Does Acute Whole-Body Vibration Training Improve the Physical Performance of People with Knee Osteoarthritis?

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Abstract

Salmon, JR, Roper, JA, and Tillman, MD. Does acute whole-body vibration training improve the physical performance of people with knee osteoarthritis? *J Strength Cond Res* 26(11): 2983–2989, 2012—The purpose of this study was to determine the effects of a single session of whole-body vibration training (WBVT) on the physical performance of individuals with knee osteoarthritis (OA) in 3 tests designed to simulate activities of daily living (ADLs). Fifteen individuals with symptomatic knee OA completed the Timed-Up-and-Go Test, step test, 20-m walk test, and visual analog scale (VAS) recordings of knee pain intensity. A main effect was detected for time to complete the step test ($F[2,28] = 6.243$, $p = 0.006$, $\eta_p^2 = 0.308$). Post hoc analyses revealed that the time to complete the step test at 5 minutes after WBVT improved significantly ($p = 0.042$) from that of the pretest. A moderate correlation ($r = 0.465$, $p = 0.001$) was found between the VAS scores and the time to complete the step test across all trials. A main effect was found for time to complete the walk test ($F[2,28] = 4.370$, $p = 0.022$, $\eta_p^2 = 0.238$). Post hoc analyses did not indicate significant improvements from pretest seen at 5 minutes after WBVT ($p = 0.110$) and 1 hour after WBVT ($p = 0.224$). The WBVT was well tolerated in nearly all the participants, and we observed that an acute bout of WBVT was effective in improving the ability of individuals with knee OA to perform a step test and 20-m walk test. Our findings suggest that WBVT may be an effective nonpharmacologic modality to treat some knee OA symptoms and improve ADLs.

Key Words visual analog scale, timed-up-and-go, arthritis, activities of daily living

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Introduction

Osteoarthritis (OA) is the most common form of arthritis (24) and the most prevalent joint disorder worldwide (31). The central feature of OA is the destruction and loss of articular cartilage, which often leads to dysfunction of the joint (23). In addition to functional abnormalities of the knee joint, pain associated with OA is the leading cause of disability in older adults (27).

Additional effects of knee OA include decreased strength in surrounding muscles (17,36) and impaired neuromuscular functioning (4). Knee OA has been shown to have numerous adverse effects on gait, including reduced velocity, reduced cadence, and shorter stride length (1). It is not surprising that people with knee OA have difficulties with activities of daily living (ADLs) such as rising from a chair, climbing stairs, kneeling, standing, and walking (3,13). Indeed, those with symptomatic knee OA have shown increased dependency performing ADLs requiring the use of lower extremities (19). Furthermore, Foley et al. (17) and Sturnieks et al. (36) have concluded that many associated factors, including pain, stiffness, and dysfunction, place these individuals at a greater risk for falls.

Patients with knee OA are frequently prescribed physical exercise routines to serve in preserving physical activity and function. Because of its wide range of potential physiological benefits (improved muscle strength and power, balance, bone mineral density) and because it can be applied in a relatively low-effort, low-impact manner with no complicated technique to learn, some have suggested that whole-body vibration training (WBVT) may be beneficial to therapists and other clinicians to use with elderly and special clinical populations characterized by impaired mobility (e.g., patients with stroke, Parkinson's disease, arthritis, osteoporosis) (9,10,30).

Although WBVT appears to present advantages over traditional exercise programs (e.g., relatively low-impact training, short duration of training sessions), there is a lack of evidence to support or preclude WBVT as a therapy. The WBVT exercise could provide similar effects as strength training, but with decreased loads on affected joint(s), because of low joint dynamics of the exercise, and improve neuromuscular performance (5,9). For example, after observing increased muscle strength in women with knee OA, Trans et al. (37) hypothesized that these positive effects observed after WBVT were because of neuromuscular adaptation, but the authors concluded that the exact mechanism underlying these strength improvements was unclear.

Although the exact mechanism regarding improvements in musculoskeletal tissues is unknown, improvements in muscle performance are believed to occur via neurogenic potentiation that involve spinal reflexes and muscle activation, which is based on the tonic vibration reflex (TVR) (20). The TVR can be activated by vibrations applied to the muscle stimulate sensory receptors, which are primarily muscle spindles that detect length changes. In an attempt to dampen the vibratory waves, muscle spindles facilitate activation of alpha-motoneurons, which initiate reflexive muscle contractions. The WBVT may also induce increased recruitment of motor units via activation of muscle spindles and polysynaptic pathways, which is seen as a temporary increase in the muscle activity (3,18,20). In addition, a second mechanism suggested for enhancing the force output of muscle may be phosphorylation of myosin light chains, which leads to increased actin and myosin sensitivity to intracellular Ca^{2+} signal, resulting in a higher rate of cross bridge attachment and increased twitch tension.

Evidence related to the effects of WBVT on functional physical performance, such as performance of ADLs and osteoarthritic knee pain is lacking; therefore, the practical focus of this study was to observe the changes in function and osteoarthritic knee pain during tasks used to simulate ADLs after an acute bout of WBVT. The purpose of this study was to test the hypothesis that a single session of WBVT would improve the performance of individuals with symptomatic knee OA in 3 tests designed to simulate ADLs: the Timed-Up-and-Go Test (TUG), a step test, and a 20-m walk test. Secondarily, we sought to examine the effect of WBVT on knee pain levels.

Methods

Experimental Approach to the Problem

Each participant attended 1 testing session in a biomechanics laboratory and completed a screening questionnaire. If the participant passed the screening questionnaire, experimental procedures and potential risks were explained, and informed consent was obtained. The following preintervention tests were then conducted (once each): Timed-Up-and-Go Test, step test, and 20-m walk test. For each test, the participants were allowed to wear their regular footwear and use their usual walking aids, if needed. The tests were separated by 5-minute rest periods. The times to complete these tasks were recorded in seconds with a stopwatch. Knee pain intensity levels were assessed immediately after each test using a visual analog scale (VAS), an established method for measuring pain levels associated with arthritis (14). This scale consisted of a 10-cm horizontal line with descriptors of “no pain” on one end and “worst pain imaginable” on the other. The participants indicated their current knee pain intensity level by marking a vertical line on the scale (11).

The TUG is a reliable test designed to measure the functional mobility of frail elderly persons (29). For this test, each participant stood from a sitting position in an armchair, walked around a small cone placed 3 m in front of the chair, and returned to the same seat and sat down. The participants were told to complete the test as fast as they comfortably were able and were allowed to practice the test one time before they were timed. The step test was similar to the self-paced step test used by Petrella et al. (28) to assess functional capacity. For this test, the participants were asked to step up and down on a 20-cm step 20 times at their preferred pace (Figure 2). An investigator counted aloud as each step was completed. The self-paced walk test is reliable and was used to assess gait speed (15,28). This walk test involved walking 20 m in a straight line from a still, standing position. The participants were told to walk as fast as comfortably able.

After the preintervention tests, the participants were given a 5-minute rest period and completed the WBVT protocol as previously described. Upon completing the WBVT, the participants were given a 5-minute rest period, after which they completed the series of TUG, step test, and 20-m walk test exactly as before, again recording their pain levels immediately after each test. These tests were performed again 1 hour after the completion of WBVT.

Subjects

This experiment was an open trial for which 17 adults with symptomatic knee OA were recruited from orthopedic clinics, fitness centers, care centers, and the community surrounding the university. Knee OA was determined by a screening questionnaire based upon self-reported previous diagnosis by a physician and symptoms consistent with ACR Clinical Classification Criteria for OA of the knee (2). There were no age requirements for participation and no formal activity level was recorded for participants. Exclusion criteria consisted of: pregnancy, epilepsy, presence of

Table 1. Demographic characteristics of the participants.*

Participants	Gender	Age (y)	Body height (cm)	Body weight (kg)
n = 17	13 F + 4 M	66.9 ± 9.39	168.2 ± 8.76	81.95 ± 19.03

*Values are mean ± *SD*.

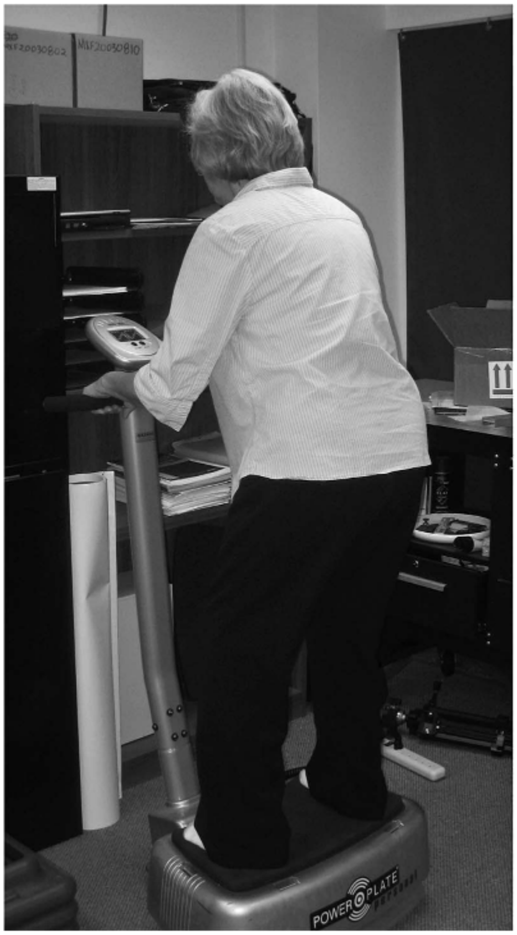

Figure 1. Participant positioning for whole-body vibration training.

a pacemaker, acute thrombosis, severe cardiovascular diseases, recent wounds from an operation or surgical intervention, synthetic-artificial joints, recently fitted IUDs, coils, metal pins, bolts or plates, acute hernia, severe diabetes, severe migraines, cancer, and retinal problems and dysfunction. Individuals who received any intraarticular injections to treat OA within 4 weeks before the study were also excluded. The day before their participation in the study, participants did not take any medications, herbal products, or supplements to treat OA. This study received University Institutional Review Board approval. The demographic characteristics of the participants are presented in Table 1.

Instrumentation

A Power Plate vibration platform (2004 model Personal Plate) was used in all WBVTsessions. The participants stood on the platform with knees slightly flexed, without shoes and received triplanar (mostly vertical), sinusoidal WBV at 35 Hz and 4- to 6-mm displacement, 10 times in 60-second increments with 60-second rest periods in between bouts of WBV (Figure 1). Total exposure time was 10 minutes. The participants stood in socks on a thin (2-cm) rubber mat that was placed between their feet and the platform.

Figure 2. Participant positioning for the step test.

Statistical Analyses

SPSS version 17 was used to perform separate repeated measures 1-way analyses of variance for each outcome variable across 3 testing intervals ($\alpha = 0.05$). Bonferroni post hoc tests were performed when necessary. Correlations were performed using an R module, Pearson Correlation (v1.0.3) in Free Statistics Software (v1.1.23-r3), to examine the relationships between VAS scores after each test and time to complete the tests.

Table 2. VAS pain scores before and after tests of physical performance.*†

Test	Pre	5 min post	1-h post
TUG	1.42 ± 0.45	1.93 ± 0.50	1.77 ± 0.58
Step	2.90 ± 0.51	2.10 ± 0.60	2.67 ± 0.63
Walk	2.15 ± 0.536	2.01 ± 0.58	2.09 ± 0.61

*VAS = visual analog scale; TUG = Timed-Up-and-Go Test.
†Values are mean ± standard error in cm; $n = 15$.

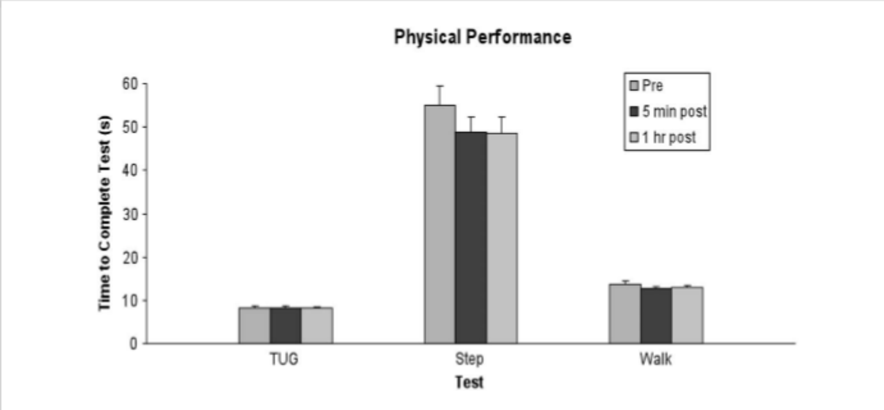

Figure 3. Mean and standard error before, 5 minutes after, and 1 hour after whole-body vibration training for the following tests: Timed-Up-and-Go, step, and walk *5-minute post values are significantly lower than pretest values ($p < 0.05$).

Results

Training Experiences and Dropout

Although most participants found the WBVT challenging, the protocol was generally well tolerated. A few participants reported itching of the legs and face after WBVT; however, this effect resolved quickly. Two participants of the original 17 were unable to complete the entire protocol because of pain (knee and ankle pain, respectively). Data for these 2 participants were not analyzed.

Timed-Up-and-Go Test

No main effect was detected for time to complete the TUG ($F[2,22] = 0.283$, $p = 0.756$, $\eta_p^2 = 0.20$). The results for TUG performance are presented in Table 1. Additionally, no main effect was found for VAS pain levels immediately after the TUG ($F[2,22] = 1.197$, $p = 0.317$, $\eta_p^2 = 0.19$). The VAS pain scores are presented in Table 2.

Step Test

A main effect was detected for time to complete the step test ($F[2,22] = 6.243$, $p = 0.006$, $\eta_p^2 = 0.308$). Post hoc analyses revealed that the time to complete the step test at 5 minutes after WBVT improved significantly ($p = 0.042$) from the pretest, whereas no change was detected from pretest to 1 hour after WBVT ($p = 0.085$). There was no change in time to complete the step test from 5 minutes after WBVT to 1 hour after WBVT ($p = 1.000$). The results for step test performance are presented in Table 1. Pain levels did not vary after the step test ($F[2,22] = 2.062$, $p = 0.146$, $\eta_p^2 = 0.128$).

20-m Walk Test

A main effect was found for time to complete the walk test ($F[2,22] = 4.370$, $p = 0.022$, $\eta_p^2 = 0.238$). Post hoc analyses, however, failed to reveal changes from pretest to 5 minutes after WBVT ($p = 0.110$) or 1 hour after WBVT ($p = 0.224$) or from 5 minutes after WBVT to 1 hour after WBVT ($p = 0.881$). Walk test performance data are presented in Table 1. The VAS pain levels were not altered after the walk test ($F[2,22] = 0.086$, $p = 0.918$, $\eta_p^2 = 0.006$). Figure 3 presents a summary of performance in all the tests.

Correlation of Pain Levels with Physical Performance

A moderate correlation ($r = 0.465$, $p = 0.001$) was found between the VAS scores recorded immediately after the step test and the time to complete the step test across all the trials. No significant correlation was found between VAS scores and time to complete the TUG ($r = 0.201$, $p = 0.186$), nor between VAS scores and time to complete the walk test ($r = 0.164$, $p = 0.282$).

Discussion

Along with pain, patients with knee OA experience decreased muscular strength, impaired neuromuscular function, reduced range of motion (ROM), and impaired balance in the affected knee(s) (27). Thus, we attempted to determine the effects of a single session of WBVT on the physical performance of individuals with knee OA in simulated ADLs. The type, intensity, and dosage of training used for evaluating function and pain in knee OA is unique to this study, and therefore, direct comparisons are difficult.

To our knowledge, this was the first study to examine the effect of an acute bout of WBVT on functional physical performance and pain levels in individuals with knee OA. The findings of this study demonstrated that a relatively short, 1-time bout of WBVT was effective in improving the ability of individuals with knee OA to complete a step test by 11%. The time to complete the 20-m walk test was also improved by 8%, although the post hoc analysis did not reach significance. The WBVT protocol did not significantly improve performance in the TUG, nor did it significantly affect knee pain levels. However, knee pain assessed with a VAS was related to step test performance. More specifically, an increase in pain related to an increase in time to complete the task (decreased performance).

Although it is beyond the scope of this study to ascertain the exact mechanism by which the step test performance was improved, findings from previous studies and our failure to find an accompanying significant decrease in pain levels suggest that the improved performance was mostly because of beneficial effects of WBVT on the neuromuscular system. Although in varying populations, short-term bouts of WBVT similar to the protocol used in our study have been shown to enhance leg muscle strength and power (6,7), postural control and balance (38), and joint ROM (9), all of which are impaired in those with knee OA (4,17,36). Together, these findings suggest that neuromuscular enhancement may have occurred in the muscles of the lower extremities in response to vibration and may also be a primary factor in improving step test performance.

Improvements in strength and power may be attributable to neural factors including increased recruitment, synchronization, muscular coordination, and proprioceptor response (9). The WBVT has been shown to elicit a reaction known as TVR (20), which is elicited by mechanical stimuli transmitted from the vibration plate through the body, which stimulates sensory receptors, mostly muscle spindles. This activates alpha-motoneurons, which initiate reflexive muscle contractions. Monosynaptic and polysynaptic pathways that monitor the TVR produce an increased activation of motor units (33). The TVR is likely dependent on frequency of vibration, muscle length, and body position (21).

One additional phenomenon suggested by prior studies is postactivation potentiation, which is referred to as an increase in muscular performance produced by a muscle contractile activity and can be measured with muscle twitch and reflex activity. The reflex activity technique involves nerve stimulation that produces 2 electromyographic wave patterns. A single muscle twitch response is characterized by an M wave, and the H-reflex is a wave pattern produce by activating a monosynaptic reflex response. The ratio of H-reflex amplitude relative to the M-wave amplitude can represent motor neuron excitability. The mechanism that may induce the H-reflex is considered to elicit reflexive activity in the spinal cord by increasing the activation of alpha-motoneurons. Conversely, muscle twitch is thought to elicit an increase in twitch tension, brought on by phosphorylation of myosin light chains.

Neither response (muscle twitch or reflex activity) was measured in this study, consequently we are unable to speculate further on the mechanism involved with improving performance after WBVT in knee OA. Observations of either increased or unchanged reflex activity after WBVT have both been noted in the literature. Disagreements among these studies may suggest that twitch response produced after WBVT may be more important than reflex response, resulting from an increase in muscle activity because of the vibrations being dampened by the muscles (10). However, it is unknown whether phosphorylation of myosin light chains and cross-bridge attachments are mediated by WBVT. Additional assumptions regarding this mechanism require verification before further conclusions can be made about improved muscle performance after WBVT.

Knee OA pain is associated with an increased fall risk (17), and knee pain relief has improved obstacle avoidance in people with knee OA (26). Additionally, Walker et al. (39) reported evidence of significantly increased fall risk associated with the use of nonsteroidal antiinflammatory drugs (a common treatment of knee OA pain). In consideration of these findings, it should be noted that, although not reaching significance, we did find that pain levels after the step test decreased on average 28% 5 minutes after WBVT. Together with the moderate correlation between pain level and step test performance, there is some evidence that pain reduction may have contributed to improved performance. Rittweger et al. (32) have suggested that WBVT may have pain-relieving effects by influencing peripheral nociception and central pain sensitivity. Furthermore, both Dworkin et al. (16) and Cepeda et al. (12) suggested that when evaluating participants with pain the intensity measured by a test such as the VAS might be very different from the patient's perspective. For example, Cepeda et al. (12) found that in participants with acute pain, the meaning of changes in a numeric rating pain scale and the meaning of percent pain reduction depend upon baseline pain intensity. Understanding the meaning of changes in the VAS is important for determining the effectiveness in a treatment, and it is possible this also contributed to improved performance. In light of this information related to knee pain and fall risk, we recommend additional investigation related to the potential of WBVT as an alternative treatment to reduce pain.

Knee OA disrupts gait in a number of ways (1) that also contribute to an increased risk for falls in this population (17,26). Previous researchers have found WBVT to be effective in improving gait, mobility, and health-related quality of life in the elderly (8,22), although these protocols involved a longer duration of training (6 weeks and 2 months) than did this study. In our study, the improvement in time to complete the walk test 5 minutes after WBVT had a mean improvement of >1 second (Table 2), though the post hoc analysis did not reach significance. Yet, the potential to decrease falls and improve health-related quality of life seems to warrant additional studies to examine the effect of WBVT on gait and mobility in those with knee OA.

The TUG was designed to measure the functional mobility of frail elderly persons. Frailty is a vague term (35); nevertheless, some, but not all, of the participants in this study could be classified as frail. Thus, the TUG may not have been a good measure of mobility in this population, which could explain the lack of significant findings related to TUG performance. It is interesting that the greatest improvements after WBVT, both in performance and in pain levels, were seen in the step test; the test with the highest mean VAS scores at pretest, followed by the walk test, which had the second highest mean VAS scores at pretest (Table 2). Although not directly measured, aside from pain levels, the step test appeared to be the most strenuous and difficult test for the participants to complete, again followed by the walk test. The demands placed on the neuromuscular system may have been greater depending on the level of difficulty of the test. For example, the possible neuromuscular effects from WBVT would be most beneficial and recognizable in the performance of the step test (Table 2). Therefore, more strenuous tests could be more sensitive measures of pain because of the increased level of difficulty. Further examination of the specific demands of the 3 tests (e.g., measurements of ROM involved, ground reaction forces, joint kinetics) would be required to confirm this hypothesis. The pain levels associated with each test may differ according to the physiological demands of each test and could result from differing mechanisms. Additional information related to physiological demands of each test could help explain differences and why a greater improvement in pain levels was seen after the step test. Further investigation of movement patterns in performance of these tests could potentially provide biomechanical explanations for changes in performance after WBVT.

Even with differences in terms of age, gender, height, and weight, the same WBVT protocol was used for all the participants. Ideally, a WBVT protocol could be tailored to best meet each individual's characteristics. Additional research to determine safe and effective WBVT protocols for various populations based on individual characteristics and fitness level is needed. Furthermore, we recommend that research be conducted to examine effects of a longer-term WBVT program on functional physical performance and knee pain levels in people with knee OA.

The limited number of participants prevented the implementation of a placebo control group into the study design. Although the results from previous placebo-controlled studies involving WBVT have shown a minimal placebo effect, on muscle strength measures, the extent to which it may have affected this study is unknown (22). Although OA is a diverse pathology (2) determination of symptomatic knee OA in this study did not involve radiographic measures. It was based on self-reported previous diagnosis by a physician and symptoms consistent with the ACR Clinical Classification Criteria for OA of the knee (2). Roux et al. (34) and March et al. (25) have developed similar questionnaires that have been shown to exhibit high specificity and accuracy upon radiographic verification. We were unable, however, to make any judgments related to the severity of knee OA. Pretest VAS pain levels appeared to be relatively low (Table 2), suggesting that the severity of knee OA for the participants in this study may have been rather mild. In an attempt to reduce the effects of residual pain and fatigue on the performance of subsequent tests, the participants were given a 5-minute rest period between tests. Thus, although tests began 5 minutes after WBVT, because of rest periods, the step test was not performed until about 10 minutes after WBVT, whereas the walk test was performed approximately 15 minutes after WBVT. The same logic applies to the tests performed 1 hour after WBVT. Because some acute effects of WBVT are reported to be relatively short lasting (9), it may have improved the design of this experiment to reduce the duration of rest periods. Despite these limitations, significant changes in performance were observed.

Practical Applications

Our findings suggest clinicians (physical therapists, etc.) may apply WBVT as an effective nonpharmacologic modality to treat some knee OA symptoms, although additional research is needed to determine the safest and most efficient training protocols and to further elucidate the mechanisms by which performance is enhanced. A short bout of WBVT was well tolerated in nearly all the participants and was effective in improving performance of a step test and 20-m walk test. When viewed in relation to previous studies (8,22,26), our findings indicate that WBVT may have potential in improving ADL-related quality of life for those with knee OA.

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