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Muscle Dynamics as the Result of Whole Body Vibration and Plyometrics

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Muscle Dynamics as the Result of Whole Body Vibration and Plyometrics

by

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the requirements for the degree
Doctor of Science in Physical Therapy

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Each person whose signature appears below certifies that this dissertation in his/her opinion is adequate, in scope and quality, as a dissertation for the degree Doctor of Science.

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DEDICATION

I want to dedicate this book to my parents, Richard and Charlene Hubbard, who dedicated their lives to the health and welfare of numerous children. In the process, they sacrificed time, finances, and energy for me and my four siblings. Their selfless, God-fearing model set the example for all of us. We are blessed because of you and you are greatly loved.

CONTENTS

TABLES

Tables Page

FIGURES

ABBREVIATIONS

WBV	Whole Body Vibration
ACL	Anterior Cruciate Ligament
VO2	Volume of Oxygen
cm	Centimeters
kg	Kilograms
in	Inches
lbs	Pounds
avg	Average
JV	Jumping with Vibration (group)
J	Jumping (group)
C	Control (group)
SD	Standard Deviation
RPE	Rating of Perceived Exertion
BMI	Body Mass Index

ABSTRACT OF THE DISSERTATION

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BACKGROUND: Whole body (WBV) vibration and plyometrics are common training techniques which increase strength, blood flow, force and power. The effects these techniques have on sedentary population is unknown. It is our aim to assess the effectiveness of WBV and plyometrics on sedentary population.

SUBJECTS: Three groups of nine sedentary subjects were assigned to either the control group (C), jumping only group (J), or jumping with vibration group (JV).

METHODS AND PROCEDURES: Measurements included: jump height (Myotest or Vertec), velocity, force, blood lactates, gastrocnemius and quadriceps strength, and exertion (RPE). Subjects were measured at the first, seventh, and eighteenth visits. C group attended measurements only. J and JV groups performed jumping from a vibrating platform (turned off for J and on for JV) to a surface 7-1/2 inches higher for 3 bouts of 20 seconds. J and JV groups attended three times per week for six weeks. Vibration was set at 40 hertz and 2-4 mm of displacement. Level of significance was set at $p \leq .05$.

RESULTS: There were no significant differences among groups for change in force ($p=.733$), velocity ($p=.862$), Vertec height ($p=.367$), and myotest height ($p=.647$). There was a significant increase in Vertec height from initial to final measure ($p=.04$) for JV group. RPE was significantly higher in JV than in C group at initial, three weeks, and six weeks ($p \leq .001$/ .008/ .004 respectively). There were non-significant decreases in blood lactate response to exercise in the experimental groups over time: J ($p=.895$) and JV ($p=.121$). There was significant interaction between group and time on quadriceps strength ($p=.02$) and a significant change of quadriceps strength between JV and C groups over 6 weeks (p-.02). There was a significant increase of gastrocnemius strength in J group ($p=.01$) by week 6.

CONCLUSION: JV group increased jump height, strength of quadriceps and gastrocnemius and greater exertion than controls. WBV with plyometrics had no effect on force, velocity, blood lactates, or calculated jump height. Further studies using an external focus may be necessary to elicit velocity, force and jump height changes.

Key Words: WBV, Sedentary, Force, Velocity, Jumping, Exertion

CHAPTER ONE

INTRODUCTION

Over the past decade, whole body vibration (WBV) has gained in popularity among athletes claiming its benefit in relation to strength and return to sports activities. Indeed, athletes have been the primary population that have been investigated. These studies have concluded that WBV not only increases strength (1-3), but also power (4), velocity and force changes (3, 5, 6).

It is believed that WBV works through increased neuromuscular changes to achieve these results, however there is little data regarding the mechanism by which WBV acts. In 2001, Staines concluded that WBV results in muscle-spindle discharge of the knee extensor muscles (quadriceps) which leads to gating of other afferent pathways (7). Another study in 2011 concluded that, although much research is being done to investigate performance changes resulting from WBV use (8). This study reported that the tonic vibration stretch reflex (TVR) may increase muscle activation through the use of stretch reflexes. They further reported that muscle tuning, neuromuscular changes may also contribute to enhanced muscle activation. But because of inconsistent methods and variables, defining the mechanism has been difficult to identify. The authors concluded that there needs to be more data to clearly understand the physiologic mechanism occurring within muscle.

WBV is most commonly applied with subjects standing on a platform that vibrates under their feet. Typically, this is performed in relation to some sort of exercise, e.g. squats, isometric holds, or even stretching. In 2007, Cardinale (9) described the optimal settings for displacement and amplitude of vibration. He identified 30-50 hertz of vibration and 2-5 mm of vertical displacement as optimal settings for performance of WBV. Many WBV studies have since applied these parameters from Cardinale's study.

In addition to physical performance changes noted above, physiologic changes have also been noted, including increased VO2 (10), and bone mineral density (11). Eckhardt (12) discovered a change in serum lactates with the use of WBV. This indicates there might be evidence of increased muscle recruitment when WBV is included with exercise. While recruitment of muscle is important, it should be noted that this study was performed over two sessions of WBV, so the long-term effects may not be clear.

Most studies involving WBV have investigated its effects upon the athletic population. This is important. However, with its increase in popularity in clinical situations, few studies have described the benefits of WBV on sedentary subjects. In 2011, Gojanovich described cardiovascular benefits (13) using WBV in the sedentary population and suggested WBV may reduce cardiovascular risk. Item et al describes further physiological benefits of a training program with WBV including an increase in capillarization, oxidative potential, endurance capacity, and muscle fiber size (14). Lohman described a doubling of skin blood flow for ten minutes after applying vibration to healthy subjects (15). It should be noted this study was performed with passive vibration (subjects laid supine with their legs on the vibration platform), not WBV, leading to the conclusion that vibration increased skin blood flow through vascular shearing. Although this study was performed on healthy subjects, an increase in skin blood flow (including nitric oxide) can be extremely helpful to persons with diabetes. Nitric Oxide, a natural chemical that has been shown to be a natural vasodilator (16), relaxes smooth muscle (17), decreases pain (18), reduces diabetic retinopathy (19) and reduces peripheral neuropathy (20). A follow up study by Johnson concluded that, although nitric oxide was not produced in greater quantities, passive vibration increased skin blood flow in subjects with diabetes (21) thus more available nitric oxide can be delivered peripherally.

A number of recent studies have highlighted the benefits of WBV in the geriatric population. Shim demonstrated improved balance scores and a decrease in fear of falling in the elderly (22, 23). This study was performed with horizontal vibration rather than vertical vibration. Although this was a pilot study, this study stands out as a very interesting study not only for its reported benefits, but the method of applying vibration in a horizontal direction. However, the author gives caution to this type of vibration as it is not commonly applied. In 2014, Perchthaler (24) reports the benefit of merging WBV with plyometrics in an older population. He reports a significant increase in strength and jump height and hypothesizes that WBV may help prevent the decline of neuromuscular performance. Filippi describes a prolonged exposure to WBV over the course of several weeks which may also increase muscle performance and standing stability in an elderly population (25). The benefits of this study were maintained for at least ninety days after the study concluded. To our knowledge, this is the only study that has investigated the effects of WBV in the elderly population three months after the intervention. This indicates that a long-term benefit may be derived from the use of WBV.

There has been a significant effort to understand what effects WBV might have on osteoporosis. According to Wolf's Law, it might appear that WBV would increase bone density. Nevertheless current studies are mixed on the efficacy of WBV in building bone density. A few recent studies indicate WBV has no effect on bone density (26, 27).

Yet a few studies starting to indicate that WBV may help lead to osseous growth (11, 28, 29). The benefit of WBV to enhancing bone density appears to result from either a prolonged use of WBV (six months) (11) or an intense WBV training regimen of 30 mins every 12 hours, five days per week (28). However, performing WBV over 6 months or an intense daily workout using WBV may not be feasible for many patients. Chow has demonstrated low-magnitude, high frequency vibration to rats has resulted in an increase in fracture healing and remodeling (30). Further study applying his parameters to human subjects may help lead to a better understanding of the benefits of WBV on bone density and healing.

Studies involving patients with neurological deficits have also reported positive changes including decreased contractures in patients with spina bifida (31). Studies of people who have suffered a stroke have reported increased EMG activity to the lower extremities (32), controlling spasticity (33), and improved task-oriented training (34). Further studies involving patients with Down Syndrome have identified WBV as helpful for improving standing balance and muscle strength (35). The use of WBV was shown to increase bone formation and strength in mice with osteogenesis impertfecta ("Brittle Bone Disease") demonstrated increased bone formation and strength (36). While this has yet to be assessed in children with osteogenesis imperfecta, it does give hope for building bone and preventing fractures. A recent study indicated that there may be potential to enhance muscle activity in patients with chronic spinal cord injuries (SCI) (37). This study indicated careful attention to amplitude and frequency would help to elicit desired electromyogram changes in patients with SCI. This phenomenon of persons with chronic

SCI being able to stand with WBV is likely due to the Tonic Vibration Stretch Reflex and as outlined earlier (8).

Studies have begun investigating the effects WBV has upon brain activity. A study in 2009 indicates WBV set at either 10 hertz or 20 hertz was responsible for decreasing subjects' attention and increasing their tendency to be tired (38) and a reduction of the wakefulness level of subjects (39, 40). Prolonged WBV has demonstrated an interruption of the cortex and subcortex (41).

Plyometric training (plyometrics) is another method of physical training used by athletes. Plyometrics is described as a rapid, lengthening stretch of the agonist muscle followed by a quick and forceful contraction of the same agonist muscle. Often plyometrics are performed with ballistic stretches and strong contractions. For example, a person is performing plyometrics by jumping from a 24 inch high surface to the ground, then immediately jumping back up to a surface 12 inches high without a rest. Plyometrics can be performed with a wide range of heights and jumps between surfaces. It can also be performed without the use of differing heights of surfaces.

Studies involving plyometric training have described benefits that include decreasing risk of ACL injuries (42, 43), increasing speed, power and endurance (44, 45), dynamic performance improvements including jumping and quickly changing speed (46), and jumping power (47, 48) and landing force reduction (48).

Studies involving plyometric training have also been shown to increase strength (45, 46, 49). This is widely believed to be a result of increasing neural adaptations within muscle. A meta-analysis of plyomterics studies concluded that several neuromuscular changes including increased neural drive and intermuscular coordination. They also concluded that there were changes in the size of the muscle-tendon complex and the mechanics of contraction (50).

In addition to performance changes noted with the use of plyometrics, recent studies have investigated the physiologic benefits. Brown (51) described a single bout of plyometric training as resulting in "increased oxygen consumption, heart rate, and blood lactate in both men and women." Behrens (52) concluded that neural adaptations were likely responsible for increasing jump height and strength.

Recent studies have begun to investigate the effects of plyometrics on groups other than athletes. A recent study found that dynamic balance was improved in the elderly population (53). A study involving young, adolescent girls demonstrated that greater bone mass was maintained over nine months after performing plyometric training than a similar group of control subjects (54). Young subjects with Down Syndrome had more lean muscle mass after application of plyometric training (55). Johnson reported two studies where plyometrics was used with pediatric patients. In his studies, plyometrics was helpful in improving gross motor ability and upper extremity use in children with unilateral cerebral palsy (56). He further reported positive changes in throwing and jumping performance in children with neurofibromatosis type-1 (57).

Reports of clinical use of plyometrics in rehabilitation of orthopedic injuries are starting to emerge. Ismail reported that plyometric training is more effective than resistance training for ankle stability (58). Huang also reports an increase in static and dynamic stability and softer landing strategies of the ankle after performing plyometrics over six weeks, as compared to a group of controls (59).

Although plyometrics have been used for many years, no standard or protocol exists for its use. In 2013, Beneka (60) has subjects perform 50 drop jumps from a 50 cm height and 50 jumps over 50 cm hurdles. Tobin (61) described drop jumps from a 70 cm height, hurdle hops and ankle hops. In Lockie's study (62), subjects performed box jumps and double-leg hurdle jumps from an undefined height. Not only did these studies have varying heights and surfaces, their repetitions and type of jumps were not similar. It is important to note this as there are no well-defined protocols. However, several studies (63-65) are in agreement that a frequency of three days per week of strength training over six weeks is sufficient to note a change in muscle strength and power.

Few studies combining both WBV and plyometrics exist. To our knowledge, there are no studies that apply WBV and plyometric exercises to a sedentary population. Since most studies performed involve athletes, there may be some benefits that WBV combined with plyometrics may demonstrate when applied to a sedentary population. Since WBV has become more popular in clinical settings, the investigation of benefits or harm to patients becomes even more important.

It is our aim to investigate effects WBV and plyometrics have upon the sedentary population. We will investigate changes in strength of the quadriceps and gastrocnemius. We will also examine if jump height, velocity, and force are changed with the use of WBV and plyometrics. Finally, blood lactates will be assessed through the duration of the study and Borg's Rating of Perceived Exertion will be used to assess the amount of exertion is experienced by subjects.

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CHAPTER TWO

MUSCLE DYNAMICS AS THE RESULT OF WHOLE BODY VIBRATION AND PLYOMETRICS

Abstract

BACKGROUND: Whole Body Vibration (WBV) and Plyometrics are two common methods to strengthen muscles. It is not clear what benefits WBV and plyometrics has on a sedentary population. Our aim was to investigate the effects of WBV and plyometrics upon the strength of sedentary subjects.

SUBJECTS: Twenty-seven healthy, sedentary subjects were placed into the Control (C), Jumping only (J), or Jumping with vibration (JV) group. Groups consisted of 9 subjects each.

METHODS AND PROCEDURES: Subjects were measured for right quadriceps and right gastrocnemius strength on the first, seventh, and eighteenth visits. The control group returned for measurements only. J and JV jumped between a vibration platform (turned on for JV and off for J) to a box 7-1/2 inches higher three days a week for six weeks. Subjects jumped for three bouts of 20 seconds at 40 hertz with 2-4 mm of displacement. Significance level was set at $p \leq .05$.

RESULTS: *Quadriceps*: Initial analysis showed a significant interaction between group and time ($p=.02$). There was a significant-difference in change of quadriceps strength between the JV and C groups over 6 weeks. ($p=.02$). Post hoc tests revealed a non-significant increase strength in the JV group and a significant decrease in strength in C group ($p=.03$). *Gastrocnemius*: There was a significant overall increase in strength across all groups over time (p=.01). However improvement in strength reached significance only in the J group (p=.01) by week 6.

CONCLUSION: WBV with Plyometrics can be an effective tool for strengthening quadriceps. Plyometrics alone produced increased gastrocnemius strength. Using both WBV and plyometrics simultaneously may be of greater benefit in strengthening the lower body.

Key Words: Strength, Quadriceps, Gastrocnemius, Sedentary, WBV

Literature Review

Many techniques are used to assist with the training of muscles. One that is gaining popularity recently is Whole Body Vibration (WBV). Current training strategies using WBV in the strengthening of muscles have been performed in a variety of ways; isometrics, plyometrics, and super-imposing an exercise regimen while performing WBV plus exercise.

WBV plus exercise has grown in popularity due, in large part, to anecdotal evidence by athletes and other high-profile personalities. Recent studies indicate WBV can improve balance and prevent falls (1-3), increase muscle mass (4), increase skin blood flow (5) which might be beneficial for people who have diabetes mellitus, improve knee stability and proprioception (6, 7) and could be potentially useful in prevention of osteoporosis (8, 9).

Initial studies investigating performance changes, however, have not had as clear of a positive effect as physiological aspects mentioned above. Some studies indicate WBV with exercise has resulted in an increase in jumping power (10) when applied to young, healthy adults over a four month period. However, another study indicates there appeared to be no difference in jump height over an eleven week period (11). What further complicates the understanding and interpretation of these results are the frequencies and displacement of the vibration platform are not uniform.

In 2007, Cardinale (12) identified standardized vibration training frequencies of WBV. Several other studies not only have agreed that the range of frequency, from 30-50 hertz and 2-5 mm of vertical displacement as ideal, but many others have also adopted those rates and applied them to research resulting in significant changes in cardiovascular benefits, VO2 increases, and isometric and explosive knee strength (2, 13, 14).

Recent studies that have applied Cardinale's vibration parameters (12) to their investigation of dynamic strength in relation to WBV, tend to indicate noted strength changes (15-17). Each of these studies, however, were performed on athletes. Indeed most studies performed with the use of whole-body vibration in relation to strength, are performed with athletic populations. This results in a lack of understanding regarding strength in relation to the sedentary population.

A further challenge when using WBV, is that there may be a ceiling effect when applied to high level athletes (18). Therefore, WBV might produce a greater benefit to a non-athletic population. This is important as we look at the population who might benefit most from WBV use in rehabilitation, and we can therefore begin to apply WBV use to the population on the whole.

Another training technique that has been used effectively in strengthening muscles is plyometric training (19, 20). Plyometrics are performed with a rapid eccentric load of a muscle followed by a rapid concentric contraction of that same muscle to gain strength and power. It is typically performed with the use of jumping (typically from a high surface to a lower surface, but not necessarily) where the quadriceps (for example) receive a rapid eccentric load, followed by that same muscle performing a strong concentric contraction in an effort to jump. Plyometric training is typically performed jumping between high and low surfaces ranging from 12 to 36 inches in height. Plyometrics are typically performed independent of any other source of training.

Plyometrics have been used for several years and have been published extensively (21-25). A recent meta-analysis identified plyometrics as effective in preventing ACL injuries in female athletes (21), improved explosive movements (22-24), and used to help prevent other injuries (25). Although studies have indicated increased strength and jumping performance (16) with the use of WBV and plyometrics in the athletic population, there are no studies in the sedentary population as yet. In the present investigation we merged these two training techniques to assess whether there are strength changes that occur when both WBV and plyometrics are combined to the sedentary population.

Subjects

Subjects were assigned to 3 groups (Control, Jumping, Jumping with Vibration), consisting of 9 subjects each. To be included in this study, subjects must have been 18-40 years of age, not currently involved in an exercise program, and able to tolerate jumping activities. Subjects did not: 1) have any lower extremity or lumbar injury from the past 2 years; 2) have any injury from the past two months; 3) have balance or equilibrium deficits; 4) be a high level athlete (high level athlete is defined as participating in an organized team or individual sport, with or without competition, which involved physical practice or preparation) or any individual exercise program; or 5) have high blood pressure (defined as 140/90 or higher blood pressure).

The control group (C) did not receive any intervention throughout the study. They were measured as outlined; at initial measure, three, and six weeks.

The plyometric jumping only group (J) performed plyometric training three times per week for the six week study. Subjects jumped laterally between the vibration platform (platform is not turned on) and a plyometric box 7 ½ inches higher than the vibration platform. Subjects jumped between the two surfaces for three bouts of 20 seconds with one minute rest between bouts. Subjects performed this activity three times per week for 6 weeks.

The plyometric jumping with vibration group (JV) performed plyometric jumps laterally from vibration platform (platform is turned on) to another platform 7 ½ inches higher than the vibration platform. Subjects jumped between the two surfaces for three bouts of 20 seconds with one minute rest between bouts. They performed this activity three times per week for 6 weeks. No jumping as performed on consecutive days.

As mentioned above, to be included in this study, subjects needed to be currently not involved in an "exercise program". This was defined as any activity, in the previous 3 months, where the subject purposely set aside time for any increase in activity outside of regular, daily work tasks. This would include obvious activities such as going to work out in a gym, jogging, or any organized team sport. This would also include such activities as going for a walk during a lunch break or in the evening.

All protocols and procedures were approved by the Institutional Review Board of Loma Linda University and all subjects signed a statement of informed consent.

Methods

Whole Body Vibration and Plyometric Performance

Whole body vibration was conducted using the stand-alone unit, Globus

Physioplate (Hi Tech Therapy, Johannesburg, South Africa). Settings were adjusted for 40 hertz of vibration with 2-4 mm of amplitude displacement. To the right of the WBV plate was a stable box measuring 7-1/2 inches higher than the plate at rest. Subjects in the jumping and jumping with vibration groups were instructed to jump from the WBV platform to the box to the right and return to the platform as quickly as they could for 20 seconds. Subjects were asked to jump to the right rather than forward due to safety concerns for subjects. Subjects in the two experimental groups were instructed to perform these 20 second bouts three times each session. Sessions were arranged three times per week over six weeks. No jumping session was performed on consecutive days.

Subjects who were in the jumping (plyometrics) with vibration group, performed the same parameters as those who were jumping only. However, the lower platform was set to vibrate at 40 hertz with a displacement of 2-4 mm vertically.

Measurement of Isometric Strength

Muscle strength of the right quadriceps was measured with a strain gauge transducer, which was attached to four strain gauges on opposite sides of a steel bar. The bar was fixed to a chair that had a strap that was adjustable to the ankle. This strap was placed distally on the leg--just proximal to the talocrural joint. With the subject seated and hips and knees in 90 degrees flexion respectively, force was exerted through the strap and the strain gauge, which was arranged in a Wheatstone bridge, and caused a bending of the bar. An electrical output was provided to a Bio Pac (Bio Pac Systems, Goleta, CA) system DAC100 c bioelectric amplifier. The signal was amplified 5,000 times and then digitized through a Bio Pac MP 150 analog to digital converter at a resolution of 24 bits and a frequency of 1,000 samples per second, and stored digitally for later analysis. Data analysis and storage were accomplished using the Acknowledge 4.1 software from Bio Pac Inc. (Bio Pac Systems, Goleta, CA). Muscle strength was measured on three occasions. On each occasion, subjects contracted their quadriceps until maximum strength was reached as noted by a decrease in strength reading. Subjects had a brief 2-5 second rest between contractions. The average of the three contractions was calculated and used in the data analysis of each subject's quadriceps maximal strength. Each strain gauge was calibrated with the use of a digital calibrator to indicate the strength exerted via the force through the strain gauges by pulling on the bar.

Measurement of the right gastrocnemius strength was performed using a simple articulating Ankle-Foot Orthosis (AFO) with adjustable Velcro strapping at the dorsum of the ankle joint. The AFO had a natural resting position of 0 degrees. The AFO was modified with the use of a plate to reinforce the plantar surface of the AFO and straight bar at the end of the AFO where a Wheatstone Bridge was constructed to determine strength of the gastrocnemius via the bending of the bar. An electrical output was provided to a Bio Pac (Bio Pac Systems, Goleta, CA) system DAC100 c bioelectric amplifier. The strength measurement was measured using the same methods and technology as the quadriceps measure. The AFO was calibrated similar to the chair for quadriceps extension where a strain gauge was calibrated with the use of a digital calibrator to indicate the strength exerted via the force through the strain gauges on the bar.

Procedures

Upon arrival to the first session, subjects signed an informed consent, were assigned to a group, and were briefly instructed in procedures to be performed.

Initial measurement of quadriceps and gastrocnemius strength was performed with use of the Bio-Pac system. Each subject performed 3 consecutive bouts of maximal contractions of each respective muscle with a rest between each bout. Subjects, then, performed their intervention activity (no activity for the control group) as described below.

Data Analysis

A two-way repeated measures ANOVA was used to assess for interaction between time and group on quadriceps and gastrocnemius strength. As the assumption of equal variances between groups was met for each outcome variable parametric tests were selected for data analysis. When there was a significant interaction, a one-way ANOVA was used to determine if there were significant differences between the groups over time followed by Bonferroni post hoc tests to identify where the difference occurred. Paired-t tests were used to compare initial measure to week 3 and week 6 within groups. The significance level was set at $p=.05$.

Results

Quadriceps

Table 1. Comparison of Quadriceps Strength (kg) Over the 6 Weeks of Study Between the Treatment Groups.

	Control Group (n = 9)		**Jumping Only Group (n = 9)**		**Jumping+Vibration Group (n = 9)**	
	Mean	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**
Baseline	30.0	7.4	33.4	13.6	33.9	12.7
6 weeks	26.8	7.6	32.1	13.4	37.8	16.4

The initial 2-way repeated measures ANOVA resulted in a significant interaction between group and time on quad strength (p=.02) (Table 1). One-way ANOVA showed that a statistical significance in at least one group made a significantly greater (p=.02) change over six weeks. Bonferroni post hoc tests further revealed a significant difference between the control group and the jumping with vibration group (p=.02) over the six weeks of the study. There were no significant differences between the C and J groups (p=1.00) or the J and JV groups (p=.11).

Paired-t tests showed that there was a significant decline in quadriceps strength in the control group (p=.03). There was no significant change in the other two groups (Figure 1).

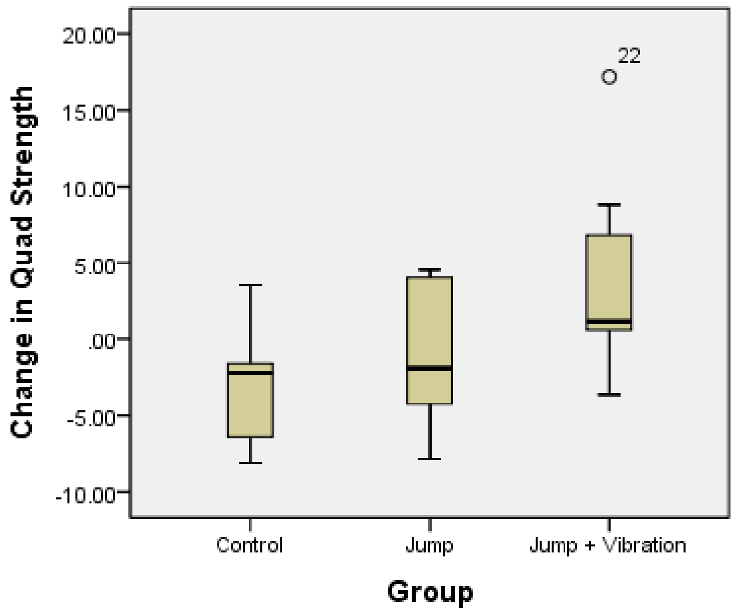

Figure 1. Percent of Change of Quadriceps Strength From Week 1 to Week 6 Displayed in Control, Jumping and Jumping with Vibration Groups

Gastrocnemius

Table 2 displays improvements in gastrocnemius strength over the course of the study.

Table 2. Comparison (Means and Standard Deviations) of Gastrocnemius Strength (kg) Over the 6 Weeks of Study Between the Treatment Groups.

	Control Group (n = 9)	**Jumping Only Group (n = 9)**	**Jumping + Vibration Group (n = 9)**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**
Baseline	14.2 (6.2)	11.4 (4.3)	14.6 (5.8)
3 weeks	14.7 (5.4)	13.7 (5.5)	16.5 (5.5)
6 weeks	14.9 (6.4)	14.0 (4.0)	16.4 (6.5)

Comparing baseline and 6 week values, 2-way repeated measures ANOVA revealed a significant effect of time across all groups (p=.006). All three groups did increase in gastrocnemius strength, however only the jumping group increased significantly in gastrocnemius strength from the first to sixth week (p=.01) (figure 2). There were not significant differences between groups in change of strength (p=.55).

The same analysis between the initial and third week, also showed an effect over time (p=.008) with the change in the jumping group reaching statistical significance (p=.03). Indeed all three groups experienced the greatest change between the initial and third week (p=.01).

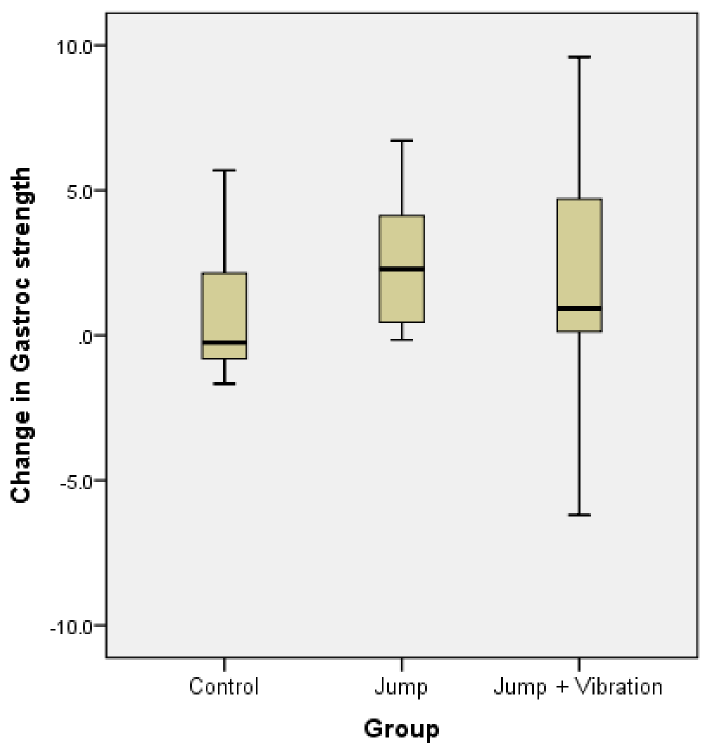

Figure 2. Percent of Change of Gastrocnemius Strength From Week 1 to Week 6 Displayed in Control, Jumping and Jumping with Vibration Groups.

Discussion

The current literature suggests that WBV is effective for increasing physical performances of strength, jump height and force (17, 18, 26-28) and each of these studies have emphasized the use of WBV on athletic populations. More recent studies are starting to focus on non-athletic populations. Several studies are now showing there are benefits of using WBV with people who have suffered a stroke. These benefits include: task-oriented training (29), increased EMG activity to lower extremities (30) and may be helpful in controlling spasticity (31). Patients with spina bifida have had documented benefits of decreased contractures and increased muscle function (32). Elderly people have demonstrated a decreased fear of falling and improved balance scores with the use of WBV (33). Although early studies have focused on changes within the athletic population, it is good to see increased testing of the effectiveness of WBV on people who may benefit from its use therapeutically. The results are encouraging.

To this point, there are no published studies that have investigated the sedentary population with regards to these measures. This is important as the use of WBV is increasing, not just in training or to increase physical performance, but for rehabilitation of injuries. Rehabilitation of injuries would likely include a sedentary population. To our knowledge, this is the first study to include plyometric training and WBV. Further, the subjects included in the study are sedentary lending to the possibility of greater notable changes. The difference between this study and most other studies investigating WBV is that we investigated a sedentary population.

Within this study we investigated three separate groups of sedentary subjects to assess whether WBV with plyometrics would result in changes to strength of the quadriceps and gastrocnemius muscles. We can see from the data that there is a significant increase in quadriceps strength noted in the JV group as compared with the other two groups over the six weeks. This change is attributable to the inclusion of both interventions simultaneously. We can conclude that the quadriceps' increase in strength is due to inclusion of WBV as the JV group had a significant change from both the control and jumping only groups. The control and jumping only groups each noted a decrease in strength over the six weeks of the study. This may be attributable to two possibilities: 1) A lack of consistency of effort; and 2) All subjects are sedentary so fatigue may be a factor, most notably for the control group. However, Bush (15) also described a significant decrease in the strength of the quadriceps muscles with dynamic and static squats without the use of WBV. This is an interesting phenomenon as one might expect strength changes to increase out of simple training effects and patient familiarity with the study measures. Nevertheless, strength decreased without the use of WBV in the current study and with the controls in his study.

Gastrocnemius strength increased significantly in each group with a notable significant change within the J group. The greatest change across all groups was appreciated between the initiation of the study and week 3. Figure 2 above demonstrates that all three groups did not continue to have such marked increase in strength from weeks four to six. This increase from initiation to week three and week six may be a result of increasing bias to using the gastrocnemius muscles for jumping as even the control increased. Arai (34) describes the medial gastrocnemius as being a predominant muscle that is contracted with jumping activities. J group and JV group each appreciated greater gains in gastrocnemius strength as compared C group. This is attributable to plyometric training as compared to WBV as the only difference between these two groups is WBV, and the JV group did not appreciate the changes of J group.

It should be noted that there was a great amount of variability of strength in percent of change in the JV group. Perhaps small sample size might contribute to this variability. However, variances were measured and determined to be equal. Therefore, although variability in the change of strength over time appears to be present, it was not determined to be significant in analysis of the data.

There are no generally accepted protocols for plyometric training. Tobin (35) describes a variety of plyometric exercises (drop jumps from 70 cm height, hurdle hops, ankle hops) included in their study. Beneka (36) describes 50 drop jumps from a 50 cm height and 50 jumps over 50 cm hurdles and Lockie (37) describes box jumps and double-leg hurdle jumps from undefined heights. In this study, it was decided that subjects would perform lateral drop jumps from 7 1/2 inch height in rapid succession over 20 seconds for a few reasons. First, this study was designed to investigate, in part, what role WBV might have in strengthening. Therefore, we needed to consistently jump in rapid succession onto the platform. Second, 7 1/2 inches height for jumping was selected due to the rapid and repeated jumping subjects would have to perform. This height (7 1/2 inches) is lower than those height reported above. However, the subjects in this study were both untrained and sedentary and it was suspected that they would fatigue more quickly so a lower height was selected for subject safety and ability to complete the jumping protocol. The length of the study (6 weeks) and sessions per week (3) were selected in agreement with other protocols as sufficient to identify the strength changes and to adequately provide rest for subjects between sessions. (38-40). Considering the lack of activity of the subjects in this study, six weeks should be sufficient to note a change for this population as Bush obtained differences with one bout of WBV (15).

Due to the size of the platform upon which subjects were jumping, the decision was made to have the subjects jump laterally for safety. Further studies to investigate a forward/backward jumping protocol or a counter-movement jump protocol (quick squat downward prior to quickly jumping straight upward) might shed further light on strength and dynamic force. Performing a similar study or one that is adjusted as noted above for the athletic population might also be helpful for physical performance measures and abilities. Adding a graduated jump height protocol where the height jumped per week is slowly increased, might also be beneficial in demonstrating an increase in force, velocity, strength, and height. Subjects would not tend to become conditioned to the exercise and differences may be noted.

The strict inclusion/exclusion criteria made recruiting difficult. Asking a sedentary group of people to participate in a study three times per week for six weeks and have them exercise each of those times (albeit for 5 minutes typically), made the recruiting difficult. Multiple potential subjects were interested, but did not ultimately participate in the study when the parameters were known.

Conclusion

This study has helped identify, within a sedentary population, that WBV can be an effective tool to strengthen the quadriceps muscle over a six week strengthening program. Strengthening of the gastrocnemius muscle had a significant increase with jumping alone. This indicates that WBV may not have a great impact in gastrocnemius strength in comparison to plyometric training alone. Using both plyometric training and WBV synonymously may be of greatest benefit to optimize functional strength in the lower body.

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CHAPTER THREE

PLYOMETRICS AND VIBRATION-NO CLEAR WINNER ON EFFICACY

by

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Abstract

BACKGROUND: Whole body (WBV) vibration and plyometrics are common training techniques which increase strength, blood flow, and lower body force and power. The effects these techniques have on sedentary population is not known. It is our aim to assess the effectiveness of WBV and plyometrics on sedentary population.

SUBJECTS: Three groups of nine sedentary subjects were assigned to either the control group (C), jumping only group (J), or jumping with vibration group (JV).

METHODS AND PROCEDURES: Measurements included: jump height (myotest or vertec), velocity, force, blood lactates (LA), and perceived exertion (RPE). Subjects were measured on the initial, seventh, and eighteenth visits. C group attended measurements only. J and JV groups performed jumping from a vibrating platform (turned off for J and on for JV) to a surface 7-1/2 inches higher for 3 bouts of 20 seconds. Each subject in J and JV groups attended three times per week for six weeks. Vibration was set at 40 hertz and 2-4 mm of displacement. Level of significance was set at $p \leq .05$.

RESULTS: There were no significant differences among groups for change in force ($p=.733$), velocity ($p=.862$), Vertec height ($p=.367$), and myotest height ($p=.647$). However, there was a significant increase in Vertec height from initial to final measure ($p=.04$) for JV group. RPE was significantly higher in JV than in C group at initial, three weeks, and six weeks ($p \leq .001/ .008/ .004$ respectively). There were non-significant decreases in blood lactate response to exercise in the experimental groups over time: J ($p=.895$) and JV ($p=.121$).

CONCLUSION: WBV with vibration increased jump height. JV experienced greater exertion than for controls. WBV with plyometrics had no effect on force, velocity, blood lactates, or calculated jump height. Further studies using an external focus may be necessary to elicit velocity, force and jump height changes.

Key Words: WBV, Sedentary, Force, Velocity, Jumping, Exertion.

Literature Review

Whole Body Vibration (WBV) is a modality that continues to gain in popularity. WBV has been applied a number of ways however, one of the more common applications is with the participant standing on a machine which performs vertical vibration.

There had been no unanimous understanding of the optimal frequency for WBV until 2007. Cardinale (1) identified optimal displacements of 30-50 hertz and small amplitudes of 2-5 mm of vertical displacement. Since that time many studies have accepted these measures. These studies have assessed several physiological changes during WBV including increased VO2 (2), lower-body power (3), strength (4-6), and physical performance(6-8) and changes increasing jump height, velocity and force.

Whole body vibration started initially as a training tool to help increase strength and physical performance (i.e. jumping) (6, 9-11). Several studies have been performed showing physiological benefits with increased VO2 (2), skin blood flow (12), and bone mineral density (13). Eckhardt recently investigated the effect WBV with exercise has upon serum lactates (14) and concluded that there may be evidence of increased recruitment of muscle when WBV is performed with exercise versus the same exercise regimen without WBV. This study was performed over only two sessions and therefore the effect over time may not be significant. It should be noted that this study was performed on subjects that were described as "recreationally active men".

Nearly every study was performed on either athletes or people who were either active or performing athletic activities. Gojanovic investigated the effects of WBV on sedentary subjects (15, 16) recently identified WBV as helpful for the sedentary population in cardiovascular improvements. Sedentary was described as "less than 20 to

60 minutes of vigorous physical activity". His second study identified WBV increasing levels of creatine kinase. However this was not long lasting and did no harm to the subjects. This is important as it identifies WBV as an effective and safe tool that sedentary people may use.

Plyometric training is another form of training that has been used for increasing strength (17, 18) and reducing the risk of ACL injuries (19, 20), increasing speed (21), and explosive movements (18, 22), and jumping (23, 24). In addition to studies regarding physical performance, recent studies have begun to investigate physiologic changes including neural adaptations after plyometric exercise (25). Brown (26) describes an increase in blood lactates, increase in O2 consumption and heart rate with a single bout of plyometric training. This was described as relating to aerobic power training.

Plyometric training is described as a quick, lengthening stretch of the agonist muscle followed by a rapid and forceful contraction of the agonist. Most notably, this is performed with jumping activities. An example would be standing still, then quickly squatting low prior to forcefully jumping upward (counter-movement jump). Plyometric training is performed repetitiously. So one would not simply perform one jump, but multiple in succession.

There are a few studies where plyometrics and WBV are combined. Those studies typically involve athletes or physically active subjects. These two training concepts were combined to assess the effects they have on jumping, velocity of jumping, and force upon sedentary subjects. Additionally, we investigated the effects of those two concepts upon physiological measures of blood lactates and affective measures using the Borg RPE scale.

Subjects

Subjects were assigned to 3 groups, consisting of 9 subjects each (table 1). To be included in this study, subjects were 18-40 years of age, not currently involved in an exercise program, and able to tolerate jumping activities. Subjects did not: 1) have any lower extremity or lumbar injury from the past 2 years; 2) have any injury from the past two months; 3) have balance or equilibrium deficits; 4) be engaged in any sort of exercise regimen; 5) have high blood pressure (defined as 140/90 or higher blood pressure).

Table 1. Group Demographics.

	Sex	Age (avg)	Height (in)	Weight (lbs)	BMI
Control	8 females 1 male	26	65	147	24.46
Jumping	8 females 1 male	29	64	133	22.80
Jumping with Vibration	7 females 2 males	26	65	146	24.39

As mentioned above, to be included in this study, subjects needed to be currently not involved in an "exercise program". This was defined as any activity, in the previous 3 months, where the subject purposely participated or exercised as a part of a team in an organized or recreational setting; participated in any individualized exercise setting; performed any exercise in a recreational setting--including walking, jogging, hiking, etc.

All protocols and procedures were approved by the Institutional Review Board of Loma Linda University and all subjects signed a statement of informed consent.

Methods

Whole Body Vibration and Plyometrics

Whole body vibration was conducted using the stand-alone unit, Globus Physioplate (Hi Tech Therapy, Johannesburg, South Africa). Settings were adjusted for 40 hertz of vibration with 2-4 mm of amplitude displacement.

Measurement of Jump Height

Jump height was measured using a Vertec® (Columbus, OH) vertical jump equipment. This device is adjustable for jump height and has several short, plastic rungs that swing away when contacted, thus identifying the height achieved (in inches). It was used at the initiation of the study and then again at three and six weeks into the study. Subjects stood below the rungs and performed a counter-movement jump (CMJ) upward to touch the highest rung they could reach. Subjects would make three attempts to jump as high as possible and that average of the three measurements would be taken.

This device does not need specific calibration. It has specific marks along the upright standard which identifies various heights (in inches). Measurements conducted with the use of measuring tape along the upright standard to verify the correct heights were as listed.

Velocity to Max Jump Height/Force/Jump Height (Calculated)

The measurement for velocity to max jump height, force, and calculated jump height was measured using the Myotest Performance Measuring System (Sion, Switzerland). This device is attached to the hip laterally. By inputting the subject's height and weight, a read out is given on the screen identifying the subject's velocity in jump height in cm/s. This device was also used to measure maximum height attained and force through lower extremities by similar method as velocity.

Once the information was put into the device, subjects would wait for five separate beeps. After each beep, the subject would perform a counter-movement jump as high as possible. After the five trials, the Myotest unit would display the average of the five trials.

Lactic Acid Measurement

Measurement for blood lactic acid (LA) was conducted with the use of the Lactate Plus Analyzer from Nova Biomedical (Waltham, Massachusetts). The finger tip blood was arterialized. Subjects pricked their finger with the lancets that accompanied the analyzer. The blood drawn would be placed on the analyzer test strips. This was conducted before and after exercise on the first, seventh and eighteenth visits (beginning of week 3 and end of week 6). Measurements of blood lactates were conducted prior to exercise and approximately 3-5 minutes after the exercise (27). The change in blood lactate levels from pre- and post-exercise was then calculated.

Rating of Perceived Exertion Measurement

After completing each measurement session, the subject expressed their rating of perceived exertion (RPE). This was performed using the standardized Borg Rating of Perceived Exertion scale which ranged from 6-20 where a rating of 6 corresponds to no exertion at all and 20 corresponds to maximal exertion.

Procedures

Upon arrival to the first session, subjects signed an informed consent form, were assigned to a group, and briefly instructed in procedures to be performed.

Initial measurement of blood lactates, vertical jump height, calculated jump height, force, jumping velocity, and RPE were conducted. Subjects, then, performed their intervention activity (no activity for the control group) as described below. The same procedure was performed for data collection on visits 7 and 18.

The control group (C) did not receive any intervention throughout the study. They were measured as outlined; at initial measure, three, and six weeks.
The plyometric jumping only group (J) performed plyometric training three times per week for the six week study. Subjects jumped laterally between the vibration platform (platform is not turned on) and a plyometric box 7 ½ inches higher than the vibration platform situated to the right of the vibration plate. Subjects jumped between the two surfaces for three bouts of 20 seconds with one minute rest between bouts. The plyometric jumping with vibration group (JV) performed the same activity, but the machine was vibrating at 40 hertz with 2-4 mm of displacement. They also performed this activity three times per week for 6 weeks. No jumping was performed on consecutive days.

Data Analysis

For quantitative outcome measures that met the assumption of equal variances between groups, two-way repeated measures ANOVA was used to analyze changes in the measures between groups and over time. Paired-t tests were used to assess for changes in outcomes over the length of the study for each group. For outcome measures that did not meet the assumption of equal variances between groups, the Kruskal-Wallis test was used to determine if changes in outcome differed by group. Post hoc pair wise comparisons were made with Mann Whitney tests. To analyze within group changes, the Wilcoxon Signed Rank test was used. Similarly, the Kruskal-Wallis test was used to assess the differences in the ordinal RPE measure followed by the Mann-Whitney test for two group comparisons. The statistical analysis was performed with the use of SPSS software (SPSS Statistics Faculty Pack, IBM Corporation, Armonk, New York, USA). Level of significance was set at $p=.05$.

Results

For each of the physical performance measures, there were no significant differences among the groups for change in Vertec jump ($p=.367$), Myotest height ($p=.647$), force ($p=.733$), or velocity ($p=.862$). When we repeated these analyses using percent of change in performance measures, there remained no significant differences between groups in Vertec height ($p=.394$), Myotest height ($p=.556$), Force ($p=.742$), or velocity ($p=.915$).

Table 2. Percent Change in Blood Lactate Levels (Pre-Post Single Bout of Exercise) Over the 6 Weeks. (p=.05)

	Jumping Only Group (n = 9)		**Jumping+Vibration Group (n = 9)**	
	Median	**(min, max)**	**Median**	**(min, max)**
Baseline	168	(-23, 400)	282	(-22, 382)
3 weeks	130	(10, 570)	123	(63, 433)
6 weeks	149	(-44, 644)	118	(67, 262)
P*	.90		.12	

On the other hand, the percent of change in blood lactate levels was not significantly different between the initial measure and three or six week measures (p=.895, p=.121 respectively) in the two experimental groups (Table 2). There were significant differences in blood lactate response to the respective interventions among the three groups at the initial measure (p=.00), three weeks (p=.00), and six weeks (p=.00). Specifically, only the two experimental groups showed significant increases in blood lactate post intervention: at initial (p=.02), three weeks (p=.01), and six weeks (p=.01) in J group and at initial (p=.02), three weeks (p=.01), and six weeks (p=.01) in JV group.

Initial analysis revealed significant overall increase in the Vertec jumping measure from initiation of the study to completion (p=.05), but no significant overall group effect. Further assessment revealed a significant increase only within the JV group (p=.04).

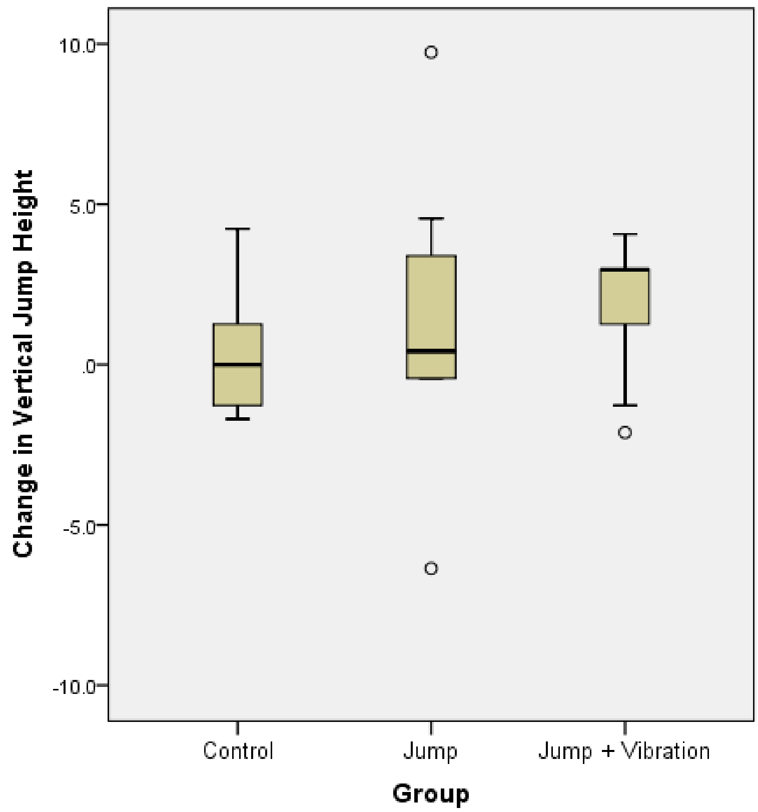

Figure 1. Pre- vs. Post-Data Collection Changes in Jumping Height Among the Three Groups.

Table 3. Comparison of Vertec Jump Height (cm) Over the 6 Weeks of Study Between the Treatment Groups.

	Control Group (n = 9)	Jumping Only Group (n = 9)	Jumping + Vibration Group (n = 9)	
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	***P****
Baseline	242 (12.5)	239 (14.8)	240 (13.2)	.91
6 weeks	243 (13.1)	241 (13.1)	242 (13.8)	
P*		.05		
P**	.67	.31	.04	

*Two way ANOVA effect of groups
**Two way ANOVA effect of time
*** Paired t-test

Statistical analysis of RPE measures demonstrated a significant difference between at least two groups at initial measurement ($p=.00$), three weeks ($p=.03$), and six weeks ($p=.02$). Further post hoc testing using independent samples Mann-Whitney test revealed that there were significantly higher RPE in the JV group than the control group at initial measurement ($p=.00$), three weeks ($p=.01$), and six weeks ($p=.00$). There was also a significantly higher RPE in the J group than the control group at initial measure ($p=.00$) but not at three and six weeks. There were no significant difference between the jumping only and jumping with vibration groups.

Comparison of RPE within groups over time, resulted in a significantly higher RPE in the JV group from initial measure to measure at week six ($p=.04$). Although there was no significant difference in J group from initial measure to week six ($p=.06$), there was a notable decrease in RPE over the course of six weeks (Table 4).

Table 4. Descriptive Statistics for RPE Measurement Among all 3 Groups at Initial Data Collection, 3 Weeks, and 6 Weeks.

Statistics					
Group			Initial	Week 3	Week 6
Control	N	Valid	9	9	9
		Missing	0	0	0
	Median		8.0000	8.0000	8.0000
	Minimum		7.00	7.00	7.00
	Maximum		10.00	12.00	11.00
Jump	N	Valid	9	9	9
		Missing	0	0	0
	Median		12.0000	11.0000	9.0000
	Minimum		8.00	7.00	7.00
	Maximum		14.00	15.00	13.00
Jump + Vibration	N	Valid	9	9	9
		Missing	0	0	0
	Median		13.0000	12.0000	11.0000
	Minimum		9.00	8.00	8.00
	Maximum		17.00	15.00	13.00

Discussion

Very few studies regarding WBV currently exist in regards to controlling for the subject's activity level. Most studies involve subjects that are either athletes (4, 6) or active, but not trained (5, 9). Plyometric training has had a significant influence in the trained athlete, so most of its understanding has been focused with that population (23, 28, 29). Therefore there is a lack of information regarding the effects of WBV and plyometrics to the sedentary person. This is important as WBV is being included in more clinical use and plyometrics are starting to be used more for rehabilitation.

Studies have concluded both WBV and plyometrics not only have performance benefits, but physiologic benefits including VO2 increases in young and older populations (2, 26) and blood lactates (14, 30). Once again, the combination of these two training techniques have not been used to assess these same physiologic effects upon a sedentary population.

No standardized protocols exists for use of plyometrics. Several recent studies (31-33) have varied in their protocols of plyometrics in type of exercise, height/depth of exercise, and amount of repetitions/time. In this study, plyometric jumping required subjects to jump onto and off of a 7 1/2 inch high box laterally for 3 bouts of 20 seconds. This time and height was selected due to likely subject fatigue and a standardized amount of time for performing the jumping task. Subjects performed the intervention three times per week for 6 weeks. This has been demonstrated in several studies to be sufficient for identifying strength changes (34-36).

In this study, we investigated the effects that combined training of WBV and plyometrics had upon two measures of jump height, velocity, force, blood lactates, and

Borg's rating of perceived exertion in the sedentary population. Several measures were deemed as having no significant changes when compared to a control group. However jump height was deemed to be significant when using Vertec; RPE was significant between groups at all three measures and over time; and blood lactates measurements resulted in significant differences in pre- and post-intervention measures in both exercise groups (J and JV groups) at all three measures.

In merging both plyometric training and whole body vibration, we noted that there were several studies that concluded positive benefits of both. Perez-Turpin (6) noted an increase in jump height in trained volleyball players with the increased benefit of WBV in conjunction with jumping activities. In this study, we combined jumping (plyometrics) with WBV and similarly obtained positive results in jump height when assessing with the use a vertec measure. Yet, we did not find similar results with the use of the myotest to calculate the changes. What the myotest does not assess is the subject's ability to stretch and reach with a lean of the trunk and full forward flexion of the shoulder. There is also an external drive by the subjects when trying to knock away rungs. Wulf (37) alludes directly to this phenomena using the vertec as the external focus for attaining this increase in jump height. In her study on behavior with relation to kinetics of movement, she concludes that an external focus produces an increase in effective and efficient movement patterns.

As the use of WBV and plyometrics are becoming more prevalent within the physical therapy settings, more research is needed to validate the use of these training techniques on all populations. As with any modality or training tool, selecting the appropriate population for use of each of these training techniques requires careful attention to each person's need and current physical level. Thus the age range selected (18-40 years old) was restricted for this study.

We attempted to control for a sedentary population and found that recruiting proved to be difficult, as subjects who are currently not active, tend to want to remain inactive. Shorter study times or a less restrictive exclusion criteria may be helpful for future studies.

Goodwin (27) cited specific peak collection times (3-8 minutes) for blood lactates and we stayed within those parameters for post-exercise measures. We attempted to control for the pre-exercise blood lactate measures in spite of many subjects walking to the study each day. The result of the difference of the blood lactate pre- and post-exercise measures demonstrate expected results as the exercising groups produced greater blood lactate levels than the control on the post-exercise analysis. This verifies correct procedures were taken for collection of the blood lactates. There was no significant change in the blood lactate levels over the course of the study, however. A noted downward trend of the JV group is noted, but was not statistically significant.

Measurement of RPE was significant for jumping with vibration group compared to controls at all three measures. This result is not entirely unexpected as the two experimental groups involved physical activity, whereas the control group had no exercise. At the completion of the intervention and measures on the initial, third and sixth week, subjects were asked, according the RPE scale, how they felt that particular day was (both numbers and the standardized, corresponding words describing each level were visible for the subjects to understand each level). The controls were rating their perceived exertion according to measures only. Whereas the other two groups (jumping and jumping with vibration) were rating their perceived exertion according to measures and the intervention they performed.

Conclusion

Among a sedentary population, whole body vibration with plyometrics is an effective tool for increasing jump height. It is helpful however, to have a source of external motivation for this to be realized. Simply having subjects jump as high as they can, may not be enough to achieve an increase in jump height. Jumping with vibration creates a higher level of perceived exertion than not jumping and when comparing not jumping to jumping and not jumping to jumping with vibration. Jumping with vibration resulted in greater perceived exertion than jumping alone. Both J and JV groups experienced a decrease in perceived exertion over time. WBV may have a conditioning component as the JV group experienced a significant decrease in perceived exertion over time. In a sedentary population, both plyometrics alone and plyometrics with WBV resulted in increased blood lactate levels after exercise indicating an increased tendency to recruit and contract fast-twitch muscles. Whole body vibration nor plyometrics have an effect on force, velocity, or jumping without external motivation.

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CHAPTER FOUR

CONCLUSION

Discussion and Conclusions

The aim of this study was to investigate what changes whole body vibration and plyometrics had on strength of quadriceps and gastrocnemius, jump height, velocity of jumping, force, blood lactates, and perceived exertion. Many results of the study indicate significant changes exist. Other results indicate there may a need for further investigation and control of variables.

WBV combined with plyometrics demonstrated a significant change in strength of the quadriceps muscle of sedentary subjects over the six weeks length of the study. This is important to note especially as WBV is becoming more popular in physical therapy clinics which means WBV has the potential to be used on more sedentary populations. Strength of the gastrocnemius muscle did not have a significant change in the jumping with WBV group. Jumping alone however, did result in a significant change in gastrocnemius strength. We can conclude that the use of WBV to strengthen the gastrocnemius muscle may not be necessary. Plyometrics alone appears to be adequate to strengthen the gastrocnemius. It is important to note that the changes in strength of the quadriceps occurred over the course of 6 weeks. Whereas the increase in gastrocnemius strength occurred over the course of 3 weeks initially and continued to progress over the final 3 weeks. Interestingly, all three groups demonstrated an increase in gastrocnemius strength over the first three weeks. The jumping group demonstrated continual increases in strength of the gastrocnemius muscle through the final three weeks. Strengthening of the gastrocnemius muscle may produce more notable changes sooner than strengthening of the quadriceps (three weeks vs. six weeks to appreciate changes). Other studies have demonstrated similar strength changes, but this is the first to note these strength changes in a sedentary population.

Jump height was calculated with two methods: the Vertec jump equipment and the Myotest. The Vertec vertical jump method demonstrated a significant change whereas the Myotest unit did not. The Myotest applied a calculation to determine the height achieved. Vertec involved using a tall metal upright with knock away plastic rungs. The Vertec demonstrated a statistically significant increase in jump height. This external focus (the rungs to knock away) may, likely, contribute to this difference. Wulf (1) notes this phenomena in her study on motivation and external focus. She noted that subjects who had an external focus demonstrated a significant change in jump height as compared to those who focused on their fingers (internal focus). This is important and may be able to be applied clinically with dynamic activities, strengthening, and to achieve tangible goals. This is another aspect that may need to be investigated. If an external focus resulted in a significant change in jump height as compared to an internal focus (finger that will touch the rung), perhaps some changes we have attributed to physiological adaptations may not be responsible for the changes we expected.

This asks a further question as to whether there is a true neuromuscular change in response to jumping or if the subjects' motivation is responsible for this change. There was a noted change in quadriceps strength in the jumping with WBV group at the six week mark, so perhaps we can note that quadriceps strength may have contributed to the increased jumping height with the Vertec apparatus. However further investigation involving a group that uses external focus without attempted to change muscle contraction or strength might be beneficial to help answer this question.

There was a significant group effect on change in pre- and post-exercise levels of blood lactate at each measurement. Those who exercised (jumping and jumping with vibration) produced greater amounts of blood lactates than controls at initial measure and three and six weeks. This information was expected and verifies the procedures taken were effective. There was not a significant difference in the change in blood lactates between the two exercise groups however. There was a noted downward trend in blood lactate response to exercise in the JV group, but the decrease was not significant. This may indicate the beginning of a training or conditioning effect for those who were in the JV group.

Both experimental groups experienced increased blood lactate levels after exercise. This is indicative of an increase in fast-twitch muscle activation. Both groups experienced dynamic jumping activities--plyometrics. It can be inferred that plyometrics are the likely reason for the increase in blood lactates. In this study, it is inconclusive as to whether WBV contributed to fast-twitch muscle activation.

Rating of perceived exertion (RPE) was significantly higher at all three measures in the jumping with WBV group than the control group. The control group was asked how vigorous their exercise was after measures only, whereas the other two groups were asked the same question after completing their measurements followed by their intervention (jumping with WBV or jumping only). This should not be a surprise as RPE was the last measure asked of subjects-after all interventions and other measures. There appears to be a form of training or conditioning performed on the jumping with WBV group as the median and maximum values each decreased from initial measure to week three and from week three to week six. Although those differences were not significant, there was a significant decrease in RPE in JV group from initial measure to week 6. Neither J group nor the control group experienced a significant change over time.

There were no changes in force, velocity, and jump height with the use of Myotest. This might be explained, in part, by the description above in regards to the use of Myotest vs Vertec on jump height. Because force, velocity and jump height was collected with the help of the Myotest unit, the subjects may have lacked an external focus with jump height. It makes sense, then, that force and velocity changes would not be significant as they were calculated using the same unit at the same time jump height was performed. This does not invalidate the Myotest unit, but it leads to further studying of these variables. Perhaps giving the subjects an external focus may increase the measures conducted with the Myotest unit. Performing a similar study to assess force and velocity using a variety of methods might be beneficial.

Our plyometric protocol was developed, in part, due to the safety of the subjects and also due to the fact that no agreed upon protocol exists. We cited three recent studies (2-4) which each had differing plyometric protocols in their studies. While one protocol very likely would not suffice for assessing changes that might occur within the variety of performance activities (jumping, force, power, sprinting), a call for developing protocols for each activity may be warranted. There are a variety of studies investigating similar outcomes but using differing techniques with differing heights of jumping and differing repetitions. When conclusions are reported, the methods used are not universal, but they are mistakenly applied universally. This can lead to a lack of true understanding of the benefits that may be derived from plyometric use.

Protocol

Our study protocol consisted of having subjects jump for 3 bouts of 20 seconds, 3 times per week over the course of 6 weeks (J and JV groups). Anecdotally, most subjects averaged approximately 20 jumps. This equates to total vibration platform contact time of approximately 5 seconds per 20 second bout (one quarter of time on platform, one quarter time in the air moving to and from the vibration platform, and one quarter of the time on the box). Further, if this time is calculated out over the six weeks, subjects contacted the vibration platform a total of 4-1/2 minutes total throughout the length of the study. Nevertheless, physiologic (blood lactates trending toward a conditioning effect), and performance measures (significant changes in Vertec jump height and quadriceps strength) were noted in the JV group. This may indicate that the proposed neuro-muscular changes that are believed to result from WBV, may result in only minimal contact with the WBV platform. Whereas some studies include subjects performing isometrics for strength and jumping benefits (5-7), this study suggests 20 seconds of plyometrics may be sufficient for the sedentary population to increase strength, jumping and blood lactates. Perez-Turpin (6) reported having subjects perform four sets of 30 seconds of isometric or squatting exercises three times per day and Bush (5) has his subjects perform up to 2-1/2 total minutes for a single session of WBV. What is interesting to note is that these two studies did not include plyometrics, but isometrics and isotonics only. Perhaps the fact that subjects performed plyometrics in conjunction with WBV rather than isometrics or isotonics is the reason for the significant changes in jump height and quadriceps strength and trending changes in blood lactates.

Subjects in this study performed their jumping laterally rather than forward and backward. The primary rationale was in regards to the safety of subjects. It should be noted that most studies regarding WBV and jumping are performed in the forward/ backward fashion. Concern regarding subjects jumping backward onto a platform with limited depth and potentially causing themselves injury, resulted in the decision to jump laterally. Dynamic lateral movement is not necessarily non-functional as lateral movement is encountered often in sports from skiing to tennis or basketball, to name a few. Dynamic lateral movement is also encountered in routine daily tasks from moving in and out of vehicles to sidestepping through a crowd. Nevertheless, this protocol deviated from how most studies typically perform plyometrics. As a result, subjects in this study likely received increased medio-lateral stability and increased lateral hip strength. Jumping forward/backward will typically result in antero-posterior stability about the knee. Both types of jumping (forward/backward and lateral) however, will result in dynamic use of the gluteal muscles, quadriceps, and gastrocnemius/soleus. Thus increased strength of each area is expected. Hip strength and knee stability were not measured and only hypothesized here, but the effect of lateral jumping upon these areas may be beneficial functionally for further studies and future patients who are in rehibilitation. Any comparing or contrasting of this study with other studies needs to be done in the light of this training protocol.

Our protocol also did not include a progression from the initiation of the study to the end. Subjects began jumping at 7-1/2 inches at the beginning of the study and continued jumping at the same height through completion of the study. Subjects also continued through the study at 20 seconds of jumping and did not progress in time. Either or both factors may have helped to shed further light on the effects of plyometrics and jumping. Perez-Turpin (6), for example, had subjects perform 4 sets of 30 seconds of exercises over the course of three week and increased to 4 sets of 60 seconds for the next three weeks. This helps to maintain a continued strength progression throughout the study rather than a plateau effect. There were two main reasons for the limitations of progression within this study. First, our subjects were not only untrained, but sedentary. The limited physical demand they had generally applied, was such that we wanted to be sure that the subjects were able to complete the study at initiation and six weeks. As a result we had no subjects drop out of the study due to the physical demands they encountered. This may also mean subjects were not sufficiently challenged, which would necessitate a graduated strengthening program. This leads to the second point. Subjects were sufficiently challenged throughout the study as demonstrated by the RPE scores. From the beginning of the study, subjects who were in the JV group indicated they experienced more physical exertion than those in the control group. These higher scores were also statistically higher between the two groups. While the JV group appeared to have a conditioning effect from the exercises (decrease in RPE score from initial session to last session), their was still a statistical difference between the two groups at the completion of the study. This would indicate that, although their perceived exertion with the exercise program was decreasing, they still experienced a notable amount of exertion at the completion of the study. Graphical data also suggests that strength measures taken from the initiation of the study to week 3 and again at week 6, indicated a progressive continual strengthening of both the gastrocnemius and quadriceps muscles. Although this may be true, further investigation of the differences between one group of sedentary subjects who maintains their consistent exercise and another group of sedentary subjects who progresses in height or time, might shed light on any real differences that may exist.

Recommendations

The primary emphasis of studying WBV with plyometrics was to assess the effectiveness of such an activity for patients who may arrive to a physical therapy setting. The increase in use of WBV clinically only emphasizes the need to investigate its effectiveness and parameters.

The need to develop and validate a WBV and plyometric regimen that is effective, progresses the patient, addresses safety concerns and gives recommendations as to which patients are more appropriate and which would not benefit from WBV with plyometrics is the aim here. I will address each of these areas and give rationale for each.

Appropriate Patient

There are some very clear guidelines that may seem obvious and some that will require some discretion from the physical therapist. First, patients need to screened and assessed for injury. Patients are present at a physical therapy clinic because they are injured. However it is expected to progress patients until they achieve their previous level of function. An example of a patient who should not be currently in a WBV and plyometric program would be a patient recovering from an ACL reconstruction performed a month ago. Patients who are experiencing pain without exercise should not be included in this exercise regimen. These patients are at a higher risk of potential further harm and injury as pain is typically an indicator of current pathology or at the very least insufficient healing.

In addition to screening for injury or potential for injury, the patient's history, age, occupation and body type should be considered. Screening these factors are important to creating a meaningful and effective program for patients, but also for prevention of injury. One might assume that performing these activities with an older patient would automatically eliminate the possibility of a rehabilitation protocol including WBV with plyometrics. However, consider the older patient who does bouldering, skiing, or recreational basketball. They might be a great candidate for such rehabilitation. Also consider the patient who may be overweight, but whose occupation requires him to jump in and out of a large vehicle as he delivers packages. He might be a good candidate for WBV with plyometrics due to the physical demands from his work duties. Obtaining a thorough understanding of the physical demands of the patient's lifestyle (both work and recreation) is important to identifying the correct activities of any patient's rehab.

The second and less clear parameter to consider are intangibles the physical therapist may consider. These are less clear to delineate or define. Perhaps the patient has no history of performing dynamic tasks of bouldering or skiing, but the physical therapist is able to determine that the performance of WBV with plyometrics may be effective in building stability about the knee, or dynamic strength for going up stairs. The physical therapist will need to screen effectively, but there may be a patient who would benefit from WBV with plyometrics from a strengthening perspective rather than only a functional task.

Safety

Safety was partially addressed above, but it should directly guide whether to perform a certain activity or not. If a patient is deemed to be unsafe with any activity, the physical therapist should not continue with that activity-whether that is WBV with plyometrics or any other activity.

Safety should be considered when deciding heights to jump, repetitions and time. A significant portion of our study was built upon the desire to identify whether WBV with plyometrics was beneficial to sedentary subjects. But the parameters were rather conservative to protect the safety of the sedentary subjects. If there is concern with respect to the safety of the patient with jumping tasks, start them on a jumping program on level ground first. When they are deemed to be safe, then progress to unlevel surfaces and finally to plyometric jumping. The physical therapist should always be near the subject in case of falls or loss of balance.

Start the plyometric jumping at a lower level of 4 to 7 inches in height. Deciding on the appropriate height should be at the physical therapist's discretion and should consider the history, age, occupation and body of the patient.

Certain safety parameters to consider with respect to the WBV unit and jumping would include: non-slip surfaces on both the WBV platform and the plyometric platform, safe and non-slip shoes for the patient, no baggy or loose clothing that may get caught on either piece of equipment, cognitive acuity of the patient is sufficient to understand the activity, and proximity of the physical therapist.

Exercise Parameters

Due to the lack of standardized protocols and parameters, I wish to propose a few parameters to an effective WBV with plyometric protocol. Further study and investigation may assist with more improved parameters over time. For the purposes of the discussion here, I would consider patients who were previously active but have not been active for over a month due to rehabilitation or recovery as being sedentary.

I would propose that WBV with plyometrics as performed in a physical therapy clinical setting upon a sedentary patient should include a lower starting point with gradual progression in time, height of jumps, and type of jumps. Most sedentary patients should start at six inches of forward/backward jumping. This is a rather lower level of jumping, but should initiate an effective beginning level of jumping. This jumping should be from back and forth between the surfaces. Further jumping should progress with lateral jumps, drop jumps (jumping from a surface that is high down to a lower surface, then attempting to jump back up), and hurdle jumps.

Progression and dosing exercise can be done in one of three differing ways: increasing time, increasing height, or increasing repetitions. Altering both at the same time is not recommended as controlling for one variable at a time is a more sound way to control for changes in the patient's progression.

Progression of time or height should be done with one of two measures: First, patient's report on Borg's Rating of Perceived Exertion to be at 11 or less for two consecutive sessions. This corresponds to "Fairly Light" exercise and should allow not only for increased tolerance to an increase in exercise, but also indicate a physical readiness to progress. Second, there is a jump increase of 20% from the initial amount jumped on the current level. For example, if the patient was jumping at 20 repetitions when starting on the current level, the patient now needs to be jumping at least 24 repetitions. You could also increase time by 10 seconds or height by 2-4 inches. This is a more objective measure to indicate further conditioning and strengthening and lends to the possibility of increased tolerance with exercise. Lastly, if the physical therapist has any concerns regarding the advancement of the patient to the next level, then advancement should not happen. Correct alignment and positioning through the landing and jumping phases must be evident for progression to next level.

Progression of height for jumping should include setting goals of repetitions over time and noting quality of the movement. Progression can include, jumping to 8, then 10 and 12 inch heights. We have cited studies that have included much higher heights of jumping, but those were performed on athletic subjects, not sedentary ones. However, if the patient's history was very active, the physical therapist should consider this and progress toward 24 or 36 inches, accordingly.

To review these parameters: 1) Once the patient is deemed safe and ready to begin WBV with plyometrics, start with hops and jumps on a level surface; 2) Slowly progress (initially) to jumping forward/backward to a surface starting at 6 inches; 3) Progression of the exercise should consider the patient's history and goals; 4) Patient can be progressed with relation to time, height, or type of jumping activity; 5) Although these parameters are listed up to 12 inches for a sedentary population, patients who have been very active and desire to return to the same level of activity may progress more aggressively.

Summary

In summary, this study did, in fact, demonstrate there are changes that occur with WBV and plyometrics in the sedentary population. The desire to keep a strict inclusion/exclusion criteria was beneficial for appreciating what a sedentary group of people may be able to use effectively in a clinical setting. WBV with plyometrics can be helpful for strengthening quadriceps and increasing jump height in the sedentary population. Plyometrics alone can be helpful in increasing gastrocnemius strength. In this study, force, velocity, and blood lactates did not have a significant increase, however further investigation may be necessary. Since the two experimental groups involved some form of exercise, RPE was higher in each group--WBV with jumping was significantly higher. Further study aimed at identifying specific exercise protocols for plyometrics; assessing the effectiveness of subjects performing activities using an external focus; better control of pre-intervention levels of blood lactate in a similar study; and initiating the investigation of similar studies on a patient population are suggested.

We have a included a recommended progression of the sedentary patient with relation to WBV and plyometrics. It can be used as a guide for progression of the patient. Consideration of the patient's history, age, occupation and body type should be made prior to initiating and progressing any patient

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