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Effect of balance exercise in combination with whole-body vibration on muscle activity of the stepping limb during a forward fall in older women: A randomized controlled pilot study

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ABSTRACT

This study investigated the effects of balance exercise combined with whole-body vibration (WBV) on step performance and lower limb muscle activity during simulated forward falls using the tether-release method in older women. Twenty older women were assigned to either a WBV plus balance exercise group (WBV, $n = 10$) or a balance exercise without vibration group (standard balance exercise group [STE], $n = 10$). WBV performed weight-bearing exercises on a WBV platform combined with other balance exercises as a home program, whereas STE performed the same exercises without WBV. The exercise volume was equal in both intervention groups (3×/week for 12 weeks × 30 min/session). The EMG and kinematic data of the stepping leg from the balance recovery step were examined before and after the intervention. While both groups extended step length during forward falls after the intervention, only WBV increased step velocity. EMG analysis of the balance recovery step showed that both groups increased peak EMG of knee flexor and extensor muscles after intervention. After intervention, WBV increased peak EMG of the plantar flexors, which are used to exert the push-off forces just before the leg swing. Balance exercise in older women resulted in significant improvements in the balance recovery step after a simulated forward fall. WBV also had the additional benefit of improved step velocity, which was reflected in increased activity of the plantar flexors in the stepping leg.

1. Introduction

Falls can result in serious injuries, leading to bone fractures and, in some cases, long-term disability. Most falls occur while walking on an even surface, followed by transfers while rising from a chair or while climbing stairs. Falls on an even surface are caused by an unexpected loss of balance such as slipping, tripping, or stumbling (Roudsari, Ebel, Corso, Molinari, & Koepsell, 2005). After an unexpected loss of balance, the immediate response is to take a step to recover balance and avoid falling. One experimental approach to examine the ability to recover balance after a forward fall is the tether-release method (Hsiao-Wecksler, 2008), in which the participant is required to recover balance from a supported, forward-leaning posture after a sudden release of the cable providing the support. Earlier studies using this method showed that older women had poor stability performance, shorter step length, and slower step speed after unexpected disturbances compared with young people and older men (Wojcik, Thelen, Schultz, Ashton-Miller, & Alexander, 1999; Wojcik, Thelen, Schultz, Ashton-Miller, & Alexander, 2001). In addition, older women with poor stability performance also had lower hip extension strength and produced less knee and ankle joint peak power during stepping (Carty, Cronin, Lichtwark, Mills, & Barrett, 2012). These results suggest that exercise interventions for older women need

Abbreviations: BF, biceps femoris; BW, body weight; EMG, electromyography; GC, lateral head of the gastrocnemius; ICC, intra-class correlation; MVC, maximal voluntary contraction; RF, rectus femoris; STE, standard balance exercise group; TA, tibialis anterior; TUG, timed up-and-go; VAS, vastus lateralis; WBV, whole body vibration.

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to target improvements in step performance, such as step length and step velocity, and lower limb muscle strength, power, and coordination, all of which are essential to improve stability performance in older women. Indeed, stepping behavior during a forward loss of balance and physiological profile assessment results were found to be independent predictors of a future fall in elderly individuals; hence, it can be assumed that exercise interventions designed to improve stepping behavior may protect against future falls (Carty et al., 2014).

A few studies have demonstrated that training in a laboratory using an unpredictable perturbation, such as a waist pull or altered base of support, improved compensatory stepping reaction for balance recovery in the elderly (Grabiner, Bareither, Gatts, Marone, & Troy, 2012; Mansfield, Peters, Liu, & Maki, 2010; Rogers, Johnson, Martinez, Mille, & Hedman, 2003). However, it is unclear whether training to improve a specific disturbance problem will help an individual avoid all potential falls in daily life. Therefore, more general training is recommended to improve stability performance and decrease falls in elderly individuals. Arampatzis, Peper, and Bierbaum (2011) and Aragão, Karamanidis, Vaz, and Arampatzis (2011) demonstrated that exercise for dynamic stability control and trampoline exercise in the elderly improved stability performance using the tether-release method (i.e., the participants were able to better recover balance from a more forward-leaning posture after the training). Because it improved step velocity and hip moment generation, the authors suggested that reinforcement of dynamic stability was caused by neuromuscular coordination upgraded to create a joint moment in the appropriate time element. However, these intervention studies used the stability performance index focusing on kinematic measurements, and no study to date has investigated changes in electromyography (EMG) activity, which serves as a neuromuscular parameter. Improvement of stability performance during balance recovery is also thought to be correlated with changes in lower-limb EMG activity, as individuals with poor stability performance counterparts recruit a lower proportion of the available motor unit pool during balance recovery compared to those with good stability performance (Cronin, Barrett, Lichtwark, Mills, & Carty, 2013).

The age-related loss of strength, power, and functional strength is termed as dynapenia (Clark & Manini, 2008), and has a negative influence on physical performance, which increases the risk of falling. Strength, power, and functional strength training are the most effective intervention methods for elderly individuals who have dynapenia. In recent years, whole-body vibration (WBV) has been the focus of attention as a method that can promote muscle strength, power, and balance control improvements in the elderly (Osawa, Oguma, & Ishii, 2013; Sitjà-Rabert et al., 2012). The mechanisms by which WBV promotes muscle strength and power are not clear, but WBV increases lower limb EMG activity during induced stretch reflexes (Ritzmann, Kramer, Gruber, Gollhofer, & Taube, 2010) and improves lower limb power, which affects vertical jump performance (Raimundo, Gusi, & Tomas-Carus, 2009; Russo et al., 2003). Therefore, WBV is a valid exercise mode of sensorimotor training for increasing power, strength, and functional strength in elderly individuals (Rogan, Hilfiker, Schenk, Vogler, & Taeymans, 2014; Rogan, Schmidtbleicher, & Radlinger, 2014). Because WBV-based training is economical, takes less time, and is convenient, its use is considered most suitable for nursing home residents. Adding WBV to a balance-training program might improve step performance during a simulated forward fall by enhancing lower limb muscle strength and power. The effect of balance training on changes in EMG activity during the balance recovery step induced by a simulated fall is currently unknown, but could provide insight into differences between WBV and STE on functional enhancement of the balance recovery step.

This study is a randomized controlled pilot trial based on a prospective intervention. The purpose was to examine the effect of balance exercise combined with WBV on step performance and lower limb EMG activity during a forward loss of balance. It was hypothesized that adding WBV training would improve step performance and enable balance recovery during a forward balance loss to a greater extent than balance training only, and that this improvement would be reflected in the EMG activity of the stepping leg.

2. Methods

2.1. Design and participants

This study involved two randomized groups in a parallel-group controlled pilot trial, which was conducted from August to December 2012. Twenty healthy older women residents were recruited from two nursing homes using advertising literature. The inclusion criteria were as follows: aged ≥65; dwelling in a nursing home; able to walk independently (without a cane); willing to participate in group exercise classes; and minimal, if any, auditory or visual impairment. Potential participants with central nervous system disorders, severe cardiovascular disease, advanced cognitive impairment, any history of major trauma, rheumatoid or osteoarthritis, or other major systematic diseases were excluded. Further exclusion criteria were any new medications during the study (e.g., against joint pain), limited range of motion in the legs affecting stepping, severe kyphosis, or pain in the trunk or lower limbs. Written informed consent was obtained from each participant in the trial in accordance with the Declaration of Human Rights, Helsinki, 1975. This research was approved by the Ethical Review Board of Kyoto University Graduate School of Medicine, Kyoto, Japan.

Participants were stratified by age and were allocated to two groups by simple randomization using a computer-generated sequence: 10 participated in standard exercise plus WBV and 10 participated in standard exercise without vibration (STE). As it was not possible to blind the subjects to the two types of exercise, on the first day of evaluation, the group assignment was orally reported to participants by nursing home staff not involved in the study. Evaluation and both types of exercise were performed in the waiting lounge of the respective nursing homes.

2.2. Training protocol

Each group exercised 3 days/week for 12 weeks × ~30 min/session, and all participants finished the experiment. The home-program intervention was conducted according to an individual schedule for each group.

Participants performed 5 min of limb stretching before training as a warm-up. Following a five-minute break, WBV performed the vibration exercise in a standing position. In each session, vibration was provided by a commercially available device (Galileo 2000, Novotec GmbH, Pforzheim, Germany). The participants stood with their feet shoulder-width apart on the board, which produced side-alternating oscillations of the whole body. WBV received three-minute vibration stimuli. During the vibrations, the participant performed a half squat, heel rise, and toe up on the WBV platform. Weight shift training was also performed on the WBV platform, including anterolateral and posterolateral weight shifting without stepping while reaching forward and laterally. Frequency, amplitude, and maximum acceleration parameters were set at 10 Hz, 3 mm, and 11.8 m s^{-2} during the first week, and increased to 21 Hz, 7 mm, and 121.9 m s^{-2} in the 12th week, respectively. Load progressions of the vibratory stimuli were increased by 1 Hz every