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Acute Effects of Whole-Body Vibration on Balance and Flexibility with and without Shoes

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Abstract

The purpose of this study was to evaluate the effects of acute whole-body vibration (WBV) on static and dynamic balance and flexibility. Eight female and eight male, mean age 25 ± 3 years, college students volunteered to participate in the study. In randomized cross-over study design, participants were assigned to complete four treatment conditions: shoes + CONTROL (CON), shoes + WBV, no shoes + CON, and no shoes + WBV and then performed maximal standing on one leg, functional reach and sit-and-reach tests. The WBV treatment was five minutes standing (alternating 30s straight knees + 30s slightly bent knees) at a frequency of 30 Hz and amplitude of 2 mm. A significant main effect of longer maximum standing on one leg time was observed following WBV regardless of shoes or no shoes condition ($p = 0.02$) for both genders. Additionally, a trend approaching significance was observed for functional reach test ($p = 0.053$), but not for sit-and-reach test ($p = 0.46$). The findings of the present study indicate that acute exposure to WBV has a potential to improve static and dynamic balance, therefore, may provide supplementary benefits to a balance training and rehabilitation programs.

Keywords: WBV; Functional reach; Sit-and- reach; Max standing on one leg

Introduction

Balance and muscular strength training are important intervention techniques in preventing falls, consequent injuries, and related disabilities. Body balance and stability require continued attention and maintenance of muscle strength. There are a number of training techniques believed to offset declining strength, to improve functional balance, and gait velocity such as resistance and endurance training, Tai Chi, Yoga, and unstable- surface balance training programs [1]. Unstable surface training can be an addition to balance training for fall risk and other injury prevention in athletic or general populations, as it is commonly added to the traditional exercise and physical therapy rehabilitation programs [2]. It is thought, that the addition of an unstable surface will increase exercise difficulty, accordingly increase muscle activity and force output to provide stability and balance [2,3].

Whole Body Vibration (WBV) is an emerging new unstable surface training technique proposed as an alternative, or addition to, resistance training (RT). In the past few decades, WBV training has been gaining popularity as a warm-up, cool-down or a training technique among athlete and general populations [4-9]. It is hypothesized that mechanical stimuli to the muscle can be an effective way of improving muscle strength and power by increasing gravitational load. While standing on the vibrating platform, individuals receive a mechanical stimulus via the feet due to the oscillatory motion of the platform and perceived mechanical stimulation to the muscles causes muscle to lengthen and contract subconsciously employing more muscle fibres [10]. Increased electrical activity [11-13,] motor unit synchronization [14], and improved strength, balance and flexibility have been previously observed [6,8, 13,15-23].

Long-term and short-term effects of WBV treatment on balance, flexibility, postural sway and control have been equivocal [6,8-10,16-26]. Previously, positive effects of WBV training for older adults were observed, for: peak-to-peak amplitude sway [26], balance measures [24,27], proprioceptive control of posture [10], and maximum standing time on one leg [22,23]. In addition, functional reach showed improvements following WBV training and no vibration intervention; however, the degree of improvement was not significantly different between control and WBV groups [17]. Other training studies observed no significant effect on postural control in young skiers [6] or body balance in young healthy adults [8].

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In younger adults, significant improvements in forward split, sit-and-reach, and stand-and-reach scores were previously observed following WBV treatment compared to no vibration [5,18,24,28]. In addition, a group of Finish scientist evaluated chronic and acute effects of WBV on balance, jump height and isometric extension strength in young, healthy males and females [7,8]. Acute effect of 4 minutes of WBV elicited positive improvements in jump height, lower limb strength and balance [7]. A 16% improvement in body balance was observed two minutes after the WBV compared to sham intervention [7]. A chronic 8-month WBV intervention program showed positive improvements in jump performance but not in balance [8]. Also, improved postural control was observed in chronic stroke patients after short term WBV treatment [9], but not in young skiers after 6 weeks at 3 times per week of WBV treatment [5]. Consequently, it is questionable whether WBV intervention favourably affects balance measures and stability.

In addition, previously it has been shown that middle-aged and older women have worse balance and respond to balance training treatment to a lesser extent compared to men [29,30]. However, previous studies used older populations; thus, the question is whether gender difference in balance test scores and response to a treatment begins at the younger age. Also, it has been shown that footwear had a positive effect on stability and balance in older adults [31]. An increase in number of falls over a 12-month follow-up among older adults was observed while barefoot or wearing socks while indoors compared to wearing footwear [32].

However, foot structure, sensation, and strength change with age, thus older adults may have an impaired ability to balance while barefoot [32,33]. One of very few studies, investigating effects of footwear in younger adults observed better movement discrimination at the ankle while barefoot compared to wearing athletic shoes [34]. It was speculated that the raised surface of the athletic shoe may have reduced cutaneous afferent feedback which may have affected postural stability and balance [34]. Thus, we aimed to examine whether footwear would affect balance and response to a WBV treatment in younger adults.

This study investigated the effects of acute WBV on static and dynamic balance and flexibility, in order to evaluate potential implementation of WBV use in training programs for adults. We hypothesized that WBV would improve static and dynamic balance and flexibility in adults due to the proposed mechanism of increased neuromuscular stimulus [12] thereby increasing stability and time to fatigue. In addition, we hypothesized that men would have better balance, as well as that participants would perform better barefoot compared to wearing shoes.

Methods

Participants

The participants of the study were eight male and eight female healthy college students between 19 and 35 years of age. All participants reported to be physically active and engaging in at least three exercise sessions per week. The protocol and informed consent forms were prepared according to the guidelines of the local Institutional Review Board for the protection of Human Participants and approved prior to the study. Participants were asked to complete the Physical Activity Readiness Questionnaire [35] and current health status [36] questionnaire prior to the study. In addition, participants were asked not to participate in physical activity and to avoid alcohol, caffeine and energy drinks at least 12 hours prior to each test session. Participants were excluded from the study if they met any of the following criteria: participant was younger than 19 or older than 35 years; screening forms indicated any previous cardiovascular, respiratory or other major chronic diseases; participant had any type of surgery or injury that may have increased their risk of exercise participation; or participant had a disease or used medications that affected coordination, balance or muscle strength.

Descriptive data including age, weight, and height were collected. Body composition was assessed using a skin fold caliper (Lange, Beta Technology Incorporated, Santa Cruz, California). Skin folds were measured at the thigh, chest and abdomen for men and at the super iliac, triceps and thigh for women [37,38]. Physical activity, prior frequency of falling and most recent fractures was assessed using an exercise and injury questionnaire.

Procedures

To evaluate the benefits and effects of acute WBV treatment on static and dynamic balance and flexibility, a randomized cross-over study was conducted. Four sessions were performed in a counterbalanced order with each session separated by at least 72 hours. Two lab sessions were performed with shoes including both treatment and testing and two lab sessions were performed with socks only (no shoes) for both treatment and testing. The same athletic shoes were used for both sessions by each participant; however, brand, type and thickness of shoes varied between participants. In addition, to minimize environmental factors that affect balance, each session was performed in the same room with only an investigator present; every test was performed in the same spot, and the room was kept at the same temperature and lighting. Each participant completed a session consisting of: warm-up, five minutes of WBV or no vibration treatment, then balance and flexibility tests.

Warm-up – Was performed on the cycle ergo meter (Monark, Ergomed, Sweden) or five minutes at self-chosen pace.

Intervention Treatment – The WBV treatment was delivered using a WBV plate (Vibe Plate, Lincoln, NE). Each participant was exposed to five continuous minutes of vibration, participants were asked to stand straight in the middle of the plate with their feet shoulder width apart for 30 seconds and, to make standing on the platform less monotonous, with slightly bent knees for 30 seconds, repeating the routine five times consecutively. The vibration platform frequency was fixed at 30 Hz with an amplitude of 2 mm. This protocol was similar to the protocol previously used by de Ruiter et al. [39]. Control treatment was the same as for WBV; however, the vibration platform was not vibrating. Both treatment and control were performed with and without shoes.

Performance evaluations

Performance evaluations were performed one minute after the WBV or CON treatments were completed. The max standing-on-one-leg was performed first, following by functional reach test and sit-and-reach test.

Max standing-on-one-leg (right/left) test (MSOL). The test was performed one time. It was measured by participant standing on either right or left leg (participant preference) with other leg being lifted off the ground and arms crossed on the chest. Participants were asked not to lock their knee while standing, not to touch or support lifted leg, and not to move the arms off the chest. A stop watch was

Table 1: Physical Characteristics of Participants (n = 16) expressed as (Mean ± SD).

Characteristics	Female (n = 8)	Male (n = 8)	*p* value
Age (y)	25 ± 3	26 ± 4	0.37
Weight (kg)	63 ± 9	84 ± 18	0.16
Height (cm)	166 ± 5	176 ± 8	0.18
Relative body fat (%)	22 ± 5*	13 ± 8	0.03

y = years, kg = kilograms, cm = centimetres, % = percent
p value represents difference between genders. *None of the differences were significant (*p*> 0.05) except for relative body fat % (*p* < 0.05)

used to record maximum stand time. The time was started as soon as the participant lifted the leg off the ground and crossed the arms on the chest and the time was stopped as soon as the participant's lifted leg touched the ground or participant lost balance as indicated by the arms moved off the chest or participant chose to discontinue. Maximum standing time was recorded in seconds.

Functional reach test (FRT). Was measured three times and the best of three was recorded. A meter stick was placed on the wall parallel to the ground at the shoulder level. Participant was instructed to stand next to the wall, with shoulders perpendicular to the wall, but not touching the wall. Participants were asked to position the arm that was closest to the wall at 90 degrees of shoulder flexion. Participants placed their feet shoulder width apart and were instructed not to move the feet off the ground while reaching as far along the meter stick as possible. Functional Reach was measured as the maximum distance that participant could reach without losing balance with straightened arm and hand made in a fist. FRT was measured in centimeters.

The sit-and-reach flexibility (SRT) test is a well-established test that has been used on numerous occasions using procedures described in the ACSM manual [36]. The test was performed three times and the best of three was recorded. Participant had to sit on the floor with the feet shoulder width apart pushing into a sit-and-reach box (Flex-Tester, Novel Products, Inc, Rockton, IL). They were asked to reach forward as far as they could for maximum distance along the measuring line with knees held flat against the floor and with hands on the top of each other. Sit-and-Reach score was measured in centimeters.

Statistical analyses

All data are presented as Mean ± SD. Differences between the treatments, shoes or no shoes condition and genders were analyzed using repeated measures mixed-model ANOVA (between and within subjects factors) (SPSS Version 16.0, SPSS Inc., Chicago, IL, USA) for max standing-on-one-leg, functional reach and sit-and reach-tests. An alpha value was set at 0.05. Individual data were analysed and expressed as positive and negative responders to WBV treatment with shoes and no shoes. Responders were determined by a least-significant-difference analysis using SD from the study and power analysis. Power analysis suggested that with this sample size (n=16), we would be able to detect an effect of 109 s for max standing-on-one-leg test, 3.2 cm for functional reach test and 3.9 cm for sit-and-reach test with an alpha level at 0.05 and power of 0.8 (Piface, by Russell V. Lenth, Version 1.72). Participants whose performance increased by an amount greater or equal to the least significant difference were considered positive responders, participants whose performance decreased by an amount greater or equal to the least significant difference were considered negative responders, and participants whose performance increased by an amount less than the least significant difference were considered non- responders.

Results

Participants reported being healthy, physically active and exercising at least three days a week. Participants' age, weight, height, and relative body fat are presented in (Table 1). On average women had lower weight and height compared to men, however, significantly higher relative body fat % ($p< 0.05$). No recent falls or fractures were reported by the participants.

Statistically significant main and interaction effects were observed for max standing-on-one-leg and sit-and-reach tests. A significant main effect for WBV treatment [$F (1, 14) = 6.813$, $p = 0.02$] was observed for max standing-on-one-leg with an effect size of $\eta^2 = 0.33$. Participants were standing on one leg 46.8 seconds longer with shoes and 81.6 seconds longer with no shoes after WBV treatment compared to control (Figure 1). A trend approaching a significant main effect for WBV treatment [$F (1, 14) = 4.128$, $p = 0.06$] was observed for functional reach test with an effect size of $\eta^2 = 0.23$. Participants tended to reach further after WBV treatment with shoes and no shoes compared to control treatment (Figure 2). There was no significant main effect for WBV treatment and sit-and-reach tests with shoes and without shoes ($p = 0.46$). However, a significant main effect was observed between genders [$F (1, 14) = 11.858$, $p = 0.004$] for sit and reach test. Women were more flexible after WBV and control treatments with shoes and no shoes, compared to males (Figure 3).

A significant interaction effect was observed for maximum standing on one leg between shoes condition and gender [$F (1, 14) = 5.336$, $p = 0.04$]. Females stood longer after WBV and control with shoes compared to no shoes, whereas, males stood longer with no shoes compared to shoes. However, no other significant interactions between the shoes and any shoes condition, WBV and control treatment or gender for max standing-on-one-leg, functional reach and sit-and-reach tests were observed ($p> 0.05$).

Individual data for the max standing-on-one-leg showed that 4 of 16 participants responded positively and only 1 of 16 responded negatively to WBV while wearing shoes and 6 of 16 participants responded positively and no negative responders to WBV for any shoes condition. Individual data for the functional reach test showed

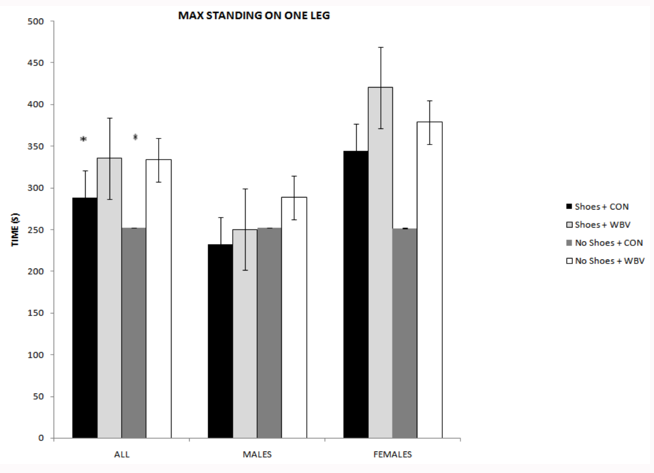

Figure 1: CON: Control; WBV: Whole-Body Vibration
*MSOL was significantly longer after WBV compared to CON (*p*< 0.05)
Effect of treatment on max standing-on-one-leg time (MSOL). Each participant performed one trial. MSOL (Mean ± SD) is presented as maximum time in seconds (n=16).

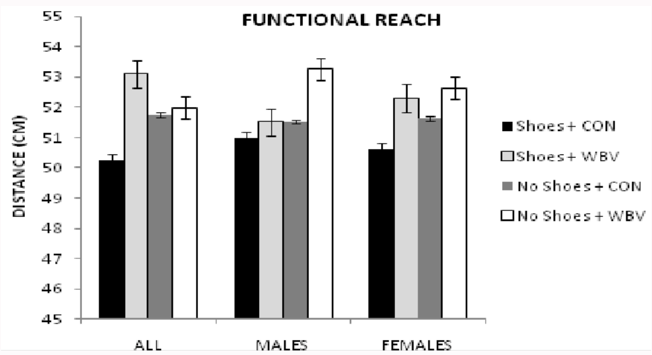

Figure 2: CON: Control; WBV: Whole-Body Vibration; cm: centimeters
Functional reach was not significantly different after WBV compared to CON (*p*> 0.05)
Effect of treatment on functional reach test (FRT). Each participant performed three trials. FRT (Mean ± SD) is presented as maximum distance reached in centimetres (n=16).

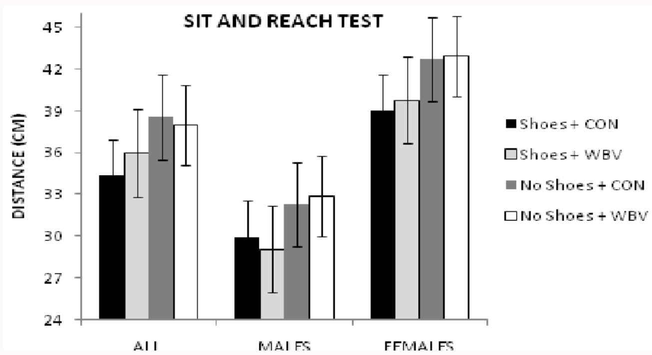

Figure 3: CON: Control; WBV: Whole-Body Vibration; cm: centimeters
Sit-and-reach was not significantly different after WBV compared to CON (*p*> 0.05).
Effect of treatment on sit-and-reach flexibility test (SRT). Each participant performed three trials. SRT (Mean ± SD) is presented as maximum distance reached in centimetres (n=16).

that 6 of 16 participants responded positively and 3 of 16 negatively to WBV while wearing shoes and 6 of 16 participants responded positively and only 1 of 16 responded negatively to WBV for no shoes condition. In addition, individual data for sit-and-reach test showed that 2 of 16 participants responded positively and 1 of 16 responded negatively to WBV while wearing shoes and only 1 of 16 participants responded positively and no negative responders to WBV for any shoes condition.

Discussion

This is one of the few studies examining the acute effects of WBV on balance and flexibility. It was hypothesized that WBV would improve static and dynamic balance and flexibility in younger adults. The findings of the present study indicate significant improvements in static balance following WBV treatment compared to no vibration. It has been hypothesized that addition of unstable surfaces such as WBV increases force output from muscles to provide stability and balance [2], as well as muscle activity which increases exercise difficulty and improves joint proprioception [3]. Previously, temporary increase in EMG activity of upper- and lower- extremities following WBV treatment at various frequencies has been reported [12,10,40].

The findings of the present study support the studies conducted by the Finish group of researchers [7] who found that an acute bout of WBV had a positive effect on balance and jump performance in younger adults. Participants underwent both WBV and sham treatments for 4 minutes following six performance tests. WBV intervention started at 15 Hz and increased every minute by 5 Hz until it reached 30 Hz. Balance measures were measured at baseline, 2 and 60 min following the treatment. Significant improvements of 16% in balance were observed after 4 minutes of WBV treatment. Thus, it was suggested that continued contraction of a muscle called tonic vibration reflex (TVR) produced during WBV tends to activate muscle receptors. Vibration produces stimulation of Golgi Tendon organs and could lead to alterations in the length of the muscle-tendon complex [4,11,41]. Thus, muscle spindles that are sensitive to stretch are activated via neural signal sent through afferent nerve fibres to activate the reflex arc and cause muscles to contract or relax [4,7,11,41,]. Therefore, improvements in balance may be attributed to increased recruitment of muscle motor units that are utilized during balance to provide strength and stability [7,11].

Previously it has been reported that women tend to have shorter balance time during one-legged stance and worse Berg balance test scores compared to men over age of 50; however, in the present study with younger participants, women tended to have longer balance time during max standing-on-one-leg compared to men, nonetheless, it was not statistically significant [29,30,42]. There is limited literature available investigating gender effects on static balance in younger populations. Thus, age related differences make it very difficult to compare the results to the previous studies. In addition, women tended to have longer balance time with shoes compared to no shoes after WBV and control treatments, whereas, men had longer balance time without shoes [34]. Investigated the effects of athletic footwear on ankle discrimination in male athletes. The results of that study suggested that young athletes were better able to discriminate ankle inversion movement while barefoot compared to wearing athletic footwear due to reduced cutaneous afferent feedback. Different types of athletic shoes worn by males and females participants is a major limitation of the present study and may partially explain differences observed in the present study. Women more often choose to wear shoes that have increased base of support, thus, had better balance and stability with shoes. Therefore, increased support of the shoes may have counteracted the negative effect of wearing shoes among women compared to no shoes. There is a limited amount of literature available to compare the results of the present study, thus, gender differences and effects of different types of footwear on balance should be further investigated.

Furthermore, functional reach tended ($p = 0.06$) to be better after WBV regardless of gender and shoes or no shoes condition; however it did not reach statistical significance. Greater benefits may have been seen in the older population with compromised standing balance compared to younger adults without existing balance or health problems. One could argue that younger adults had no need to adjust to the vibration loading, thus, no statistically significant improvements were observed. However, findings are consistent with previous WBV training study [16]. In a study by Cheung et al. [16], improvement in functional reach were observed following WBV training intervention compared to control; however, it did not reach statistical significance ($p = 0.22$). Vibration load and mode may have been insufficient for this younger population, as well as, not task specific to have a significant effect on functional reach. In addition, no gender or shoe condition differences and functional reach scores were observed in the present study. The results of the present study are consistent with findings of [31]. They observed no significant differences between barefoot or wearing walking shoes and functional reach test scores in older adults. However, it was suggested that the two conditions should not be viewed as producing the same result in functional reach test. Great variability among the subjects was noted in previous study, thus, results should be interpreted with caution and tested for performance consistency. Note that in the present study 38% of our participants showed a positive response to WBV for functional reach test.

Females were more flexible than men as would be expected; however, flexibility did not show significant improvements following WBV treatment compared to control. Significant improvement in flexibility including forward split, and stand-and-reach were observed in multiple investigations [4,17,18,20,24,28]. In a study by Sands et al. [28], participants performed pre- and post-flexibility tests immediately before and after 4 min of stretching performed on a vibration device with similar frequency mode used (30 Hz, 2 mm). Significant increases in both right and left forward splits following vibration treatment were observed following acute exposure to vibration compared to no vibration. Additionally, Di Giminiani et al. [4], observed significant improvements in a stand-and-reach following 10 x 1 minute bouts of individualized WBV (20 - 55 Hz) exposure [17]. Observed significant improvements in sit-and-reach following six different exercises performed on WBV at 26 Hz. Similarly [24], observed significant improvements in sit-and-reach after 6 min of standing on WBV at 26 Hz compared to cycling.

Various frequencies and durations of WBV interventions have been used across the studies making it very difficult to determine the best type of routine, frequency and duration, which may explain some discrepant findings. Adams et al. [27], observed the highest performance peak at 1 min post-treatment, performance remained elevated at 5 min post-treatment and declined thereafter. Additionally, Di Giminiani et al. [4], observed significant differences6 min after the conclusion of WBV treatment. Most of the previous studies that evaluated the effects of WBV on flexibility tested flexibility immediately after the treatment. In the present study, flexibility was measured after both static and dynamic balance tests, in contrast to other studies. Various lengths of balance test in the present study made it very difficult to standardize the time after the treatment. Therefore, lack of improvements in functional reach and flexibility performance may be partially attributed to time elapsed after vibration treatment for some participants as the effect may have declined over time. In addition, previous studies implemented various exercise routines combined with WBV interventions; thus, it may be suggested that stretching exercises during vibration treatment should be performed in order to provide increased range of motion benefits. In addition, our participants reported being physically active; however not accustomed to the WBV; therefore, the absence of improvements could be due to the limited adaptations to the vibration stimulus and intensity.

There was no way of determining the degree of muscle tension applied with the vibration due to varied knee angles and body weight; therefore, WBV could have varied effects depending on those factors. If participants were adapted to the WBV routine and vibration stimulus was performed more often, participants may have gained greater benefits. Therefore, under conditions of the present study WBV treatment benefited static balance and potentially dynamic balance but not flexibility.

Perception of the environment can influence performance and varies within each individual. Balance and flexibility can be influenced by the inputs from the visual, vestibular and somatosensory systems. Any distractions such as noise, lighting and temperature can affect performance and were controlled in the present study. Every testing session was performed in the same quiet room, room temperature and lighting was kept the same to minimize the environmental factors that could affect performance. In addition, there might be physiological and psychological differences between those who respond and those who don't respond to the WBV treatment. One third of participants responded positively to WBV vibration treatment and improved their max standing-on-one-leg and functional reach test score regardless of shoe or no shoe condition. Thus, it could be suggested that several participants positively responded to the short bout of WBV treatment that lead to improvements in static and dynamic balance.

In conclusion, WBV could be a beneficial addition to the training and rehabilitation programs that aim to improve balance, stability and health related quality of life among adults, however, further investigations are needed to determine the efficacy of WBV use over a longer period of time. Acute exposure to WBV may not be sufficient for some individuals to achieve improvement in balance and flexibility, thus, repeated exposure may be needed. Unstable surface balance training can be used as an alternative or an addition to traditional training routines to improve functional ability and increase exercise compliance in adults due to higher compliance observed in non-traditional training programs compared to the traditional training routines [43-45].

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