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The Effects Of A 6-Week Controlled Whole-Body Vibration Training Program In Reducing Falls Risk Among Healthy Older Adults

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THE EFFECTS OF A 6-WEEK CONTROLLED WHOLE-BODY VIBRATION TRAINING

PROGRAM IN REDUCING FALLS RISK AMONG

HEALTHY OLDER ADULTS

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Doctoral Program in Interdisciplinary Health Sciences

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Dedication

This work is dedicated to my family, my partner, and close friends who always encouraged me and were proud of me when I was not. Thank you for always pushing me during the extremely difficult times and for letting me know I was more than capable of completing this degree. I am also indebted to the staff and professionals at the University Counseling and Psychological Services Center who guided me through extremely difficult times during the dissertation phase of my academic career. Thank you all. I am forever indebted to you.

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by

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Abstract

Falling is the second leading cause of accidental or injury-related death in the aging population worldwide and a leading cause of serious injury. Whole-body vibration (WBV) training has been implemented as a way to improve functional performance among the elderly and reduce the falls risk. The purposes of this study were: 1) examine to what extent a six-week course of WBV training reduced falls risk and improved fall outcomes in response to slips, and 2) examine whether the benefits of WBV training could be retained at least 2 months after the completion of the entire training session. A total of 17 independently living, healthy older adults were recruited for the 6-week WBV intervention and were randomly assigned to the WBV group or the control (CON) group. Participants in the WBV group performed three ten-minute sessions per week for six weeks with a vibration frequency of 20 Hz and 1.3-millimeter vibration amplitude. The CON group performed the same protocol, but instead of vibration, they encountered an audio recording of the vibrator motor noise. Fall risk evaluation and treadmill slip outcomes were assessed prior to the six-week training period, at the end of the six-week training period, and two-months after the completion of the protocol. There were no significant ($p<0.05$) improvements between groups in any of the measures for the fall risk evaluation or the treadmill slip outcomes. Both groups saw significant improvements throughout the study, showing signs of performance retention for the ten-minute walking test (10MWT) and the two-minute walking test (2MWT). Overall, the study findings revealed that six weeks of WBV was no more beneficial than the CON group.

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CHAPTER 1

Introduction

Falls among Older Adults

Falling is the second leading cause of accidental or injury-related death in the aging population worldwide (World Health Organization, WHO 2018) and a leading cause of serious injury. Annually, an estimated 420,000 individuals die as a direct result of falls or fall-related injuries and it has been reported that falls claim one life every 20 minutes (Centers for Disease Control and Prevention, 2018). Falls can occur at any age, but they are more common in adults 65 years of age or greater. The highest morbidity related to falls occurs in individuals over the age of 65; these individuals are more likely to succumb to fall-related injuries (WHO, 2018). Annually, more than one-third of all elderly (i.e. 60 years and older) persons in the United States fall (Berg, Alessio, Mills, & Tong, 1997; Campbell et al., 1990; Tinetti & Powell, 1993). The increased prevalence of falls creates a significant global healthcare issue, because among all annual worldwide falls, 37.3 million are serious enough to require medical attention (WHO, 2018). Furthermore, falling once increases the chances of falling again, which could potentially lead to further injury (Stevens et al., 2012). In 2006 there were a total of 36,689 accidental injury mortality cases among the elderly, and of these cases approximately 29% were attributed to falls (CDC, 2018). Moreover, unintentional mortality related to falls was the leading cause of emergency room visits among adults aged 65 years or older (Florence et al., 2018). In 2008, there were a reported 2.1 million reported cases of falls, and of these cases 560,000 individuals required hospitalization (Florence et al., 2018). Approximately 10% of all reported falls resulted in injuries that required medical attention (Alexander, Rivara, & Wolf, 1992; Tinetti, Speechley, & Ginter, 1988; Tromp et al., 2001).

Approximately one-third (28-35%) of community dwelling elderly fall per year and this number is projected to rise as the older population is expanding (National Council of Aging; NCOA, 2015). A recent study investigated which groups are most vulnerable to mortality due to unintentional falls and found that 22% of fall mortalities took place in only three states: Florida (n = 6,640; 8.4%), California (n = 6321; 8.0%), and Texas (n = 4576; 5.8%) (Alamgir, Muazzam, & Nasrullah, 2012). Furthermore, between 2003 and 2007 there were 79,386 reported fall fatalities and a significant increase in fall fatalities within those years. In other words, the fall mortality rate increased by 22.14 per 100,000 during this time. Falls accounted for 43.8% of the total unintentional injury mortalities during 2003 and 2007 (Alamgir et al., 2012; Hu & Baker, 2010). The National Health Interview Survey has also indicated that falls are the primary factor leading to restricted activity days among older adults (Rubenstein, 2006). Falls have accounted for approximately 18% of restricted days among the older adult population (Rubenstein, 2006). Older studies have also reported the negative impact of falls among older adults in the United States. A study conducted by (Kosorok, Omenn, Diehr, Koepsell, & Patrick, 1992) examined the number of restricted activity days among older adults in the United States and determined that of the 31 days of restrictive activity throughout the year, up to 20% of the restricted activity days were due to falls.

Global Economic Burden of Falling

The procedures and care associated with typical aging can be costly. The average annual direct and indirect cost of age-related medical procedures and hospital visits in 2013-2014 was approximately $40 billion; direct medical costs alone were $23.6 billion (Degrauw, Annest, Stevens, Xu, & Coronado, 2016). Expenses for hospital visits, inpatient stay, medication, surgical procedures, as well as outpatient care can create tremendous stress and family burden.

Moreover, when combined with fall-related injuries and the expenses associated with additional treatment due to falls, overall quality of life can be impacted.

Increased fall risk is mainly due to the loss of physical ability, other age-related changes, and complications stemming from the aging process (Alexander et al., 1992). This presents a critical issue, because older adults are more likely to be hospitalized because of falls. Moreover, older adults are more likely to experience more severe injuries (e.g. hip fractures) associated with the fall, which can further result in greater medical expenses (Covington, Maxwell, & Clancy, 1993).

Overall, the direct costs of fall-related injuries and complications can be considerable. Other items, such as personal care services or other non-medical services (i.e. transportation, pain and suffering, loss of productivity) can contribute to increased burden, which can ultimately affect the quality of life for the elderly and their caretakers (Carroll & Slattum, 2005).

Fall Prevention and Fall Intervention State-of-the-Art

In an attempt to mitigate the costs of medical procedures and rehabilitation associated with age-related changes and accidents (i.e. falls), several types of fall prevention programs for elderly individuals have been implemented. To date, the common approaches to fall prevention in older adults have attempted to mitigate specific risk factors associated with increased falls risk, such as muscle weakness (Woo, Hong, Lau, & Lynn, 2007), decreased mobility and range of motion (Pang, Eng, Dawson, McKay, & Harris, 2005), sensory loss (Pereira, Vogelaere, & Baptista, 2008), and deficits in balance (Pollock, Martin, & Newham, 2012). Some studies have examined the effects of surgery (Kannus, Sievänen, Palvanen, Järvinen, & Parkkari, 2005), medication or supplementation (Broe et al., 2007) to reduce falls, while others have used wearable technology to improve visual acuity (Fung, Richards, Malouin, McFadyen, &

Lamontagne, 2006). Still others have used traditional means of fall prevention, such as aerobic and resistance exercise.

While some wearable technology (e.g. foot orthotics or exosuits) has been shown to be productive with regards to stability at the lower extremity, there are still some limitations that prevent older individuals from benefiting (i.e. comfort and affordability). Similarly, while medication and surgery may have a positive impact on overall physical function, these methods of fall prevention can be costly and may also have undesired side-effects, which can further increase falls risk. For example, polypharmacy or simultaneous use of multiple drugs can result in physiological changes (i.e. hypotension) that can increase the risk for falls (Baranzini et al., 2009). Similarly, surgery may also result in secondary complications, such as infection or pain, which can alter gait and increase the risk for falls. Task-specific exercise programs have been shown to be more beneficial compared to other methods, such as supplementation (Smith, Forster, & Young, 2006), surgery (e.g. corrective vision surgery) (Kannus et al., 2005), and use of wearable technology (Awad et al., 2017). Research suggests that task-specific programs have the ability to drive neural plasticity and therefore restore function (Shepherd, 2001). However, much like medication or wearable technology, fall prevention programs centered round exercise regimens are not without their limitations. For example, some exercise programs might require specialized equipment that can be cumbersome, confusing to use, or difficult to access. One study found that older adults were less likely to participate in a personal exercise regimen because of high costs associated with memberships (62%) or a lack of knowledge on how to exercise properly (42%), and even a lack of transportation to the facility (57%) (Rimmer, 2008). Furthermore, depending on physical ability, older adults may not be able or willing to use the specific equipment needed for the fall prevention program to be effective (Shaughnessy, Resnick, & Macko, 2006). This point is important to address because if compliance in rehabilitation programs is poor, then improvements in performance could be delayed or restricted (Damush, Plue, Bakas, Schmid, & Williams, 2007).

Recently, a method known as whole-body vibration (WBV) training has been implemented as a way to improve functional performance among the elderly. Compared to traditional exercise programs, WBV is less strenuous, has the ability to be portable and cost-effective, and requires little to no previous experience with physical exercise. Several studies have shown that WBV has the ability to significantly improve risk factors associated with falling in elderly individuals, therefore possibly reducing the risk of falls and injury (Choi, Kim, Cho, & Lee, 2016; Lee, Cho, & Lee, 2013; Merkert, Butz, Nieczaj, Steinhagen-Thiessen, & Eckardt, 2011; Tankisheva, Bogaerts, Boonen, Feys, & Verschueren, 2014; Van Nes et al., 2006). Although several studies have examined the effects of WBV in older adults, none have systematically or comprehensively assessed the effects of WBV in reducing fall incidences. Therefore, it remains unknown whether WBV could prevent falls in real life. Furthermore, current studies have failed to assess whether or not the effects of training can be retained over time. Therefore, it is not well-understood if whole-body vibration training can: 1) be an effective method in reducing the rate of actual falls and 2) nurture long-term health benefits.

Purpose of the Study

Although previous studies have examined some of the effects of WBV in elderly patients, existing studies have only examined a limited number of fall risk factors, such as balance or strength deficits. Furthermore, no study has yet determined if WBV can reduce the rate slip-related falls. Finally, the majority of existing studies only investigated the short-term effects of WBV (i.e. immediately after training or days after training). The retention (if any) of the WBV training effect on lowering risk of falls among frail or elderly populations still remains relatively unknown. Given these constraints, the comprehensive therapeutic effects of the WBV on reducing risk of falls are still unknown. Consequently, it is highly desirable to conduct a systematic study to identify the extent to which the WBV could reduce the risk of falls among this population. Therefore, the purposes of this study were: **1)** examine to what extent an 6-week course of the WBV training reduced falls risk (determined by a comprehensive battery of risk factors) and improved fall outcomes in response to slips, and **2)** examine whether the benefits of WBV training could be retained at least 2 months after the completion of the entire training session.

Background and Significance of the Study

Most falls are linked with postural instability and gait disturbance, which are frequent symptoms found in older adults (Meuleners, Fraser, Bulsara, Chow, & Ng, 2016). Previous studies have demonstrated that among people who experience frequent falling, older adults (60 and over) fall most frequently (Stolze et al., 2004). Age-related impairments, such as poor balance and impaired gait presumably contribute to the large number of falls. It has been reported that 73% of community dwelling older adults experience falls each year (Teasell, McRae, Foley, & Bhardwaj, 2002). Hip fractures, a common result of falling, are also prevalent in the elderly who suffer high levels of osteoporosis. It has been shown that elderly patients have a four-fold increased risk of hip fractures associated with a high incidence of falls and loss of bone mass in the lower extremities (Dennis, Lo, McDowall, & West, 2002; Ramnemark, Nyberg, Borssén, Olsson, & Gustafson, 1998). Older adults have varying degrees of muscle weakness, mobility deficits, postural instability, and other motor impairments, which render them highly susceptible to falls (Czernuszenko & Czlonkowska, 2009; Lamb, Ferrucci, Volapto, Fried, & Guralnik, 2003).

Recently, WBV exercise has been developed as a new modality to train older adults (Lam, Lau, Chung, & Pang, 2012; Yang, King, Dillon, & Su, 2015a) and people with multiple sclerosis (Yang, Estrada, & Sanchez, 2016; Yang et al., 2018) to reduce their falls risk in the field of physical therapy. The transmission of vibrations and oscillations to the human body can lead to physiological changes on numerous levels (Madou & Cronin, 2008). It has been suggested that WBV training increases bone density, neuromuscular performance, improves body balance and proprioceptive function (Fontana, Richardson, & Stanton, 2005), and improves gait parameters and coordination among older adults (Sitj-Rabert et al., 2011). These effects of

WBV exercise have been recognized immediately after exercise (Cardinale & Bosco, 2003), within six weeks (Bautmans, Van Hees, Lemper, & Mets, 2005a), four months (Torvinen et al., 2002), nine month (Stolzenberg, Belavý, Rawer, & Felsenberg, 2013), one year (Bogaerts, Verschueren, Delecluse, Claessens, & Boonen, 2007), and 18 months (Stengel, Kemmle, & Engelke, 2011). It has also been demonstrated that vibration is an effective method for improving postural control in elderly subjects (Bogaerts et al., 2007). Improvements have been reported associated with both posture control (van Nes, Geurts, Hendricks, & Duysens, 2004) and lower extremity torque production (Tihanyi, Horvath, Fazekas, Hortobagyi, & Tihanyi, 2007).

Given the projections over the next 40 years and the rapid expansion of the aging population ($\geq$ 60 years of age), establishing a cost-effective and low-impact alternative to traditional training methods to improve physical performance and reduce the risk of falls is vital.

Conceptual Framework

As discussed previously, older adults are at high risk for falling, with up to 65% of individuals falling at least once during hospitalization (Davenport, Dennis, Wellwood, & Warlow, 1996; Nyberg & Gustafson, 1995; Teasell, McRae, Foley, & Bhardwaj, 2002). Given the vulnerable state of these individuals, falls can have severe outcomes both physically and mentally (Weerdesteyn, de Niet, van Duijnhoven, & Geurts, 2008). There is considerable evidence showing that traditional forms of exercise, such as resistance training, can alleviate the neuromuscular and physical constraints and reduce the risk of falls and life altering injuries. However, in order to be effective and to increase compliance, existing methods of rehabilitation need to be made more accessible to individuals who are most likely to benefit from its use.

Traditional forms of exercise suffer from cost, participation, physiologic and operational barriers (Damush et al., 2007). Although these methods have the potential to reduce fall risk, these barriers can reduce compliance in rehabilitation and can affect patient self-management (Wagner, Austin, & Korff, 1996). WBV has emerged as an effective method to improve performance and reduce the risk of fall in older adults. The user-friendly interface associated with WBV appliances has the potential to increase compliance, which can lead to an improvement in fall-related performance variables (i.e. fall risk factors), thus reducing the rate of real-life fall and improving independence and quality of life.

A simple conceptual model (Fig. 1) was developed to guide the proposed research and was based off existing research pertaining to the use of WBV and performance improvements in older adults. Older adults commonly experience age-related deficits associated with an increased risk of falls (Mackintosh, Goldie, & Hill, 2005). These deficits include decreased, strength, balance and sensory deficits, decreased flexibility, and diminished mobility (Mackintosh, Goldie,

& Hill, 2005). Traditional forms of exercise can be effective in reducing the real-life falls in elderly individuals, however, there are limitations with this form of rehabilitation, which can deter regular use. WBV can serve as a feasible alternative and can lead to improved performance and decreased risk of falls. WBV conducts mechanical vibrations to the body, which elicit responses in mechanoreceptors (e.g. Golgi tendon organ and muscle spindles) responsible for detecting stretch and tension (Rittweger, Beller, & Felsenberg, 2000; Zaidell, Mileva, Sumners, & Bowtell, 2013). Through a mechanism known as the tonic stretch vibration reflex (TVR), older adults undergoing age-related performance deficits may experience increased muscle activation and can potentially experience physiological and neurological changes (Zaidell et al., 2013). These changes can lead to improvements in fall risk factors (e.g. balance, strength, mobility, sensation, range of motion), and therefore, can result in decreased fear of falling, improved self-esteem, and ultimately fewer falls. These psychological, physical, functional, and behavioral improvements can lead to increased independence, increased community involvement (Moyes, 2012), and improvements in ADL's (Delbaere, Close, Brodaty, Sachdev, & Lord, 2010).

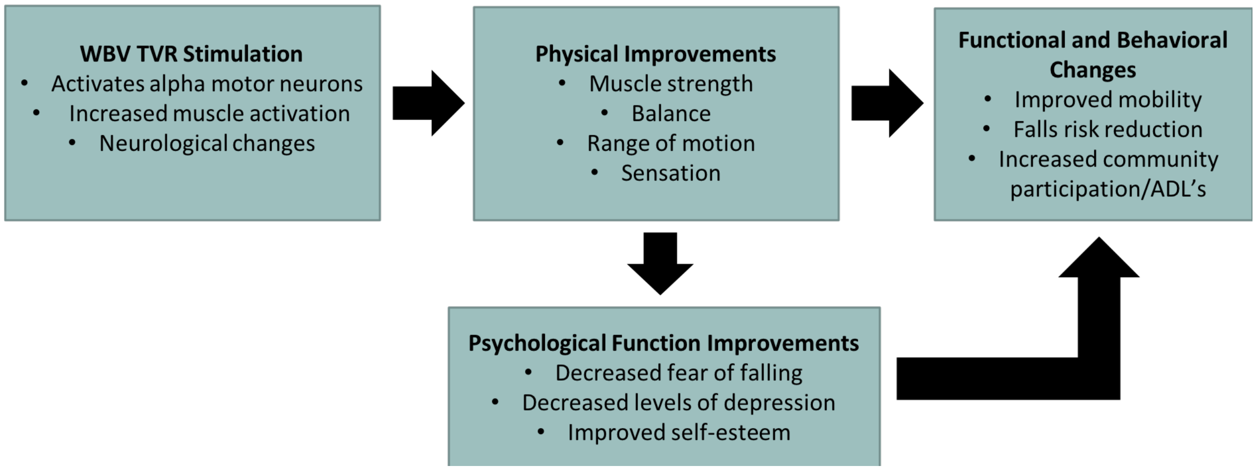

Fig. 1. Conceptual Framework

Statement of the Problem

No study has systematically investigated the effect of WBV training on improving fall risk factors among older adults. Additionally, existing studies have not assessed if the therapeutic effects of WBV can be effective in reducing the rate of slip-related falls. Finally, the majority of studies have only examined the acute effects of WBV and therefore, it is uncertain if the therapeutic effects of WBV can be retained over long durations. It is, therefore, highly desirable to conduct a systematic study to identify the extent to which WBV training reduces the risk of falls and real-life falls among older adults. This study was conducted to fill this knowledge gap.

Research Questions and Hypotheses

This study on the effects of WBV training in reducing the risk of falls among healthy older adults investigated the following:

1. If and to what extent a 6-week course of the WBV training improved fall rates in response to an unexpected gait slip and improved the risk factors of falls among healthy older adults.
2. If the therapeutic effects of WBV could be retained at least 2 months after the completion of the entire training session.

Aligning with our aims, we tested the following hypotheses:

1. WBV training would improve fall rates during the unexpected treadmill-slip, stemming from the training-induced improvements in the fall risk factors.

2. WBV training effects would last at least 2 months among older adults.

Definitions

For the purposes of this proposed study, the following terms were defined:

a. Activities of Daily Living (ADL). Activities performed throughout a 24-hour period, which require basic skill and focus. These activities typically pertain to tasks of self-care, such as bathing or showering (Pedretti, Pendleton, & Schultz-Krohn, 2013).

b. Fall Risk Factor. A measure or variable that increases a person's risk for experiencing a fall.

c. Fear of Falling. How worried an individual is about falling while carrying out several indoor or outdoor activities of daily living (measured with the Fall Efficacy Scale).

d. Frequency of Falls. The number of times the participant's center of mass shifts and inadvertently descends to the floor with or without injury (Lamb, Jorstad-Stein, Hauer, & Becker, 2005).

e. Older adults. Defined as an individual 60 years of age or older (National Institutes of Health (NIH), 2013). The current study will expand this age group to individuals 60 years of age or older.

f. Placebo Training. A procedure that has no therapeutic effect. In this case, placebo training will involve standing on the vibration platform without any vibration for the same time period as the experimental group.

g. Self-selected walking speed- walking velocity (meters per second) which participant selects and can walk comfortably at for two-minutes on standard treadmill. This is selected prior to performing walking trials on the perturbation treadmill.

h. Slip Perturbation. Abrupt change of direction to walking surface, resulting in an unexpected and sudden forward shift in the subjects' base of support relative to the center of mass, resulting in a slip.

i. Vibration Amplitude. The deflection of the training platform upwards or downwards in millimeters (mm).

j. Vibration Frequency. The intensity or speed of the vibration measured in hertz (Hz).

k. Whole-body Vibration. Training modality, which transmits oscillations and vibrations to the human body via vibrating platform (Lam et al., 2012; Madou & Cronin, 2008).

Limitations

The study may have the following possible limitations:

1. This study only examined healthy older individuals which might only provide insight to a narrow subset of individuals with similar functional profiles. This may have hindered our ability to generalize the study findings to the broader aging population.
2. Although study findings may have provided evidence of retention, it is not certain if the benefits from the six-week WBV intervention (if any) can sustain beyond the 2-month interest window.
3. Because participation in the study was voluntary, adherence to the vibration training protocol may have varied due to loss of interest or other limitations in certain individuals. However, we did anticipate a moderately better adherence rate with WBV training in comparison with conventional exercise-based programs.
4. Participants' performance in the outcome measures of interest may have varied according to personal conditions, such as disease, fatigue, attitude or mood change, self-efficacy, or feelings towards research setting and protocols. The randomization procedure typically addresses this concern. However, to be more conservative, these potential confounders were included as covariates and were controlled for in statistical analyses. Moreover, a matched-pair study design was used to reduce the effects of heterogeneity and decrease the effects of performance variability among participants.
5. Given the longitudinal nature of the study, attrition occurred, which reduced the statistical power of the study and made it difficult to accurately assess the effects of vibration training and retention.

Although these limitations exist, the findings from this study can provide evidence of the possible effects of vibration training in reducing falls in response to simulation treadmill slips, which may be used to develop more effective interventions that can prevent falls in real-life scenarios.

Summary

This chapter provides an overview and introduction to the proposed research, which includes the purpose, background and significance, conceptual framework, statement of the problem, research questions, hypotheses, definitions, assumptions, and limitations. The purposes of this study were to examine if and to what extent a six-week course of the whole-body vibration training reduces the fall risk and the fall rate in response to a simulated slip during walking among healthy older individuals. Finally, the study set out to examine whether the WBV training effect could be retained at least 2 months after the completion of the entire training session healthy older individuals. The findings from this study could be utilized to develop more affordable, accessible, and effective training regimens to reduce falls in individuals not only affected age-related performance deficits, but other movement disorders, such as multiple sclerosis, stroke, Parkinson’s disease, and spinal cord injury.

CHAPTER 2

Literature Review

Risk Factors for Falls

Risk factors are aspects of an individual's lifestyle or environment that may increase the probability of experiencing a negative event, such as a fall (Masud & Morris, 2001). In some cases, intrinsic issues, such as disease or pathology might be contributing factors, which may result in the undesired event. Age-related physiologic and motor changes (i.e. functional impairment or disease) present a significant challenge to the health care industry. Compared to healthy young adults, elderly individuals tend to be more associated with frequent use of medication, cognitive decline, functional decline, and disability or disease. Despite numerous studies examining the risk factors for falls and falls prevention in the elderly, falls among older adults and those with disease still impose a great societal burden. As a result, the prevention and management of falls among the elderly and populations with limited mobility have become a health initiative.

As alluded to previously, age-related and disease-related changes in physical function can increase the risk for falls. Typically, the risk for falls varies depending on biological and functional capabilities within different age-groups, but falls are less likely to be driven by simple age-dependent variability (Lord, Sherrington, Menz, & Close, 2007). The majority of falls are caused by a combination of factors, as stated previously (Hornbrook & Stevens, 1994; Lord et al., 2007) and studies have recognized numerous risk factors that can be linked to falls (Oakley et al., 1996). This review will briefly discuss some risk factors for falling that might present in the elderly, such as medication, physical environment, cognitive and emotional state, but will primarily highlight impaired physical function and disease given that WBV can directly modify these fall risk factors. Furthermore, this review will dissect the global burdens associated with falls and will discuss the state-of-the-art with respect to controlled whole-body vibration, human performance, and fall prevention.

Medication

Given the advances in medicine, people are living longer. As a result, people experience more age-related changes, which includes disease. The demand for care among this population requires different health care needs, and this means medical treatment for conditions such as, hypertension, epilepsy, insomnia, and even dementia. Studies have shown that consumption of certain prescription medications can increase the risk for falls among the elderly. Specifically, findings have revealed that the classes of medications that are strongly associated with falls include: central nervous system (CNS) medications, cardiovascular medications, and polypharmacy. CNS medications are drugs that affect the central nervous system (i.e. brain or spinal cord) and produce a response to alleviate a given medical ailment. Cardiovascular (CV) medications are prescription drugs for diseases relating to the function of the heart and blood vessels. Polypharmacy refers to the simultaneous use of multiple drugs to treat one or a combination of conditions.

cns, cv, and polypharmacy medication use. The literature has reported that the use of prescribed medications significantly increases the risk for falls (Ensrud et al., 2002; Faulkner et al., 2009; Kallin, Gustafson, Sandman, & Karlsson, 2004). This is likely due to their undesired side-effects, such as hypotension and dizziness, which may leave individuals at higher risk for falls (Li, Hamdy, Sandborn, Chi, & Dyer, 1996; Rubenstein, Josephson, & Robbins, 1994). One study revealed that CNS medications were prescribed more frequently to patients who reported falls compared to patients in a control group (97% vs. 55%, respectively; $p < 0.001$) (Walker, Alrawi, Mitchell, Regal, & Khanderia, 2005). A study by Thapa (1995) revealed that compared to non-users, the rate recurrent falls was significantly higher for CNS drugs users ($p < 0.05$) (Thapa, Gideon, Fought, & Ray, 1995). Several other studies have concluded that CNS class medications, along with CV medications, and polypharmacy can have a significant impact on falls risk (Cumming et al., 1991; Marcum et al., 2016) and can therefore be classified as fall risk increasing drugs. Specifically, it has been reported that individuals taking these medications have an increase in the risk of falls by 2-fold (Cumming et al., 1991; Landi, Onder, & Cesari, 2005; Lavsa, Fabian, Saul, Corman, & Coley, 2010). Several studies have shown that polypharmacy can have a significant impact on overall well-being, and can significantly increase the risk of injurious falls, as well as recurrent falls (Hajjar, Maher, & Hanlon, 2014; Richardson, Bennett, & Kenny, 2015; Ziere et al., 2006). French et al., (2006) identified that patients who were classified as fallers were prescribed significantly more medications than the matched control group (French et al., 2006).

Environment

Falls can occur for a multitude of reasons and one element aside from medication that contributes significantly to the occurrence of falls is the physical environment. Findings from several studies have shown that how a person interacts with the environment and the hazards within the environment can dictate whether or not a fall will occur. Given the complex etiology of falls, every aspect of a person's environment must be assessed for environmental hazards, which may increase the risk for falls. This section will briefly discuss fall risk hazards associated with community (indoor and outdoor) and hospitals or chronic care facilities.

community. Falls often result from environmental hazards while performing activities of daily living (ADL). For example, clutter around the home, abrasive walking surfaces (e.g.

carpets or rugs, or exposure to stairs or steps) can lead to unexpected trips, stumbles, or falls, in which older or frail individuals may not be able to recover from quickly (Bergland, Jarnlo, & Laake, 2003; Faulkner et al., 2009; Lord, Ward, Williams, & Ansety, 1993; Prudham & Evans, 1981). Studies have reported that up to 30% of community living individuals over the age of 65 fall every year (A. Campbell, Reinken, Allan, & Martinez, 1981; Prudham & Evans, 1981). Several authors have stated that environmental hazards are more likely to result in falls in individuals who report better health compared to those who report issues with health (Bergland et al., 2003; Lord et al., 2007; PA et al., 2000; Weinberg & Strain, 1995). This suggests that healthier individuals interact more with their environment and are more likely to perform more hazardous tasks that may put them at greater risk for falls. Active elderly persons might be more able and willing to navigate throughout the home and might be more likely to perform more demanding tasks, such as stair navigation.

community in-home risks. In most cases, falls occur on level surfaces within the home (e.g. bedroom, kitchen, or living room). A study performed my Northridge et al., (1995) revealed that 46.8% of all reported falls were attributed to environmental hazards. It was found that participants who reported having loose grab bars or no grab bars around the home experienced significantly ($p < 0.05$) increased rates of falls than participants who did not report these hazards (Northridge, Nevitt, Kelsey, & Link, 1995). Additionally, clutter and the presence of rugs and carpet throughout the home were associated to increase frequency of falls. The findings from this study highlight the fact that falls tend to occur where people spend the most time (Northridge et al., 1995). Therefore, more emphasis should be placed on prevention strategies and home hazard modification to effectively reduce the rate of falls in frail individuals and older adults (Nevitt, Cummings, Kidd, Black, 1989).

Other studies have shown similar findings in regard to the importance of home hazard modifications and the effectiveness of decreasing falls risk. A study by Lord et al., (1993) revealed that the most common causes of falls were trips, slips, and loss of balance. The majority of falls were a result of trips (45.1%), followed by lost balance (18.3%) and slips (16.3). These findings are consistent with several other studies, which state that falls normally results from a combination of multiple and varying risk factors (Lipsitz et al., 1991; Lord et al., 2007; O'Loughlin, Robitaille, Bolvin, & Suissa, 1993). A study by Bergland et al., (1998) reported similar findings and found that up to 41% of falls occurred indoors. Data presented by the National Council of Safety (2018) indicated that the leading cause of accidental death associated with falls occurred on stairs (National Safety Council, 2018). Approximately 10% of fall-related deaths occur as a result of stair-related falls and up to 75% falls occur during decent (National Safety Council, 2018). The characteristics of stairs and other similar obstacles (i.e. ramps) present specific challenges. Certain features, such as railing, compliant surfaces and adequate lighting are imperative to reduce the risk for falls when navigating stairs and other areas of the home, such as hallways or bedrooms. It has been reported that participants who have undergone home modifications experience fewer falls that participants who did not receive modifications (Nikolaus & Bach, 2003).

community outdoor risks. Outdoor environments present a significant challenge to older adults and individuals with mobility impairments. The outdoors in particular introduce excessive environmental demands that these populations may have difficulty adjusting to physically (Connell & Wolf, 1997; Li et al., 2006). Regardless of where the falls occur, environmental factors, such as misalignments in the walking surface, steps, uneven ground, or low-friction surfaces all increase falls risk (Lord et al., 2007). Findings from several studies have reported that between 39.5% and 61.4% of falls occur outdoors (Downton & Andrews, 1991; Lord et al., 1993; Weinberg & Strain, 1995). Another study by Li et al., (2006) reported that outdoor falls accounted for 72% of the most recent falls in middle aged-men, 57% of the most recent falls in older men, and 51% of the most recent falls in middle-aged women (Li et al., 2006). For older adults (men and women) over 80 years of age, outdoor falls accounted for 48% of the most recent falls. These findings are in line with those reported by Bergland & colleagues (2003) who found that outdoor falls were significantly more frequent outdoors than indoors (57.5 vs. 42.5%). The study found that more than half (57.5%) of the falls reported in the study occurred in an outdoor setting (Bergland et al., 2003).

Weinberg et al., (1995) reported that the main causes of falls were environmental features, such as sidewalks or uneven terrain; approximately 22.2% of falls were attributed to sidewalks. These findings are consistent throughout the literature. Li et al., (2006) reported that the majority of falls outdoors occurred during walking when participants were exposed to sidewalks or curbs, and uneven surfaces. Given that active lifestyles are generally promoted for older adults and other populations, studies suggest that improvements to these environments are vital to decrease the risk for falls (Li et al., 2006).

hospitals and chronic care facilities. Although not the main focus of this review, it is important to acknowledge that falls also frequently occur in hospitals or chronic care facilities (Morgan, Mathison, & Rice, 1985). Studies have shown that 2 to 12% of patients experience at least one fall during hospital stays (Vlahov, Myers, & Al-Ibrahim, 1990). A prospective observational study by Vassallo, Amersey, Sharma, & Allen (2000) investigated the influence of hospital ward design on fall characteristics of rehabilitation patients. The findings of the study revealed that rehabilitation wards in which 85% of patients who were in beds in direct view of the nurse's station experienced fewer falls in comparison to rehabilitation wards in which 15% of patients that were in beds not in direct view of the station (Vassallo, Amersey, Sharma, & Allen, 2000). The majority of studies have acknowledged that falls that occur in clinical or assisted living settings are not necessarily due to risk factors within the facilities (i.e. bed-rails or high beds), but rather the current condition of the individuals who experience the falls (Jones, Simpson, & Pieroni, 1991; Raz & Baretich, 1987). Individuals residing in chronic care facilities typically present with other risk factors (i.e. cognitive and physical impairments), which may increase their risk of falls (Rubenstein, Josephson, & Osterweil, 1996; Thapa et al., 1996).

Compromised Cognitive and Emotional State

Approximately two thirds of all cognitively and emotionally impaired older adults fall annually (Dijk & Meulenberg, 1993). This represents a rate that is two to eight times greater than healthy older adults (Tinetti et al., 1988). Although mental and cognitive risk factors for falls have received less attention than physiological risk factors, several studies have provided evidence for the association between cognitive and emotional impairments and falls (Kvelde et al., 2013; Nevitt, Cummings, Kidd, Black, 1989; Tinetti et al., 1988). Identifying cognitive impairments and changes in emotional status can play an important role in identifying individuals who are at risk for falls. Depression, a fear of falls, and dementia has been widely reported to be associated with an increased risk of falls (Allan, Ballard, Rowan, & Kenny, 2009; Kallin et al., 2004).

depression, fear of falls, and dementia. It has long been accepted that depression is associated with falls in the elderly (Lord et al., 2007). Depression has been shown to affect executive function, attention, and processing speed (McDermott & Ebmeier, 2009). Control of stability during walking requires intact cognitive function, specifically attention and executive function (Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008). Older adults require greater allocation of attention to account for changes in sensory and motor function when navigating through new environments or throughout a living area. Depression can affect these processes and can leave individuals at greater risk for falls (Wright, Kay, Avery, Giordani, & Alexander, 2011). Additionally, depression can lead to changes in motor function, which can be characterized by slow gait patterns, shorter stride length, and increase variability (low stability), which are all recognized fall risk factors (Hausdorff, Rios, & Edelberg, 2001; Hausdorff, Peng, Goldberger, & Stoll, 2004; Maki, 1997; Michalak et al., 2009). Research has shown that depressive symptoms are especially high in those who experience recurrent falls (Iabonir, Phil, & Flint, 2013). An 8-year prospective study revealed that an increase in depressive symptoms was positively associated with increased fall rates (Somadder, Mondal, & Kersh, 2007). The study found that in depression was significantly more common in recurrent fallers than non-fallers (44.8% vs. 26.9%).

fear of falls. There are several consequences that are associated with falls. Aside from the risk of injury, psychological trauma also exists, of which fear of falls is the most common (Miller, Speechley, & Deathe, 2001). Despite being a consequence of falls, fear of falls is part of a cycle that revolves around falls. A history of falls often times results in post-traumatic stress or fear of falls, which can lead to a variety of avoidance or safety behaviors (Chung, McKee, & Austin, 2009; Iabonir et al., 2013), which can increase falls risk. Research has shown that fear of falls is strongly associated with falls (Arfken, Lach, Birge, & Miller, 1994). In some cases, intense fear can be excessive and disabling, and these behaviors can result in falls due to changes in gait patterns (Iabonir et al., 2013). Fear of falls is common in the elderly, especially for those who have experienced recurrent falls, with the majority of studies reporting a prevalence of 25-

50% (Howland et al., 1998; Murphy, Williams, & Gill, 2002). Many community-based investigations report that 48% of persons over the age of 75 years who experienced a fall in the previous year acknowledge a fear of falls (Tinetti & Powell, 1993). Findings from other studies have concluded that persons most afraid of falls do suffer more falls (Arfken et al., 1994; Lord et al., 2007). Studies have shown that anxiety or fear of falls can be persistent, with up to 80% of elderly participants reporting fear of falls over a three year period (Austin, Devine, Dick, Prince, & Bruce, 2007).

Delbaere et al., (2010) assessed community-dwelling older adults and found that those who showed low physiologic falls risk but exhibited high perceived falls risk were more at likely to show signs of cognitive impairment or anxiety (Delbaere et al., 2010). These findings are important because as previous studies have shown, there is a strong association between the fear of falls and risk of future falls (Friedman, Munoz, West, Ruben, & Fried, 2002). As previously mentioned, fear of falls has been shown to manifest as changes to the gait pattern (Iabonir et al., 2013). Research has shown that cautious or fearful walkers tend to have greater kinematic variability, which is indicative of poor stability (Chamberlin, Fulwider, Sanders, & Medeiros, 2005; Rochat et al., 2010). Other studies have shown that participants who are more fearful of falls tend to produce inaccurate adjustments to posture when exposed to obstacles or threats in the environment (Delbaere et al., 2010). Although the adoption of a cautions gait pattern may be suitable for some individuals, some studies suggest that there may be an optimal range of cautiousness that may serve as a protective mechanism against falls (Davis, Campbell, Adkin, & Carpenter, 2009; Nagai et al., 2011).

dementia. The annual incidence of falls in individuals with dementia is between 70 and 80% (Dijk & Meulenberg, 1993; Shaw, 2007), which represents twice the incidence of healthy individuals (Tinetti et al., 1988). Similar to depression and fear of falls, studies have suggested that cognitive decline associated with dementia can result in serious motor dysfunction, which can lead to falls in elderly persons (A. Campbell et al., 1981; Clark, Lord, & Webster, 1993). Specifically, studies have shown that patients with senile dementia of Alzheimer's disease tend to fall more frequently and suffer more severe outcomes than healthy adults (Brody, Kleban, & Moss, 1984; Buchner & Larson, 1987; Dijk & Meulenberg, 1993).

One study assessed the prevalence of falls among elderly individuals and found that the odds of experiencing a fall were almost two to three times greater for participants with dementia (Finkelstein, Prabhu, & Chen, 2007). Another examined older adults with dementia living in a nursing home and found that residents with dementia were almost twice as likely to fall compared to healthy residents (Doorn et al., 2003). Findings from this study also revealed that the rate of injurious falls was higher for patients with dementia compared to healthy residents (1.61 vs. 0.99 injurious falls per person-year, $p < 0.002$) (Doorn et al., 2003). Similar findings were reported by (Eriksson, Gustafson, & Lundin-Olsson, 2008; Kiely, Kiel, Burrows, & Lipsitz, 1998; Rubenstein et al., 1994; Thapa et al., 1996).

Dementia can lead to limited attention (Sheridan & Hausdorff, 2007), behavioral risk factors (Doorn et al., 2003), hypotension (Passant, Warkentin, & Gustafson, 1997), impaired visual-spatial perception (Buchner & Larson, 1987), and impaired gait and balance (Tanaka, Okuzumi, & Kobayashi, 1995), which can limit the capacity for individuals to recognize and avoid hazards, which can lead to falls (Rubenstein et al., 1994). Several studies have shown that dementia can lead to decreased control of postural balance and increase gait variability, such as increased step variability and stride length variability (Gabell & Nayak, 1984; Visser, 1983). Findings from one study suggest that stride length variability in particular was significantly affected by senile dementia (Nakamura, 1996). Studies have also shown that senile dementia during the moderate stages can significantly decrease step length (shuffled gait), and result in bradykinesia or slower gait (Visser, 1983). A combination of these risk factors increases the risk for falls in patients with dementia. Visser (1983) suggested that interventions to target gait abnormalities and motor dysfunction during the advanced stages of dementia is essential to reduce falls in this population.

Impaired Physical Function

The current understanding of fall risk factors and their effects on the elderly suggests that individuals with physical impairments or disease leading to physical impairments are vulnerable to experiencing falls or recurrent falls (Sattin, 1992; Schwenk et al., 2013). Additionally, aging and disease can negatively affect important mechanisms for falls prevention, such as sensation and balance, strength and power, flexibility, spasticity, and gait characteristics.

sensory and balance impairments. Balance is controlled by afferent information from several physiological systems, which include the somatosensory system and the visual system. Both of these systems are responsible for detecting or sensing physical changes the environment (van Deursen, 1999). This somatosensory system is particularly important for controlling posture and balance, as it allows the feet to detect surface textures and changes while standing or walking. Research has shown that physical impairment stemming from trauma or disease can result in sensory and balance deficits. As balance is fundamentally important for preventing falls, balance dysfunction can lead to increased falls risk and fear of falls (Sattin, 1992), which can ultimately lead to a reduction in physical activity and loss of independence (Austin et al., 2007).

disease impact on balance. Findings from several studies have indicated that metabolic and chronic neurological diseases, as well as age-related changes can have an impact on peripheral sensation that can negatively affect balance and increase the risk for falls (Lamb et al., 2003; Leonard, Farooqi, & Myers, 2004; MacGilchrist et al., 2010; Mackintosh, Hill, Dodd, Goldie, & Culham, 2005). A study by Priplata et al., (2006) found that application of vibration noise ameliorated sensation impairments in patients with neuropathy and improved balance parameters. Application of noise resulted in reductions of sway ranging from 2.9% to 53.8% displacement (Priplata, Patritti, Niemi, & Hughes, 2006). These findings suggest that improved cutaneous sensation of the feet can improve postural control and balance to reduce the risk of falls.

range of motion impairment. Flexibility and range of motion (ROM) plays a vital role in preventing falls. Older adults and individuals with diseases affecting flexibility at the ankle and hip are at significantly greater risk for falls (Kemoun, Thoumie, Boisson, & Guieu, 2002; Menz, Morris, & Lord, 2006). Studies have shown that the risk for falls increases by 35-40% after 60 years of age, which is a consequence of reduced flexibility (Hornbrook & Stevens, 1994). A reduction in flexibility decreases the ability to clear obstacles and the lack of stretch reflexes decreases the ability to produce rapid adjustments to compensate for the loss of balance (Pyykko, Jantti, & Aalto, 1990). Studies have revealed that fallers show significantly less ankle dorsiflexion (drop-foot) and hip extension than non-fallers (Barak, Wagenaar, & Holt, 2006; Mecagni, Smith, Roberts, & O'Sullivan, 2000). This would suggest that it is more difficult for individuals to step over or clear obstacles when ankle and hip flexibility is limited. Limited ankle and hip flexibility can result in shuffled walking patterns, much like that those exhibited by the elderly and patients with stroke or Parkinson's disease (Weerdesteyn et al., 2008). These gait characteristics significantly increase the risk for falls among the older adults and have the potential to significantly impact overall quality of life (Weerdesteyn et al., 2008).

A study by Menz et al., (2006) revealed that fallers had significantly ($p < 0.05$) less ankle flexibility than non-fallers. This study also revealed that in addition to ankle dorsiflexion deficit, toe (Hallux) plantarflexion impairment was also highly prevalent in fallers compare to non-fallers (Menz et al., 2006). The authors suggest that the flexibility in the toes plays an important role to stabilize the body when the center of mass is altered during locomotion, and the impaired grasping reflex of the toes can contribute to a loss of stability and falls (Menz et al., 2006). Two other retrospective studies also revealed that fallers had significantly reduced ankle flexibility than non-fallers (Gehlsen & Whaley, 1990; Nitz & Choy, 2004). The study by Gelhsen & Whaley (1990) found that reduced flexibility, especially at the ankle might increase the risk of falls and significantly impact the performance of tasks associated with daily living. A study by Mecagni et al., (2000) found significant correlations between ROM and the Performance-Oriented Mobility Assessment (POMA). Pearson product moment correlations ranging between (0.26 - 0.63) suggest that range of motion plays a vital role in balance and falls prevention (Mecagni et al., 2000). A study by Kemoun et al., (2002) supported these findings and determined that ankle flexibility, specifically dorsiflexion during the second phase of double support and dorsiflexion at the beginning of swing, was significantly lower in fallers ($p = 0.040$ and $p = 0.020$) than non-fallers (Kemoun et al., 2002).

Older individuals often times experience a significant decrease in ankle dorsiflexion strength due to muscle atrophy, and may develop a foot characteristic similar to drop-foot, which hinders the ability to clear obstacles successfully, and increases the risk for falls (R. W. Teasell, Bhogal, Foley, & Speechley, 2003). Several studies have shown the effectiveness of improving weak ankle dorsiflexion and plantarflexion for prevention of falls. More recent studies emphasize the importance of a multifocal intervention to improve overall function in the elderly and those with clinical impairments, but most agree that improvements to flexibility is key for falls prevention (Chan et al., 2012).

strength, and power deficits. Strength impairments and gait deficits are two strongly interrelated factors that can increase the risk for falls. In older adults, deficits in strength can lead to changes in gait characteristics, such as step length, that can contribute to falls. Some studies have supplemented balance training with forms of resistance training to develop muscle strength and muscle power to facilitate optimal gait patterns. Numerous studies have highlighted the importance of developing strength and power. Muscle strength is related to bone strength, which is a key mechanism for preventing fractures upon falls; whereas muscle power is more related to falls as it is the key mechanism responsible for producing the necessary responses to slips or trips (Runge, Rehfeld, & Resnicek, 2000; Runge & Hunger, 2006). Therefore, developing muscle strength and power is important in fall prevention programs because not only does strength and power reinforce control of balance and stability, but developing these two properties facilitates proper compensatory movements when presented with a slip or trip, facilitates fall recovery, and prevents fractures upon experiencing falls.

Buchner et al., (1997) implemented a 26-week resistance-training program in a sample of 105 older adults and found that participants in the strength-training group had lower fall rates compared to those in the control group. The study found that strength training had a protective effect on the risk of falls. Individuals who were part of the control group had significantly more hospital visits during the follow-up period compared to the training group ($p < 0.05$) (Buchner et al., 1997). A study by Liu-Ambrose et al., (2004) found that resistance training for strength development significantly reduced falls risk in older adult women. The study found that fall risk scores were reduced by 57.3% in the strength-training group compared to 20.2% for a stretching only group. Additionally, the authors observed an increase in the normalized squat loads (load (kg)/body mass (kg)) in the resistance training group, which were significantly associated with reductions in postural sway scores ($p < 0.01$), indicative of balance control, an essential mechanism for fall prevention (Liu-Ambrose et al., 2004). Another study found similar results and reported that a five-month exercise program with strength training lead to beneficial effects in preventing falls in elderly participants. Those involved in the strength training program experienced a significant decrease in the incidence of falls compared to those in the control group (0.0% vs. 12.1%, $p < 0.05$) (Iwamoto et al., 2009).

The study conducted by Perry et al., (2007) found that overall; fallers had only 85% of the strength, and only 75% of the power exhibited by non-fallers ($p < 0.001$). The fallers were weaker than the non-fallers on three primary strength measurements: isometric hamstrings flexion ($p = 0.02$), isometric dorsiflexion ($p = 0.004$), and isometric plantarflexion ($p = 0.002$) (Perry, Carville, Smith, Rutherford, & Newham, 2007). These findings are consistent previous findings from other studies, which revealed that individuals who experienced multiple falls (>2) exhibited weaker quadriceps strength than those who only reported one fall or no falls (Lord & Ward, 1994). Additionally, the above findings are in line with a meta-analysis conducted by Moreland et al., (2004). The analysis found that participants who reported at least one fall, or experienced recurring falling exhibited significant lower-extremity weakness compared to non-fallers ($p < 0.05$) (Moreland, Richardson, Goldsmith, & Clase, 2004).

gait impairments. Musculoskeletal and neurological changes associated with aging can also impact gait characteristics, which in turn can negatively affect balance and contribute to an increase in the risk for falls. For example, older adults might exhibit a condition known as drop foot, in which the foot of the weaker lower extremity drags during locomotion (Olney & Richards, 1996a). This condition results in excess rotation or circumduction of the weakside hip to compensate for the lack of activation of the weaker lower limb. This gait pattern can significantly increase the risk of tripping due to the drop foot and can also result in rapid fatigue, due to the energy cost associated with the compensatory hip rotation (Olney & Richards, 1996b; Titianova, Pitkänen, & Pääkkönen, 2003). Similar patterns are observed in more frail older adults (Lu, Chen, & Chen, 2006) and studies have shown these impaired gait patterns can reduce obstacle clearing, which as stated previously, can increase the risk of falls. As mentioned previously excess stride length variability is often present in individuals age-related gait impairments (Nakamura, 1996). Studies have also shown that some elderly individuals may present with decrease step length (shuffled gait), which can result in bradykinesia or slower gait (Visser, 1983). A combination of these risk factors increases the risk for falls, especially in patients with dementia.

The findings from these studies highlight the importance of muscle strength and power in preventing falls. Moreover, these studies also highlight the importance of developing flexibility and efficient walking kinematics. Developing strength and power is highly desirable for the beneficial effects these elements can have on facilitating more efficient gait patterns and making the process of locomotion more automatic. Exercise interventions for fall prevention focus on developing muscle strength and power to aid in the performance of more demanding task and to reduce the risk of falls and fall-related injuries. Additionally, fall intervention programs should aim to address the physical risk factors previously discussed in this section to improve overall quality of life.

It is important to note that these risk factors could potentially be multi-correlated. In some circumstances, it might be possible that improving one of these risk factors via intervention could lead to improvements seen in other factors. For example, improving muscle strength and power of the lower limbs could potentially result in better control of the limbs, and thus lead to improved gait patterns, such as smooth gait and longer step length.

Limitations Regarding Fall Risk Factors

A major limitation associated with studies assessing the risk factors resulting in falls is that many findings are based on self-report, which could dramatically alter the manner in which investigators interpret patient findings. Information regarding medication prescriptions might be inaccurate and could hinder progress in fall prevention interventions. Inaccurate recollection of dosage and types of medications could potentially increase the risk of falling and serious injury. In a similar manner, limitations can potentially arise with regard to the literature examining environmental risk factors for falls. Often time's investigators fail to assess risk factors within the home and only focus on those that are common in public spaces (i.e. uneven pavement, cracks in the street, steps, and crowds). Furthermore, in many studies, investigators have failed to consider changes in lifestyle exhibited by each participant. Dramatic lifestyle changes may result in exposure to new environments such as parks or high-traffic areas, which may increase the risk of falls. With regard to impaired physical function, one limitation that presents itself, is that it is not well-understood how individuals with mild impairments are affected. The majority of research looking at impaired physical function as a risk factor for falling has examined individuals in a hospital or clinical setting with more severe impairments.

Direct and Indirect Consequences of Falling

The adverse effects associated with falls are not limited to direct injury stemming from the fall itself, but also extend to economic and family burdens, which can also contribute to the diminished quality of life. Both falls and their subsequent additional burdens can be grouped under unique classifications often referred to as direct and indirect consequences (Heinrich, Rapp, Rissmann, Becker, & König, 2010).

Direct Consequences

Falls can lengthen hospital stays, increase medical expenses, cause injury and discomfort and cause skepticism towards treatment and healthcare providers (Byers, Arrington, & Finstuen, 1990). There is no doubting that the monetary expenses, which will be discussed below can result in excess family burden and can result in excess stress, but the direct consequences stemming from the fall itself can profoundly affect activity, independence, and lifestyle (Alexander et al., 1992). Direct consequences refer to physical or mental trauma stemming from the actual fall incident, and may include broken bones, contusions, head trauma, and even internal organ damage or death.

Among people aged 65 years and older, falls are considered the leading cause of fatal and non-fatal injuries (CDC, 2016). If recalled from previous sections, older adults have a greater risk of experiencing falls, mainly due to performance changes associated with aging (Alexander et al., 1992). Falls in this population can result in significant injuries, such as head contusions or hip fractures that can adversely affect lifestyle and quality of life. One study found that in 180 reported falls, 49% resulted in contusions and 41% resulted in soft tissue abrasions (Teasell, McRae, Foley, & Bhardwaj, 2002).

Recent studies have continued to document the adverse effects associated with falling in both healthy older adults (Hoffman, Hays, Shapiro, Wallace, & Ettner, 2017; P. et al., 2015; Roubik et al., 2017; Wallander, Axelsson, Nilsson, Lundh, & Lorentzon, 2017). In this case, falls can lead to significant injuries, which can result in loss of independence, depression, and overall poor quality of life. It is important to note however, that the injuries associated with falling, in some cases, may only be one aspect that can affect quality of life. The indirect consequences can also take a significant toll on one's rehabilitation and can potentially hinder any progress with recovery. As briefly stated above, secondary complications associated with falling, such as medical costs, family burden, and excess stress can severely impact lifestyle and can transform into a pattern (i.e. vicious cycle), which can further increase the risk for falling.

Indirect Consequences

Indirect consequences of falls refer to circumstances that may negatively impact quality of life after the fall incident has taken place. Secondary complications, such as medical costs, severe fear of falling, and even depression may arise and can severely impact overall quality of life by resulting in decreased independence (Heinrich et al., 2010). Moreover, excess family burden could potentially affect caretaker dynamics, which could lead to excess stress in the household, resulting in disputes and unstable living environments.

One of the most common indirect consequences stemming from falls is economic burden. The fees associated with rehabilitation alone are extremely costly and can become an overwhelming source of stress when combined with secondary trauma associated with falls and injuries stemming from falls. Alarmingly, elderly patients who are discharged from hospitals after falls are more likely to have recurrent falls while at home, resulting in secondary visits to the hospital (Forster & Young, 1995), and therefore increases medical expenses. Results from the study by Davenport et al., (2009) found that up to 63% of falls reported in the study occurred in the initial two-weeks following hospital discharge, some of which required secondary medical attention (R. D. Davenport et al., 2009). Several other studies have reported similar findings, which indicate that recurrent falls in older adults after discharge remains a serious issue that can lead to severe economic burden (Berg, Alessio, Mills, & Tong, 1997; Buatois et al., 2010; Moylan & Binder, 2007; Shumway-Cook, Brauer, & Woollacott, 2000).

Studies have identified that medical costs associated with fall-related trauma can be financially crippling and can often severely impact quality of life and result in increased levels of stress and family burden. Falls can lead to extended hospital visits and the additional sessions that might be needed for therapy, and other procedures, such as x-rays can be extremely costly even with insurance (Gelber, Josefczyk, Herrman, Good, & Verhulst, 1995). Studies showed that individual hospital visits associated with falls averaged between $17,000 and $23,000 in 2004 (Roudsari, Ebel, Corso, Molinari, & Koepsell, 2005). One study conducted by (Alexander et al., 1992) found that of the almost $1billion in hospital charges in Washington State, for patients ≥65 years, roughly 5% ($53 million) were attributed to hospitalization for fall-related trauma. With regards to aggregate spending, a more recent study found that up to $6.2billion were spent nationally on fall-related medical conditions (Druss, Marcus, Olfson, & Pincus, 2002). This amount equates to a rough annual average of $2,000 per individual (Cohen & Krauss, 2003). According to a more recent study, annual costs for non-fatal fall injury treatment is $31.1billion, with the average individual cost of treatment significantly greater at roughly $10,000.00 (E. R. Burns, Stevens, & Lee, 2016).

depression and fear of falling.

Falling among older adults can result in financial burden, but repeated falling can also lead to depression, fear of falling, and ultimately a loss of independence (Allan et al., 2009). As discussed in the section on risk factors for falls, it is well-established that altered cognition and mental state can significantly impact physical performance (Hausdorff et al., 2004; Michalak et al., 2009), which can lead to an increased risk for falling. As the meta-analysis conducted by Deandrea and colleagues (2010) showed, there is a significant association between depression and falls. Moreover, other studies also provided evidence for a strong relationship between fear of falling and recurrent falls. Repeated fall episodes can result in post-traumatic, which alter performance and avoidance strategies (Chung et al., 2009; Iabonir et al., 2013), which can increase falls risk (Chung et al., 2009; Iabonir et al., 2013). Identifying this vicious cycle early after discharge is an integral component of fall prevention, especially amongst the elderly and individuals with stroke in the chronic stage of recovery.

mortality (rate of death in the population).

While injuries, medical expenses, and behavior changes are commonly considered as the burdens associated with falls, many tend to overlook the fact that death is a very real possibility that may occur as a result of falling. After all, falls are currently classified as the leading cause of injury and death among the elderly (CDC, 2018). Death typically occurs in vulnerable populations from secondary complications stemming from the fall injuries. Unlike younger patients who are often healthier, elderly individuals or individuals with compromised physiological systems do not have the ability to adapt to trauma as effectively and are more likely to succumb to their injuries, especially when those injuries are severe (Johnson, Margulies, Kearney, Hiatt, & Shabot, 1994; Samayoa et al., 2018). One Canadian report found that the number individuals $\geq$65 years of age who died as a direct result of a fall increased significantly ($p < 0.05$) from 3,209 between 1997-1999 to 4,110 during 2000-2002 (Stinchcombe, Kuran, & Powell, 2014). In 2016, 29,668 United States residents age $\geq$65 years died as a result of a fall; a significant increase from 18,334 deaths, which occurred in 2007 (Burns & Kakara, 2018). Overall, the rate of fall-related deaths in older adults increased 31% during this time period (Burns and Kakara, 2018).

One major factor that affects these populations is their limited physical ability; if a person has issues with recovering from a fall and is unable to get up after a fall, then it is likely that they will remain on the floor for a prolonged period of time, which may lead to more severe complications, such as hypothermia or dehydration (Simpson & Mandelstam, 1995). It is these secondary complications that can ultimately result in death. Batchelor and colleagues (2012) stated that between 30 and 40% of older adults are not able to stand back up after a fall, which can increase their risk of death by exposure or 'long-lie' (Batchelor, Mackintosh, Said, & Hill, 2012; Simpson & Mandelstam, 1995). In order to prevent these 'long-lie' episodes or better yet, in order to prevent the falls altogether, mechanisms and preventive strategies need to be implemented to assist and prepare vulnerable individuals. Fall prevention programs or interventions to target specific risk factors for falling, such as muscle weakness or balance deficits have been developed and the following section will discuss these in greater detail.

Interventions for Falls Prevention

Historically, fall intervention programs have included a battery of modalities to address the fall risk factors previously mentioned. The majority of studies have implemented aerobic or resistance-training programs combined with exercises designed to address balance deficits (e.g. static squats). Although the majority of these interventions observed improvements in balance and other fall risk factors, many of the fall intervention programs have only included healthy younger populations. Therefore, many of the traditional forms for fall prevention may not be accessible to more frail individuals, such as older adults. Recently, whole-body vibration (WBV) training has been become popular for use as an effective and cost-effective method to improve risk factors for falls in the elderly, as well as persons with neurological disorders. However, methodological variance and design flaws in the current literature have hindered the development of standard protocols, which may be deemed more effective.

Whole-Body Vibration

WBV training is a neuromuscular technique that has historically been used on athletes to enhance performance measures, such as strength, and has also been applied in the prevention and therapy of osteoporosis (Issurin, Liebermann, & Tenenbaum, 1994; Kerschan-Schindl et al., 2001; Rittweger, Beller, & Felsenberg, 2000). However, in recent years, WBV has emerged as an effective means of to battle age-related performance deficits. During the past decade, especially, the use of WBV has been used frequently in research and clinical settings as a means to improve risk factors commonly associated with falls.

As part of a WBV training regimen, participants sit or stand on an oscillating platform that delivers vibratory mechanical stimulation at frequencies ranging from 20-50 Hz (Delecluse, Roelants, & Verschueren, 2003) while the participant performs static or dynamic exercises (i.e.

double or single legged squats). The relatively low frequency mechanical stimulation provided by the vibrating platform is delivered to the body and results in the stimulation of sensory receptors in the muscles (i.e. muscle spindles) (Delecluse et al., 2003). The stimulation of the muscle spindles results in the activation of alpha-motor neurons in the CNS to elicit tonic or sustained muscle contractions in the lower limbs (Delecluse et al., 2003). These sustained muscle contractions are an inherent reflex in healthy adults that facilitates the maintenance of posture, which is important for independent locomotion and fall prevention.

Similar to other widely-implemented fall prevention programs based on techniques like functional electrical stimulation (FES) to promote muscle and limb function, WBV can directly stimulate and strengthen the muscles responsible for postural control. Improvement of these components over time can decrease the risk for falls and can be applied to task specific activities, such as treadmill walking or even overground walking, thereby increasing independence for activities of daily living. In addition to receiving direct vibratory stimulation of the muscles, participants can also perform static or dynamic exercises to directly promote development of strength (Tankisheva et al., 2014), cardiovascular fitness, and coordination (Choi, Kim, Cho, & Lee, 2016), which are key elements that can aid in fall prevention.

Studies involving individuals with older adults have focused on the specific effects of WBV on balance and postural control, mobility and motor function, muscle strength and architecture, and spasticity, and although not directly targeted towards gait recovery or fall prevention per se, findings from several studies have reported benefits. Findings have indicated that repeated exposure to WBV can potentially promote brain plasticity, strength, balance and can serve as a platform to regain independent control of balance and gait, thus reducing the risk of falls (Chan et al., 2012; Liao, Ng, Jones, Chung, & Pang 2016; Liao, Lam, Pang, Jones, & Ng, 2014). Studies have reported improvements in weight shifting and balance (van Nes, Geurts, Hendricks, & Duysens, 2004), walking performance (Guo et al., 2015), and strength (Tankisheva et al., 2014) associated with WBV training programs among older adults.

wbv, postural control, and balance. A study by (Verschueren et al., 2004) was among the first to examine the effects of WBV on postural control in older adults. Participants in the study underwent vertical WBV training for 24-weeks at moderated vibration intensities (35-40 Hz) and were then assessed for balance and maintenance of posture via posturography assessment. The study findings revealed that postural sway in the anterior-posterior (A/P) direction, along with the peak-to-peak amplitude of the sway were significantly ($p < 0.05$) deceased for the WBV training group post-training. These changes were not observed in the control group. Another study (Cheung et al., 2007) assessed balance by exploring the limits of stability before and after 3-months of side-alternating WBV (20 Hz) and found that when compared to two control groups, participants in the WBV group displayed significant improvements in movement velocity ($p < 0.01$), maximum distance of sway excursion ($p < 0.01$), and directional control ($p < 0.05$), all indicative of enhance postural control. Similar findings have been reported throughout the literature (Bogaerts et al., 2011; Ko et al., 2017; Mikhael, Orr, Amsen, Greene, & Fiatarone Singh, 2010; Tseng et al., 2016) and have provided substantial evidence that WBV might be an effective training modality to improve postural control, which is key factor in the prevention of falls.

While some studies have explored the effects of WBV on body balance in older adults by assessing static and dynamic balance via posturography, a large proportion of studies have adopted a different approach and have used clinical tools, such as the Berg Balance Scale (BBS), Romberg Test, or the Tinetti Balance Assessment Tool to assess WBV effects on balance. One study assessed the effects of a 6-week WBV (35-40 Hz) training program and found that compared a control group who only performed static exercises, participants in the WBV groups exhibited significant (p= 0.002) improvements in performance for the Tinetti Balance Assessment Tool (Bautmans, Hees, Lemper, & Mets, 2005). In fact, the study findings showed that participants in the control group experienced significant (p= 0.004) performance deficits after the 6-week protocol. Another study by (Bruyere et al., 2005) discovered similar results and found that after 6-weeks of WBV training, participants in the training group improved significantly ($p < 0.001$) compared to the control group who only experienced traditional physical therapy. Specifically, members of the WBV group improved their performance on the Tinetti Balance Assessment Tool by 2.4 $\pm$ 2.3 points, while members of the control group actually showed a decrease ($p < 0.001$) in performance. In general, the literature is consistent in findings, much like findings on posturography reported above, with regard to the effects of WBV on postural control and balance as measured by clinical tools. The majority have identified significant benefits in postural control and balance associated with WBV (Bissonnette, Weir, Leigh, & Kenno, 2010; Furness & Maschette, 2009; Kim. et al., 2014; Kim et al., 2014; Simão et al., 2012).

In spite of the findings reported above, there have been studies which did not yield any performance benefits associated with WBV. The study by (Avelar et al., 2011) examined the effects of a 12-week WBV protocol and found no significant differences ($p > 0.05$) in the WBV group with regard to performance on the BBS. In fact, only the exercise control groups experienced any benefits. The authors of this study attributed the lack of significant improvements to the protocol, stating that it may have been insufficient to yield any physiological benefits, and thus no performance benefits. Similar results were reported in the study by (Nils Stolzenberg, Belavý, Rawer, & Felsenberg, 2013) who reported no significant findings between groups in balance and postural control after 9-months of WBV training. These findings were attributed to the fact that participants in the control group displayed poorer balance at the start of the study relative to the WBV group and were therefore more likely to experience performance benefits regardless of the intervention. Finally, the studies by (Buckinx et al., 2014; Sitjà-Rabert et al., 2012) also failed to reported significant improvements in balance and postural control among older adults. Buckinx and colleagues attributed the lack of findings to extra cushioning that was placed between the feet of the user and the vibration platform. This component decreased the intensity of the protocol and may have resulted in insufficient dosage. The latter attributed that lack of statistically significant performance findings to insufficient power in the sample of their study (Sitjà-Rabert et al., 2012a).

wbv, muscle strength, and muscle power. In addition to examining the effects of WBV on balance and postural control, several studies have also examined the potential benefits of WBV on muscle strength and power, which can be significant risk factors for falls. As previously discussed, muscle strength is related to bone strength, which is a key mechanism for preventing fractures upon falls; whereas muscle power is strongly related to falls, as it is the key mechanism responsible for producing the necessary responses to slips or trips (Runge, Rehfeld, & Resnicek, 2000; Runge & Hunger, 2006). WBV has demonstrated that it can yield improvements in muscle strength, muscle power, and even muscle architecture, which can be key to minimizing the risk of falls and injuries stemming from these falls in older adults.

A study by (Russo et al., 2003) examined the effects of six-months of WBV (12-28 Hz) on muscle power in post-menopausal women. The study findings revealed that women who received WBV during the 6-months significantly ($p < 0.02$) improved muscle power by approximately 5% while performing a vertical jump (pre: 178.9 ± 9.6W to post: 187.3 ± 9.5W), while women who did not receive WBV actually decreased slightly from pre-testing to post-testing with regards to muscle power. Despite improvements seen in the ability to generate power, participants in neither group showed significant improvements in force development. The study by (Hawkey, Griffiths, Babraj, & Cobley, 2011) examined the effects of a 5-week WBV (30-45 Hz) training program on counter movement vertical jump performance in middle-age adults and found similar results. Compared to a control group who underwent no vibration, older adults in the study training group significantly ($p < 0.05$) improved in VCMJ performance after the intervention (pre vs. post: 22.3 ± 4.3cm vs. 24.9 ± 3.3cm and 24.2 ± 4.8 vs. 24.1 ± 4.0cm). A final study by (von Stengel, Kemmler, Engelke, & Kalender, 2011) examined performance of the VCMJ and corroborated the findings above. After completion of an 18-month WBV (25-35 Hz) training program, participants in the experimental group exhibited significant improvements in the vertical jump compared to the control group. Specifically, participants displayed a significant ($p < 0.05$) increase of (1.7 + 2.6W/kg) during the VCMJ, compared to virtually no difference in the control group (0.4 + 2.0W/kg).

While some studies have found improvements in muscle power during CMJ performance associated with WBV training, other have found improvements in muscle power by examining performance on the chair rise test. The study by (Runge et al., 2000) was among the first to examine the effects of WBV (27 Hz) on muscle power in older adults by using the chair rise test. In this study, authors examined the effects of two months of WBV on leg power strength as quantified by performance on the chair rise test. The chair rise test requires that participants rise five times as quickly as possible without upper extremity assistance. The study findings revealed that participants in the training group improved significantly in the chair rise time by about 36%

(i.e. faster times), while no difference was observed in the control group. Another study by (Yang, King, Dillon, & Su, 2015) implemented the five repetition chair rise test to assess the effects of the effects of eight-weeks of WBV (20 Hz) on muscle power and also found that performance was significantly improved after the intervention. From pre-training to post-training participants in the study experienced improved times in the chair rise test (10.36 $\pm$ 2.62 vs. 13.17 $\pm$ 3.57s, $p< 0.001$).

While the studies described above examined the effects of WBV on power development of the lower-extremities, several others have examined the therapeutic effects of WBV lower leg strength. As previously mentioned, muscle power gives one the ability to generate compensatory steps needed to resist falling; however, muscle strength allows one to maintain the support of the body while performing the compensatory step. Therefore, muscle strength is also an important component of that must be addressed for falls prevention. Similar to the studies by Runge et al., 2000 and Feng et al., 2015, several studies have utilized the chair rise test to assess the effects of WBV on muscle strength. However, instead of using the five-repetition chair rise test, the following studies used the 30-second chair rise test, which requires one to rise as many times as possible in 30 seconds.

The study by (Bissonnette et al., 2010) evaluated the effects of eight-weeks of WBV on performance in older adults and found that participants involved in the WBV protocol significantly improved the number of chair rise repetitions during the 30-second period. After the eight-week intervention, there was an average increase in the number of repetitions of 61.91% (10.37 $\pm$ 3.34 vs. 16.79 $\pm$ 4.22, $p< 0.05$). Similar results were also observed in a study conducted by (Marín et al., 2011). Not only did participants in the study experience significant $p< 0.05$ improvements in the 30-second chair rise test, but participants actually showed signs of declined performance after a three-week detraining period ($p < 0.05$). These improvements with regards to leg strength as quantified by the 30-second chair rise tests have been reported throughout the literature (Santin-Medeiros, Santos-Lozano, Cristi-Montero, & Garatachea Vallejo, 2017; L. Zhang et al., 2014; Alvarez-Barbosa et al., 2014) and indicated that WBV might be an effective method to improve muscle strength and specifically chair-rise performance, which can be a good indicator of falls risk in older adults.

The majority of studies have utilized isokinetic dynamometers to examine the effects of WBV in muscle strength in older adults, specifically knee flexor and extensor strength. A study by (Roelants, Delecluse, & Verschueren, 2004) examined the effects of 24-weeks of WBV (35-40 Hz) on performance outcomes in post-menopausal women. Specifically, the authors aimed to identify the effects of WBV on isometric and dynamic knee strength. The findings revealed that members of the WBV group showed significant improvements (12.4% $\pm$ 2.1%) in dynamic knee extensor strength after 12-weeks of training compared to the control group. Similar to the results presented by (Russo et al., 2003), this study also found that participants in the control group experienced decreases in extensor strength during the course of the study (-4.3 $\pm$ 1.6%, $p < 0.05$). The decrease in muscle strength observed in both control groups described above was likely attribute to age-related changes or changes associated with post-menopausal symptoms.

Several other studies have reported similar findings and all support that WBV training can be a feasible and effective method to improve strength among older adults. The studies by (Verschueren et al., 2004) and (Bautmans, Hees, et al., 2005) both examined the effects of moderate intensity WBV (35-40 Hz) and found that isometric knee extensor strength improved significantly in the training group. The former identified a between-group difference in isometric strength ($p < 0.001$), while the study by Bautmans and colleagues (2005) did not identify and between-group difference with respect to muscle strength. The study by (Bogaerts et al., 2011) assessed isometric strength and found that after a 12-month WBV (35-40 Hz) program, participants showed significant improvements (9.8%, $p = 0.005$) in isometric strength compared to the control group who showed no change at all. Several other studies have reported similar results, which show that maximum isometric and dynamic knee extension and flexion show significant ($p < 0.05$) improvements after participation in a structured WBV training program (Cristi, Collado, Márquez, Garatachea, & Cuevas, 2014; Ko et al., 2017; Leung et al., 2014; Ochi et al., 2011; Perchthaler, Grau, & Hein, 2015; Tseng et al., 2016; Verschueren et al., 2011; L. Zhang et al., 2014). These performance gains are likely due to the fact that frail elderly adults are highly trainable and are physiologically receptive to training, specifically balance and training target to weight-shifting (Bautmans, Hees, et al., 2005). Even short bouts of WBV can potentially lead to acute neurological changes or adaptations that could lead to improved strength and power development that are essential in preventing falls.

Overall, the findings from the studies discussed above provide some evidence, which indicates that WBV can be an effective training modality to improve power development and strength of the lower extremities. These improvements are important in producing compensatory movements in response to slips or trips (Levinger et al., 2018). Failure to generate sufficient power in response to these perturbations in the base of support can result in delayed slip responses or complete absence of the compensatory step or steps needed to resist falling altogether. For this reason, effective WBV training regimens should aim to target these important falls risk factors.

wbv and gait function. As stated previously, impairment in gait is one of the primary factors that increases the risk for falls among older adults. Evidence in the literature has suggested that WBV can be a useful intervention to improve mobility in older adults. Studies show that WBV has the potential to improve balance and postural control, as well as power development and muscle strength. As a result, individuals who undergo these physiological changes may also experience significant improvements in locomotion and mobility (i.e. weight shifting, turning, obstacle avoidance). Improved mobility, especially during transfer tasks (i.e. sit to stand), is important as it allows older adults to successfully navigate through the environment and perform practical activities of everyday living. A number of studies have assessed the effects WBV on functional mobility in older adults and have used various assessment tools to identify improvements. While varying in their methods, the majority of studies reported functional improvements associated with WBV.

For example, the study by (Rees, Murphy, & Watsford, 2007) assessed the effects of WBV (26 Hz) in older adults while performing stair climbing tests, a task that represents one of the common activities performed by the elderly, which results in injurious falls. The study found that after partaking in a regiment of WBV, older adult participants significantly improved performance during the stair climbing tasks. Rees and colleagues (2007) found that the time to complete the stair climb (e.g. 2 complete ascents) task improved from the pre-training to the post-training evaluation. Despite these improvements, the findings identified that there were no significant between group differences between the WBV group and the standard exercise group. Although lacking between group differences, this study still provided some evidence for the potential functional benefits to be gained by WBV.

While the study discussed above described a task-specific assessment to examine performance, several others have implemented more practical tools to assess functional performance in older adults. The studies by (Cristi et al., 2014; Mikhael et al., 2010; Simão et al., 2012) assessed the effects of WBV on six-minute walk performance in older adults. The test requires that the participant walk the greatest total distance in the six-minute window and provides a good indication of functional performance (Mikhael et al., 2010), walking function (Simão et al., 2012), and endurance (Cristi et al., 2014). The study by (Mikhael, et al., 2010) investigated the effects of 13-weeks WBV (12 Hz) on functional performance that participants involved in WBV training did not exhibit any significant (p>0.05) improvements within-group or between groups in performance during the six-minute walking test. Similarly, Cristi et al., 2014 also reported that no significant findings were discovered after nine-week WBV (30-45 Hz) program. In both cases, it is likely that the pilot nature of the studies (i.e. small sample) and type II errors resulted in a lack of significant findings (Mikhael et al., 2010).

While the study by Mikhael and colleagues (2010) did not yield and significant findings with respect to the 6-minute walking test, the study by Simao et al., (2012) did in fact see improvements in this test associated with WBV training. The study by Simao and colleagues (2012) investigated the effects of a 12-week WBV (30-40 Hz) and found that after the training protocol was completed, participants in the WBV group walked significantly further (p< 0.05) during the 6-minute walking test compared to the control group. Another study showed that after an 8-week WBV (27 Hz) program, participants in the training group were able to significantly improve on the 2-minute step test (78.9 $\pm$ 22.3steps vs. 98.5 $\pm$ 22.4steps) (Dudoniene et al., 2013). No differences were observed between groups however. While slightly different from the 6-minute walking test, the test described in this study provides a good measure of aerobic endurance and thus, overall functional ability.

The studies described above utilized longer (endurance-based) assessments tools to identify the impact of WBV on overall performance. While the findings from these studies can be useful in assessing overall functional benefits, they fail to assess certain aspects of performance. Several studies have utilized tests, such as the five and ten-meter walk, and the Timed-Up-and-Go (TUG) Test to evaluate agility and walking speed, which can provide more insight into the benefits associated with WBV. While these tests typically provide an index of muscle power (Kawanabe et al., 2007), they can also provide valuable information with regards to agility, body balance, and posture. Overall improvements in these tests may indicate that WBV may be effective in improving locomotor risk factors for falling.

A total of five studies have examined the effects of WBV in older adults on 10-meter walking performance, and all have shown that WBV significantly improves performance (i.e. increase walking speed and decreased completion times). After a two-month WBV program (12-20 Hz) Kawanabe et al., (2007) found that ten-meter walking time was significantly ($p < 0.05$) improved (decreased 14.9%) in the WBV training group compared to the control group. Similar findings were reported in the study by (Rees et al., 2007), which showed that participants involved in WBV training (26 Hz) significantly decreased ten-meter walking time (4.40 $\pm$ 0.40s vs. 4.45 $\pm$ 0.59s) and five-meter walking time (2.30 $\pm$ 0.15s vs. 2.38 $\pm$ 0.23s) compared to a control group. Significant 10-meter walking improvements (i.e. increased walking speed and faster completion times) after WBV interventions were also reported by (Bogaerts et al., 2011; Ochi et al., 2011; Simão et al., 2012).

Historically, the TUG test has been implemented to provide an index of agility and functional mobility in older adults (Podsiadlo & Richardson, 1991). During the test, the participant is observed and timed as they rise from a chair, walk a distance of three meters, turn and walk back to return to the seated position (Podsiadlo & Richardson, 1991). A large body of literature reports that WBV may significantly improve performance on the TUG test, indicative of better agility and thus, decreased falls risk. A meta-analysis conducted by (Orr, 2015) reported on 11 studies in which the TUG test was used to assess functional mobility in older adults. The analysis showed that in seven of the studies, participants involved in WBV training experienced improvements in performance of the TUG test. An analysis of 12 tests revealed that WBV training resulting in significant improvements in TUG test results compared to participants in a control group. While this meta-analysis identified the benefits associated with WBV in studies conducted up to 2015, to date, a total of 23 scientific articles have reported on the benefits of WBV in older adults on TUG performance (Radlinger et al., 2015; Santin-Medeiros, Rey-Lopex, Santos-Lozano, Cristi-Montero, & Garatachea Vallejo, 2015; Sucuoglu, Tuzun, Akbaba, Uludag, & Gokpinar, 2015; Yang et al., 2015).

This section has described many of the functional gait and performance benefits associated with WBV training. However, the studies described above have used assessment tools that fail to provide insight into the body mechanics that occur during walking that are essential to identify falls risk (i.e. dysfunctional gait kinematics). To date, only four studies have assessed the effects of WBV on gait kinematics in older adults directly.

A study conducted by (Kawanabe et al., 2007) assessed the step length and maximum standing time in older after a two-month WBV program. The study revealed that participants involved in the WBV training program exhibited significantly improved walking kinematics compared to the control group, as made evident by increase step length and increase single-leg support. A second study by (Pollock, Martin, & Newham, 2012) also found that participants involved in the training program exhibited significant increases (p=0.002) in stride-length during a walking task. This increased stride length is indicative of a more stable and confident walking pattern, which is essential in reducing the risk of falls among the elderly, and has also been reported by (Ochi et al., 2011) . The overall performance improvements associated with WBV (i.e. balance and postural control, muscle power and strength, agility, and endurance) ultimately result in more stability during walking and potentially less falls. A final study by (Beaudart et al., 2013) examined the effects of WBV on stride length and stride symmetry in older adults during walking, but ultimately did not observe any difference within or between groups with regards to body kinematics.

Once again, the findings from the studies discussed above provide some evidence, which indicates that WBV can be an effective training modality to improve overall functional performance and physiological performance among older adults. Collectively, these performance improvements are important in producing compensatory movements, which are necessary to resist falls (Levinger et al., 2018). Although methodological differences exist in the literature, ultimately the findings provide support for the feasibility and efficacy of WBV training as a tool to improve quality of life in the elderly.

wbv and fall prevention. While the majority of studies described above primarily examined the effects of WBV on risk factors for falling (e.g. muscle strength and power, balance, and gait function), only five studies have assessed the effects of WBV on the rate of actual falls, falls incidence, or fear of falling, and only one has examined responses to simulated falls (Ochi et al., 2011). The fact that other studies have assessed whether or not vibration training can be beneficial for fall prevention in older adults is significant, however, failure to directly assess if WBV can prevent falls may result in speculation to if in fact WBV is actually beneficial for accident prevention in older adults.

The studies by (von Stengel et al., 2012) and (Buckinx et al., 2013) examined the effects of WBV training on the falls frequency among older adults. One study found that after 18-

months of WBV, participants exhibited significantly lower falls frequency compared to a control group (0.7 falls/person vs. 1.5 fall/person) (von Stengel et al., 2012). Although not significant, the findings in the study by (Buckinx et al., 2013) showed a trend to decreased falls frequency amongst participants who took part in WBV training. A study by (Leung et al., 2014) examined the effects of WBV (35 Hz) on fall incidence and recurrent falls among older adults. The findings of the study revealed that participants who were involved in the training protocol exhibited a significantly lower (46% lower) incidence rate of falls compared to members of the control group (p=0.001). Moreover, participants in the training group also reported fewer recurrent falls compared to the control group. Approximately 2.1% of participants reported recurrent falls in the training group, compared to 6.4% of participants reporting in the control group.

(Shim et al., 2014) examined the effects of WBV on fear of falling among older adults. The Falls Efficacy Scale (FES) was used to quantify fear of falling and it was found that the FES scores improved significantly (decreased) after 6-weeks of WBV training (baseline 23.00 ± 19.16 vs. follow-up 11.18 ± 10.41). Another study (Yang et al., 2015a) also examined fear of falling among older adults after 8-weeks of WBV and found similar findings that revealed an improvement in FES scores from baseline to follow-up (12.20 $\pm$ 2.54 vs. 10.87 $\pm$ 1.64, $p< 0.05$). The findings from these studies are important because studies have shown that FES scores are closely related to control of balance and gait function (Liu-Ambrose et al., 2006).

Only one study has investigated the effects of WBV on actual fall responses among older adults. This study examined responses to simulated forward slips before and after 12-weeks of WBV training and found that participants in the training group displayed significant improvements in step performance during recovery after the slip compared to the control group.

Training participants had a longer step length and increased step velocity during the recovery phase. These findings indicate that these participants were able to more effectively produce the compensatory movements associated with fall-resistance. Although this is the only study to examine these effects among older adults, these findings have been reported in the literature among other populations (Yang, Munoz, Han, & Yang, 2017). Despite the improvements discussed in this section, studies investigating the effects of WBV training on risk factors for falls and on fall prevention are not without their limitations.

Limitations with WBV Literature

Although the majority of the studies described above have observed functional benefits associated with WBV, other studies have reported no benefits associated with WBV training. The disconnect between studies has been attributed mainly to differences in methodology. While some studies have kept the frequency of vibration constant, others have varied the vibration intensity within the same study. Moreover, some studies have utilized vibration machines, which provided vertical rather that horizontal stimulation, which directly impacts the postural responses produced by the participants. Finally, some studies have introduced visual conditions as postural feedback during training sessions. These confounders and lack of standardized protocols have made it difficult to assess the effectiveness of WBV and have also made it difficult to compare findings between different studies. One important item to note, is that only four of the studies described in this section have examined if the effects of WBV can be retained over prolonged periods, and in these studies vibration frequency and type differed substantially. In some cases, vertical vibrations were implemented and in others side-alternating machines were used. In addition, the vibration frequencies ranged from 15-40 Hz. Therefore, it is uncertain if there is any sort of true retention effect associated with WBV training benefits.

CHAPTER 3

Methodology

Experimental Design and Sampling

This exploratory study used a randomized controlled design. Participants in this study were healthy older adults between the ages of 60 and 85 years. Participants were recruited throughout the Greater El Paso Region and through our contacts with different institutes and hospitals in the city of El Paso. Study participants were randomly and evenly assigned into one of two groups (vibration-WBV or placebo-CON) using a computer-generated random sequence. Participants in the WBV group underwent a six-week vibration training protocol, while individuals in the CON group received the six-week placebo training protocol (Fig. 1a). Participants in each group attended a total of 18 sessions (three sessions per week for six weeks) throughout the six-week training period and were assessed on three occasions: pre-training, post-training, and two-month follow-up (Fig. 1a). An *a priori* sample estimate of 32 participants was calculated in G-Power 3.1 using historical findings based on step-time data from (Ochi et al., 2011), with a critical alpha-level set at 0.05, a large effect size (d= 1.03), and power of 0.80.

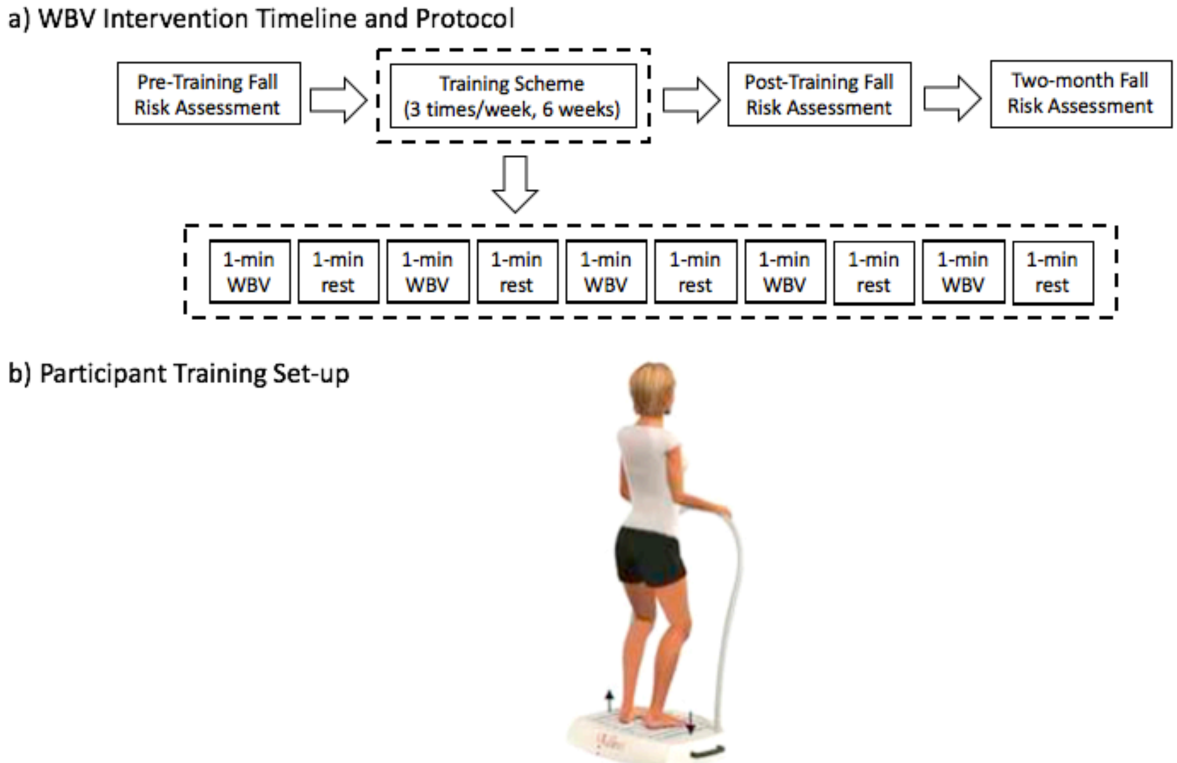

Fig. 2. Schematics of (a) the whole-body vibration timeline and protocol breakdown and (b) participant set-up on the side-alternation vibration platform. Vibrations were delivered intermittently at a frequency of 20 Hz and a vibration amplitude of 1.3mm.

Participants

Recruiting efforts were aimed at healthy older individuals living in the Greater El Paso Region. A total of 17 healthy older adults were recruited for the study. To exclude any effects resulting from confounding factors, such as health status, the inclusion criteria for this study included the following: (1) adults aged 60 to 85 years old; (2) able to follow balance assessment instructions provided in English or Spanish; (3) able to stand and walk, with or without assistive device or braces as part of their activities of daily living (self-report). The exclusion criteria included the following: (1) Significant cognitive or communication impairment, indicated by a score on the MMSE of < 24 out of 30; (2) Presence of concurrent severe medical illness, including unhealed pressure sores, active or untreated infection, thromboembolic disease, active heterotrophic ossification in the lower extremities, lower limb fractures in the past 12 months, known history of peripheral nerve injury in the lower legs, history of cardiovascular or pulmonary complications, or with pacemakers and history of metabolic (endocrine, hepatic) or renal dysfunction (Self-report); (3) Inability to tolerate standing positions of greater than 30 minutes (decrease in blood pressure by 20 mmHg systolic and 10 mmHg diastolic); (4) Uncontrolled hypertension (systolic blood pressure (SBP) > 165 mmHg and/or diastolic blood pressure (DBP) > 110 mmHg during resting) (Hidler et al., 2009; Hornby, Campbell, Kahn, & 2008); (5) Resting heart rate (HR) > 85% of age-predicted maximal heart rate (HRmax) (HRmax = 220 – age) (Hornby et al., 2008); (6) Oxygen saturation (measured by pulse oximeter) during resting < 95%; (7) Severe cardiac disease (New York Heart Association classification of II-IV) (Hidler et al., 2009); (8) Uncontrolled seizures; and (9) Participants greater than 250 pounds in weight. The inclusion and exclusion criteria were assessed by the primary investigator.

Human Participant Interactions

initial screening. Potential participants were initially contacted by the primary investigator through telephone (Attachment #1: telephone scripts). A screening questionnaire (Attachments #2 and #3: screening forms) was used during the phone conversation to pre-determine if the candidates qualified for the study. If potential participants qualified for the study after the phone interview and were still interested in the study, they were scheduled for a visit to the research laboratory to undergo further screening tests for eligibility. The screening results (including initial telephone screening and further laboratory screening) for each individual were documented on a data collection sheet and were also documented on a computer spreadsheet with the de-identified participant identification number on one column and a "pass" or "fail" identifier in an adjacent column.

Upon obtaining permission for data collection from the Institutional Review Board, researchers met with interested participants to provide detailed information of the study requirements. The researchers explained the purpose of the study, study procedures and requirements to all interested participants and answered all study related questions. Participants were asked to provide written consent to participate on an informed consent form. Once the consent forms were obtained, participants contacted their primary physicians to request the most accurate and recent medical information. Upon completion of these tasks, participants visited the laboratory to perform the baseline measurement and respective training sessions (i.e. WBV or CON).

Research Protocol

After participants passed the initial screening tests and consent forms were read and signed, participants were assigned to either the WBV training group or the CON group using a randomly generated number sequence created prior. All participants performed a warm-up exercise prior to performing training protocol. A research assistant guided each participant through a 10-minute standardized warm-up session before beginning the actual experiment. This session was composed of stretching and dynamic exercises, including light walking and stepping in place. This was selected because this exercise was likely to reduce the risk of muscle or joint injury during strenuous movements that participants may have encountered during testing.

Baseline measurement: All study participants were assessed for balance, mobility, gait speed, body composition, muscle strength, and gait performance. This portion of the evaluation took approximately two hours to complete. Upon completion of the baseline session, participants actively enrolled in the study began the training regimen.

Vibration training: The vibration platform rotates about an anteroposterior axis such that positioning the feet farther from the axis of rotation results in larger-amplitude vibration. The vibrator provides an oscillation type vibration. Its vibration frequency varies between 5-30 Hz and amplitude changes from 0-25 mm. At the beginning of the training period, participants received an introductory practice session to become familiar with positioning on the vibration platform. In this study, the vibration frequency was fixed at 20 Hz and the amplitude was 1.3 mm.

During each training visit, each participant completed one set of WBV training. The participants stood on the vibration platform with the knees flexed at approximately 20º during the training sessions to avoid any adverse effects or discomfort stemming from the vibration (Fig. 1b). To avoid the dampening effect resulting from shoes, participants were requested to stand on the platform in bare feet. The vibration training was delivered in an intermittent way: each one-minute vibration was followed by a one-minute rest for 10 minutes. This exact program was repeated three times per week, for six weeks. Successful completion of the training protocol occurred when each participant completed 18 sessions. At least 24 hours were observed between two consecutive training sessions.

Placebo training: Participants in the CON group visited the laboratory for the placebo training three days per week for six weeks. The only difference between vibration training and placebo training was that the vibration frequency and amplitude for the placebo training was set to 0 (e.g. no vibration) while the participants stood on the platform. Furthermore, an audio recording of the vibrating motor was played during the training to mimic the actual vibration protocol (Bautmans, van Hees, Lemper, & Mets, 2005; Corrie et al., 2015; Turner et al., 2011).

Each training session was conducted individually at the Gait Research & Movement Analysis Laboratory under the supervision of the Principle Investigator. A stability bar attached to the vibration platform was located directly in front of the participants during training and all participants were asked to hold the stability bar to minimize any risk of falling.

Post-training measurements: After the completion of all 21 training sessions, all variables related to fall risk were reassessed at two different time nodes: immediately after the completion of the 18 sessions, and two months following the training completion.

Measurements of Interest

All measurements of interest were recorded at approximately the same time of day and were assessed on three occasions: pre-training, post-training, and two-month follow-up.

laboratory fall characteristics. Both groups were exposed to an identical simulated slip on a specialized treadmill while under the protection of a full body harness system in a laboratory environment (Fig. 2). All participants encountered unanticipated slip perturbations while walking on the ActiveStep treadmill (Simbex, Lebanon, NH) (Yang, Bhatt, & Pai, 2013).

During each slip test session, participants were moved to the ActiveStep treadmill following a 10-minute warm-up walking on a regular treadmill (Tracmaster TMX425, Newton, KS, USA). Before the simulated slip test, they were informed that they would experience normal walking initially and a “slip-like” movement on the treadmill “later” without knowing when, where, and how the slip would be initiated while walking on the treadmill. The participants were instructed to maintain forward gaze during walking, and to try to recover balance and resume walking (if) any slip perturbation was encountered.

After completing five normal walking trials without slip perturbation on the ActiveStep treadmill, participants were then exposed to five trials with the slip perturbation. The slip trial began with 1.5-second ramp up, followed by a 4-second steady state with a backward-moving belt speed of 0.6 m/s. After the detection of 8-16 (randomized) steps were detected, at the beginning of the next single stance phase, the top belt accelerated suddenly in the forward direction, which abruptly reduced its backward speed and thereby induced a forward displacement of the participants’ base of support relative to their center of mass. Such an abrupt change in belt speed produced a slip perturbation, which was unannounced and unpredictable by the participants. The total slip distance of the treadmill belt was 12 cm. Following the slip perturbation, the belt speed returned to the initial speed. The treadmill kinematic profile of each slip trial was fixed and pre-defined by a software program. Five consecutive slips trials were delivered.

During all trials on the ActiveStep treadmill, a full body safety harness, connected by shock-absorbing ropes at the shoulders to an overhead arch, was employed to protect participants while imposing negligible constraint to their movement. Participants’ lower-body kinematics were captured by a 10-camera motion capture motion system at 200Hz (Vicon Motion Systems

Ltd., Oxford, United Kingdom). Marker paths were low-pass filtered with a cut-off frequency of 6 Hz using a fourth-order, zero-lag Butterworth filter and 21 retro-reflective markers were used to calculate the body center of mass (CoM) (C-Motion Inc., Germantown, MD) and segment kinematics. One component of the CoM motion-state was computed (i.e. CoM position) with respect to trailing heel position during the slip. A CoM position beyond the limits the trailing heel during the slip phase was classified as a slip. A COG position located anteriorly with respect to the trailing heel (i.e. within the base of support) during the slip was classified as a recovery.

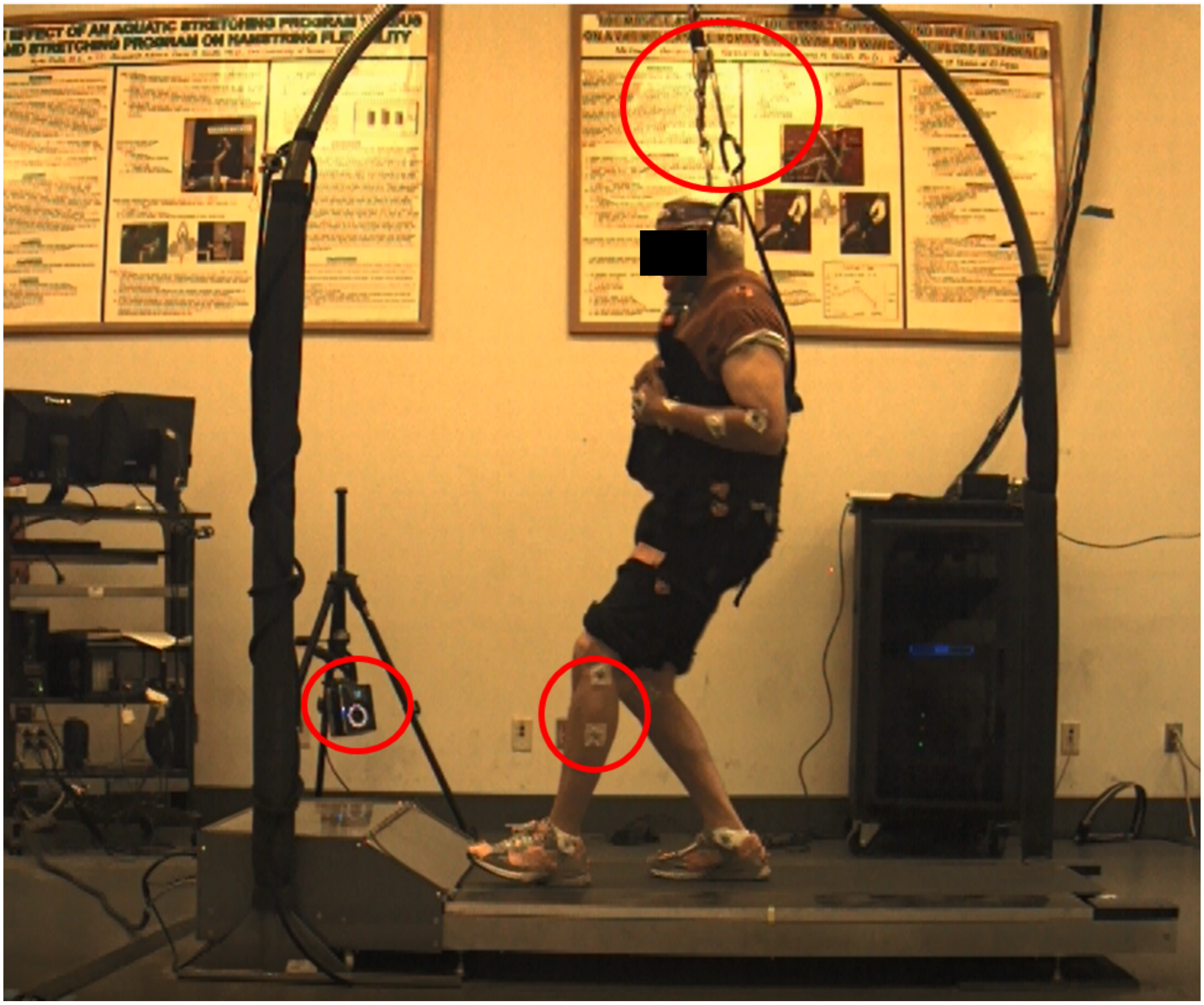

Fig. 3. Image depicting the treadmill, computer, and camera set-up for the slip perturbation protocol. Participants' were tethered and secured during all walking trials with a harness and dynamic ropes attached to an overhead arch on the treadmill.

body balance. Participants' body balance was assessed using the Berg Balance Scale (BBS) test (Berg, 1992). During the BBS test, participants performed a series of 14 functional balance tasks of increasing difficulty from quiet stance, sit-to-stand, weight shifting and reaching, turning in place, to single leg and tandem stance. Participants rested as needed between tasks. The degree of success in achieving each task was given a score of 0 (unable) to 4 (independent), and the final measure was the sum of all of the scores. The final score (/56) was used for analyses.

gait performance. Participants performed three walking trials of self-selected normal gait and along a 10-meter straight walkway (10MWT) section of the laboratory. Time to complete each trial in seconds was recorded to the hundredth.

functional mobility. Functional mobility was evaluated by using the timed-up-and-go test (TUG) (Podsiadlo & Richardson, 1991). In the TUG test, participants rose from an armed chair, walked forward three meters, crossed a marked line on the floor, turned around, walked back, and returned to the seated position. The chair was adjusted to the height of each person and was fixed to floor to avoid any unwanted movement during testing. The test began when the investigator said "go" and ended when the participant sat with their back against the backrest of the chair. Participants were instructed that their back must contact the backrest to complete the test. The total time taken to complete the task at maximal speed was used for analysis. Participants were briefed with regard to all procedures.

muscle strength. The maximum isometric voluntary contraction of the quadriceps and hamstrings was assessed for all participants. Before testing, all participants underwent a standardized warm-up and test protocol on a motor-driven dynamometer (System 3, Biodex Medical Systems, Inc., Shirley, NY). During the warm-up, the participants perform isometric contractions, which were similar to those experienced during testing. The knee extension/flexion isometric (static) strength assessment was performed unilaterally on both sides, in a seated position on a posterior-inclined (15°) chair. The proximal portion of the leg, the hips, and the shoulders were stabilized with safety belts. The rotational axis of the dynamometer was aligned with the transverse knee-joint axis and connected to the distal end of the tibia using a length-adjustable rigid lever arm. The three-dimensional positions of the rotational axis, the position of the chair, and the length of the lever arm were recorded and were identical for the strength assessment during the other testing sessions (e.g. post-training and two-month follow-up). Each participant performed three repetitions, each lasting seven seconds for both flexion and extension on the dominant and non-dominant leg. A one-minute resting period was administered between repetitions.

endurance capacity. The endurance capacity of the participants was assessed using the two-minute walk test. During this test, the participant was instructed to walk back and forth, as fast as possible, for two minutes between two cones set 30.48 meters (100 feet) away from each other. Participants were permitted to rest during the two-minute test but were made aware that the timer would continue to run until time expired. Total distance traveled during the two-minutes was used as a measure of endurance capacity.

Statistical Analysis

All analyses were performed using SPSS software version 24 (IBM, Armonk, New York). A Chi-Square Test was conducted to assess any between group differences in baseline characteristics and Fisher's Exact Test was used to denote significance. The primary analysis for this study was conducted for participants who had complete data for the three time points of interest (pre-training, post-training, retention). For continuous variables (fall risk factors and fall rates), including the muscle strength, BBS, TUG, two-minute walk, gait performance, and fall characteristics during the simulated slip, a repeated measure analysis of variance (ANOVA) was used to identify the potential effect of the WBV training upon reducing the fall risk within each group. The within subject factor was the time instances (pre vs. post vs. retention) while group (WBV vs. CON) served as the between subject factor. For all analyses, a critical alpha level of $p < 0.05$ was used to determine statistical significance and post-hoc Bonferroni corrected pair-wise comparisons was performed on significant effects.

CHAPTER 4

Presentation of the findings

Data collection occurred from June 1, 2019 to March 13, 2020 in the Gait Research & Movement Analysis Laboratory (GAIT) at the University of Texas at El Paso in El Paso, Texas. Participants completed all 21 sessions of the study protocol and reported no adverse effects associated with the fall risk assessments or the WBV training program. Two participants withdrew from the sample for reasons not associated to the study protocol. Baseline characteristics for the two study groups can be are presented in Table 1. Independent *t*-tests revealed no differences ($p > 0.05$) between the study groups in age (yrs.), height (m), or mass (kg). The Chi-Square Test showed no differences in gender between the study groups ($p > 0.05$).

The ANOVA revealed a significant main effect of time for the 10MWT [$F(2,14)=3.94$, $\eta_p^2= 0.360$, $p=0.044$) and the 2MWT [$F(2,14)=7.29$, $\eta_p^2=0.510$, $p=0.007$), but not for the fall rates ($p > 0.05$), BBS ($p > 0.05$), TUG test ($p > 0.05$), the right and left measures of isometric extension ($p > 0.05$) and ($p > 0.05$), and flexion ($p > 0.05$) and ($p > 0.05$). No significant time by group 2-way interaction was detected for any of the variables, however, isometric extension (N/kg) of the left leg approached significance [$F(2,14)=0.193$, $\eta_p^2=0.27$, $p=0.09$]. Mean and standard deviation values are displayed in Fig. 4-7.

The findings for the 10MWT and 2MWT indicate that all participants, regardless of study group demonstrated equal improvements in performance throughout the three time points in the study (e.g. pre-test, post-test, and retention). There were no significant differences observed between the WBV and CON group. Pairwise comparisons revealed that participants in the study experienced significant performance improvements within pre-test, post-test, and retention evaluations for the 10MWT and the 2MWT. Performance benefits were detected in the 10MWT with participants showing faster completion times between sessions (post-test vs. retention: 8.00 ± 0.31 vs. 7.24 ± 0.39s, $p = 0.33$) (Fig. 5a). Participants also showed significantly increased walking distance during the 2MWT (pre-test vs. retention: 168.12 ± 5.04 vs. 177.52 ± 5.73m, $p < 0.05$) (Fig. 5b).

Table 1. Participant characteristics at baseline and differences between groups.

Parameter	WBV (n = 9)	CON (n = 8)	p value
Age (years)	71.44±7.07	69.13±5.19	0.730*
Sex (female)	7	6	0.563$^{\Delta}$
Body height (m)	1.61±0.06	1.58±0.09	0.355*
Body mass (kg)	76.71±13.27	82.91±18.71	0.792*

Note: Values are n, mean ± standard deviation, or as otherwise indicated. $^{\Delta}$Chi Square Test used. *Independent *T*-Test used.

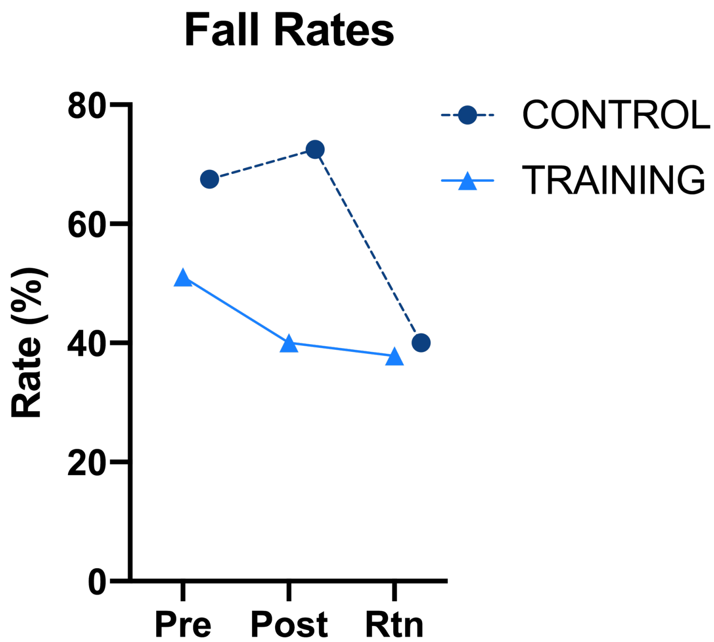

Fig. 4. Group fall rate percentages for the pre-test, post-test, and two-month retention. Fall rates were calculated as the quotient between the total number of falls recorded for the entire group and total number of valid slip trials for the group.

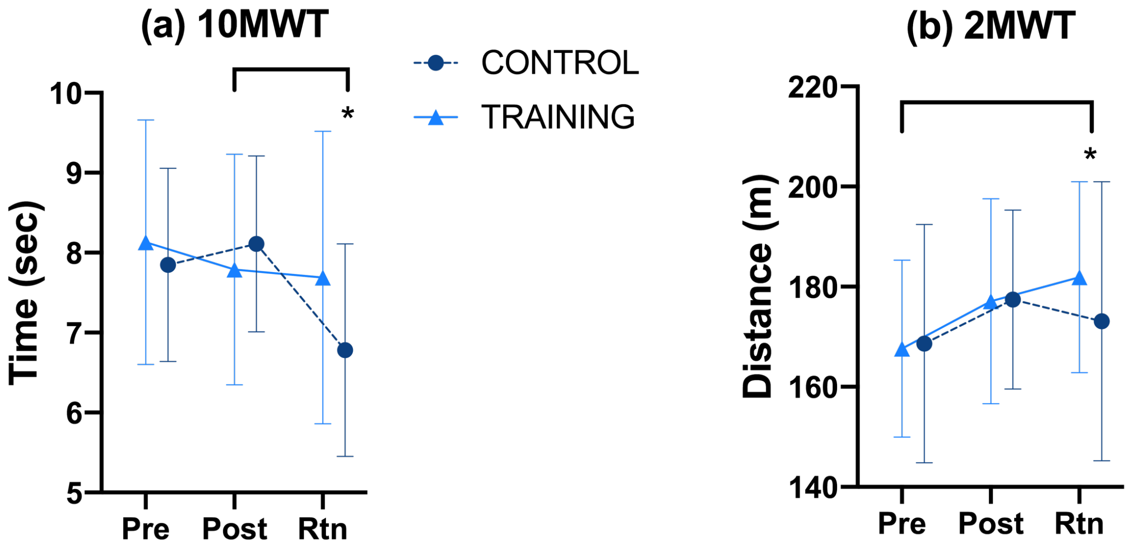

Fig. 5. Group means and standard error bars for the time to complete the 10-meter walk (sec) (a) and distance walked for the two-minute walking test (b) for the pre-test, post-test, and two-month retention. *p<0.05

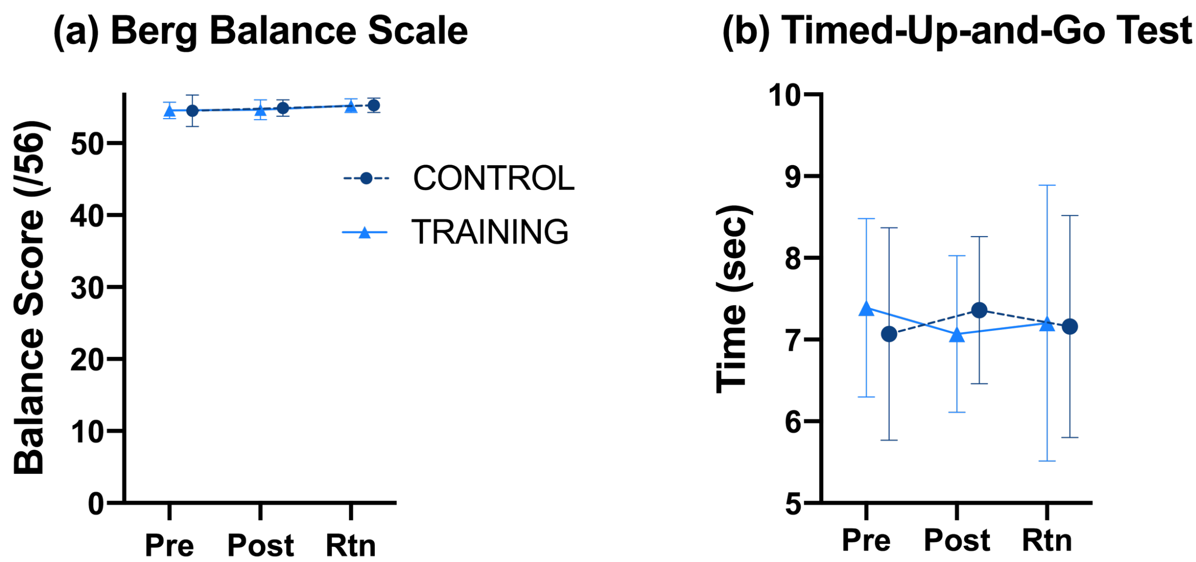

Fig. 6. Group means and standard error bars for the BBS composite scores (a) and time to complete the TUG Test (sec) (b) for the pre-test, post-test, and two-month retention.

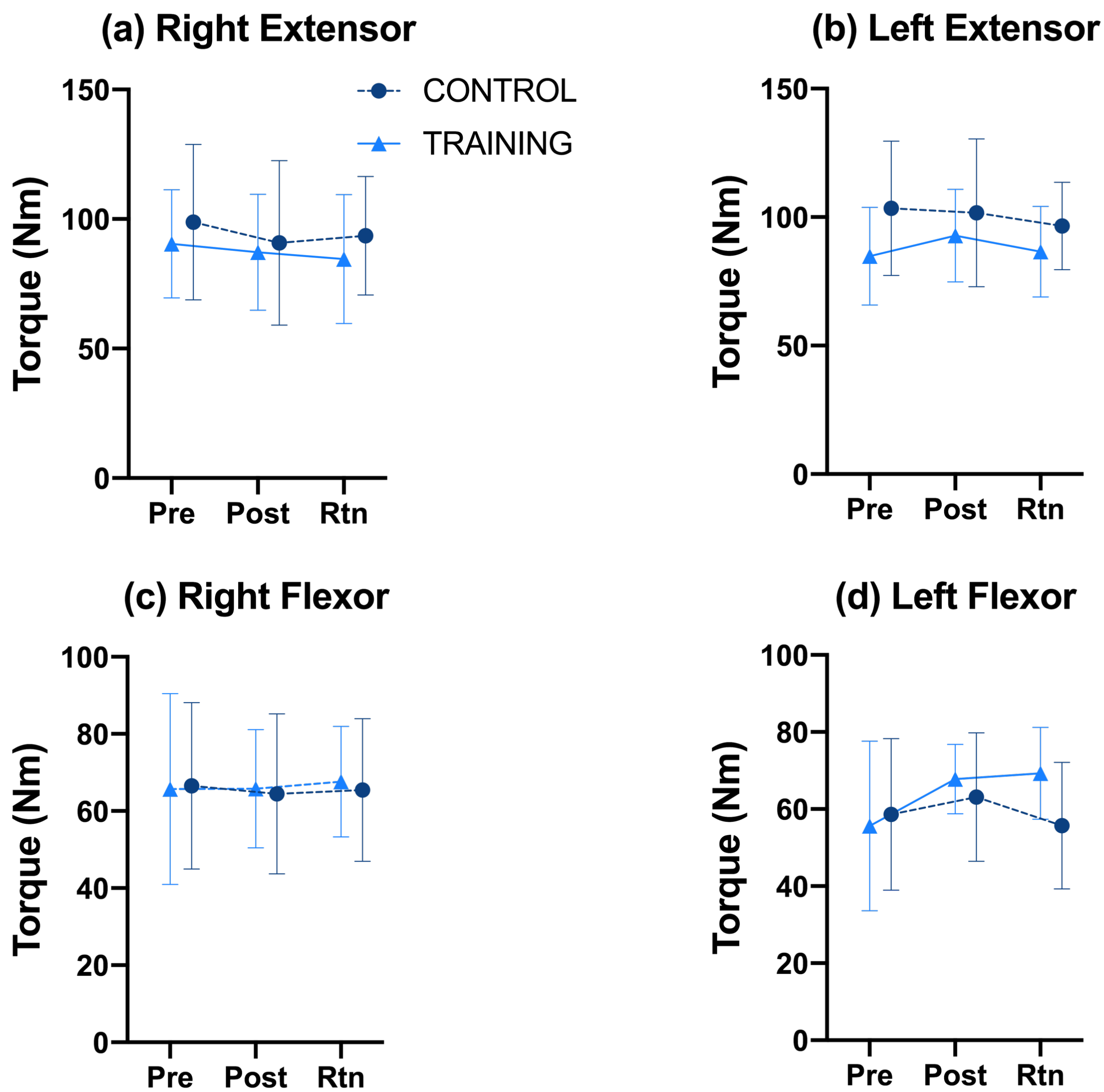

Fig. 7. Group means and standard error bars for the right (a) and left (b) max extensor torque and right (c) and left (d) max flexor torque for the pre-test, post-test, and two-month retention.

CHAPTER 5

Summary, Discussion, and Recommendations

This study sought to examine the effects of a six-week whole-body vibration training program on improving fall risk factors and fall rates in response to a simulated treadmill slip. WBV has become an effective alternative to battle age-related deficits in older adults and has also shown promise in improving balance and reducing falls-risk. However, existing literature has failed to systematically investigate the effect of WBV training on improving fall risk factors among older adults (Lee et al., 2013; Tankisheva et al., 2014; Verschueren et al., 2011). Additionally, existing studies have not assessed if the therapeutic effects of WBV can be effective in reducing the rate of slip-related falls. Finally, the majority of studies have only examined the acute effects of WBV and therefore, it is uncertain if the therapeutic effects of WBV can be retained over long durations. There is substantial evidence that resistance and aerobic exercise can be effective in mitigating age-related performance deficits. Several studies have reported that interventions integrating both resistance and aerobic components can be effective in improving muscle strength and power, flexibility, mobility, cardiovascular endurance, and balance (del Campo Cervantes, Macías Cervantes, & Monroy Torres, 2019; Sañudo et al., 2019; Yoon, Ha, Kang, & Ko, 2019). Although this traditional approach has been shown in some cases to be effective for improving performance and reducing the risk for falls, several factors, such as cost, ease of use, and exertion reduce accessibility for older adults (Damush et al., 2007; Wagner et al., 1996).

The results revealed that there were no differences in performance on the functional performance tests (i.e. fall risk factors) or the treadmill fall rates between the WBV and CON group. The results determined that participants in the WBV group and the CON group experienced equal benefits throughout the duration of the study associated with the six-week training program, specifically in 2MWT and 10MWT performance, which quantified mobility, walking capacity, and muscle endurance. The results did not support our first hypothesis, that participants in the WBV group would experience significant ($p<0.05$) improvements in fall risk factors and slip responses compared to participants in the CON group. As mentioned above, participants in both groups experienced equal benefits, but only on a small portion of the test battery (e.g. 10MWT and 2MWT; Fig. 5). Furthermore, there were no significant between-group differences in performance outcomes observed for the two-month follow-up (retention), which opposed our second hypothesis. Both groups exhibited retention at the two-month follow-up with faster completion times for the 10MWT than recorded at baseline (Fig. 5a). Similarly, both groups showed retention at the two-month follow-up with longer walking distance in the 2MWT compared to the six-week post-test (Fig. 5b). These findings indicate that WBV was no more effective than the placebo condition based on our measures of interest.

The findings from our study are in line with those reported by (Dudoniene et al., 2013), which revealed no performance changes between an eight-week WBV group and an eight-week WBV plus exercise group. The study reported benefits for both groups in performance outcomes (TUG Test, Dynamic Gait Index, 30 second sit-to-stand) throughout the duration of the study. Although the study did not implement a placebo group, the findings still imply that WBV was no more beneficial than traditional methods. Other studies have also shown that WBV is no more effective than placebo conditions or traditional methods of intervention (Bogaerts et al., 2011; von Stengel, Kemmler, Engelke, & Kalender, 2011). The findings from these studies as well as our study contrast those reported previously by (Kawanabe et al., 2007) and (Simão et al., 2012). The study by Kawanabe and colleagues found that incorporating WBV training into a conventional regimen consisting of lower extremity strength exercises significantly improved walking speed in the 10MWT compared to the exercise only group. Simão et al., (2012) determined that WBV signifcanlty improved BBS balance scores, distance walked during the 6MWT (similar to our 2MWT), and walking speed in the 10MWT. However, much like the study by Kawanabe et al., (2007), the participants in this study underwent a combination of WBV and squat therapy. The study was however, able to isolate the effects of WBV by reporting that the WBV group walked significanly faster than the sqaut only group. Several other studies have reported improvements associated with WBV, but these too have combined exercise with a WBV regimen (Bautmans, Hees, et al., 2005; Bogaerts et al., 2011; Pollock, Provan, Martin, & Newham, 2011; Sitjà-Rabert et al., 2012). The systematic review by Sitjà-Rabert and colleagues (2012) concluded that WBV can be an integral tool to elicit performance improvements for fall prevention, but the issue remains that training effects in WBV participants may not be immediately apparent when compared to a control group that undergoes conventional exercise or a combination of exercise and WBV.

A small proportion of studies conducted previously have implemented protocols similar to that in our study. Participants in the study by (Cheung et al., 2007) who underwent WBV exhibited improved postural control as quantified by limits of stability compared to a true control group. Machado, García-López, González-Gallego, & Garatachea (2010) reported significant between group differences with participants in the WBV group showing greater increases in muscle strength and muscle hypertrophy compared to the control group. Finally, (Yang et al., 2015) reported significant improvements in participants who underwent 8-weeks of WBV. Participants experienced improvements in balance scores (BBS), isometric knee extensor and flexor strength, range of motion, and fear of falling scores. This study did not include a control group, as our study, limiting their ability to make the claim that improvements in performance were directly associated with the WBV intervention and not a confounding factor (Yang et al., 2015). Postive outcomes with WBV may be confounded if there is no control group; these performance improvements can be linked to learning effects, which can occur throughout the duration of the study (Yang et al., 2015). Despite lacking the control group, the findings from this study as well as the two described above still provide substantial evidence showing the therapeutic benefits of WBV.

Our study did not yield results indicating any therapeutic effects of WBV, indicating that WBV was no better than the CON condition. One possible reason for this outcome may relate to the duration of the study intervention. Other studies have commonly implemented WBV training periods lasting between three and eight months (Bogaerts et al., 2011; Leung et al., 2014; Russo et al., 2003; Nils Stolzenberg et al., 2013; Verschueren et al., 2011). While the six-week period that we chose may be sufficient to yield neuromuscular adaptations or increase neural activation (Baroni et al., 2013), which in turn might have aided physical performance or lead to acute benefits, it may be possible that six weeks does not suffice to obtain benefits from WBV. Though it should be noted, that other studies have implemented six-week WBV interventions in older adults and have reported improved balance and mobility/walking scores (Bautmans, Hees, et al., 2005; Bruyere et al., 2005; Furness & Maschette, 2009), and even improved jump height (Perchthaler et al., 2015). With the exception of the negative findings reported by (Sitjà-Rabert et al., 2015), the majority of studies implementing six-week interventions have shown improvements in fall risk factors and therefore other explanations for the findings in our study must be considered.

One possibility is that the training intensity and frequency were not adequate to elicit physiological changes leading to the improvements in fall risk factors and fall rates. The vibration frequency selected for the current study was 20Hz and it was delivered intermittently for 60-seconds for a total of five-minutes, three times weekly. The reason the 20Hz vibration frequency was selected is two-fold: 1) to maximize comfort and retention in the protocol and 2) to reduce the risk of excess stimulation or stimulation resembling that of the physiological systems (Muir, Kiel, & Rubin, 2013). Vibration frequencies ranging from 12.5 to 20Hz have typically been classified as low-intensity, while frequencies from 30-50Hz have been classified as high-intensity (Muir, Kiel, & Rubin, 2013). In theory, higher vibration frequencies elicit greater responses from the proprioceptors of the lower-extremities, however, many studies have shown that WBV interventions utilizing 20Hz still result in improvement performance outcomes (i.e. lower falls risk) (Abbasi et al., 2011; Bruyere et al., 2005; Cheung et al., 2007; Furness & Maschette, 2009; Kawanabe et al., 2007; Machado et al., 2010; Ochi et al., 2011; Pollock et al., 2011; Russo et al., 2003; Tseng et al., 2016; Yang et al., 2015).

The lack of significant findings in the present study is potentially attributed to the small sample size. Based on the *a priori* sample size estimation, a total of 32 participants was required to achieve sufficient statistical power. A posteriori power-analysis revealed that with the 17 total participants that were recruited, the present study only yielded a statistical power of 0.22 at the 0.05 level, thereby impacting the likelihood of detecting any statistical significance between groups. One study reported statistically significant performance improvements from only nine participants, but there was no control group involved in the study and participants were permitted to perform exercise outside the study if desired (Giombini et al., 2013). Given the nature of our protocol, the inclusion criteria narrowed the pool of eligible participants to those that were generally healthy and high-functioning and considering the small sample size, a ceiling effect for some of the performance variables could have resulted. For example, scores for the BBS (Fig. 5a) showed very little variance for both groups. All participants scored close to maximum (56/56), which thereby reduced our ability to discriminate between the two groups.

We acknowledge several limitations in this study. The study sample size was small, which possibly resulted in low statistical power making it difficult to identify any performance differences between the WBV and CON group. Future studies will aim to increase the study sample size to increase study power. The inclusion criteria can be modified to broaden the participant recruitment pool, while upholding research integrity safety. The small sample size, paired with the fact that the majority of the study participants were high-functioning possibly resulted in a ceiling effect, which as stated previously reduced the study's ability to discriminate performance outcomes between the two groups. Another limitation in the study was the short duration of the WBV intervention. While other studies have shown that six-weeks of WBV can be effective in improving performance and possibly reducing falls risk, no other study has integrated a true control group in their protocol, as we did. The majority of studies have included a control exercise group. It is possible that the six-week intervention only produced acute benefits that were not detected due to our study design. A more thorough assessment of WBV dosage (time and frequency) needs to be conducted to identify if there is an optimal intervention length to yield benefits. The methodology utilized in the study could have also been a limiting factor in identify significant results. For example, isokinetic dynamometry was used to assess leg strength, specifically knee flexion and extension torque and no significant findings were found (Fig. 7) While WBV can be effective in stimulating proprioception of the lower extremity, the vibratory stimulation is mainly targeted distally at the ankle joint because this is where the majority of the signal is dampened (Pollock et al., 2011). Therefore, it would be more appropriate for future studies to examine ankle plantarflexion and dorsiflexion. Finally, the fall detection method implemented in this study was likely not robust enough to detect a significant reduction in fall rates. Other studies have used more comprehensive approaches to quantify the limits of stability or center of mass (CoM) with respect to the base of support (Young, Wilken, & Dingwell, 2012). Despite modifying these parameters in the present study, the method is justified. If body CoM exceeds the posterior limits of the trailing heel during the slip (e.g. backwards fall), the argument can be made that there is excess instability leading to a fall outcome. Although there was not a significant change observed between groups in the fall rates (main outcome) (Fig. 4), we speculate that with a larger sample size and the current fall detection method, we can identify a greater reduction in fall rates stemming directly from WBV. Future studies however, should aim to adopt the comprehensive method for fall detection and assess the limits of stability and recovery steps following the slip event.

The overall conclusion from this study was that six-weeks of WBV was no more effective in improving fall risk factors and decreasing fall rates among healthy older adults. While the findings from this study did not show many statistically significant findings, there are some strengths and clinically significant findings, which merit some attention in future studies. Our study did not look specifically at actual falls, but rather at the outcome of simulated falls. This study represents the only one of a few studies to have looked at simulated-slip outcomes during treadmill walking in healthy older adults. The results showed a reduction in the fall rates in the WBV group compared to the CON group throughout the duration of the study (including retention) (Fig.4). Although not significant, these findings could potentially have important clinical implications for the rapidly growing number of aging adults worldwide. Future studies are required to identify the full benefits of improving fall risk factors and reducing fall rates in older adults.

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Appendix A: Informed Consent Form

University of Texas at El Paso (UTEP) Institutional Review Board
Informed Consent Form for Research Involving Human Subjects

Protocol Title: Effects of a 6-week Controlled Whole-body Vibration Training Program on Reducing Falls Risk among Healthy Older adults

Principal Investigator: Fabricio Saucedo

UTEP: Department of Interdisciplinary Health Sciences

1. Introduction

In this consent form, “you” always means the study subject. If you are a legally authorized representative (such as a parent or guardian), please remember that “you” refers to the study subject.

You are being asked to take part voluntarily in the research project described below. Please take your time deciding and feel free to discuss it with your friends and family. Before agreeing to take part in this research study, it is important that you read the consent form that describes the study. Please ask the study researcher or the study staff to explain any words or information that you do not clearly understand.

2. Why is this study being done?

You have been asked to take part in a research study of examining the overall effects of 6-weeks of controlled whole-body vibration training on preventing falls among healthy older individuals.

Approximately, 40 study healthy older adults will be enrolling in this study, which will take place at The University of Texas at El Paso (UTEP).

You are being asked to be in the study because you are a healthy community-dwelling adult aged 60 years or over and you have expressed interest in being involved in this research study.

If you decide to enroll in this study, your involvement will be about 21 individual sessions within 4 months. Three of these 21 sessions will last approximately 1-2 hours while the remaining ones last about 15 minutes.

3. What is involved in the study?

If you agree to take part in this study, the research team will ask you to do the following things:

1. General Screening

In order to reduce the risk of injury, we will use telephone screening to assess your suitability for participation. During the telephone screening after the initial contact, a questionnaire will be used to exclude those who have a medical history of muscle, bone, never, heart or lung problems or those who use certain medications for sleeping or depression. We will also exclude patients suffering from coexisting psychiatric disorders or other neurological conditions. *If recruits are not eligible for the study, all information from the telephone screening procedures will be kept on file and will not be used for data collection. Files will only be used to keep track of the number individuals screened and actually enrolled in the study.*

You may be asked to participate in the baseline test session and 20 additional follow-up sessions (See follow-up sessions). Three of these 21 sessions last approximately 1-2 hours while the remaining ones take about 15 minutes to complete.

2. Baseline Session of the Research

The baseline session consists of a measurement session and a training session.

Measurement The measurement session includes the following tests:

1) A free bone density test. A qualified project staff will use an ultrasound device that will determine your calcaneus (heel) bone mass density. The device will emit ultrasound to assess the bone density. This procedure is non-invasive, and the soundwave is considered harmless to your body.
2) Body balance skill test. Two types of methods will be used to test your body balance skills: Berg balance test and posturography test. For Berg balance test, you will be

scored while performing a series of 14 functional balance tasks of increasing difficulty from quiet stance, sit-to-stand, weight shifting and reaching, turning in place, to single leg and tandem stance. Balance during quiet stance will be quantified by measuring spontaneous sway as you stand on side-by-side force plates. Three trials of 10 seconds will be tested in sequence for each of the 3 following conditions: eyes open, eyes closed, and eyes open while standing on a block of compliant foam.

3) Functional mobility test. Timed Up and Go test will be used to evaluate your functional mobility. You will begin the test in a seated position. You will be asked to rise from a chair, walk to a line on the floor about 10 feet away, turn around, walk back to the chair and sit down. The time it takes you to perform this test will be recorded.
4) Muscle strength test. Your muscle strength will be assessed with a Biodex muscle testing and training system on your right knee in a seated position on a backward-inclined chair. Your upper leg, the hips, and the shoulders will be stabilized with safety belts. You will be asked to extend your right knee as hard as you can.
5) Dynamic gait stability. You will be evaluated for normal walking trials over ground and on the slip trials on the treadmill. During normal walking and slip trials, a motion analysis system is used to record the positions of feet, ankles, knees, hips, shoulders, elbows, and wrists at known landmarks*. For this portion of the testing, reflective markers will be place on bony landmarks on the body to create a digital computer model. This process is non-invasive, and markers will simply be attached to the body with hypoallergenic porous skin tape.*
6) Fall rate test. You will be exposed to an unannounced simulated slip while walking on a treadmill under the protection of a full body harness. When you walk on the treadmill, the belt speed of the treadmill will suddenly change and produce a simulated slip. Your response to the slip will be recorded.

Training After the baseline measurement, you will be assigned to one of two training regimens (CWBV or Placebo). The vibration group will be asked to stand on a vibration platform with lightly bended knees at 20º during the training. The platform will deliver oscillation type vibration. The amplitude of the vibration is less than 0.6 in. To avoid the vibration reduction resulted from shoes, you will be requested to stand on the platform in bare feet. The vibration platform will be cleaned by using alcohol after each training session. The vibration training will be delivered in an intermittent way: each 1-minute vibration will be followed by a 1-minute rest for 10 minutes. The placebo group will perform a similar routine; however, the platform will not vibrate. Rather, an audio recording of the motor will play over a speaker.

Follow-up Sessions

You will be asked to come to the laboratory 3 times per week to receive the aforementioned training for 6 weeks. Immediately after the training sessions in weeks 6, we will conduct the same measurement tests as expressed above.
You will be asked to return to the laboratory 2 after your completion of the 6-week training. We will then measure all parameters expressed above.

4. What are the risks and discomforts of the study?

Rigorous safety protection measures will be adopted to prevent subjects from any potential risk resulting from the vibration training or slip perturbation. Before each training session, a 5-minute warm-up walking on a regular treadmill will be given to subjects. The known risk that may occur with participation in the proposed research includes itching in the lower legs during the training session and possible injuries resulting from slip perturbation. During training, all participants will be closely supervised by a research assistant in case of any balance losses or fall incidents. Subjects may experience itching in their lower legs. The itching will disappear quickly following the training session. If the itchiness stays longer than 3 minutes, we will apply cold compresses to the itching parts of the legs to alleviate the itchiness. To prevent any part of the body other than the feet from striking the treadmill belt surface during a falling caused by the slip perturbation, subjects will be placed in a full-body safety harness attached by a pair of dynamic ropes from the shoulders to a load cell and then to an overhead arch. The length of the dynamic ropes, which are typically used for fall protection in rock climbing, will be adjusted so that neither the knees nor the hands can touch the flooring. The dynamic ropes and full-body harness both have shock-absorption capacity. The full-body harness is padded and provides support over a large contact area (> 1500 cm^2), primarily in regions that are able to withstand larger forces without injury (i.e., the pelvis and buttocks). All participants will be given food and water along with rest periods, if needed.

5. What will happen if I am injured in this study?

The University of Texas at El Paso and its affiliates do not offer to pay for or cover the cost of medical treatment for research related illness or injury. No funds have been set aside to pay or reimburse you in the event of such injury or illness. You will not give up any of your legal rights by signing this consent form. You should report any such injury to Fabricio Saucedo at 915-747-6010 or fsaucedo3@miners.utep.edu and to the UTEP Institutional Review Board (IRB) at (915-747-8841) or irb.orsp@utep.edu.

6. Are there benefits to taking part in this study?

This study could possibly reduce your risk of fall and improve your fall resistance skills through the vibration training. Further, your participation in this study may help contribute to our understanding of the effect of the controlled whole-body vibration training in reducing the risk for falls among older adults. This knowledge will provide a basis for the development of optimal controlled whole-body vibration training paradigm to reduce the chance of fall-related physical injury.

7. What other options are there?

You have the option not to take part in this study. There will be no penalties involved if you choose not to take part in this study.

8. Who is paying for this study?

Internal Funding:

Funding for this study is provided by UTEP Department of Kinesiology and the Department of Interdisciplinary Health Sciences.

9. What are my costs?

There are no direct costs. You will be responsible for travel to and from the research site and any other incidental expenses.

10. Will I be paid to participate in this study?

You will be paid $120 participation in this study. The payment will be made after the completion of the study *and will be documented using a reimbursement form that will be kept on file along with all research documents.*

11. What if I want to withdraw, or am asked to withdraw from this study?

Taking part in this study is voluntary. You have the right to choose not to take part in this study. If you do not take part in the study, there will be no penalty.

If you choose to take part, you have the right to stop at any time. However, we encourage you to talk to a member of the research group so that they know why you are leaving the study. If there are any new findings during the study that may affect whether you want to continue to take part, you will be told about them.

The researcher may decide to stop your participation without your permission, if he or she thinks that being in the study may cause you harm, or if you miss more than 2 training sessions in any single week, or if you miss more than 5 sessions in the 6-week training period.

12. Who do I call if I have questions or problems?

You may ask any questions you have now. If you have questions later, you may contact Fabricio Saucedo by phone at (915-747-6010) or via email at fsaucedo3@miners.utep.edu.

If you have questions or concerns about your participation as a research subject, please contact the UTEP Institutional Review Board (IRB) at (915-747-8841) or irb.orsp@utep.edu.

13. What about confidentiality?

1. Your part in this study is confidential. None of the information will identify you by name. All records will be at a single office and in a locked file. Only the personnel directly related to the project will have access to the records.

2. Every effort will be made to keep your information confidential. Your personal information may be disclosed if required by law. Organizations that may inspect and/or copy your research records for quality assurance and data analysis include, but are not necessarily limited to:

- The sponsor or an agent for the sponsor
- Department of Health and Human Services
- UTEP Institutional Review Board

Because of the need to release information to these parties, absolute confidentiality cannot be guaranteed. The results of this research study may be presented at meetings or in publications; however, your identity will not be disclosed in those presentations. All records will be stored at a single office and in a locked file. Only the personnel directly related to the project will have access to the records.

During the experiment your movement response will be videotaped. You have the right to request to review/edit the tapes. Your personal identity will not be revealed in the videotape. We will give access only to investigators directly related to this project. The videotape or its reproduction may be used for publication in scientific journals or presentations at scientific meetings. All of the videos are taken from the side and back, where no facial feature will be identifiable. Thus, you would not be recognizable by a stranger without other identification from the record. The video tapes will be kept in a locked office. Only the Principal Investigator has the access key, and there are no duplicate keys. All records and video tape will be destroyed after the completion of the entire project.

14. Mandatory reporting

If information is revealed about child abuse or neglect, or potentially dangerous future behavior to others, the law requires that this information be reported to the proper authorities.

15. Authorization Statement

I have read each page of this paper about the study (or it was read to me). I know that being in this study is voluntary and I choose to be in this study. I know I can stop being in this study without penalty. I also acknowledge that my contact information will be kept on file and I may be contacted for future studies or follow-up sessions. I will get a copy of this consent form now and can get information on results of the study later if I wish.

Participant Name: _________________________ Date: ______________

Participant Signature: ______________________ Time: ______________

Participant or Parent/Guardian Signature: _______________

Date: ________________

Consent form explained/witnessed by (Signature): __________________

Printed name: __________________

Date: _______________ Time: __________________

Vita

Fabricio Saucedo received his bachelors and masters in Kinesiology from the University of Texas at El Paso. During his tenure at the University, Fabricio published scientific papers based on his research and disseminated the findings of his work at several national and international scientific conferences. In 2018, he was recognized by the American Kinesiology Association (AKA) for research and academic excellence. In addition to staying active in fall prevention research at the Gait Research and Movement Analysis Laboratory, Fabricio was also active as a lecturer in the Department of Kinesiology. Over the span of 2.5 years, Fabricio was responsible for Anatomical Kinesiology and undergraduate Biomechanics. Now he will serve as tenure-track assistant professor of biomechanics at Penn State Altoona in Altoona, Pennsylvania.

Contact information: fsaucedo3@miners.utep.edu

This dissertation was typed by Fabricio Saucedo Jr.