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Whole-body vibration training improves flexibility, strength profile of knee flexors, and hamstrings-to-quadriceps strength ratio in females

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ABSTRACT

Objectives: Short-term whole-body vibration training (WBVT) has emerged as an exercise method for improving neuromuscular performance and has been proposed for injury prevention and rehabilitation. This study investigated the effects of a *short-term* (≤2 months) WBVT program using a *side-to-side* vibration on: (i) strength profile of knee extensors (KE) and flexors (KF), (ii) "functional" hamstrings-to-quadriceps ratio (ECC_{KF}/CON_{KE}), (iii) flexibility and (iv) vertical jumping performance (VJ). Furthermore, we explored the retention of performance gains 21 days following WBVT.
Design: Randomized-controlled trial.
Methods: Twenty-six moderately active females (20.40 ± 0.27 years) were assigned to a vibration (VG) or a control group (CG). The *short-term* WBVT program consisted of sixteen-sessions on a *side-to-side* vibration platform (frequency: 25 Hz, amplitude: 6 mm, 2 sets × 5 min). Isokinetic and isometric peak torque of KE and KF, ECC_{KF}/CON_{KE}, flexibility, and VJ were measured pre, 2 days post, and 21 days following the cessation of WBVT.
Results: Post-training values of flexibility, isokinetic and isometric peak torques of KF and ECC_{KF}/CON_{KE} ratio were higher than pre-training values in VG ($p < 0.05$); however, they remained unchanged in CG. Post-training values were greater in VG vs. CG ($p < 0.05$). Twenty-one days following WBVT, post-training values were no longer *significantly* different than pre-training values. The short-term WBVT program had no effect on strength profile of KE and on VJ.
Conclusions: A short-term *side-to-side* WBVT program improved flexibility, the strength profile of knee flexors, and the "functional" hamstrings-to-quadriceps ratio in moderately active females. Coaches and clinical practitioners should consider this type of training as an effective exercise mode for improving the strength asymmetry of reciprocal muscles at the knee joint.

1. Introduction

Whole-body vibration (WBV) is an alternative mode of exercise training that has been used in sport and rehabilitation for improving neuromuscular performance.[1] *Long-term* (>2 months) WBV-training may increase muscular strength, power and jumping ability, with greater improvements observed in untrained and elderly individuals.[2] Recently, *short-term* WBV-training has been proposed as an exercise method for injury prevention and rehabilitation.[3–5] Research has now been focusing on the efficacy of a *short-term* WBVT program to improve attributes of neuromuscular performance and flexibility. *Short-term* WBV studies (up to 24 sessions or 2 months) have been shown to either increase[3,6–9] or to have no-effect[6,10] on strength of knee extensors (KE) and vertical jumping performance (VJ). The few studies that examined the effects of a *short-term* WBVT program consisting *solely* of WBV on strength of knee flexors (KF)[6,10] and on flexibility[3,11,12] have also reported inconsistent findings.

All the aforementioned studies (except for one[7]), have utilized platforms that vibrate *simultaneously* in vertical direction. However, the effects of WBV are influenced by the method that the vibration is transmitted to the body (vertical simultaneous vs. side-to-side alternating movement).[1,13] Platforms producing *side-to-side* alternating vibration may induce a different degree of muscle stretch and tissue vibration on leg muscles that could lead to different neuromuscular responses compared with platforms using *vertical simultaneous* movement.[13] Therefore, it is of interest to examine the short-term (≤2 months) effect of WBV on the flexibility and strength profile of lower limbs with a platform that produces *side-to-side alternating* vibration.

The few studies that examined the effects of a *short-term* (≤2 months) side-to-side alternating WBVT program on neuromuscular performance have focused on VJ and strength of KE. The authors reported either a marginal increase[14] or no change[15,16] in VJ with

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no improvements in strength of KE[17] after, however, a few training-sessions (six–ten). To our knowledge, no study has examined the effects of a *short-term* (up to 24 sessions or 2 months) WBVT program, using *side-to-side alternating* vibration, consisting *solely* of WBV on flexibility and on isokinetic (concentric and eccentric) and isometric strength of KF. Eccentric muscle action is as important as concentric activation for performing daily activities and isometric strength is a main contributing factor in the independent performance of daily tasks (such as grocery carrying, posture, dynamic stability, etc.).[18] In addition, the asymmetry in strength properties of reciprocal muscle groups is a contributory factor for muscle injury.[19] In fact, the ratios of eccentric-to-concentric actions of the antagonists muscles constitute a measure of strength imbalances and knee joint stability,[19] and may provide information on knee function.[19,20] Increased strength of hamstrings muscles have been reported to deter lower-limb injuries and to contribute to the maintenance of muscular balance and joint stability preventing knee injury.[19] The hamstrings-to-quadriceps (H/Q) torque ratio is used in sports medicine to monitor potential hamstring- and knee-related injuries,[19,21] and to assess the strength profile of the knee joint. An increased H/Q torque ratio following training, may result in increased knee joint stability, and in reduced anterior cruciate ligament and knee-related injuries.[21] Thus, it is of interest to examine the effects of a short-term *side-to-side* WBVT program on strength of KF, on different types of muscle contraction (concentric, eccentric and isometric), and on the H/Q torque ratio.

The aims of this study were to examine the effects of a short-term (16 sessions) *side-to-side alternating* WBVT program on: (i) flexibility, (ii) isokinetic (concentric and eccentric) and isometric peak torque of KE and KF muscles, (iii) the "functional" reciprocal muscle group torque ratio at the knee joint, and (iv) VJ. We have also evaluated the retention of performance gains 21 days after the completion of the training regime.

2. Methods

Twenty-six moderately active young females were randomly assigned to either a vibration (VG; $n = 13$; age: 20.4 ± 0.4 years; body mass: 59.9 ± 3.5 kg; height: 167.2 ± 2.3 cm) or a control (CG; $n = 13$; age: 20.5 ± 0.4 years; body mass: 60.9 ± 3.5 kg; height: 168.0 ± 1.9 cm) group. All participants were healthy with a regular menstrual cycle (28.3 ± 0.3 days), participated in low-level physical activities 2–3 times/week, and had no previous experience in WBV-training. Before the initiation of the study, the institutional review board committee approved the experimental protocol and all participants signed an informed consent form.

A familiarization session and anthropometric measurements were performed a week prior to the study. The VG participated in a 16-session WBVT program that was completed in 21 days. Flexibility of hamstrings and low back muscles (sit-and-reach test), VJ, and isokinetic and isometric peak torque of KE and KF were measured the day before training, two and 21 days after the completion of training. The 2-day post-training measurement was selected to avoid potential fatigue and acute effects of the last WBVT session. The 21 days post-training measurement was adopted based on the short-term nature of our training intervention (3 weeks) and the fact that several studies that examined the short-term effects of neuromuscular training and detraining on strength indices have used training and detraining periods of similar duration.[22–24] All tests were performed in the same order, and were separated by a 10 min resting period. The testing- and training-sessions were performed at the same time of the day. The VG was instructed to avoid any type of other physical activity, whereas the CG was instructed to maintain their normal daily living activities. To avoid the potential physiological effects of the menstrual cycle on performance in our study, the pre-training testing was arranged so that in each group an equal number of women would be in the follicular and in the luteal phase on the day of pre-training testing and the start of training.

The participants in the VG performed a 16-session WBVT program at frequency of 25 Hz and amplitude of 6 mm for 2 sets of 5 min (2 min rest between sets). The frequency and amplitude selection was based on the fact that most short-term studies that used side-to-side alternating vibration applied frequencies of 20–34 Hz and amplitudes 4–9 mm.[7,15–17] Since a prolonged exposure to a continuous vibration is known to suppress the tonic vibration reflex and decrease muscle activation and force, an *intermittent vibration* protocol has been used in this study. The WBV sessions were performed on a commercial vibrating platform (Galileo Fitness, Novotec, Germany) that produces a side-to-side alternating vibration. During the WBV sessions, the participants wore non-slippery socks and maintained an upright position with their knees flexed at 10°.[7,25,26] The knee angle was controlled during the WBV training sessions with a goniometer (Gollehon, Lafayette). The WBV amplitude was determined as the extent of the oscillatory motion (peak-to-peak displacement). More specifically, the participants' right and left foot were placed on marks 3 of the platform that corresponded to the WBV amplitude of 6 mm.

Prior to testing, the participants performed a *standardized* 10 min warm-up that included 5 min of stationary cycling and a 5 min combination of static and dynamic stretching exercises. Flexibility was assessed with the sit-and-reach test using a Flex-Tester box (Novel Products Inc., Rockton, IL), as previously described.[3] VJ was assessed using the squat jump (SJ) and the countermovement jump (CMJ) tests with a force-platform (Bertec Corp., Worthington, OH). Following three preliminary familiarization trials, the participants performed three maximal trials for each type of jump with a rest period of 60 s.[3,27] The best performance on each type of jump was considered for analysis.[3,27]

The isokinetic and isometric peak torque of KE and KF muscles was assessed using a Cybex dynamometer (Cybex Norm, NY).[27] All tests were performed from the seated position with a hip flexed at 90° and the participants' arms crossed over their chest.[27] Velcro straps were used to stabilize the trunk, waist, and thigh of the tested leg. The isokinetic protocol included five maximal concentric and eccentric knee extension and flexion efforts at angular velocity of 60°/s.[27] The range of motion for knee flexion was set from 0° (full extension) to 105°. The isometric protocol included three maximal efforts for 5 s at 65° and 25°, for knee extension and flexion, respectively.[27] All tests were separated by a 5 min resting period. Visual feedback and consistent verbal encouragement were provided during the pre- and post-testing evaluations of all strength parameters. The functional H/Q torque ratio was calculated by dividing the maximal eccentric torque of KF (ECC_{KF}) by the maximal concentric torque of KE (CON_{KE}).[20]

All data are presented as means ± SE and were analyzed using Statistica software (StatSoft Inc., Tulsa, OK). The normality of data was examined using the Kolmogorov–Smirnov test. A two-way ANOVA (group × time) with repeated measures and Newman–Keuls post hoc tests were used to analyze the data and to locate the significantly different means. The level of significance was set at $\alpha = 0.05$. The effect sizes were calculated using the following equation: d = difference between means/pooled SD.

3. Results

ANOVAs revealed significant "group × time" interactions on concentric, eccentric, and isometric peak torques of KF ($p < 0.001$–0.05; Table 1). In VG, post-training values of all torque variables of KF were significantly higher than the respective