due to the longitudinal period in which the vibration was delivered. These combined studies suggest high amplitude whole-body vibration to be a safe an effective exercise modality for improving bone density in animals and humans.

Balance and strength improvements demonstrated within the review of literature prompted the inclusion of a dynamic balance assessment called the Y-Balance Test™ and submaximal leg extensor strength testing in Study 2. There were dramatic improvements in ankle spasticity, balance, mobility, muscle performance, ankle stability, and postural control (Goudarzian, Ghavi, Shariat, Shirvani, & Rahimi, 2017; In, Jung, Lee, & Cho, 2018; Ko et al., 2017; Sierra-Guzman, Jimenez-Diaz, Ramirez, Esteban, & Abian-Vicen, 2018; Uhm & Yang, 2017) with the application of balance training. Research suggests that balance is a factor of proprioception, flexibility, a fully activated nervous system and core muscle control (Chiacchiero, Dresely, Silva, DeLosReyes, & Vorik, 2010; Han, Anson, Waddington, Adams, &

Liu, 2015; Sibley, Beauchamp, Van Ooteghem, Straus, & Jaglal, 2015). The nature of the vibration stimulus suggests that as the platform exerts force into the limb, the limb muscles react back in a functioning manner thereby engaging the entirety of the nervous system. Strength improvements were demonstrated in two studies involving older adults (A. Bogaerts et al., 2007; Dallas et al., 2015). Strength is largely a factor of motor unit recruitment (Kaya, Nakazawa, Hoffman, & Clark, 2013) and the results expressed after whole-body vibration sessions indicate motor unit recruitment is occurring as an adaptation.

Chronic obstruction of the airways (COPD) (Buist, McBurnie, & Vollmer, 2012; Buist et al., 2007; Celli et al., 2004; Celli, Macnee, & Members, 2006) can be improved with exercise interventions (Vogiatzis, Nanas, & Roussos, 2002; Weiner, Azgad, & Ganam, 1992). The studies on COPD and vibration treatments presented in this literature review show promise for vibration training in improving breathing rate and blood flow. Whole-body vibration is also classified as a mild exercise stimulus, and might be a great stimulus for alleviating some COPD symptoms and improving other associated health concerns including hypertension and decrease vascular compliance.

The research studies presented in this dissertation address many of the factors associated with aging and a sedentary lifestyle and use valid and reliable means by which to measure them. The initial question when beginning our research was if there would be a profound effect of whole-body vibration on an active population. The active population recruited for Study 1 (Chapter 3) was specific to recreational golf, and all the participants played golf at least 3 times per week. This study included adults with an average age of 52 years which provided us a view of the effects of vibration on aging recreationally active adults. Study 1 included a control group and a group that did exercises without vibration. The study identified that high amplitude whole-body vibration was aggressive enough of a stimulus to improve human performance variables in a recreationally active population with very little effort put forth by the subject. The vibration group improved more than the exercise only and the control group in a variety of measures. As a result, Study 2 (Chapter 4) was designed to cover a complete spectrum of physical function testing (endurance, power, strength, dynamic balance, and range of motion) which has lacked in other studies of its kind, while also including subjective assessment of how the participant feels as a result of the training protocol. Study 2 was designed to investigate the physical function and subjective health changes associated with whole body vibration in non-exercising individuals and to identify if a dosage effect exists. Study 2 will be the first of its kind to adequately investigate both physical function and vascular health before and after a WBV training program that is offered once a week or three times a week. Because improved cardiovascular function is linked to quality of life, WBV training might play a role in the in preventing and treating cardiovascular (CVD) and cardiopulmonary diseases (COPD) by improving vascular function. The results of this study indicated that there was no dosage effect between the once a week group and the three times a week group. Both groups had significant improvements in hip rotation, plank time, kneeling medicine ball throw, leg strength and dynamic balance. The SF-36 reports showed improvements in physical functioning, limitations in physical function, sense of energy, improvements in perceived pain and general health.

The ease of the application of WBV adds an additional benefit to this treatment modality because its use does not require drastic changes in physical activity level. WBV can likely be added to very common body weight activities like squatting. Coincidentally, the at-risk CVD and COPD patient populations are typically unable to perform very much voluntary activity;

therefore, WBV with body weight exercises may be an affordable and easy solution to a sedentary lifestyle and can be employed without extensive training, monitoring, or space.

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Chapter 2

Whole Body Vibration: Potential Benefits in the Management of Pain and Physical Function

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Whole body vibration (WBV) is a form of treatment that has been shown to have an important role in increasing neuromuscular performance, improving muscular strength, balance, gait mechanics, and quality of life (Alvarez-Barbosa et al., 2014; Olivares, Gusi, Parraca, Adsuar, & Del Pozo-Cruz, 2011; Rehn, Lidstrom, Skoglund, & Lindstrom, 2007; Rhea, Bunker, Marin, & Lunt, 2009). The technique involves standing and holding positions, or performing prescribed exercises, on a platform that is vibrating at a programmed frequency, amplitude, and magnitude of oscillation (Cardinale & Bosco, 2003). WBV was first introduced in the clinical setting to enhance bone-mineral density in patients with osteoporosis, (Rubin et al., 2003) and has since expanded to help improve strength and neuromuscular activation in more sedentary populations, such as older adults; (Cardinale & Wakeling, 2005) to decrease pain and fatigue levels in patients with fibromyalgia syndrome; (Alentorn-Geli, Padilla, Moras, Lazaro Haro, & Fernandez-Sola, 2008) to improve postural control and functional mobility (Rubin 2003) in patients with multiple sclerosis; (Schuhfried, Mittermaier, Jovanovic, Pieber, & Paternostro-Sluga, 2005) and to improve gait mechanics in patients with Parkinson's disease (Ebersbach, Edler, Kaufhold, & Wissel, 2008; Turbanski, Haas, Schmidtbleicher, Friedrich, & Duisberg, 2005). The benefits of WBV may also apply to pulmonary strength and body composition, which are reviewed in this article. In fact, within recent years, WBV therapy has emerged in the field of research as a possible method for pain relief across multiple conditions.

While the technique is still relatively new and requires further research to determine full efficacy and sustainability, the therapy has been indicated across the literature as an effective, noninvasive, nonpharmacological, relatively easy-to-use, and comparatively inexpensive therapy that could provide relief from chronic pain, as described herein.

WBV for Chronic Pain Conditions

Pain is a primary symptom of osteoarthritis (OA) (Cardinale & Wakeling, 2005), diabetic peripheral neuropathy (Alentorn-Geli et al., 2008) (DPN), and fibromyalgia (Schuhfried et al., 2005). Whole body vibration has demonstrated a high adherence rate, which is not often the case for many interventions used to help treat individuals with chronic pain (Alentorn-Geli et al., 2008).

Research by Park et al. concluded that individuals suffering from chronic pain produced by knee OA found relief after practicing WBV therapy in conjunction with a home-based exercise program (Park et al., 2013). More specifically, the individuals that participated in WBV therapy and home-based exercise had reduced pain intensity when compared to those who practiced only home-based exercise.

A case study by Hong, Barnes, & Kessler (2013) examined patients with DPN who experienced slight numbness, mild tingling sensations, and severe pain on a daily basis – including one male patient who struggled to put pressure on his feet due to pain and needed to frequently sit or lay down (Hong, Barnes, & Kessler, 2013). In this particular patient, WBV therapy was used as an interventional method to relieve his pain. The therapy decreased his pain after each session for an average of three hours. The patient also reported less pain over time. Kessler and Hong examined the effects of this case on a larger scale study. Similarly, their research indicated WBV was effective at lowering pain over time in individuals suffering from DPN (Kessler & Hong, 2013).

Alentorn-Geli, Padilla, Moras, Lazaro Haro, & Fernandez-Sola (2008) examined the effects of WBV therapy on fibromyalgia patients. Not only did their results support WBV therapy for chronic pain, but interestingly, there was a 0% dropout rate among participants (Alentorn-Geli et al., 2008).

In regard to chronic pain that is not associated with a particular disease or disorder, such as low back pain (LBP), del Pozo-Cruz et al. (2011) examined the effects of WBV on this type of pain (del Pozo-Cruz et al., 2011). Research indicated evidence for WBV relieving back pain, but also suggested that additional investigations be conducted.

For decades, kinesiologists have studied the effects of flexibility on body performance, pain, strength, and quality of life. It has been observed that the more flexibility an individual displays, the more lengthened the muscle group becomes, and this lengthening may lead to fewer feelings of body stress and pain. The "sit-n-reach test," for example, came to fruition during a time when the prevalence of LBP was emerging frequently (Majid & Truumees, 2008; Wells & Dillon, 1952). The test was used to measure hamstring flexibility and trunk flexion ability. It has been theorized that if an athlete possesses a greater range of motion, then the possibility of injuries on the field will be lower(Fradkin, Gabbe, & Cameron, 2006; Shrier, 2000).

Older adults have improved function when static stretching programs are adopted and consistently followed, also leading to an increase in quality of life (Jacobs, 2018). Therefore, it may be advantageous to find a tool that provides easy, quick, and less intense forms of stretching, while also providing equal to or greater increases in joint range of motion (ROM) than traditional static stretching alone.

Whole body vibration may offer a unique exposure mechanism to the nervous system that inhibits the proprioceptors from being overactivated and, in turn, may leave the muscle in a lengthened, more relaxed position. This phenomenon is often observed during static and dynamic flexibility training programs. The rapid vibrations appear to desensitize the muscle spindles which allows the muscle cells to lengthen without excessive static stretching (Haff GG, 2016). Dynamic stretching techniques are typically performed through deep ROM, held for a short period of time, and performed rather quickly to provide increased ROM through neural mechanisms (Haff GG, 2016). Research has demonstrated that WBV platforms may provide the body with a stimulus similar to that of a dynamic stretching routine (Houston, Hodson, Adams, & Hoch, 2015; Tseng et al., 2016).

Additional studies have examined the acute effects of WBV and measured flexibility after a single exposure. Results have indicated that brief exposure to whole body vibration may acutely improve flexibility when compared to stable ground stretching (Annino et al., 2017; Burns & Kakara, 2018; Dallas et al., 2015). Whole body vibration has also been shown to be an adequate warm-up for athletes prior to competition (Bunker, Rhea, Simons, & Marin, 2011). Overall, the technique has proven to be an adequate training tool to produce greater improvements in flexibility than traditional stable ground-based stretching, allowing the inhibition of the muscle spindle activity to cause muscle relaxation (Annino et al., 2017; Burns & Kakara, 2018; Dallas et al., 2015; Houston et al., 2015).

Bone Density: WBV as a Possibility for Osteoporosis Patients

Whole body vibration provides a unique stimulus to the body, in that it utilizes and magnifies body weight during a vibrational oscillation. Currently, WBV platforms produce a large range of amplitudes, where some vibrate with vertical displacement at ~4 mm and some oscillate to provide ~20 mm of displacement. Although each platform may stimulate bone growth, it could be expected that a platform with a larger amplitude would potentially manipulate the body weight in a more aggressive manner, which would lead to an increase in bone fortification (Martinez-Pardo, Romero-Arenas, & Alcaraz, 2013).

In general, any bone marrow density increases experienced from WBV exercises may be attributed to a similar type of adaptation to plyometric and resistance training. The most effective way to stimulate bone to restructure and strengthen is to provide the body with a stimulus that causes the bone to slightly bend. If an aggressive force is sent through the bone, it will stimulate osteoblast production and initiate the redirection of calcium to the bone shaft (Haff GG, 2016). This type of stimulation is commonly experienced during resistance training. Therefore, resistance weight training is often recommended to osteoporotic individuals as it can slightly cause bone to bend and reform. Similarly, plyometric exercises provide an aggressive stimulus that causes the bones to quiver, bend, and undergo the same strengthening restructuring as resistance training.

In fact, plyometrics may be considered the more aggressive exercise due to the amplification of body weight with each jump. An individual's body weight may be amplified by up to 10 times depending on the height of the jump (Haff GG, 2016). This amplified body weight is then sent into the limbs, joints, and muscles of the lower body which cause the bones to quiver. When compared to a low-amplitude platform, WBV exercises performed on a high amplitude platform would be expected to amplify the body weight more and may initiate the same bone deformations as a resistance exercise or a plyometric jump (Martinez-Pardo et al., 2013). Multiple studies have demonstrated improvements in bone density while using a low-amplitude vibration platform, however, research is currently being conducted on a high-amplitude vibration platform (Rubin, Xu, & Judex, 2001; Saquetto et al., 2018).

Overall, the majority of research investigating the use of WBV to treat osteoporosis has indicated that there are no improvements in bone density (Kavanaugh AA, 2011; Slatkovska et al., 2011). However, the literature cited in the paragraph above investigated the effects of a low-amplitude, high-frequency WBV stimulus which may not cause much bone deformation during training compared to a high-amplitude vibration stimulus. High-amplitude WBV theoretically could produce more body perturbations which could lead to greater improvements in bone density. In general, traditional studies that have demonstrated improvements in bone density from other anaerobic exercise sessions have demonstrated changes in BMD in about a year. However, to the authors' knowledge, there have been no WBV studies to date that engaged participants in vibration training for more than one year.

Contrary to previous belief, osteoporosis may not be the leading cause of hip fractures in the mainstream population. Instead, recent literature shows that poor balance may be emerging as a primary cause of hip injuries (read about pain care and risk fall in the elderly) (Turbanski et al., 2005). If individuals had better balance overall, it is possible that the number of falls might decrease, thus avoiding injury from ground forces. Balance is discussed in more detail in the next section.

Balance

Balance is a multifaceted ability that may influence physical capabilities over the lifespan. For example, inadequacies in balance during infancy may result in limited mobility while middle-aged and older adults that lack balance generally report a decrease in quality of life due to the inability to live independently (Jacobs, 2018). Among other factors, a lack of nervous system flexibility, hip tightness, and hip weakness may be attributed to poor balance at any age. Whole body vibration training provides the body with a form of exercise that may help to improve all of these factors and has been shown through research to improve balancing tasks (Goudarzian, Ghavi, Shariat, Shirvani, & Rahimi, 2017; In, Jung, Lee, & Cho, 2018; Ko et al., 2017; Sierra-Guzman, Jimenez-Diaz, Ramirez, Esteban, & Abian-Vicen, 2018).

When the body is in contact with a WBV training device, the vibratory wave is transmitted through the limb, which contacts the platform and is sent up the body to the joint. Once the vibratory wave reaches the joint, the muscles and tendons at the joint are slightly and rapidly shifted, causing a brief contraction and relaxation of the musculature. The rapid stretch causes the muscle spindle to engage, which causes the stretch reflex to activate and cause a reflexive contraction of the muscle. The mobilization and contraction of all the hip musculature during the vibrations are likely to lead to increased hip strength and flexibility, both of which are needed to improve balance.

Strength: WBV for Aging Adults with Increased Immobility

As a whole, the human neuromuscular (Park et al., 2013) system is a complex entity that delivers electrical charges to the muscles from the high brain centers. There are many factors that may alter the effects of this system, including intensity of physical exercise, the amount of stress on the body, and how often the exercise pattern is changed (Coburn JW, 2012; Haff GG, 2016; Kraemer & Looney, 2012). The main indicator of a highly functioning nervous system is the high force production of the muscles, which are associated with the body's ability to move more weight (Haff GG, 2016).

Infants may be perceived as possessing a high strength-to-mass ratio due to the cellular freshness of the structures and the high conductivity of the nervous system. However, after a certain age, the nervous system passes its peak and begins to become a poor conductor of movement impulses. This results in the system becoming slower and weaker. It has been reported that anaerobic exercises, such as plyometric exercise, may provide a resistance great enough to cause adaptational improvements in this regard (Dobbs, Simonson, & Conger, 2018).

Since WBV exercises use gravity as a possible way to increase weight bearing on the body, it may provide a resistance stimulus for the muscles and nervous system for several repetitive short durations or time. During each wave, the body is minimally propelled vertically and then returned to the normal platform height during the next vibratory wave. The painful lactic acid build up felt during a traditional anaerobic set is not common during a vibration exercise set due to the myogenic effect of the skeletal muscle pump (Kang, Min, Yu, & Kwon, 2017). This makes for a unique training stimulus, one that can overload the muscles and nervous system, yet does not fatigue as quickly due to a delay in lactic acid build-up.

In a study conducted by Bogaerts et al. (2007), it was shown that a year-long body weighted WBV training program produced similar results to a traditional strength training program in older adult men (Bogaerts et al., 2007). Therefore, the amplification of the body weight seemed to serve as a sufficient stimulus to maintain the nervous system conductivity.

Wang et al. (2014) concluded that the addition of WBV exercise to a traditional strength and conditioning program increased the strength of track athletes. It also has been hypothesized that WBV stimuli may enhance recovery by providing a rest for the muscle tissues while still providing stimulation to the nervous system (Wang et al., 2014). It has been theorized that this process allows the athlete to continue through a periodization cycle while resting the muscles and not allowing the nervous system to become deconditioned. Although tested primarily in athletes, WBV may offer an optimal training tool for the older adult population in which the nervous system has become deconditioned, leading to movement inabilities.

Pulmonary Rehabilitation: WBV for COPD

The most studied pulmonary complication in terms of WBV benefit has been chronic obstructive pulmonary disease (COPD). Early forms of WBV were localized chest wall vibrations (CWV). The effectiveness of CWV has been supported in individuals with COPD, with improvement in breathlessness (Marciniuk et al., 2011; Roberts & Care, 2008). The movements of CWV in the management of dyspnea might be related to the activation of muscle spindles in the intercostal muscles.

More recently, WBV has demonstrated improved quality of life and exercise capacity in those with COPD (Braz Junior et al., 2015; Cardim, Marinho, Nascimento, Fuzari, & de Andrade, 2016; Greulich et al., 2014; Pleguezuelos et al., 2013; Spielmanns et al., 2017). WBV does not exacerbate perceived dyspnea (Furness, Joseph, Naughton, Welsh, & Lorenzen, 2014) and may safely improve clinical parameters of the patient with COPD (Braz Junior et al., 2015). Researchers also have found little to no negative side effects of the technique in COPD patients, (Cardim et al., 2016; Furness et al., 2014; Sa-Caputo et al., 2016) and thus, WBV has been highly recommended as a component of pulmonary rehabilitation when treating (Braz Junior et al., 2015; Cardim et al., 2016; Sa-Caputo et al., 2016; Spielmanns et al., 2017).

However, a systematic review by Yang, Zhou, Wang, He, & He (2016) concluded that, as of 2016, there was insufficient evidence to support the use of WBV to improve pulmonary function in patients with COPD (X. T. Yang, Zhou, Wang, He, & He, 2016). The authors pointed out that it was difficult to compare WBV interventions as each study in the review used a slight variation of the treatment.

In patients who have had lung transplants, WBV significantly improved quality of life, maximal workload, vital capacity, and aerobic workouts; however, peak cough flow and forced expiratory volume showed no significant change due to WBV (Brunner, Brunner, Winter, & Kneidinger, 2016). WBV may, therefore, offer a safe and feasible treatment to rehabilitate post-surgical patients after intensive care unit (ICU) treatment in those with COPD.

Low Back Pain: WBV as a Cause or Cure?

Whole body vibration has been a particular area of contention as it relates to low back pain (LBP) (Hong et al., 2013). At particular frequencies, vibration has been demonstrated as a factor in the cause of low back pain (Pope, Wilder, & Magnusson, 1999). Early studies established an association between WBV and LBP in primarily occupational exposure, (Cardinale & Bosco, 2003; Lings & Leboeuf-Yde, 2000; Pope et al., 1999) including as a result of prolonged sitting in a vehicle (Lings & Leboeuf-Yde, 2000; Pope et al., 1999).

More recent research has shown that, at frequencies below 20 Hz, vibration may actually reduce LBP by inducing muscle relation and improving the strength of abdominal and back extensor muscles (Fischer AA, 1985; Rittweger, Mutschelknauss, & Felsenberg, 2003). Research led by two groups has further supported the evidence that WBV may be effective in managing LBP (Maddalozzo, Kuo, Maddalozzo, Maddalozzo, & Galver, 2016; J. Yang & Seo, 2015). Specifically, a distinction was made between WBV therapy and whole-body vibrations that may be experienced passively.

For example, Kaeding et al. (2017) proposed that there are substantial negative effects of occupational WBV that individuals may experience while driving a vehicle for long periods of the day (Kaeding et al., 2017). The frequency and amplitude of these passive vibrations are often considerably higher than would be while experiencing WBV as a therapy. Researchers concluded that WBV therapy was an effective, safe, and suitable intervention that requires little infrastructure, time, and/or investment.

Conclusion

Overall, whole body vibration appears to be a promising, complementary, easy-to-integrate tool for the management of certain types of chronic pain, physical functioning and mobility, bone strength, and balance. Benefits of WBV therapy, when combined with exercise, appear to be even more promising. Healthcare professionals are urged to take a serious investigation into the promising effects of WBV in regard to sedentary, rehabilitating, chronic pain, and older adult populations as the aforementioned effects of WBV show support of offering a low-impact, low-stress method to help recondition individuals. These factors, along with increased functional mobility and decreased pain, may be the main proponents to high adherence to WBV treatment protocols. The evidence WBV has demonstrated on individual health measures warrants further investigation into its effectiveness as a method for relieving pain and improving overall strength and physical function.

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Chapter 3

Short-term Training Program Using Whole Body Vibration with Body Weight Exercises Improves Physical Functioning

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ABSTRACT

The purpose of this study was to assess a short-term low frequency, high amplitude oscillatory whole body vibration (WBV) training program on muscular power, trunk strength/endurance, dynamic balance, and squat mechanics in adults. Over 4 weeks, twelve training sessions consisting of four body weight exercises (squat, hip hinge, quadraped, and single leg stance) were performed on a WBV platform or on stable ground. Twenty-seven participants (19 males and 18 females; mean age 53.1 years) were randomized into 3 groups: Vibration (VIB), Stable Ground (GRD), and Control (CON). Pre- and posttests were Timed Plank(sec), Kneeling Chest Launch(cm), Y-Balance Test™ (%), and a composite score(%) from Fusionetics® Squat Analysis program. VIB group achieved significant improvements ($p < 0.01$) across measures. VIB group improvements from pre to posttest for the Kneeling Chest Launch were 10.3±7.3% and for the Timed Plank were 20.2±5.9%. These data suggest WBV during body weight exercises overloads and allows adaptations.

Key Words: Balance, Oscillation, Power, Performance, Gravity

INTRODUCTION

Training programs are essential to prevent both traumatic and overuse injuries in recreational, professional, and collegiate athletes (Hootman, Dick, & Agel, 2007; Riva, Bianchi, Rocca, & Mamo, 2016; Silvers-Granelli et al., 2015). Popular activities often require various combinations of core muscular strength and endurance, dynamic balance, flexibility, and lower and upper body muscle endurance, strength, and power (Hootman, et al., 2007; Riva, et al., 2016; Silvers-Granelli, et al., 2015). Improving these characteristics may have the twofold benefit of improving performance (Berryman et al., 2018) and reducing the risk of injury (Hootman, et al., 2007; Riva, et al., 2016; Silvers-Granelli, et al., 2015). A popular recreational sport is golf (Dai et al., 2015). Golf is unique as it uses the whole body but presents a relatively low risk for injury (*2018 Physical Activity Guidelines Advisory Committee Scientific Report.*, 2018), mostly from overuse injuries (Cabri, Sousa, Kots, & Barreiros, 2009; McHardy, Pollard, & Luo, 2006).

Reviews of literature have determined that progressive resistive strength training and aerobic exercises (Liu and Latham, 2009; Manini and Pahor, 2009)can correct muscle imbalances and improve physical characteristics in adults. Despite this evidence, traditional weight or other physical activity programs are often avoided because of a lack of time and physical activity guidelines (Gray, Murphy, Gallagher, & Simpson, 2016). The understanding of guidelines, equipment, and the supervision necessary to complete strength and conditioning exercises as part of a physical activity program may be daunting. Therefore, body weight exercise training programs that are easy and quick to complete at a local fitness facility or community recreation center may promote participation in physical activity programs.

The addition of whole body vibration (WBV) to standard body weight exercises may provide a plyometric like stimulus and increase force development (Issurin, 2005; Rauch, 2009).

WBV is a stimulus delivered to the body through the use of platforms that deliver multiple consecutive rapid waves of vibration (Bogaerts et al., 2007; Fagnani, Giombini, Di Cesare, Pigozzi, & Di Salvo, 2006; Issurin, 2005; Rauch, 2009; Salmon, Roper, & Tillman, 2012; Wang et al., 2016). Bogaerts et al. (2007) demonstrated near equal improvements in strength and power in older men using body weight vibration training as compared to a traditional strength training program of an equal length (Bogaerts, et al., 2007). WBV provides a unique exercise stimulus due to its simplicity, little need for space and relative low impact delivery mechanism. Evidence regarding the effects of using WBV during body weight exercises on the physical characteristics associated with many recreational activities is under developed. Therefore, the purpose of this study was to determine the efficacy of a short-term low frequency (3-10 Hz), high amplitude (10-18 mm) oscillatory WBV training program on physical function characteristics including muscular power, trunk strength and endurance, dynamic balance, and squat mechanics. We hypothesize that body weight exercise movements performed on a WBV platform will improve physical function characteristics when compared to the same body weight exercises performed on stable ground.

Method

Participants and Design

Twenty-seven healthy adults (n=9:females, n=18:males) who self-reported as recreational golfers from a local country club volunteered and qualified for inclusion (Table 1). Inclusion criteria required the participant to be between 18 and 70 years old, healthy with no surgeries within the last year, and identify as a recreational golfer. Subjects were excluded if they reported an acute musculoskeletal injury, severe pain, or pregnancy. Subjects who possessed a contraindication mentioned in the WBV platform's operations manual (e.g., epilepsy or active migraines) or indicated another medical condition (e.g., high blood pressure, cancer) on their health history form could participate only with physician's clearance. There were no subjects who presented a contraindication for the equipment and one subject had to obtain medical clearance; however, clearance was granted. All subjects were randomly assigned to an intervention group: VIB (n=11), GRD (n=8), or CON (n=8). The VIB group performed exercise movements on the vibration platform, the GRD group performed the exact same exercise movements but on the stable floor, and the CON group was asked to cease all outside exercise activity other than golf for the month. The research study was conducted ethically according to international standards (Harriss, Macsween, & Atkinson, 2017).

To investigate the effects of WBV on physical function measures in recreationally active adults, we used a 3 x 2 (group x time) mixed model repeated measures design. Independent variables included intervention group ((Vibration+Training (VIB), Stable Ground+Training (GRD), and a Control (CON)) and time (Pre and Post training intervention). Testing was performed over two separate time periods before and after intervention (Figure 1). Dependent variables collected at two time points were Y-Balance™ composite score for right and left leg (%), Timed Plank (sec), Kneeling Chest Launch (cm), and a composite score from Fusionetics® Squat Analysis program.

Measures

Assessments

Pre and post intervention assessments are described below, these tests aligned with the recommendations of a PGA strength and conditioning specialist.

The Y-balance Test™ (Wood, n.d.-c) is a highly reliable dynamic balance test. The participant stood with the arch of their foot on a spot at the center of a "Y". The participant then balanced on one leg and reached with the other leg in three directions (anterior, posterior medial, and posterior lateral). Three trials in each direction were performed and the maximum reach was recorded. The composite score for "leg function" of each leg was calculated by adding up the distances for all 3 directions of reach and dividing it by 3 times the participant's leg length (Hertel, Braham, Hale, & Olmsted-Kramer, 2006; Wood, n.d.-c).

The Kneeling Chest Launch (Peterson; Wood, n.d.-a) involves throwing a weighted medicine ball for maximum distance while kneeling to exclude the distal lower extremities. It measures muscular coordination and upper body and lumbopelvic hip strength and power. The participant started in a kneeling position with the back erect and faced the direction they were to throw. Their thighs were parallel and their knees were at a start line. Their toes were pointed backwards and not curled up so there was no traction advantage. The ball was grasped in both hands at the chest and the hips were brought back to the heels. Then in one motion the ball was pushed forward and up trying for maximum launch distance. The participant could fall forwards over the line after the ball was released but their knees were not to leave the ground and they could not favor one arm or rotate the spine. The maximum throw of two attempts was recorded (Wood, n.d.-a).

The Timed Plank Test (McGill, 2010; Wood, n.d.-b) is a fitness test of core muscle strength and endurance(McGill, 2010; Wood, n.d.-b). The plank test involved holding an elevated trunk position for as long as possible and measured the control, strength, and endurance of the trunk/core stabilizing muscles. The upper body was supported on the ground by their elbows and forearms and their legs were kept straight with the weight taken by the toes. The hips were lifted off the floor creating a straight line from head to toe. The test was over when the hips were lowered and the subject was unable to hold the elevated trunk position in a straight line (Wood, n.d.-b).

The Fusionetics® Squat Analysis software was used during this experiment as a method by which to track movement efficiency during an overhead squat (Clark, n.d.). Deviations in optimal overhead squat form are usually an indication of poor flexibility, muscle imbalances or nervous system dysfunction. The software allows for the tester to organize and track squat deficiencies into four main areas including the shoulder, lumbopelvic hip complex, knee, and foot/ankle. The software identifies common movement inefficiencies include varus and valgus knee deviations, excessive forward lean of trunk, arching or rounding of the low back, or the weight shifting from one leg to the other. Each subject performed 10 parallel body weight squats with arms overhead and then the software presented the tester with a composite score on a scale of 0-100 (Clark, n.d.; Cornell and Ebersole, 2018). Typical classification related to composite score is Poor (0-49.99) Moderate (50-74.99), or Good (75-100) movement efficiency.

Instrumentation

The Dr. Fuji® FJ-700 vibration platform (Fremont, CA) (Figure 2) was used in all VIB sessions. Dr. Fuji® FJ-700 has an oscillation amplitude range between 10 and 18 mm and a frequency range from 3 Hz to 10 Hz (Levels 1-Level 10). The platform oscillates rather than using a vertical displacement pattern (Figure 3). The oscillating (pivoting) amplitude pattern allows for greater magnitude of displacement when compared to linear or vertical vibration plates. An oscillating machine can support more body weight and have a smaller impact on the body because it is not creating an up and down piston-like vibration but rather a swing-like vibration that encourages the body to actively contract muscles on alternating sides in an effort to maintain equilibrium. The Dr. Fuji® FJ-700 provides amplitudes that range between 10-18 mm based on the width of foot placement on the vibration plate (Figure 2 and 3). The amplitude experienced will be greater with a wider foot stance. The oscillation pattern and greater amplitude range provides gravity force amplification or muscular overload during body weight exercises.

Procedures

Training Intervention Protocol

Upon arrival to the country club fitness center on exercise days, subjects were asked to sign in on the log sheet for session tracking purposes. Subjects from the VIB group and the GRD group reported to the fitness center 3 times a week for one month (4 weeks) to perform the exercise protocol while guided by a fitness instructor. The control group did not perform any specific exercises. All training sessions lasted 21 minutes and all movements were timed. The exercise sessions included all body weight movements and were performed slowly (3 second eccentric, 3 second concentric). The exercises performed included: a double legged hip hinge (Romanian Deadlift motion), double legged quarter squat, a kneeling quadruped with the hands on the platform, and a single legged stance (Figure 4 a-d). Every subject wore shoes. The hip hinge and squat were done with feet in comfortable stance position toward the outside of the plate, the quadruped was done with hands slightly greater than shoulder width towards the outside of the plate, and the single leg stance was done with their foot in the center of the platform. The participants stood with knees slightly flexed and/or maintained a neutral back position to prevent any possible injuries during the start and finish positions. Three sets of 1-minute duration were performed in each position. There was a 1-minute rest between all movements and all positions. All subjects began at frequency level 5 (~6.5 Hz) on the platform on their first visit and spent the first 5 sessions gradually increasing the frequency following a progressive overload. The first 5 sessions were as follows: session 1 – Level 5, session 2 – Level 6, session 3 – Level 7, session 4 – Level 8, session 5 – Level 9, sessions 6 – 12 were all at level 10.

Data Analysis

Data were analyzed using SPSS version 25.0 for Windows 10 (Armonk, New York). The distributions were analyzed for normality and the existence of outliers using histogram plots, boxplots and Quantile-Quantile plots. A single factor ANCOVA was used to determine the effects of training type (VIB, GRD, CON) on the change (post – pre) of the following dependent variables: plank time (secs), kneeling chest launch distance (cm), Y balance composite left (%) and right (%) (5), and Fusionetics® composite score (%). Pre-measurements were used as the covariates. Follow-up tests for group differences were done using the Sidak post hoc test. The level of significance was set at alpha = 0.05. Values are expressed as means ± SD (95% CI).

Results

Trunk Muscle Strength and Endurance

Group differences were detected ($F_{(2,23)}$=6.31, p=0.007, η^2=0.365, ß=0.852) for the timed plank test. There was a significant difference between the VIB and the GRD group (p=0.002), where the VIB group demonstrated significantly better holding times for the timed plank test (Table 2).

Upper Extremity and Lumbopelvic Hip Strength and Power

Group differences were detected ($F_{(2,23)}$=6.74, p=0.005, η^2=0.37, ß=0.877) for the kneeling chest launch. Both the VIB and GRD training groups had significantly greater changes (p<0.04) than the CON training group (Table 2).

Dynamic Balance

There were no group significant differences for the Y-Balance Test™ for the right leg ($F_{(2,23)}$=2.7, p=0.089, η^2=0.19, ß=0.48) but there was a larger improvement in composite score change for the VIB group (Table 2). Group differences were detected in the Y-Balance™ left leg composite score ($F_{(2,23)}$ = 7.9, p = 0.002, η^2=0.41, ß=0.93). The VIB group was significantly greater than the GRD training group (p=0.001) and the CON group (p=0.013)(Table 2).

Movement Efficiency

There were no group significant differences ($F_{(2,23)}$=1.81, p=0.187, η^2=0.14, ß=0.34) for the composite score from the Fusionetics® Squat Analysis but there was a larger improvement in composite score change for the VIB group (Table 2).

Discussion

The purpose of this study was to determine the efficacy of a short-term low frequency (3-10 Hz), high amplitude (10-18 mm) oscillatory WBV training program on physical performance characteristics of recreationally active adults including muscular power, trunk strength and endurance, dynamic balance, and squat mechanics. Our data suggests the possibility for physical performance improvements with the addition of WBV to simple body weight exercises within a short 4-week training period. The VIB group improved in several variables compared to GRD and CON; therefore, we believe the VIB training overloaded the muscles and activated neuromuscular pathways via a plyometric like stimuli without heavy weights or impact loading (Cardinale and Wakeling, 2005; Issurin, 2005; Rauch, 2009). A twenty-one minute training session performed 3 times a week for 4-weeks using the four body weight exercise motions (hip hinge, squat, quadruped, single leg stance) on stable ground did not fully overload the body as only the kneeling chest launch was significantly different between the GRD and CON group. Therefore, exercises without vibration may need to be more aggressive and include plyometrics and heavier weights; however, both of these can increase the possibility for injury, overtraining and excessive fatigue.

The effects of WBV as a training stimulus has been noted across many peer reviewed research studies and commentaries (Bogaerts, et al., 2007; Cardinale and Wakeling, 2005; Fagnani, et al., 2006; Issurin, 2005; Jones, Martin, Jagim, & Oliver, 2017; Rauch, 2009; Salmon, et al., 2012; Wang, et al., 2016), so our adaptations in the VIB group were not surprising. We demonstrated that body weight only exercises with the addition of WBV can accomplish changes in muscle strength, endurance, power, dynamic balance, and movement efficiency in less time. Whereas, previous studies (Álvarez, Sedano, Cuadrado, & Redondo, 2012; Doan, Newton, Kwon, & Kraemer, 2006) that focused on improving physical function and performance needed more time and used more aggressive exercises. However, more research is needed to determine the most beneficial dose of vibration of WBV training. To our knowledge, this is the first study to use a short term body weight exercise plus vibration as a training program for improvement of physical function measures in a group of adult recreational athletes (golfers).

We theorize the low frequency but higher amplitude oscillatory swing like vibration waves delivered to the contact limb(s) caused a multiplication of the participant's body weight which caused an overload stress but with minimal impact loading (Cardinale and Wakeling, 2005). The FJ-700 may overload the muscle better with lower impacts. Avoiding injury due to excessive impacts, yet still achieving maximal force production is the goal of most training programs and the addition of a vibration stimulus seems to be ideal for improving function but decreasing overall stress.

The repetitive and comfortable overload of mechanoreceptors within the muscle during the concentric and eccentric phases of body weight exercises may allow for better timing of agonists and antagonist muscles thereby providing for better movement efficiency and strength improvements (Hagbarth and Eklund, 1966). The vibratory perturbations may also improve the amount and rate of force development and muscle performance. In general, adding a vibration stimulus will demand more motor unit recruitment for a given production of muscle force thereby promoting overload, adaptation, and improved muscle synchronization. However, there may be a vibration threshold with increasing frequency because the inertia of the body may be too great to dampen with muscular contractions (Mester, Spitzenfeil, Schwarzer, & Seifriz, 1999).

The time course (4 weeks) of our improved physical performance outcomes with body weight exercises performed on the FJ-700 was faster than other interventions (Bogaerts, et al., 2007; Fagnani, et al., 2006; Jones, et al., 2017; Salmon, et al., 2012; Wang, et al., 2016). For example, Fort, Romero, Bagur, & Guerra (2012) demonstrated a 10% increase in power and a 14% increase in postural control during a single leg hop test after 15-weeks of WBV combined with a normal basketball training regimen (Fort, Romero, Bagur, & Guerra, 2012). In comparison, our study used a higher amplitude vibration platform and demonstrated slightly greater improvements while only using a 4-week training program. However, the recreational adults in this study also were not participating in a regular training regimen and that could have contributed to the changes noted. Our results demonstrate that a higher amplitude provided with an oscillatory pattern produced notable improvements with a short-term body weight only training program; however, future research should include those which compare and contrast benefits amongst different WBV machines with varying amplitudes and different types of exercises.

Limitations to this study include small sample sizes which likely reduced power and prevented significance from occurring in each assessment and our subjects were a convenience sample of interested participants. It is also possible that a learning effect occurred in the squat assessment and Y-Balance Test™ from the pre to post test and this may have washed out any group differences. We also did not measure isolated strength gains of any specific muscle groups targeted by body weight exercises and did not measure golf performance variables associated with swing mechanics or swing outcomes.

CONCLUSIONS

Body weight exercises combined with a low frequency (3-10 Hz) and high amplitude (10-18 mm) oscillatory vibration stimulus may be able to overload targeted musculature safely without unnecessary impact or discomfort. Therefore, these data provide promising results for fitness professionals looking to provide increases in key components of physical performance when their clients do not have advanced weight training equipment or access to guided personal training sessions. The four body weight exercises can be easily instructed and WBV plates are easy to store in fitness centers. An oscillatory vibration stimulus with body weight exercises can also be simply integrated into an any existing strength training program.

ACKNOWLEDGEMENTS

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Figure Legend

Figure 1. Outline of study procedures including pre and post assessments and training regimen.

Figure 2. Dr. Fuji-700 vibration plate.

Figure 3. Oscillation patterns of vibration plates. (A) Vertical displacement and (B) Oscillation. Adapted from: Cardinale, M. and Wakeling J.

Figure 4. Body weight exercises performed in VIB and GRD groups. (A) hip hinge, (B) squat, (C) quadruped, and (D) single leg stance.

Table Legend

Table 1. Demographic characteristics of the participants [mean±SD (range)].

Table 2. Functional performance data pre and post intervention [Pre & Post: mean±SD (95%CI); Change: mean±SE (95%CI)]. Covariate Pre test value appears in model for change score.

Figure 1: Outline of study procedures including pre and post assessments and training regimen.

<table>
<tr><th>Pre Tests</th><th>Week 1</th><th>Week 2</th><th>Week 3</th><th>Week 4</th><th>Post Tests</th></tr>
<tr><td>• Y-balance Test (cm)
• Timed Plank (sec)
• Kneeling medicine ball throw (in)
• Fusionetics™ squat analysis</td><td colspan="4">Training groups (VIB and GRD) performed exercises 3 X week.
• hip hinge
• squat
• quadruped
• single leg stance
Three sets of 1-minute duration were performed in each position.
• Maximum repetitions were completed using a 3 second eccentric phase, 3 second concentric phase pace
One-minute rest between all movements and all positions.</td><td>• Y-balance Test (cm)
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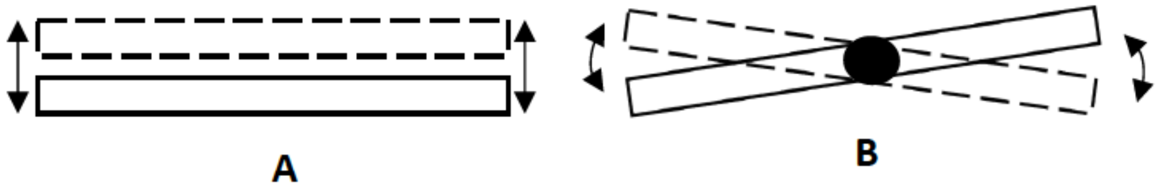

Figure 4. Body weight exercises performed in VIB and GRD groups. (A) hip hinge, (B) squat, (C) quadruped, and (D) single leg stance.

Table 1. Demographic characteristics of the participants [mean±SD (range)].

Group	Participants	Gender	Age (yrs)	Height (cm)	Mass (kg)
VIB	n=11	n=7 males n=4 females	51.9±13.9	173.6±13.6	80.8±12.2
GRD	n=8	n=6 males n=2 females	52.1±14.1	178.8±12.4	83.9±16.5
CON	n=8	n=6 males n=2 females	55.9±4.7	177.8±12.1	84.5±14
ALL	n=27	n=19 males n=8 females	53.1±11.7 (27-69)	176.4 ± 12.5 (152-193)	82.8 ± 13.7 (52-102)

Table 2. Functional performance data pre and post intervention [Pre & Post: mean±SD (95%CI); Change: mean±SE (95%CI)]. Covariate Pre test value appears in model for change score.

	VIB Group			GRD Group			CON Group		
DV	**Pre**	**Post**	**Change**	**Pre**	**Post**	**Change**	**Pre**	**Post**	**Change**
Timed Plank (s)	99.5 ± 51.1 (69.4-129.7)	119.9 ± 11 (113.4-126.4)	20.2 ± 5.9* (7.9-32.5)	100.6 ± 31.6 (81.9-119.3)	95.1 ± 6.7 (91.1-99.0)	-12.1 ± 6.9 (-26.4-2.3)	124.5 ± 40.5 (100.7-148.5)	113.7 ± 6.4 (109.9-117.5)	3.7 ± 7.4 (-11.6-19.1)
Kneeling Chest Launch (cm)	189.2 ± 62.7 (152.1-226.0)	208.7 ± 44.9 (182.2-235.3)	19.4 ± 7.0† (4.9-33.5)	212.8 ± 38.9 (189.8-235.9)	221.5 ± 42.4 (196.5-246.6)	8.7 ± 24.7† (-10.9 -24)	188.4 ± 40.7 (163.3-212.4)	174.5 ± 68 (134.3 – 214.7)	-3.9 ± 40.9 (-36.8 - -2.8)
Y Balance Right leg (%)	76.3 ± 10 (70.4-82.2)	85.4 ± 8.8 (80.1-90.6)	9.2 ± 1.5 (6.0-12.4)	77.4 ± 6.4 (73.6-81.1)	82.3 ± 11 (75.8-88.8)	4.4 ± 1.8 (0.6-8.2)	74.4 ± 6.2 (70.7-78.1)	79.7 ± 8.9 (70.7-78.1)	4.7 ± 1.8 (0.9-8.5)
Y Balance Left Leg (%)	77 ± 8.0 (72.3-81.7)	84.9 ± 5 (81.9-87.9.6)	8.0 ± 1.2‡ (5.6-10.5)	77.6 ± 10.6 (71.1-83.9)	79.8 ± 4.1 (73.4-82.2)	1.1± 1.4 (-1.8 - 4.0)	72.6 ± 7.9 (68-77.3)	76.2 ± 3.7 (74-78.4)	2.9 ± 1.4 (-0.2-5.9)
Fusionetics Score (%)	92 ± 4.4 (89.4-94.6)	97.4 ± 4.0 (95.0-99.7)	4.6 ± 1.4 (1.7-7.6)	91.9 ± 5.0 (88.9-94.9)	95.3 ± 5.6 (91.9-98.6)	1.5 ± 1.6 (-1.9-4.9)	96.8 ± 4.3 (94.2-99.3)	96.6 ± 5.8 (93.1-100)	0.64 ± 1.9 (-3.3-4.6)

*VIB group significantly better change in core muscle endurance compared to GRD group (p=0.002)
†VIB and GRC group demonstrated significantly better change in power than CON (p<0.04)
‡VIB group significantly better change in dynamic balance on left leg compared to GRD (p=0.001) and CON (p=0.013)

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Chapter 4

Vascular and Neuromuscular Changes After 8 Weeks of Whole-Body Vibration Training in Sedentary Volunteers

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The information age created a dramatic shift in the human condition as there has been a steady decline in locomotion and physical activity plus an increase in disease and bodily pain over the past several decades (Di Pietro, Dziura, & Blair, 2004). These sedentary behaviors have given rise to childhood obesity, musculoskeletal inflammation and pain, and poor function starting at even early ages (Biddle, Pearson, Ross, & Braithwaite, 2010; Ng et al., 2014; Salmon, Tremblay, Marshall, & Hume, 2011). However, a continued sedentary lifestyle can lead to a poor quality of life, a need for medications and medical devices and also a higher instance of depression (Mitchell, Lord, Harvey, & Close, 2015; Weyerer, 1992). But most concerning is that a sedentary lifestyle seems to contribute directly to an increased risk of falling.

Falls are a concerning public health issue as they are the leading cause of fatal and nonfatal injuries among older adults (aged ≥65 years) because approximately 30% of older adults fall each year (Bergen, Stevens, & Burns, 2016). In 2015, the estimated medical costs attributable to fatal and nonfatal falls was approximately $50.0 billion (Florence et al., 2018). Predicting falls is difficult, but increasing age, slower walking speed, and being depressed are all strong predictors of injurious falls in older adults (Clemson, Kendig, Mackenzie, & Browning, 2015). Unfortunately, adults who adopt a sedentary lifestyle are more likely to experience loss of strength, range of motion, and balance which reduces gait stability and gait speed (Clemson et al., 2015) and they are also likely to experience changes in mental health including depression (Teychenne, Ball, & Salmon, 2010). Therefore, a sedentary lifestyle where people sit more and move less is also a concerning public health issue because of its detrimental health implications. Additionally, each year there are approximately 27,000 deaths in America associated with falls and the indirect costs are roughly $52 billion (Burns & Kakara, 2018; Finlayson & Peterson, 2010).

Recent surveys have shown that only roughly 16% of the US population can be found in a fitness center, only 19% of the adolescent US population is intentionally physically active and only 23% of the US population meeting the requirements for aerobic and muscular fitness (Prevention, 2018; Tharrett, 2017) for a healthy lifestyle. These statistics strongly suggest that the majority of the population desires and would benefit from an exercise modality which was not exhausting yet provided strength, muscle tone and general fitness, however that is not currently available.

Whole-body vibration (WBV) has been researched for approximately the past 10 years and has shown through multiple studies to improve strength, balance, flexibility, bone density and muscle density (Annino et al., 2017; A. Bogaerts et al., 2007; A. C. Bogaerts et al., 2009; Dallas et al., 2015; Fort, Romero, Bagur, & Guerra, 2012; Ko et al., 2017; Sanudo et al., 2010). The intriguing factor with whole-body vibration is that these physiological responses to the body can be achieved by merely standing on the platform with no additional weight added to the body (Calder, Mannion, & Metcalf, 2013; Roelants, Delecluse, & Verschueren, 2004). Limb shaking produced by a vibration platform is an energy form and our body absorbs the energy within our musculoskeletal system by increasing muscle tension in an effort to dampen the shaking. The increased tension in the muscles is mediated by our proprioceptive system including the muscle spindle. As a result, the muscles are tensioned at a much higher level than would be necessary for quiet standing. The body then responds to the muscle activity just as it would an exercise bout.

WBV offers a unique strength to the deconditioned population because of ease of use (Iwamoto, Takeda, Sato, & Uzawa, 2005; Rauch, 2009; Rauch et al., 2010). Traditional resistance exercise has been reported as too difficult to perform for healthy individuals

(Alexander et al., 2001; Focht, 2007; Harada, Shibata, Lee, Oka, & Nakamura, 2014), let alone to someone who can barely sit, stand, or climb flights of stairs (Alexander et al., 2001). Controversially these exercises are the very solution to their functional problems as shown through many of studies (Kraemer, Ratamess, & French, 2002; Latham & Liu, 2010; Stone, Fleck, Triplett, & Kraemer, 1991; Tsutsumi, Don, Zaichkowsky, & Delizonna, 1997; Winett & Carpinelli, 2001). In an effort to provide efficacy for vibration training, Bogaerts et al (2007 & 2009) followed a large population of older men over a one-year period (A. Bogaerts et al., 2007; A. C. Bogaerts et al., 2009). The men were separated into two groups, one which completed body weight training on a vibration platform only and one group who exercised traditionally using cardiovascular, resistance, balance and stretching exercises. Measures such as strength, power and flexibility (those necessary for proper locomotion) were observed and measured at several time points during the study. Both training groups improved similarly in VO_2 peak and muscle strength demonstrating that WBV training using simple motions like the squat and toe raises (A. Bogaerts et al., 2007; A. C. Bogaerts et al., 2009) can successfully improve physical fitness.

WBV provides a unique exercise stimulus due to its simplicity, little need for space and relative low impact delivery mechanism. Evidence relating the effects of using WBV during body weight exercises on a variety of physical characteristics in sedentary adult populations aged over 40 years is underdeveloped. In addition, the dosage and overall duration of WBV in sedentary adults also needs to be investigated. Therefore, the purpose of this study was to investigate the physical function and subjective health changes associated with whole body vibration in non-exercising individuals and to identify if a dosage effect exists, and secondly to compare the effects of two dosages of whole-body vibration on vascular function as measured with resting blood pressure. Objective and subjective characteristics including muscular power, core strength, dynamic balance, leg strength, hip flexibility, resting blood pressure, and quality of life were measured three times over 8 weeks (pre, mid, post) for two different WBV dosage groups including 1-time per week and 3 times per week. There are no current studies on whole body vibration dosage; therefore, we hypothesize that body weight exercise movements performed on a WBV platform three times a week will provide greater physical benefits than when performed one time a week with a sedentary population.

METHODS

Experimental Approach to the Problem

To investigate the effects of an 8-week whole-body vibration training program on physical function measures in sedentary adults over 40 years of age, we used group x time between-within repeated measures designs. Independent variables included group and time. There were two WBV training intervention groups (One session per week (1X/Week) and three times per week (3X/week)) and three time points (Pre, Mid, and Post training) or two time points (Pre and Post). Physical functioning tests were performed over three separate time periods before, at 4 weeks, after the 8-week intervention, whereas vascular testing was performed over two separate time periods before and after intervention (Table 1). Dependent variables collected at all three time points were Y-Balance Test™ composite score for right and left leg (%), Timed Plank (sec), Kneeling Chest Launch (cm), Leg Extension 5-Repetition Maximal Strength (kg), Hip Internal and External Range of motion (deg), and the health status questionnaire (SF-36). Resting blood pressure (mmHg) was measured at the pre and post assessment sessions.

Subjects

Twenty-five healthy sedentary adults (n=23: females, n=2: males) who self-reported as not engaging in any form of structured physical activity volunteered from a local University and also from the DFW metroplex, were included in this research study. Two female subjects dropped out after the pre-test assessments due to schedule concerns and not being interested in completing vibration training. The demographic characteristics of the 23 remaining participants are presented in Table 2. Inclusion criteria required the participant to be over the age of 40 with no cap on the maximal age, healthy with no surgeries within the last year, and identify as being sedentary (having no structured exercise routine). Subjects were also excluded if they reported an acute musculoskeletal injury or severe pain or pregnancy. Subjects who possessed a contraindication mentioned in the whole body vibration platform's operations manual (epilepsy, diabetes, heart condition, slipped disc, knee and hip implants, pacemaker, IUD, thrombotic conditions, tumors, infections, open wounds, or have active migraine headaches) or possessed another medical condition (e.g., high blood pressure, cancer) indicated on the health history form given to all participants could participate only with physician's clearance. There were no subjects who presented a contraindication for the equipment and two subjects had to obtain medical clearance for a health history condition; however, clearance was granted. All subjects were randomly assigned to an intervention group: 1X/week (n=13) or 3x/week (n=10). The 1X/week group performed the prescribed exercise movements on the vibration platform one time a week and the 3X/week group performed the exact same exercise movements but reported for workout sessions three times a week. Both groups were asked to not begin any other exercise activities for the two-month period when the study was being conducted. This study was approved by the University's Institutional Review Board (IRB) (IRB # 2019-0144). Prior to participation in the study our subjects were informed of the benefits and risks of the investigation and signed an institutionally approved informed consent document.

Procedures

Assessments

Assessments were collected prior to the beginning of the study, at the mid-point (4 weeks) and at the end of the intervention (8 weeks) (Table 1). The following pre-intervention assessments were then conducted: Y-Balance Test™ (Hertel, Braham, Hale, & Olmsted-Kramer, 2006; Wood, n.d.-c), Kneeling Chest Launch Throw (D. Peterson; D. D. Peterson; Wood, n.d.-a), Timed Front Plank (McGill, 2010; Wood, n.d.-b), 5 Repetition Maximum Leg Extension (Brzycki, 1993; Haff GG, 2016; Phillips, Batterham, Valenzuela, & Burkett, 2004) and Hip Internal and External Range of Motion Tests (Miller, 2012). The five assessment tests included were chosen because they are the most highly reliable forms of measurement for the variables they measure, thus are valid. The following pre-intervention assessments were conducted prior to the beginning of the study and at the end of the intervention (8 weeks): The 36-item Short Form Health Survey (SF-36) (Ware & Sherbourne, 1992), Arterial Blood pressure (Climie et al., 2012). (Table 1) These variables were agreed by the research team to have the most performance-based effects on physical function.

The Y-Balance Test™ assessment test (Wood, n.d.-c) is a highly reliable dynamic balance test which is ideal for measuring an athletic population. The investigator measures the leg length of the participant, then instructs the participant to stand with the arch of the foot on a marked spot on the floor at the center of the “Y”. The participant then balances on one leg and reaches with the other in three directions; one direction being anterior of the subject, and the others begin behind and to the side. All of the reaches are performed for three trials. The participant then switches legs and completes the same guidelines on the opposing leg. The composite score for "leg function" of each leg is calculated by adding up the distances for all 3 directions of reach, then divided by 3 times the leg length (Hertel et al., 2006; Wood, n.d.-c).

The Kneeling Chest Launch Throw (D. D. Peterson; Wood, n.d.-a) involves throwing a weighted medicine ball for maximum distance while kneeling so the distal lower extremities are excluded. It is considered a measure of upper body strength and power. The Kneeling Chest Launch is one of the tests of the Speed Power Agility Reaction and Quickness (SPARQ) rating system (Wood) for ice hockey and it has recently been added to the football SPARQ testing for upper body strength and power (it replaced the maximum bench press). This aim of the test is to measure upper body coordination, strength and power and hip extension power during the explosive parts of the test. The equipment required is a 2 kg (females) or 3 kg (males) kg power ball, tape measure, foam pad for kneeling, clear open area for testing. The testing procedures are to start the participant in a kneeling position with the back erect and facing the direction they are going to throw. The thighs should be parallel and the knees at the start line. Ensure that the toes are pointed backwards, as curled up toes can be used for greater traction. Starting with the ball grasped with both hands at the sides, and held out and above the head. The ball is brought down to the chest as the hips are brought back to the heels, then in one motion the ball is pushed forward and up (optimally between 30-45 degrees). A practice trial is allowed to learn the correct movements and get the best trajectory for maximum distance. The participant must not throw favoring one arm or rotate about the spine. The participant is permitted to fall forwards over the line after the ball is released. The knees are not to leave the ground. Two attempts are allowed, with at least 45 seconds recovery between each throw (Wood, n.d.-a).

The Timed Plank Test is a simple fitness test of core muscle strength, and can also be used as a fitness exercise for improving core strength (McGill, 2010; Wood, n.d.-b). The plank test measures the control and endurance of the back/core stabilizing muscles. The test is simple and requires little equipment such as a flat and clean surface, a stopwatch, recording sheets and a pen. The aim of this test is to hold an elevated trunk position for as long as possible. The upper body is supported on the ground by the elbows and forearms and the legs are kept straight with the weight taken by the toes. The hips are lifted off the floor creating a straight line from head to toe. As soon as the subject is in the correct position, the stopwatch is started. The test is over when the subject is unable to hold the back straight and the hip is lowered (Wood, n.d.-b).

The 5-RM knee extension test for quadriceps strength (Brzycki, 1993; Haff GG, 2016; Phillips et al., 2004) is a commonly used assessment for recreational or sedentary individuals to assess quadriceps strength in the thigh. The quadriceps muscles are a vital component of health as many injuries and health conditions are linked to its weakness. The 5-RM test allows for a sufficient estimate of lower body strength. The procedures for obtaining a 5 RM included 1) instructing each subject to warm-up with a light weight they could easily do for 10 repetitions, 2) rest one-minute, 3) lift an estimated weight load based on body mass and warm-up weight that would allow the subject to likely complete at least 5 repetitions, 4) add 10-20% more to the weight stack if the subject could complete 5 repetitions with the estimated previous weight, 5) rest two-minutes, 6) perform additional sets by adding another 10-15% to the weight stack until the subject could no longer perform 5 full repetitions. Ideally, the client's 5RM will be measured within three testing sets.

Hip internal rotation and external rotation (Miller, 2012) were measured with the subject in a prone position strapped to a therapy table. The subject was instructed to bend their knee to 90 degrees and rotate their hip externally by moving their lower leg toward the midline of the body and then to rotate their hip internally by moving their lower leg away from the midline. Subjects were instructed to not raise hips at the end of range of motion so true hip internal and external rotation. The subject was then told to alleviate joint stiffness by moving their hip in and out of internal and external rotation with their knee bent up 5 times. Then the digital protractor was then zeroed out on a leveled surface and then placed on the subject's calcaneus. The subject is then instructed to bring their foot out to measure internal rotation and then to bring their foot in to measure external rotation without lifting their hips off the table to gain extra range. The best of two measurements was recorded.

The 36-item Short Form Health Survey (SF-36) is a measure of health-related quality-of-life. It is a subset of questions from longer instruments that has been used frequently. There have been a variety of iterations of this tool, and the version presented here is more specifically known as the RAND SF-36. The SF-36, as described in the name, is a 36-item patient-reported questionnaire that covers eight health domains: physical functioning (10 items), bodily pain (2 items), role limitations due to physical health problems (4 items), role limitations due to personal or emotional problems (4 items), emotional well-being (5 items), social functioning (2 items), energy/fatigue (4 items), and general health perceptions (5 items). Scores for each domain range from 0 to 100, with a higher score defining a more favorable health state. This form was administered at all three measurement time points (pre, mid, post)

Arterial blood pressure was collected at two time points (pre-post) in a quiet dark laboratory with the patient supine. Continuous beat-by-beat arterial blood pressure was recorded non-invasively from a finger (Finapres, FinometerPro). Intermittent blood pressure measurements were obtained by listening to the brachial artery via electronic device that mimics a blood pressure cuff and stethoscope (Tango+; SunTech, Raleigh, NC). The blood pressure cuff was inflated up to 20 mmHg above the subject's systolic blood pressure (during the intermittent measurements).

Instrumentation

The Dr. Fuji® FJ-700 vibration platform (Fremont, CA) (Figure 1) was used in all VIB sessions. Dr. Fuji® FJ-700 has an oscillation amplitude range between 10 and 18 mm and a frequency range from 3 Hz to 10 Hz (Levels 1-Level 10). The platform oscillates rather than using a vertical displacement pattern (Figure 2). The oscillating (pivoting) amplitude pattern allows for greater magnitude of displacement when compared to linear or vertical vibration plates (displacement usually up to 6 mm). An oscillating machine can support more body weight and have a smaller impact on the body because it is not creating an up and down piston-like vibration but rather a swing-like vibration that encourages the body to actively contract muscles on alternating sides in an effort to maintain equilibrium. The Dr. Fuji® FJ-700 provides amplitudes that range between 10 mm and 18 mm based on the width of foot placement on the vibration plate (Figure 1 and 2). The amplitude experienced will be greater with a wider foot stance. The oscillation pattern and greater amplitude range provides gravity force amplification during body weight exercises on the Dr. Fuji® FJ-700. The levels (1-10) of frequency range (3-10 Hz) and the amplification of one's body mass during body weight exercises on the plate simulates higher loads allowing exercise progressions to adhere to the overload principle. The addition of WBV during body weight exercises allows for the body to experience loads that would normally only occur with actual weight lifting.

Training Intervention Protocol

Subjects arrived to either the Therapeutic Interventions lab at the University of Texas at Arlington or Vigor Active Fitness Center for exercise sessions. Upon arrival to the exercise site, the subjects study number, date, vibration frequency level and visit number was documented by the study staff. Subjects from the 1X/week group reported to an exercise site 1 time a week for the 8-week period, and the 3X/week group reported to an exercise site 3 times a week for the 8-week period to perform the exercise protocol while guided by a fitness instructor. All training sessions lasted approximately 30 minutes and all movements were timed. The exercise sessions included all body weight movements and were performed slowly (3 second eccentric, 3 second concentric). The exercises performed included: a double legged hip hinge (Romanian Deadlift motion), double legged quarter squat, a double legged supine hip bridge, a kneeling quadruped with the hands on the platform, a single legged stance, a standing double legged heel raise, and (Figure 3 a-f). Every subject wore shoes. The hip hinge, squat, heel raise and supine hip bridge were performed with feet in comfortable stance position toward the outside of the platform, the quadruped was performed with hands slightly greater than shoulder width towards the outside of the plate, and the single leg stance was done with their foot in the center of the platform. The participants stood with knees slightly flexed and/or maintained a neutral back position to prevent any possible injuries during the start and finish positions. Three sets of 1-minute duration were performed in each position. There was a 1-minute rest between all movements and all positions. Examples of workout positions are depicted in Figure 3. All subjects began at frequency level 2 (~4.6 Hz) on the Dr. Fuji® FJ-700 platform on their first visit and spent the first 5 sessions gradually increasing the frequency following a progressive overload. The first 5 sessions were as follows: session 1 – Level 2, session 2 – Level 4, session 3 – Level 6, session 4 – Level 8, session 5 – Level 10, the remaining sessions were all at level 10 (Table 1). Total exposure time was 30 minutes for each training session at a progressing frequency and at an oscillation amplitude range of 15-24 mm.

Statistical Analyses

Data were analyzed using SPSS version 25.0 for Windows 10 (Armonk, New York). The distributions were analyzed for normality and the existence of outliers using histogram plots, boxplots and Quantile-Quantile plots. A two factor ANOVA (2 x 3) was used to determine the effects of training type (1X/week and 3X/week) and time (pre, mid, post) on the following dependent variables: plank time (secs), kneeling chest launch distance (cm), Y-Balance Test™ composite left (%), Y balance composite right (%), leg extension 5RM (kg), and internal and external hip range of motion (degrees). Follow-up tests for group and time intervention differences were done using the Sidak post hoc test. Resting blood pressure was analyzed using a single factor ANOVA (time) to determine the effects of vibration training on blood pressure. We collapsed groups as previous measures found no group main effects or interactions. The level of significance was set at alpha = 0.05. Values are expressed as means ± SE (95% CI).

RESULTS

Dynamic Balance (Left Composite)

The Y-Balance Test™ was used to assess the participants' left leg lower dynamic balance.

No group*time differences were detected ($F_{(1,21)}$=0.000, p=0.984, η^2=0.000, ß=0.050). But there were main effects for time ($F_{(1,21)}$=37.05, p=0.000, η^2=0.638, ß=1.000). There was a significant difference between the pre assessment and both the mid and post assessments (p=0.000) and a statistical significance between mid and post (p=0.000) (Table 3).

Dynamic Balance (Right Composite)

The Y-Balance Test™ was used to assess the participants' right leg lower dynamic balance. No group*time differences were detected ($F_{(1,21)}$=0.193, p=0.665, η^2=0.009, ß=0.070). But there were main effects for time ($F_{(1,21)}$=28.30, p=0.000, η^2=0.574, ß=.999). There was a significant difference between the pre assessment and both the mid and post assessments (p=0.000) and a statistical significance between mid and post (p=0.000) (Table 3).

Power

The Kneeling Medicine Ball Chest Launch was used to assess the participants' bodily power. No group*time differences were detected ($F_{(1,20)}$=1.057, p=0.316, η^2=0.050, ß=0.165). But there were main effects for time ($F_{(1,20)}$=7.34, p=0.013, η^2=0.269, ß=0.732). There was a significant difference between the mid and post assessments (p=0.040) and no statistical significance between pre and mid or post (p=0.066) (p=0.681) (Table 4).

Core Muscle Strength and Endurance

The timed plank test was used in this study to assess the participants' ability to activate the core. No group*time differences were detected ($F_{(1,21)}$=0.003, p=0.957, η^2=0.000, ß=0.05). But there were main effects for time ($F_{(1,21)}$=21.95, p=0.00, η^2=0.511, ß=0.994). There was a significant difference between the pre assessment and both the mid and post assessments (p=0.000) but no statistical significance between mid and post (p=0.066) (Table 5).

Leg Extension Strength

The 5 Repetition Max Leg Extension was used to assess the participants' lower body strength. No group*time differences were detected ($F_{(1,21)}$=0.181, p=0.674, η^2=0.009, ß=0.069). But there were main effects for time ($F_{(1,21)}$=45.43, p=0.00, η^2=0.684, ß=1.00). There was a significant difference between the pre assessment and both the mid and post assessments (p=0.000) and a statistical significance between mid and post (p=0.001) (Table 6).

Right Hip Internal Range of Motion

The Prone Internal Range of Motion Test was used to assess the participants' right hip internal range of motion. No group*time differences were detected ($F_{(1,21)}$=0.020, p=0.889, η^2=0.001, ß=0.052). But there were main effects for time ($F_{(1,21)}$=116.97, p=0.000, η^2=0.001, ß=.052). There was a significant difference between the pre assessment and both the mid and post assessments (p=0.000) and a statistical significance between mid and post (p=0.000) (Table 7).

Right Hip External Range of Motion

The Prone External Range of Motion Test was used to assess the participants' right hip internal range of motion. No group*time differences were detected ($F_{(1,21)}$=0.576, p=0.456, η^2=0.027, ß=0.112). But there were main effects for time ($F_{(1,21)}$=52.25, p=0.000, η^2=0.713, ß=1.00). There was a significant difference between the pre assessment and both the mid and post assessments (p=0.000) and a statistical significance between mid and post (p=0.000) (Table 7).

Left Hip Internal Range of Motion

The Prone Internal Range of Motion Test was used to assess the participants' left hip internal range of motion. No group*time differences were detected ($F_{(1,21)}$=0.045, p=0.835, η^2=0.002, ß=0.055). But there were main effects for time ($F_{(1,21)}$=42.86, p=0.000, η^2=0.671, ß=1.000). There was a significant difference between the pre assessment and both the mid and post assessments (p=0.000) and a statistical significance between mid and post (p=0.011) (Table 7).

Left Hip External Range of Motion

The Prone External Range of Motion Test was used to assess the participants' left hip external range of motion. No group*time differences were detected ($F_{(1,21)}$=3.092, p=0.093, η^2=0.128, ß=0.389). But there were main effects for time ($F_{(1,21)}$=53.029, p=0.000, η^2=0.716, ß=1.00).

There was a significant difference between the pre assessment and both the mid and post assessments ($p=0.000$) but no statistical significance between mid and post ($p=0.092$) (Table 7).

SF-36 Questionnaire

Physical Functioning

The SF-36 Physical Function was used to assess the participants' perceived physical abilities. No group*time differences were detected ($F_{(1,21)}=2.863$, $p=0.105$, $\eta^2=0.120$, ß=0.365). But there were main effects for time ($F_{(1,21)}=15.886$, $p=0.001$, $\eta^2=0.431$, ß=0.967). There was a significant difference between pre and the mid ($p=0.028$) and post assessments ($p=0.002$) and no statistical significance between mid and post ($p=0.534$) (Table 8).

Physical Limitations

The SF-36 Physical Limitation was used to assess the participants' perceived physical limits. No group*time differences were detected ($F_{(1,21)}=0.904$, $p=0.353$, $\eta^2=0.041$, ß=0.148). But there were main effects for time ($F_{(1,21)}=12.934$, $p=0.002$, $\eta^2=0.381$, ß=.929). There was a significant difference between pre and the mid ($p=0.03$) and post assessments ($p=0.005$) and no statistical significance between mid and post ($p=0.918$) (Table 8).

Mental Limitations

The SF-36 Mental Limitations was used to assess the participants' perceived mental limits. No group*time differences were detected ($F_{(1,21)}=0.002$, $p=0.966$, $\eta^2=0.000$, ß=0.050). No time differences were detected ($F_{(1,21)}=0.956$, $p=0.339$, $\eta^2=0.044$, ß=0.154). There were no significant statistical differences ($p>0.70$) (Table 8).

Energy

The SF-36 Physical Limitation was used to assess the participants' perceived physical limits.

No group*time differences were detected ($F_{(1,21)}$=0.822, p=0.375, η^2=0.038, ß=0.139). But there were main effects for time ($F_{(1,21)}$=29.889, p=0.000, η^2=0.587, ß=.999). There was a significant difference between pre and the mid (p=0.00) and post assessments (p=0.000) and no statistical significance between mid and post (p=0.380) (Table 8).

Emotional Well-Being

The SF-36 Emotional was used to assess the participants' perceived emotional well-being. No group*time differences were detected ($F_{(1,21)}$=1.633, p=0.215, η^2=0.072, ß=0.230). No time differences were detected ($F_{(1,21)}$=2.185, p=0.154, η^2=0.094, ß=0.292). There were no significant statistical differences between pre (p=1.00) and mid or post (p=0.395). Significance was observed between mid and post (p=0.040) (Table 8).

Social Functioning

The SF-36 Social Functioning was used to assess the participants' social functioning. No group*time differences were detected ($F_{(1,21)}$=0.537, p=0.472, η^2=0.025, ß=0.108). No time differences were detected ($F_{(1,21)}$=3.052, p=0.095, η^2=0.127, ß=0.385). There were no significant statistical differences. (p>0.25) (Table 8).

Pain

The SF-36 pan score was used to assess the participants' perceived bodily pain. No group*time differences were detected ($F_{(1,21)}$=1.611, p=0.218, η^2=0.071, ß=0.228). But there were main effects for time ($F_{(1,21)}$=5.114, p=0.034, η^2=0.196, ß=0.578). There were no significant statistical differences. (p>0.10) (Table 8).

General Health

The SF-36 general health score was used to assess the participants' overall health.

No group*time differences were detected ($F_{(1,21)}$=0.445, p=0.512, η^2=0.021, ß=0.098). But there were main effects for time ($F_{(1,21)}$=9.349, p=0.006, η^2=0.308, ß=0.830). There was a significant difference between pre and the mid (p=0.006) and post assessments (p=0.018) and no statistical significance between mid and post (p=0.970) (Table 8).

Heath Change

The SF-36 health change score was used to assess the participants' improvement in health.
No group*time differences were detected ($F_{(1,21)}$=0.000, p=0.985, η^2=0.000, ß=0.050). But there were main effects for time ($F_{(1,21)}$=28.738, p=0.000, η^2=0.578, ß=0.999). There was a significant difference between pre and the mid (p=0.003) and post assessments (p=0.000) and no statistical significance between mid and post (p=0.731) (Table 8).

Resting Systolic and Diastolic Blood Pressure

The resting systolic and diastolic blood pressures were used to assess the participants' vascular changes in response to vibration training. We collapsed group and only analyzed time (pre and post). There was no main effect for time ($F_{(1,24)}$=2.90, p=0.10, ß=0.37) for systolic blood pressure. There was no main effect for time ($F_{(1,24)}$=1.97, p=0.17, ß=0.27) for diastolic blood pressure (Table 8).

DISCUSSION

The purpose of this study was to investigate the physical function and subjective health changes associated with whole body vibration (WBV) in non-exercising individuals and to identify if a dosage effect exists, and secondly to compare the effects of two different dosages of whole-body vibration on vascular function as measured with resting blood pressure. Objective and subjective characteristics including muscular power, core strength, dynamic balance, leg strength, hip flexibility, and quality of life were measured three times over the 8 weeks (pre, mid, post) whereas resting blood pressure was measured twice (pre and mid) for the two different WBV dosage groups that included 1 time per week and 3 times per week. The results support our hypothesis that whole-body vibration stimulates improvements in internal and external hip range of motion, core muscle endurance, dynamic balance, leg extension strength, and quality of life in a sedentary population over the age of 40 with only 4 weeks of training. The objective physical function variables even continued to improve over the remaining 4 weeks. However, trunk power only significantly improved after the full 8 weeks of training. Therefore, the hypothesis that WBV training with simple body weight exercises would result in significant physical function improvements after completion of training was supported; however, a dosage effect for the 3X/week whole-body vibration training did not exist compared to the 1X/week training as both groups improved there was not a group x time interaction.

Leg extension strength was assessed in this study using a 5-RM seated leg extension selectorized weight machine. Maximal strength testing for a variety of muscles and body areas, like the 5-RM, has been performed for many years and is a valid means of collecting strength data (Brzycki, 1993; Phillips et al., 2004). Subjects in this study had a 35% increase in the 1X/week group and 38% increase in the 3X/week group from the ~30-minute session on the WBV platform over the 8-week period. We theorize that the vibrational impact to the limb caused a rapid reflexive activation of the quadriceps muscles through proprioceptive pathways including the muscle spindle and the myotatic stretch reflex. The vibration platform oscillates at 9Hz and with a ~15mm amplitude this caused the muscles to contract as a reflexive and protective mechanism. These repeated contractions help facilitate the nervous system by increasing motor unit recruitment and decreasing motor unit inhibition (De Luca & Mambrito, 1987; Sale, 1987). Loss of strength with age can lead to the inability to briskly move, locomote and maintain balance due to an inhibited nervous system (Bergen et al., 2016; Campbell, Borrie, & Spears, 1989; Tinetti, Speechley, & Ginter, 1988). WBV appears to be a simple, effective way to produce improvements in strength while required little external effort.

Hip range of motion in all subjects showed improvements on right leg internal rotation (67%), and external rotation (46%). Many quality of life improvements can occur from a greater hip range of motion. It has been identified that imbalances in hip range of motion can lead to low back pain and other dysfunctions in the body (Reiman, Weisbach, & Glynn, 2009; Vad, Gebeh, Dines, Altchek, & Norris, 2003) and it has also been shown to be a contributing factor to falls (Gehlsen & Whaley, 1990). Therefore, the increase in hip range of motion post WBV training may actually contribute to both less back pain and fall prevention. In activities like golf and tennis where range of motion imbalances and tightness can result from repetitive motions, the result is usually low back pain (Vad et al., 2004; Vad et al., 2003). Repetitive motions performed by the body can also lead to shortened muscles, unequal agonist-antagonist relationships and nerve pain (Novak, 1997). Most humans perform small repetitive motions daily which create imbalance, such as pedaling only with the right leg while driving. The subject population in this study presented imbalances in hip range of motion and subjective physical limitations at the start as exhibited by the objective and subjective measurements. The SF-36 measures for pain were not significant before and after the 8-week vibration intervention; however, there was a trend toward improvement. Notably, after 4 and also at 8 weeks several other SF-36 variables including physical function, physical limitations, energy, general health and health change did improve significantly.

In addition to hip range of motion, dynamic balance as measured by the Y-Balance Test™ (Coughlan, 2012; Shaffer et al., 2013; Smith, Chimera, & Warren, 2015) also improved throughout the study. Subjects frequently possessed a left leg deficiency yet it improved to that of the right leg over the course of the study. The 1X/week group began the study with an average composite score on their right leg of 70% and after the 8-week intervention had an average of 86% showing an improvement of 23% on the right leg composite function. The same group began the study with an average composite score on their left leg of 66% and after the 8-week intervention had an average of 87% showing an improvement of 32% on the left leg composite function. The 3X/week group began the study with an average composite score on their right leg of 73% and after the 8-week intervention had an average of 93% showing an improvement of 27% on the right leg composite function. This group also began the study with an average composite score on their left leg of 71% and after the 8-week intervention had an average of 92% showing an improvement of 30% on the left leg composite function.

Improvements on the Y-Balance Test™ denote an improvement in the body's ability to dynamically balance and move through a greater range of motion while the center of mass is perturbed by a moving leg. The combined increases in hip range of motion and improved dynamic balance seem to indicate a favorable improvement in two areas that are linked to falling. Therefore, after the WBV training our subjects may experience a lower likelihood of falling. Several of the subjects in the study, due to being sedentary, were actually unable to stand on one leg let alone perform the dynamic movement of the Y-Balance Test™ during pre-test assessments. We were very satisfied with the significant improvements in dynamic balance and the link to fall prevention these data may represent. After the 8-week vibration intervention one subject who could not even balance on one leg at the pre-test, presented a 64% on both the left and right leg at the post test. Another subject with only a 39% left and 55% right composite ended up completing the study with an 88% left and 89% right composite scores. These dramatic improvements show positive outcomes for high amplitude whole-body vibration and its ability to improve dynamic balance and potentially prevent falls.

Core muscle endurance was assessed using the timed front plank test. This assessment identifies the fatigability of the low back, abdominal, transverse abdominis, rectus femoris and deltoids (Byrne et al., 2014). Subjects in the 1X a week group showed a 40 % improvement and the 3X a week group presented a 50% improvement in plank duration over the 8-week intervention. These results are interesting because we intentionally did not include any exercises in the protocol which mimic a plank or specially strengthen the abdominals. However, the hip bridge, kneeling quadruped, and squat all allow for adequate muscle activation to improve endurance of the muscles needed to perform the plank. The timed plank is a valid method of testing trunk function (Allen, Hannon, Burns, & Williams, 2014; Atsushi, 2016; Okada, Huxel, & Nesser, 2011) but sometimes subjects may not be able to perform this challenging movement. Therefore, in an effort to train the body so a plank can be performed simple body weight positions can be performed on a vibration platform. Possessing greater trunk function and core activation also can improve a person's ability to balance while also alleviating low back pain (Mayer, Smith, Keeley, & Mooney, 1985; Sibley, Beauchamp, Van Ooteghem, Straus, & Jaglal, 2015).

Overall, the dynamic balance of the subjects improved by between greater than 30% on each leg's composite score. In comparison, Vitale, La Torre, Banfi, & Bonato (2018) used an 8-week neuromuscular training program focused on core stability, plyometric, and body weight strengthening to assess dynamic balance and vertical jump and their results demonstrated only a 6% increase in the subjects' Y-Balance Test™ composite scores (Vitale, La Torre, Banfi, & Bonato, 2018). Our results from a high-amplitude oscillatory WBV training program were almost 3-fold and the subjects in this study only had to perform simple movements on the vibration plate. The Y-Balance Test™ improvements observed in this study could be due to the other physical improvements, as balance is a result of strength, flexibility and core control (Chiacchiero, Dresely, Silva, DeLosReyes, & Vorik, 2010; Cosio-Lima, Reynolds, Winter, Paolone, & Jones, 2003; Han, Anson, Waddington, Adams, & Liu, 2015). For example, hip range of motion improvements will greatly affect the body's ability to perform the posterior lateral reach of the Y-Balance Test™, which requires the subject to reach behind themselves and across. The stance leg's ability to internally rotate more, would allow for a greater score to be attained on the posterior lateral reach and increase the composite percentage score.

The ability to rapidly explosively extend the hip and produce large force in minimal time is known as bodily power. Improved power suggests that a body is able to react and move more quickly this could potentially prevent a more severe fall should a person trip, slip, or catch a limb on and object and begin to fall. The subjects all observed increases in muscular power by an average of 34.5 cm from the beginning of the intervention until the 8-week period. The rapid proprioceptive adjustments required in response to the vibratory stimulus provided by the vibration platform cause the muscles to twitch at a very high rate. This training adaptation allows for a greater rate of force development to occur at the hip and in the upper body, which translated to improvements in the complex movement of the kneeling chest launch.

This study added vascular measures to our dependent variables as one of the purposes of exercising is to reduce the chances of developing cardiovascular disease. We were able to collect 12 subjects' pre and post systolic and diastolic blood pressures. Analysis revealed no statistical differences but there was a 7.5% decrease in systolic blood pressure and a 4.5% decrease in diastolic blood pressure. To achieve a reduction in these measures without dietary changes or extensive exercise prescription in 8 weeks of vibration training is noteworthy and should be investigated further.

We also explored subjective changes in function by using a popular patient rated outcome questionnaire called the SF-36(McHorney, Ware, Lu, & Sherbourne, 1994). The SF-36 has eight independent scales that are used to assess both a physical and mental component related to quality of life. There is also a health change (transition) rating assessing patient improvement or increased disability. The scales used specifically for physical component are physical functioning, physical role limitations, and bodily pain, whereas the scales used for the mental component are social functioning, emotional well-being (role limitations related to emotions), and mental health. Scores from two other scales general health and vitality (energy) are considered as a part of both physical and mental components (McHorney et al., 1994). We found significant differences ($p<0.05$) in physical functioning, physical role limitations, vitality, general health, emotional well-being, and health change. Review of literature regarding minimal detectable change and meaningful important change(Quintana et al., 2005) revealed that our significant differences did exhibit meaningful clinical changes for all but emotional well-being scale; therefore, we believe there were more subjective changes related to their physical status versus their mental status with WBV training.

The remarkable strength and balance increases observed in this study deserve explanation. Strength is a multi-factorial comprising of the activation of the nervous system (conductivity, myelination, end plate diameter) and the number of myofibrils a muscle possesses (Haff GG, 2016). Balance tends to improve with greater flexibility, muscle strength, neuromuscular control, and the ability to isometrically hold posture are essential. Whole body vibration poses an interesting stimulus because it aggressively, yet mildly sends multiple abrupt waves into the limb placed on the platform. The vibration training is not viewed to be as aggressive as tradition weight lifting exercises because it is often not associated with excessive amounts of delayed onset muscle soreness or discomfort during a set of repetitions.

The numbers of Americans who are not physically active is staggering despite the benefits that many public health movements have presented. The human body is made to move, yet in today's society we do not regularly use the body for its intention and poor health has been the outcome. In 2016, approximately 30,000 life ending falls occurred and were likely due to reduced neural activation, muscle weakness, reactive power, and core muscle strength (Burns & Kakara, 2018). These data suggest that the use of WBV exercises as an interventional modality can produce significant quality of life and physical function improvements with only 30 minutes a week.

Limitations to this study include small group sample sizes which likely reduced power and prevented significance from occurring in between dosage levels and our subjects were a convenience sample of interested participants. It is also possible that a learning effect occurred in all of the measurements from the pre to mid to post test. Our subject population was also primarily female, educated, and employed; therefore, generalization may be limited. This research study was also performed on a specific vibration platform that provides high amplitude oscillatory vibrations.

PRACTICAL APPLICATIONS

As a society the lack of engagement in physical activity and fitness programs have many reasons but often stem from barriers including ease of access and ease of completion. The traditional means of exercise is highly effective for the people who have the physical wherewithal to use it; however, it is poorly addressing the masses in our country. Surveys show the traditional means of exercise is not applicable for most Americans due to travel distance, intimidation factors and lack of hope in success (Frederick & Shaw, 1995; Sallis et al., 1990; Tharrett, 2017). WBV platforms can easily be kept in the home and take up minimal space and do not require the performance of complex exercises. Therefore, high amplitude oscillatory whole-body vibration, seems to be a potential solution for many of the problems associated with a sedentary lifestyle and lack of participation in movement-based activities because we observed increases in many aspects of biopsychosocial function of our subjects with minimal effort from the person using the device.

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Rachel Hudler guided research subjects through exercise sessions at Vigor Active

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John Akins, PhD Candidate

John Akins assisted the authors of this study in collection of all vascular function data.

POTENTIAL CONFLICT OF INTEREST

Stephen Newhart is owner of Vigor Active and co-founder of Science Based Body that actively uses the products from this study. The results of the present study do not constitute endorsement of the products used by the authors.

Figure Legend

Figure 1. Dr. Fuji-700 vibration plate.

Figure 2. Oscillation patterns of vibration plates. (A) Vertical displacement and (B) Oscillation. Adapted from: Cardinale, M. and Wakeling J.

Figure 3. Body weight exercises by dosage groups. (A) hip hinge, (B) squat, (C) Supine bridge, (D) quadruped, (E) single leg stance and (F) double leg calf raise.

Tables Legend

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Table 6. Main effect for time for the 5-RM Leg Extension (kg) assessment. [Pre, Mid & Post: mean±SE (95%CI). Covariate Pre-test value appears in model.

Table 7 (a-d). Main effect for time for the Hip Internal and External Rotation (deg) assessment. [Pre, Mid & Post: mean±SE (95%CI). Covariate Pre-test value appears in model.

Table 8 (a-i). Main effect for time for the SF-36 Qualitative Questionnaire (score) assessment. [Pre, Mid & Post: mean±SE (95%CI). Covariate Pre-test value appears in model.

Table 9. Main effect for time for the Systolic and Diastolic Blood Pressure (mmHg) assessment. [Pre & Post: mean±SE (95%CI).

Table 1. Outline of study procedures: Pre and post assessments and training regimen

Pre-Assessments

- 5-RM Quadriceps strength test
- Y-Balance Test™ Test (cm)
- Timed Plank (sec)
- Kneeling medicine ball throw (in)
- Hip Internal and External rotation
- Vascular health
- SF-36 form

Exercises performed:

Squat; Hip Hinge; Single Leg Stance; Calf Raise; Quadruped; Bridge

Three sets of 1-minute duration were performed in each position
Maximum repetitions were completed using a 3 second lowering (muscle lengthening) phase, 3 second raising (muscle shortening) phase pace

Week 1	Week 2	Week 3	Week 4
Level 2	Level 4	Level 6	Level 8

Mid Assessments

- 5-RM Quadriceps strength test
- Y-Balance Test™ Test (cm)
- Timed Plank (sec)
- Kneeling medicine ball throw (in)
- Hip Internal and External rotation
- SF-36 form

Exercises performed:

Squat; Hip Hinge; Single Leg Stance; Calf Raise; Quadruped; Bridge

Three sets of 1-minute duration were performed in each position

Maximum repetitions were completed using a 3 second lowering (muscle lengthening) phase, 3 second raising (muscle shortening) phase pace

Week 5	Week 6	Week 7	Week 8
Level 10	Level 10	Level 10	Level 10

Post Assessments

- 5-RM Quadriceps strength test
- Y-Balance Test™ Test (cm)
- Timed Plank (sec)
- Kneeling medicine ball throw (in)
- Hip Internal and External rotation
- Vascular Health
- SF-36 form

Table 2. Demographic characteristics of the participants [mean±SD (range)].

Group	Participants	Gender	Age (yrs)	Height (cm)	Mass (kg)
Once	n=13	n=1 male n=12 females	58.8±9.9 (40-75)	167.8±6.9 (153.7-182.9)	83.2±20.3 (45-113.2)
Thrice	n=10	n=1 male n=9 females	55.5±7.8 42-65)	165.3±9.7 (152.4-179.1)	88.1±24.9 (59.5-144.1)

Table 3. Main effect for time for the Y-Balance Test™ (Composite %) assessment. [Pre, Mid & Post: mean±SE (95%CI).

Right Leg Composite

	Pre*	Mid	Post
1X/Week Group	70.1 ± 6.5 (56.5-83.7)	83.2 ± 3.3 (76.4-89.9)	86.4 ± 2.6 (80.9-91.8)
3X/Week Group	73.5 ± 7.5 (58.0-89.0)	86.9 ± 3.7 (79.2-94.7)	92.7 ± 2.9 (86.5-98.9)

Left Leg Composite

	Pre*	Mid	Post
1X/Week Group	65.9 ± 6.4 (52.6-79.1)	82.2 ± 3.3 (75.2-89.1)	86.5 ± 2.7 (80.9-92.2)
3X/Week Group	71.4 ± 7.3 (56.3-86.5)	88.2 ± 3.8 (80.3-96.1)	92.2 ± 3.1 (85.8-98.6)

*Pre duration for composite score for both Right and Left Y-Balance Test™ was less than both mid and post values (p=0.000)

Table 4. Main effect for time for the Kneeling Medicine Ball Throw (cm) assessment. [Pre, Mid & Post: mean±SE (95%CI).

	Pre*	**Mid**	**Post**
1X/Week Group	426.7 ± 26.4 (371.7-481.7)	448.2 ± 27.1 (391.6-504.8)	448.0 ± 27.3 (390.9-505.1)
3X/Week Group	418.5 ± 31.7 (352.4-484.6)	453.4 ± 32.6 (385.4-521.4)	465.9 ± 32.9 (397.3-534.5)

*Pre distance for Kneeling Medicine Ball Throw was less than post (p=0.040)
No significant difference between Mid and Pre (p=0.066)
No significant difference between Mid and Post (p=0.681)

Table 5. Main effect for time for the Timed Plank (s) assessment. [Pre, Mid & Post: mean±SE (95%CI).

	Pre*	Mid	Post
1X/Week Group	55.8 ± 11.1 (32.8-78.9)	77.5 ± 12.2 (52.1-103)	91.3 ± 18.8 (52.0-130.6)
3X/Week Group	34.5 ± 12.6 (8.3-60.8)	51.3 ± 13.9 (22.3-80.3)	69.2 ± 21.5 (24.4-114.0)

*Pre duration for timed plank was less than both mid and post (p=0.00)
No significant difference between Mid and Post (p=0.066)

Table 6. Main effect for time for the 5-RM Leg Extension (kg) assessment. [Pre, Mid & Post: mean±SE (95%CI).

	Pre*	**Mid**	**Post**
1X/Week Group	45.8 ± 5.5 (34.4-57.2)	56.0 ± 5.8 (43.9-68.1)	61.8 ± 6.7 (47.9-75.7)
3X/Week Group	47.3 ± 6.3 (34.3-60.3)	58.1 ± 6.6 (44.3-71.9)	65.4 ± 7.6 (49.6-81.2)

*Pre 5-RM Leg Extension was less than both mid and post values (p=0.00)
Significant difference between Mid and Post (p=0.001)

Table 7 (a-d). Main effect for time for the Hip Internal and External Rotation (deg) assessment. [Pre, Mid & Post: mean±SE (95%CI).

a. Right Hip Internal Rotation

	Pre*	Mid	Post
1X/Week Group	24.4 ± 2.7 (18.7-30.0)	35.5 ± 2.4 (30.4-40.5)	42.1 ± 2.2 (37.6-46.6)
3X/Week Group	30.6 ± 3.1 (24.1-37.0)	40.4 ± 2.8 (34.6-46.2)	47.8 ± 2.5 (42.7-52.9)

*Pre hip internal rotation degrees were less than both mid and post values (p=0.00)

b. Left Hip Internal Rotation

	Pre*	Mid	Post
1X/Week Group	24.7 ± 3.1 (18.2-31.2)	35.7 ± 2.4 (30.6-40.7)	45.8 ± 3.7 (38.2-53.4)
3X/Week Group	28.2 ± 3.6 (20.8-35.6)	40.8 ± 2.8 (35.0-46.6)	48.0 ± 4.2 (39.3-56.7)

*Pre hip internal rotation degrees were less than both mid and post values ($p \leq 0.011$)

c. Right Hip External Rotation

	Pre*	Mid	Post
1X/Week Group	48.7 ± 3.9 (40.6-56.7)	60.2 ± 3.4 (53.2-67.3)	66.8 ± 2.3 (62.0-71.7)
3X/Week Group	45.3 ± 4.4 (36.1-54.6)	58.3 ± 3.9 (50.3-66.3)	67.8 ± 2.7 (62.3-73.3)

*Pre hip external rotation degrees were less than both mid and post values(p=0.00)

d. Left Hip External Rotation

	Pre*	Mid	Post
1X/Week Group	49.0 ± 3.8 (41.1-56.9)	62.2 ± 2.6 (56.9-67.6)	64.6 ± 2.7 (58.0-70.3)
3X/Week Group	41.7 ± 4.3 (32.7-50.7)	59.7 ± 2.9 (53.6-65.8)	67.2 ± 3.9 (60.8-73.6)

*Pre hip external rotation degrees were less than both mid and post values (p=0.00)

Table 8 (a-i). Main effect for time for the SF-36 Qualitative Questionnaire (score) assessment. [Pre, Mid & Post: mean±SE (95%CI).

a. Physical Functioning

	Pre*	Mid	Post
1X/Week Group	73.8 ± 6.4 (60.4-87.1)	81.7 ± 6.3 (68.5-94.8)	84.6 ± 5.3 (73.5-95.7)
3X/Week Group	60.0 ± 6.7 (46.1-73.9)	80.5 ± 6.6 (66.7-94.2)	86.8 ± 6.6 (75.2-98.4)

*Pre Physical Function scores were less than both mid (p=0.028) and post values (p=0.002)

b. Physical Limitation

	Pre*	Mid	Post
1X/Week Group	62.5 ± 10.4 (40.8-84.2)	93.8 ± 6.9 (79.5-108.0)	93.8 ± 6.5 (80.3-107.2)
3X/Week Group	72.7 ± 10.9 (50.1-95.4)	86.4 ± 7.2 (71.5-101.3)	90.9 ± 6.7 (76.9-104.9)

*Pre Physical Limitation scores were less than both mid (p=0.031) and post values (p=0.005)

c. Mental Limitations

	Pre	Mid	Post
1X/Week Group	97.2 ± 3.4 (90.3-104.2)	100.0 ± 6.0 (87.5-112.5)	100.0 ± 2.0 (95.8-104.2)
3X/Week Group	93.9 ± 3.5 (86.7-101.2)	90.9 ± 6.3 (77.9-104.0)	97.0 ± 2.1 (92.6-101.3)

d. Energy

	Pre*	Mid	Post
1X/Week Group	55.8 ± 6.0 (43.4-68.3)	62.3 ± 5.2 (51.5-73.1)	69.2 ± 5.2 (58.4-80.0)
3X/Week Group	41.4 ± 6.2 (28.4-54.3)	61.4 ± 5.4 (50.0-72.7)	60.0 ± 5.4 (48.7-71.3)

*Pre Energy scores were less than both mid (p=0.001) and post values (p<0.000)

Table 8 (a-i). Main effect for time for the SF-36 Qualitative Questionnaire (score) assessment. [Pre, Mid & Post: mean±SE (95%CI).

e. Emotional Well Being (EWB)

	Pre	**Mid***	**Post**
1X/Week Group	84.0 ± 2.8 (78.2-89.8)	84.7 ± 3.1 (78.3-91.1)	89.0 ± 3.1 (82.6-95.4)
3X/Week Group	82.6 ± 2.9 (76.5-88.6)	82.2 ± 3.2 (75.5-88.8)	82.9 ± 3.2 (76.2-89.6)

*Mid EWB was significantly less than post (p=0.040)

f. Social Functioning

	Pre	**Mid**	**Post**
1X/Week Group	88.5 ± 6.0 (76.2-100.9)	95.6 ± 4.4 (86.5-104.7)	96.9 ± 4.2 (88.2-105.6)
3X/Week Group	84.1 ± 6.2 (71.2-97.0)	87.5 ± 4.6 (77.9-97.0)	85.5 ± 4.4 (78.4-96.6)

g. Pain

	Pre	**Mid**	**Post**
1X/Week Group	71.7 ± 5.2 (60.8-82.5)	83.5 ± 5.6 (71.9-95.1)	85.4 ± 4.2 (76.6-94.2)
3X/Week Group	74.5 ± 5.5 (63.2-85.9)	75.5 ± 5.8 (63.4-87.6)	78.4 ± 4.4 (69.2-87.6)

h. General Health

	Pre*	**Mid**	**Post**
1X/Week Group	66.7 ± 5.4 (55.5-77.8)	73.8 ± 4.7 (64.0-83.5)	75.4 ± 3.9 (67.3-85.5)
3X/Week Group	58.2 ± 5.6 (46.5-69.8)	75.5 ± 4.9 (65.3-85.6)	71.8 ± 4.0 (63.3-80.3)

*Pre General Health scores were less than both mid (p=0.006) and post values (p=0.018)

Table 8 (a-i). Main effect for time for the SF-36 Qualitative Questionnaire (score) assessment. [Pre, Mid & Post: mean±SE (95%CI).

i. Health Change

	Pre*	Mid	Post
1X/Week Group	56.3 ± 6.0 (43.8-68.7)	73.3 ± 5.6 (61.7-84.9)	83.3 ± 5.9 (70.9-95.7)
3X/Week Group	43.2 ± 6.2 (30.2-56.2)	70.5 ± 5.8 (58.3-82.6)	70.5 ± 6.2 (57.5-83.4)

*Pre Health Change scores were less than both mid (p=0.003) and post values (p=0.000)

Table 9. Main effect for time for the Systolic and Diastolic Blood Pressure (mmHg) assessment. [Pre & Post: mean±SE (95%CI).

	Pre	**Post**
Systolic BP	131.8 ± 1.3 (121.7-141.9)	121.9 ± 1.1 (113.3-130.5)
Diastolic BP	75.5± 0.5 (71.6-79.5)	72.1± 0.5 (68.1-76.1)

No statistical significance between pre and post measures

Figure 1: Dr. Fuji-700 vibration plate.

Figure 2. Oscillation patterns of vibration plates. (A) Vertical displacement and (B) Oscillation. Adapted from: Cardinale, M. and Wakeling J (2005).

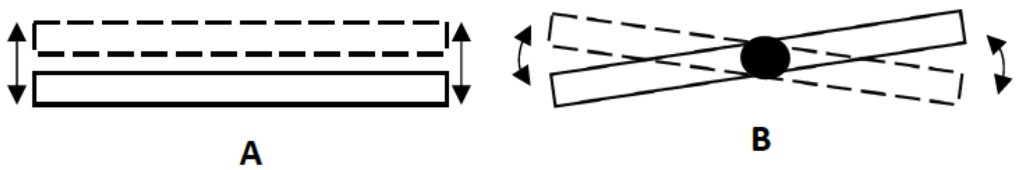
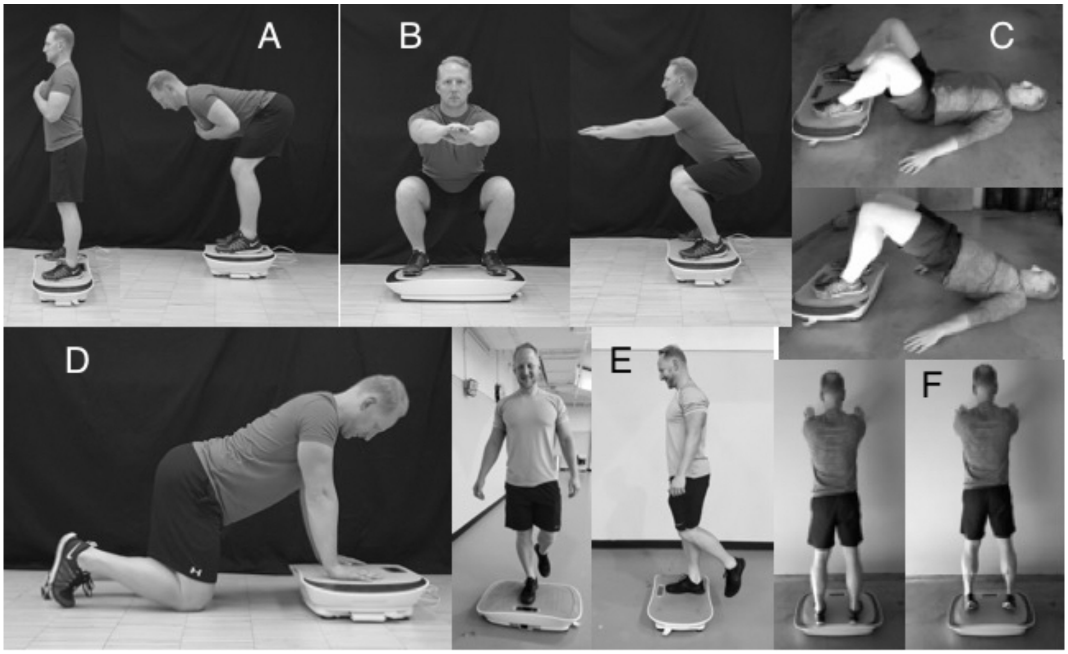


Figure 3 (A-F). Body weight exercises by dosage groups. (A) hip hinge, (B) squat, (C) Supine bridge, (D) quadruped, (E) single leg stance and (F) double leg calf raise.



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Chapter 5

Summary and Future Directions

In summary, there has been an extensive body of literature outlining the performance enhancements that whole-body vibration can bring to trained athletes (Fagnani, Giombini, Di Cesare, Pigozzi, & Di Salvo, 2006; Fort, Romero, Bagur, & Guerra, 2012; Wang et al., 2014). Our studies and previous research demonstrate that whole-body vibration can increase physical function and quality of life while using only body weight exercises with minimal movement (Bogaerts et al., 2007; Kawanabe et al., 2007; Martinez-Pardo, Romero-Arenas, & Alcaraz, 2013). As technologies in our country continue to emerge, the need for humans to move their bodies regularly is steadily decreasing. With sedentary behaviors on the rise any exercise stimulus is important to sustain biopsychosocial wellness. Surveys show the traditional means of exercise is not applicable for many Americans due to travel distance, intimidation factors and lack of hope in success (Frederick & Shaw, 1995; Sallis et al., 1990; Tharrett, 2017) Therefore, a less aggressive exercise stimuli, like whole-body vibration, appears to provide a great benefit to the body. A typical training program designed to produce significant gains in physical function and resting blood pressure traditionally involves exercises like submaximal or maximal aerobic training and weightlifting. These intensities and types of exercises cause excitation of the nervous system, improved cardiovascular efficiency, and a stimulus for muscle and bone tissues to be broken down and rebuilt. Vibration added to body weight exercises seems to act as a stimulus for the sedentary adult and a periodization program with progression and recovery could allow vibration training to be a very useful exercise intervention.

The review of literature presented in Chapter 2 addressed the effects of vibration training on a myriad of factors including pain, flexibility, bone density, balance, strength, and pulmonary rehabilitation. This review presents findings from 65 studies, all which incorporate the use of a whole-body vibration platform on different populations and all possessing the common goal of assessing the body's response to vibration. Every condition studied in the review showed improvements with vibration even pulmonary conditions like COPD. In particular, Chapter 2 discussed the use of whole-body vibration treatments in the alleviation of multiple types of chronic pain. Vibration exercise treatments have been shown in this review to create improvements in balance and strength. Chronic pain is linked in part to musculoskeletal issues such as muscle weakness, muscle tension/flexibility imbalance, and poor posture (Burnham, May, Nelson, Steadward, & Reid, 1993; Greigelmorris, Larson, Muellerklaus, & Oatis, 1992; Hurley, 1999; Lee et al., 1999; Nadler et al., 2002; O'Sullivan, Mitchell, Bulich, Waller, & Holte, 2006) Traditional treatments for chronic pain due to musculoskeletal issues have commonly included muscle activation through resistance training (Andersen et al., 2011; Berg, Berggren, & Tesch, 1994; Nash, van de Ven, van Elk, & Johnson, 2007) thereby demonstrating that chronic muscular pain can respond positively to activation exercises. It is thought that whole-body vibration is an effective and simple way to activate the muscles through proprioceptive pathways which in turn leads to better muscle activation, less muscle weaknesses and imbalance and potentially less feelings of chronic pain.

Study 1 (Chapter 3) investigated the use of whole-body vibration on a recreationally active population with an average age of 53 years old and a max age of 65 years old. This study added to the literature that a population who is active and performs an recreational activity several times a week can experience functional improvements in balance, muscle endurance, power and squat mechanics from the performance of 4 simple body weight exercises (squat, calf raises, single leg stance, and hip hinge) on a vibration platform. The recreationally active golfers did not partake it any specific fitness regimen or strength training program. The pre and posttests administered to the study population were chosen to reflect characteristic variables needed for golfing as well as daily living. Subjects were tested for power using a kneeling chest launch, dynamic balance using the Y-Balance Test™, core muscle endurance using the timed plank, and contralateral movement efficiency using a kinetics tool called Fusionetics®. The study population was separated into 3 groups, one which performed the 4 simple body weight movements while standing on the whole-body vibration platform (VIB), one which completed the same movements while standing on stable group (GRD), and a control group who was asked to maintain their current regimen and not add additional exercise in (CON). There were significant improvements for VIB group ($p< 0.01$) for many of the assessments. Percent improvements from pre to posttest for the kneeling chest launch were 10.3±7.3% (VIB), 2.7±4.2% (GRD), -9.5±16.3% (CON) and for Y-Balance Test™ composite scores for left leg (typically non-dominate) were 10.7±7.6%, 1.1±3.5%, 5.7±6.3%, respectively.

Study 2 (Chapter 4) addressed the effects of whole-body vibration training on physical functioning in a sedentary population over the age of 40. It was hypothesized after study 1 was completed that greater improvements in function would likely be observed if the population was sedentary vs. recreationally active. Our hypothesis was correct as the whole-body vibration training program produced significant improvements in internal and external hip range of motion, core muscle endurance, dynamic balance, leg extension strength, and quality of life with only 4 weeks of training. Trunk power increased after the 8-week timepoint. The objective physical function variables measured at 4 weeks even continued to improve over the remaining 4 weeks of training. For example, in Study 1 with the recreational golfers we reported a 10% increase in the Y-Balance Test™ composite score for the non-dominant leg, but for our sedentary population we achieved approximately a 30% improvements in the composite score for both legs. The timed plank also improved remarkably more in Study 2 than in Study 1 as we observed a 20% in the vibration group in Study 1, but we observed greater than 80% increase in time the sedentary subjects could hold a plank from the pre to the posttest. Our hypothesis that dosage of the WBV training would matter and that the 3X a week would be better than the 1X a week was not supported. Both groups improved and there was not an interaction between group and time over the 8-week training period. Therefore, even one day a week of an approximately 30-minute WBV training session using six simple body weight exercises resulted in notable increases in physical functioning scores that may reduce falls and other health complications in sedentary adults. One of the unique parts of Study 2, was the inclusion of patient rated outcomes as we chose to administer the SF-36 at the three time points. All subsections of the SF-36 that represent both physical and mental aspects of quality of life improved for subjects over time. Physical functioning, physical limitations, energy, general health, and health change subsections of the SF-36 demonstrated significant improvements at 4 and 8-week. Emotional well-being improved between the 4 week and the 8-week measure; however, pain, mental limitations, and social functioning did not experience significant increases.

Future Directions

Overall, whole body vibration appears to be a promising, complementary, easy-to-integrate tool for the management of certain types of chronic pain, physical functioning and mobility, bone strength, and balance. Benefits of WBV therapy, when combined with exercise, appear to be even more promising. Healthcare professionals are urged to take a serious investigation into the promising effects of WBV in regard to sedentary, rehabilitating, chronic pain, and older adult populations as the aforementioned effects of WBV show support of offering a low-impact, low-stress method to help recondition individuals. These factors, along with increased functional mobility and decreased pain, may be the main proponents to high adherence to WBV treatment protocols. The evidence WBV has demonstrated on individual health measures warrants further investigation into its effectiveness as a method for relieving pain and improving overall strength and physical function. Areas like bone density, athletic performance, depression, and obesity deserve to be investigated using only body weight exercises on a vibration platform.

Bone Density

The minimal essential strain is a term we use to explain the magnitude of force sent vertically through a bone to cause enough bent to prompt the body to produce osteoblast. Osteoblasts are essential in the reformation of bone as these cells secret the matrix required for bone formation. It has been discussed that plyometric jumping amplifies the body weight to possibly 10 times the force of gravity upon returning to the ground. This is enough force to produce enough minimal essential strain and bone deformation to stimulate osteocytes. We believe through preliminary data collection that the bone vibrated enough, as it does during a jump, to categorize the same minimal essential strain as a plyometric.

The height at which the body leaves the ground during a jump can vary depending on the amount of effort exerted at the initiation of the jump to propel the body upwards. Exercises such as a "two-foot ankle flip" (Haff GG, 2016) where it is not very aggressive can cause osteocytes to being their production. Plyometric exercises are all categorized in low, medium and high levels so they can be progressively prescribed to allow for the bones to properly adapt. We hypothesize that the minimal essential strain deformation occurring from time on the device is the equivalent of performing a plyometric jump in the low or medium intensity categories. The vibration device also has the ability to be progressive as the level can be modified to deliver between 4Hz on the low end and 9Hz on the high end. The wider the feet are placed on the platform the higher the amplitude of displacement is therefore wide feet would be more aggressive, and close together feet would be less aggressive.

The vibration platform delivers close to 600 cycles per minute; therefore, the proper prescription must be analyzed to discover what the proper dosage will be to stimulate bone from an osteoporotic zone where the bones are brittle. Safety is always the number one concern when attempting to treat the osteoporotic population with resistance training, due to the fragile nature of the bone. However, give the easy of usability of the WBV device we feel this method of reforming bone would be 95% more applicable than the fitness center for people who suffer from osteoporosis. We might find that a woman only has to step on the platform for 3x of 1 minute on a level 10 and that provides enough bone vibrations to stimulate bone growth, where a traditional activity might require aggressive plyometrics. We might find that the addition of 10-pound dumbbells in the hands of women standing on the WBV device provides the additional load needed to produce the proper number of osteocytes. This research appears promising because 8 million women worldwide suffer from and are treated for osteoporosis.

Gusi, Raimundo, & Leal (2006) compared low intensity (12.6 Hz) whole-body vibration to walking program to identify which exercise modality provides the best stimulus to lower the risk of fractures (Gusi, Raimundo, & Leal, 2006). The study identifies that an increased bone density is not the only factor which can prevent fractures, but also improved balance which whole-body vibration has shown to improve through multiple studies (In, Jung, Lee, & Cho, 2018; Kawanabe et al., 2007; Ko et al., 2017). The study by Gusi et al. (2006) provided results that whole-body vibration delivered at a low intensity provides a 4.3% increase in bone mineral density at the femoral neck, while simultaneously improving balance by 29% as measured by the flamingo balance test after an 8-week intervention 3 times a week (Gusi et al., 2006). This area of study warrants attention as osteoporosis is a chronic disease that is only corrected with intense weight bearing exercise that the majority of the population cannot perform.

Athletic Performance

In America, athletes are looked to as the gladiators of our time; the warriors who place their bodies on the line for entertainment. Sports are incredibly aggressive, high impact and dangerous; therefore, humans who have better control over their nervous system and its engagement are most likely to participate in high level sports (Haff GG, 2016). WBV should not be studied as the sole exercise modality of the athlete, but more so where the device can be implemented as a supplement to the athlete's regular training regimen. We feel there are possibilities for athlete performance research in the areas of implementing the high amplitude oscillatory WBV platform into the macrocycle for recovery or to enhance sets of strength training. It is theorized that by implementing WBV during rest times of a training year will not only maintain or increase the nervous system activity but will simultaneously allow the muscles to recover because of the mild nature of the stimulus. WBV appears to evoke full activation of the limb's motor unit pool when it is in contact with the platform. If an athlete spends significant time on the WBV platform during their offseason periods then they may engage the motor units which activate motor patterns which they rarely perform, while also maintaining the nervous system and providing recovery to the body simultaneously.

There is also a possibility for research in the area of activating muscles that might be suffering from reciprocal or autogenic inhibition due to muscle imbalance or previous injuries and surgeries. Neural recruitment dictates how fast an athlete can run, how high they can jump and how quickly they can change the direction of their body in response to a sport situation (Haff GG, 2016).

Performing traditional weight training while standing on a vibrating platform is an area of study that has been investigated. Wang et al. (2014) introduced strength training while on a vibration platform in a study performed in 2014 (Wang et al., 2014). Twenty-one track athletes were separated into three groups, one which performed 75% of 1RM strength training which standing on a vibration platform, one group which performed the same exercises and load on stable ground, and one group which only performed vibration training with body weight. The results stated that the group performing resistance training while on the vibration platform exhibited significant improvements for all the dependent variables after training, whereas the group only performing body weight exercises exhibited significantly reduced sprint speeds. The loaded vibration group demonstrated significantly superior eccentric strength compared with the other two groups after the 4 weeks, and the loaded vibration group also produced significantly superior sprint speeds compared with the body weight vibration group. The research team concluded that vibration combined with extra-load training for 4 weeks significantly increased the muscle strength and speed of the elite male track and field athletes.

Depression

Depression is a rising concern across all age groups and a more natural means of reversing the condition is needed. We have multiple studies showing improvements in depression with physical activity (Camacho, Roberts, Lazarus, Kaplan, & Cohen, 1991; Fox, 1999; Ross & Hayes, 1988; Weyerer, 1992), and the use of WBV devices may be able to provide this benefit. Our results from Study 2 (Chapter 4) demonstrated a significant improvement in emotional well-being after 8 weeks of WBV training and we also observed trends toward improvement in mental limitations and social functioning. An intervention of moderate exercise as little as 20 minutes of walking four days a week has shown to significantly increase serum serotonin levels in breast cancer patients compared to usual care patients (Payne, Held, Thorpe, & Shaw, 2008). Other studies have demonstrated walking, biking, and other aerobic activity significantly effecting serotonin levels (Valim et al., 2013; Wipfli, Landers, Nagoshi, & Ringenbach, 2011; Zimmer et al., 2016). The mechanism of action of increased serotonin from aerobic exercise may be partially due to the high frequency of repetitive locomotion patterns done in aerobic activity such as in walking, jogging, and biking (Meeusen, Piacentini, & De Meirleir, 2001). The decreased levels of serotonin in depressed individuals may make it difficult for them to begin engagement in a repetitive locomotion aerobic activity, such as walking creating a positive feedback loop of low production of serotonin, causes less movement, causing even lower serotonin.

Babyak et al. (2000) studied depression with three treatments, only exercise, medication, and a combination of medication and exercise (Babyak et al., 2000). The exercise only group was almost 100% cured from depression by the end of the 10-month monitoring study, where the medication and combination group had almost a 50% relapse rate. It would appear from this study that exercise is the best treatment for depression over medication. With transcranial magnetic stimulation (TMS) having a 75% success rate for alleviation of medications, we feel vibration can act as the curing exercise stimulus and extend the TMS treatments or work towards a 100% medication free success rate. The phase 2 of a TMS WBV study would require the patient to return home with a whole-body vibration platform for 90 days and engage in vibration exercise during that time frame.

The possible aim of a depression study would be to have depressed patient's stand for ten minutes in 3 different exercise positions on a WBV platform equaling 30 minutes total of exercise. The WBV platform may provide a less intimidating and less physically exhausting form of repetitive locomotion movement than aerobic exercise. This possibly could increase the likelihood of engagement in repetitive locomotion movement in depressed patients than aerobic exercise and help improve psychosocial measures associated with depression. The WBV platform may provide a stop-gap or bridge for depressed individuals to get the benefits of repetitive locomotion in a shorter duration of time at a lower effort intensity than aerobic exercise.

Obesity

Obesity has been well documented to be a condition not that of limited physical activity but of poor diet and excesses of saturated fat and processed sugars. The combination of fat and excessive fructose cause fat to store on the body at an alarming rate, and even a majority of the fructose will transform into fat and store. Diabetes, which plagues 100 million Americans and forces them to be supported by medications is a product of the excessive sugar hidden in the American diet. Diabetes however has been shown to be treatable with exercise due to the sugar consumption of the body during exercise (Zurlo et al., 2019). The obese population also has significant limitations to the amount and type of exercise they can perform due to limited range of motion, excessive weight and heat intolerance. This poses the need for a modality of exercise which is easy, does not require much effort and results in daily increased sugar consumption by the muscles. This is a population who might benefit from spending an hour or two a day on the WBV platform at lower frequency levels and warrants research efforts.

Chapter 4 (Study 2) in this paper investigated the use of WBV on sedentary individuals, many of who were also classified as obese according to their body mass indices (BMI). The subjects who were in the obese BMI category experienced the same improvements in leg strength, dynamic balance, hip range of motion and muscle endurance as did the non-obese cohort. These findings suggest that physical functioning in an obese population can be improved through WBV vibrations and can increase the physical functioning of the individual. As it was noted, one reason obese individuals experience a lowered quality of life is due to lack of movement abilities and motor function and we determined that the WBV training improved function both objectively and subjectively; therefore, this may enhance their desire to participate in other exercises interventions. The WBV platform at the highest frequency will burn about 100 calories an hour for a 200-pound fit male in a static standing position, as measured through a cos med metabolic cart during preliminary data collection. This caloric expenditure is nowhere near enough to cause the level of weight loss needed to eliminate an obese condition from someone who suffers from the condition, as it might require a deficit of 1000 calories per day to achieve a healthy body fat percentage in a reasonable amount of time. Where we may struggle improving the body composition of this population, we can at least intervene with an exercise modality which can improve function and motor capabilities.

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