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Research article

Acute Whole-Body Vibration Does Not Facilitate Peak Torque and Stretch Reflex in Healthy Adults

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Abstract

The acute effect of whole-body vibration (WBV) training may enhance muscular performance via neural potentiation of the stretch reflex. The purpose of this study was to investigate if acute WBV exposure affects the stretch induced knee jerk reflex [onset latency and electromechanical delay (EMD)] and the isokinetic knee extensor peak torque performance. Twenty-two subjects were randomly assigned to the intervention or control group. The intervention group received WBV in a semi-squat position at 30^{o} knee flexion with an amplitude of 0.69 mm, frequency of 45 Hz, and peak acceleration of 27.6 m/s^{2} for 3 minutes. The control group underwent the same semii-squatting position statically without exposure of WBV. Two-way mixed repeated measures analysis of variance revealed no significant group effects differences on reflex latency of rectus femoris (RF) and vastus lateralis (VL; p = 0.934 and 0.935, respectively) EMD of RF and VL (p = 0.474 and 0.551, respectively) and peak torque production (p = 0.483) measured before and after the WBV. The results of this study indicate that a single session of WBV exposure has no potentiation effect on the stretch induced reflex and peak torque performance in healthy young adults.

Key words: Acute whole body vibration, neuromuscular performance, stretch reflex, peak torque.

Introduction

Whole-body vibration (WBV) has been widely used as an adjunct to traditional resistance training among sports and rehabilitation professionals to improve muscular performance. WBV differs from traditional weight training program in which the loading is a passive sinusoidal vibration induced to the musculoskeletal system while for weight training program, the targeted muscles are actively recruited and loaded at specific intensity. The sinusoidal vibration has been suggested causing rapid lengthening and shortening of the muscle tendon unit (Crochrane et al., 2009). This is based on the earlier work by Eklund and Hagbarth (1966); vibration evokes muscle contractions via tonic vibration reflex (TVR) produced by tendon vibration. The change in muscle length during vibration is detected by muscle spindles, innervated by the Ia-afferents resulting in facilitating homonymous alpha-motorneurons and induces a non-voluntary muscular contraction. Therefore, it is reasonably hypothesized that vibration of the musculoskeletal system leads to enhancement of the stretch-reflex loop and subsequently improves neuron excitability and motor recruitment of the muscle (Bosco et al., 1999). However, this proposed mechanism has seldom been investigated in either acute or chronic exposure to whole body vibration. If immediate muscle facilitation is the consequence of facilitation of the homonymous alpha-motorneurons via the enhancement of the muscle spindles activities, the stretched induced reflex should be the most direct measurement of this response. Moreover, the enhanced motoneuron excitability should facilitate the peak torque performance. However, the stretch reflex amplitude had been shown increase (Rittweger et al., 2003), remain static (Cochrane et al., 2010; Hopkins et al., 2009), and even decrease (Ritzmann et al., 2013) following acute exposure of WBV. In the same light, research on the effects of acute WBV on muscular performance has not provided unequivocal results. An acute bout of WBV has been reported to improve power (e.g., Cochrane and Stannard 2005; Ronnestad 2009), but its effects on strength seems to be less clear (e.g., Torvinen et al., 2002a; 2002b). However, there are also studies that showed WBV did not enhance muscle performance (e.g., Bagheri et al., 2012 and Gerodimos et al., 2010). Thus, the possible underlying neuromuscular mechanisms and muscular performance in response to acute exposure to WBV are not well understood.

The neurophysiological effects of isolated vibration applied to muscle belly or the tendon has been well established. Earlier studies by Burke and others (1976) have shown that the TVR is primarily attributable to muscle spindle Ia fibers, which are able to respond one-to-one to vibration frequencies of up to 200 Hz. In humans, it has been reported that tendon vibration of the pretibial muscles with a peak-to-peak amplitude of 0.2–0.5 mm, selectively activating the muscle spindle Ia afferents (Roll et al., 1989), and larger amplitude vibration (1–5 mm) causes muscle spindle primary and secondary endings in the same muscles to respond in a 1:1 manner with vibration frequency of up to 100 Hz (Burke et al., 1976). While these phenomenons were primarily shown in vibration applied directly to the muscle belly and tendon, Pollock et al. (2012) recorded the effects of WBV on the motor units (MU) discharge of the vastus lateralis muscle. The results demonstrated that the MU firing is phase locked to the vibration cycle, indicating the presence of reflex muscle activity similar to the TVR. If the TVR were observed during WBV, then a reduction in MU recruitments threshold were likely occur, and this might result in the

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enhancement of power and strength performance.

The aims of this study were to determine whether stretch-induced patellar tendon reflex will be enhanced after acute exposure to WBV, and if stretch reflex is enhanced, whether isokinetic knee extensor peak torque performance will be improved. More specifically, the reflex latency and electromechanical delay (EMD) of the patellar tendon reflex subjected to a WBV protocol of 45 Hz, amplitude of 0.69 mm, and duration of 3 minutes were investigated. The reflex latency is the time interval from the impact to the onset of muscle activation and is a good indicator of the muscle spindle sensitivity. EMD refers to the lag time between the stimulation of a muscle and the development of muscle tension; it is an indicator of spindle sensitivity through alpha-gamma co-activation. We opted for WBV device that produced vertical oscillation with a higher frequency (ie > 30 Hz and low amplitude < 1 mm) as previous works that studied the neuromuscular mechanism and produced mixed findings are all using the side to side alternating vibration platform with a WBV frequency ranged from 22-30 Hz and amplitude of 4-6 mm (Rittweger et al., 2003; Hopkins et al., 2009; Cochrane et al., 2010; Ritzamann et al, 2013).

Methods

Experimental approach to the problem

A prospective, double-blinded, randomized study was designed to compare the neurophysiological changes and muscular performance in the intervention group and the control group. Both the assessor and the subjects were blinded to the group assignment. The intervention session was supervised by another assessor who was not involved in the measurements. The subjects participated in a single testing session. The neural effect (the latency of reflex and the EMD) and the muscular performance (i.e., the peak torque) were performed before (pre) and immediately after (post) the intervention.

Subjects

A total of 27 subjects, 11 male (age 25.7 ± 3.1 yrs, body height 1. 72 ± 0.10 m, body mass 64.5±13.4 kg) and 16 female (age 25.8±3.7 yrs, body height 1.61 ± 0.11 m, body mass 50.2 ± 10.4kg), volunteered to participate in the study. Participants were between 20 and 35 years old. Ten of the subjects (37.03%) did not regularly exercise, 11 (40.74%) exercised 1–3 hours per week, 3 (11.11%) exercised 3–6 hours per week, 2 (7.41%) exercised 6–10 hours per week, and 1 (3.7%) exercised for more than 10 hours per week. None of the subjects trained regularly with sports teams or clubs. Inclusion criteria required that subjects did not have any of the following: history of lower limb injury in the previous 2 years, neurological or circulatory disorders, lower limb prosthesis, or current pregnancy. Subjects were randomly assigned to the intervention group (with WBV) or the control group (without WBV) by drawing ballots from a sealed envelope marked "I" (Intervention group) or "C" (control group). After randomization, five subjects (one from the control group and four from the intervention group) did not produce a measurable patellar tendon reflex response and were excluded from the study, Therefore, 22 subjects (3 males and 7 females in the intervention group; 5 males and 7 females in control group) completed the intervention and measurements. The study was approved by the ethic committee of the administrating institute and was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki.

Procedures

Subjects performed warm-up exercises on a Monark stationary bike (Monark Exercise AB, Sweden) at a self-selected moderate intensity for 5 minutes and performed standardized lower limb stretching exercises for 5 minutes. After the warm-up, subjects were prepared for application of the pressure sensor, goniometer, and EMG surface electrodes. Subjects were tested in a dynamometer chair with the seat back positioned at upright position with 85° hip flexion and the knee resting in 80–90° flexion. Data of patella tendon reflex and peak torque performance were collected as baseline measurement.

Measurements

All data were collected from the subject's dominant leg. All subjects reported right leg dominance.

Knee jerk reflex

Knee jerk reflex was induced by a custom made jig with an attached reflex hammer mounted onto it (Figure 1). The jig was vertically adjustable such that when properly adjusted the reflex hammer hit onto the subject's middle third of the patellar tendon. The exact point of the tendon strike was marked on the skin for subsequence trials. A pressure sensor was attached to the skin of the tendon strike point to record the time of impact. The reflex hammer allowed for free swinging motion from a fixed axis, and was lifted to 60° from vertical before release to produce a consistent tapping force in every trial. Subjects closed their eyes during the administration of the knee jerk reflex. Three patella tendon strikes with 15 seconds rest between each strike were administered before and immediately after the intervention. An electronic goniometer (PennyGile, Biometrics Ltd, Gwent, UK) attached to the lateral aspect of the knee, in line with femur and fibula with the strain coil positioned across the knee was used to detect the onset of knee movement.

Neuromuscular responses to the stretch reflex were measured by EMG measurement of the rectus femoris (RF) and vastus lateralis (VL) muscle. A double differential EMG surface electrode with an inter-electrode distance of 10 mm (DE-3.1, Delsys Inc., USA) was used for signal recording as we have previously reported (Chan et al., 2001) . In brief, electrode placements were standardized by having each subject actively perform isometric maximal voluntary contraction and placing the EMG electrode at the most palpable portion of each muscle belly. The electrodes were aligned along the longitudinal axis of the muscle fibers. The indifferent electrode was placed over the head of fibula. The skin was prepared by abrading with fine sandpaper and cleaning with alcohol to ensure the skin resistance was less than 5,000 ohms. The EMG signal was pre-amplified by 1000× and differen-

tially amplified with common mode rejection ratio >80 dB and filtered with a bandwidth of 20–450 Hz (Bagnoli-2 EMG system, Delsys Inc., USA). Signals were digitized by the A-D converter with a sampling rate of 2000 Hz and were displayed online on a personal computer for visual examination.

Isokinetic knee extensor peak torque

Concentric peak torque of the quadriceps at angular velocitiy of 60°s^{-1} was measured with an isokinetic dynamometer (Cybex Norm, version 2.04 Henly Healthcare, USA). The subjects were positioned in the dynamometer chair with the seatback tilted at 85° of hip flexion and the knee in 80–90° flexion aligned with the axis of the dynamometer. The trunk, thigh, and shank of the leg were secured to the chair by padded Velcro straps. The subjects performed three trials of concentric contraction at 60°s^{-1}. This was then followed by five maximal concentric efforts of the knee extensors. The average peak torque of the five maximum concentric contractions was taken as the peak toque of the knee extensor.

Interventions

A WBV device (JET-VIBE, Woojin System Co., Ltd. Korea) was used to administer the vibration intervention. The device is a motorized vibration exercise platform that produces vertical vibration with frequency ranges from 20–55 Hz and amplitude ranged from 0.55-1.2mm. A 45-Hz frequency with peak-to-peak vertical amplitude of 0.69 mm was used in this study. Linear variable displacement transducers (Honeywell's Model JEC-C DC-DC, Honeywell, MN USA) mounted on the platform of the vibration device was used to monitor the output of the frequency and the amplitude. The subjects stood on the vibration platform in bare feet with the feet shoulder-width apart. The distance between each foot and the central axis was equal. The subjects were asked to maintain a static semi-squat with the knee flexed at 30° (Figure 1). An electronic goniometer was used to monitor the knee flexion angle throughout the intervention. The subjects in the intervention group received 3 minutes of WBV. The control group underwent the same protocol, except the vibration was not administered when the subjects stood in static semi-squat position on the vibration plate. Immediately after the exercise, the subjects were repositioned on the dynamometer chair for the post-treatment measurements of knee jerk reflex and isokinetic measurement (Figure 1 and 2).

Figure 1. Subject's position during whole body vibration and reflex jig testing.

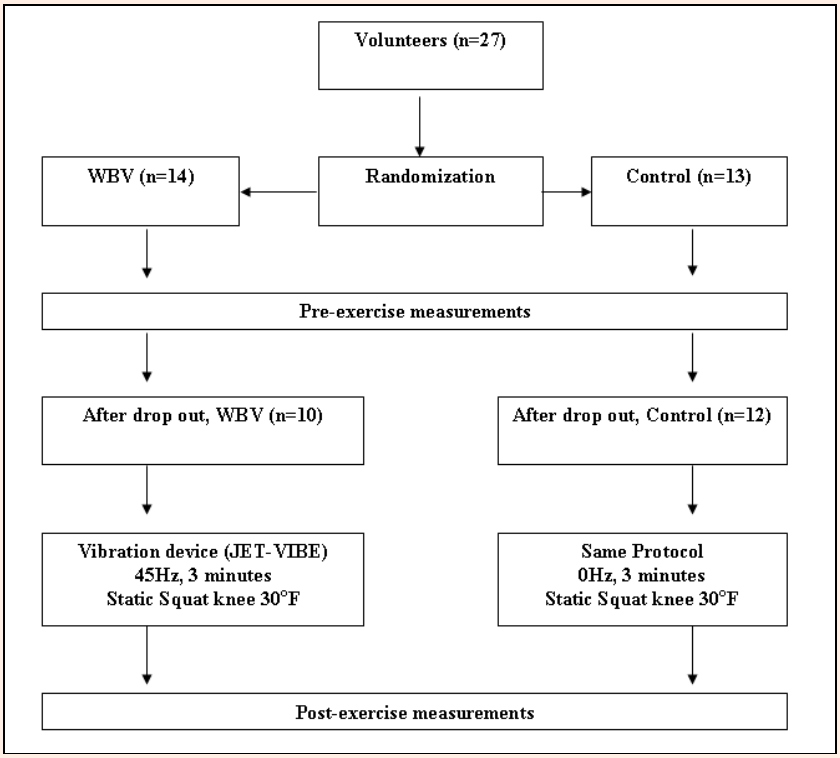

Figure 2. Workflow of the study design.

Table 1. Subjects' characteristics and baseline comparison of all outcome measures of the intervention and control groups. Data are means (±standard deviation).

	Intervention group (n=10)	Control group (n=12)
Age (years)	26.4 (2.3)	25.8 (3.9)
Height (m)	1.66 (.10)	1.67 (.09)
Weight (kg)	57.8 (12.8)	59.1 (9.8))
Pre RF reflex latency (ms)	23.05 (3.85)	22.89 (2.68)
Pre VL reflex latency (ms)	22.48 (2.83)	22.41 (1.10)
Pre RF EMD (ms)	71.92 (18.48)	76.22 (20.20)
Pre VL EMD (ms)	72.48 (18.69)	76.67 (20.24)
Pre peak torque (Nm 60°s^{-1})	92.51 (15.46)	107.66 (37.84)

RF: rectus femoris, VL: vastus lateralis, EMD: electromechanical delay.

Data analysis

A custom-made program by Labview software (National Instruments Corporation, Austin, USA) was used to record and determine onset of the reflex hammer contact, onset of EMG signals, and knee jerk movement. Reflex hammer contact was defined as the point at which a sharp peak occurred in the signals collected from the pressure sensor. Pre-motor time (i.e., reflex latency) was calculated as the time interval from the point of reflex hammer contact to onset of muscle activation (i.e., onset of EMG activities). EMD was calculated as the time from the onset of muscle activation to the start of knee movement measured by goniometer. Both the onset of muscle activation and the start of knee movement were determined when the signals exceed three standard deviations of the mean baseline value. Peak torques were recorded by an isokinetic dynamometer (Cybex Norm, version 2.04, Henly Healthcare, USA).

Statistical analysis

Statistics were performed with SPSS software version 17.0 (SPSS Inc., Chicago, IL, USA). Two-way mixed repeated measures analysis of variance were performed to examine the differences between groups over time for reflex latency, EMD, isokinetic peak torque production. The significance level was set at $p < 0.05$.

Results

Table 1 shows the demographic data (age, height, and weight) of the intervention and control groups. No significant differences were found between groups. Similarly, there were no significant differences between groups in the baseline of all the outcome measures (RF latency, VL latency, EMD_{RF}, EMD_{VL}, isokinetic knee extensor peak torque).

Acute WBV did not affect reflex latency, EMD, and isokinetic peak torque of knee extensors (Table 2). Table 2 shows no group/time interaction effect. There was a significant time effect of the changes in knee extensor peak torque ($p = 0.049$) but this effect did not differentiate between the intervention and the control groups ($p = 0.483$). Between-group differences were also not significant for the reflex latency of RF and VL ($p = 0.934$ and 0.935, respectively), EMD_{RF} and EMG_{VL} ($p = 0.474$ and 0.551, respectively), and the isokinetic peak torque of the knee extensors ($p = 0.483$).

Discussion

The present investigation revealed no changes in the reflex latency and EMD for both the RF and VL muscles following acute exposure of WBV. Similarly, Acute WBV did not improve the isokinetic peak torque knee extensors performance in healthy young adults.

Effect of acute WBV on the stretch reflex

Our present investigation concurs with the findings of Hopkins et al. (2009) and Cochrane et al (2010) which reveal no changes in latency, EMD, and twitch force following acute exposure WBV. Ritzmann et al (2013) showed suppression of the stretch reflex amplitude following acute exposure of WBV. It has to note that these three studies used side to side alternating vibration platform with a WBV frequency ranged from 22-30 Hz and amplitude of 4-6 mm. Our studies extended further from these studies by exploring if there are possible neurophysiological effects on WBV device that produced vertical oscillation with a higher frequency (ie > 30 Hz) and low amplitude (< 1 mm). Several studies have reported that the reflex amplitude is enhanced with the hypothesized mechanisms that WBV lowers the firing threshold

Table 2. Summary data for dependent variables (RF and VL reflex latency, RF and VL EMD, isokinetic peak torque of knee extensors). Intervention group (n = 10) received 3 minutes WBV, whereas the control group (n = 12) assumed the same position on the WBV platform with no vibration. pre-measures were collected prior to the intervention; post-measures collected immediately following the treatment. Data are means (±standard deviation).

	Intervention group		Control group		Group/time interaction	Within-group difference	Between-group difference
	Pre	Post	Pre	Post			
RF reflex latency (ms)	23.05 (3.85)	24.23 (6.42)	22.08 (2.68)	24.11 (4.00)	p = .979	p = .079	p = .934
VL reflex latency (ms)	22.48 (2.83)	23.38 (3.25)	22.42 (1.10)	23.18 (3.13)	p = .969	p = .082	p = .935
EMD_{RF} (ms)	71.92 (18.48)	63.48 (18.29)	76.22 (20.20)	71.57 (27.28)	p = .618	p = .095	p = .474
EMD_{VL} (ms)	72.48 (18.69)	64.43 (21.67)	76.67 (20.24)	70.37 (23.66)	p = .811	p = .061	p = .551
Peak torque (Nm 60°s^{-1})	92.51 (15.46)	105.01 (29.90)	107.66 (37.84)	109.08 (37.99)	p = .111	p = .049	p = .483

RF: rectus femoris, VL: vastus lateralis, EMD: electromechanical delay

of muscle spindle primary endings, increased synaptic efficacy between 1a-afferent terminals and alpha-motorneurons, and enhanced sensitivity of alpha-motorneurons (Cardinale and Bosco, 2003; Rittwegger et al., 2003). In our present investigation, myotatic patella tendon reflex was recorded before and after the intervention to investigate the effect of WBV on the stretch reflex. More specifically, the reflex latency and EMD were investigated. The patella tendon reflex is a monosynaptic reflex that included 1a-afferent and an alpha-motorneuron, and should be the best mechanism to study the sensitivity of the muscle spindles. During vibration, muscle stiffness increases to dampen the vibration (Cardinale and Bosco, 2003). Because less time is needed to remove any intrinsic 'slack' in a stiffer muscle, WBV is expected to shorten the EMD. However, our results do not support this assertion.

Effect of acute WBV on peak torque performance

WBV has been used for muscle training for more than 20 years, but its effectiveness on the short-term enhancement of muscular performance remains unequivocal. For instance, Bosco et al. (2000) report a significant improvement in leg press vertical jump performance after 10 minutes of WBV. Torvinen et al. (2002a) conclude that one session of 4 minutes of WBV training results in a significant increase of isometric knee extension strength by 3.2% in healthy young subjects compared to placebo. Cochrane et al. (2010) demonstrate 5-minute WBV training facilitates knee extensor muscle twitch peak force by 12.4% in athletes competing at the national level. Similar results are also shown by the same group in elite hockey players (Cochrane and Stannard, 2005).

Conversely, De Ruiter et al. (2003) indicate that the maximal voluntary knee extensor contraction is reduced to 93% of the baseline after 5 minutes of vibration, and Rittweger et al. (2000) show that knee extensor strength is reduced to 91%. Although it might be concluded that the discrepancy in the findings is related to the differences in the frequency range, amplitude, and posture when subjected to WBV, a closer investigation of the results of these findings could indicate other explanations. In the studies that report improvement in muscle performance, the subjects were either elite or national-level athletes (Cochrane and Stannard, 2005; Cochrane et al., 2010), recreationally trained subjects (McBride et al., 2010), or healthy subjects (Bosco et al., 2000; Torvinen et al., 2002a). However, in studies that did not report any improvement following acute WBV, the subjects were all untrained subjects (De Ruiter et al., 2003), healthy subjects (Bagheri et al., 2012), or female subjects (Gerodimos et al., 2010). In our study, 10 of our subjects did not exercise regularly, more than 70% of our subjects exercised less than 3 hours per week, and only three regularly exercised more than 6 hours per week.

After WBV training, most of the subjects in the WBV group complained of tiredness of the lower limb muscles. Thus, it is unclear whether this sense of tiredness affected the subjects' determination to produce the peak torque force production. Indeed, our results indicate that the peak torque of the knee extensors in the intervention group increased from 92.51 to 104.60 (Nm), with an increment of 13.06%. The peak torque slightly increased from 107.66 to 109.08 (Nm) in the control group after the placebo treatment, which is less than 0.13% of improvement. Although there was no significant group effect demonstrated in the present investigation, there was an increasing trend in the changes in peak torque percentage in the intervention group. Thus, it is unclear if this perceived tiredness influences the subjects' effort in exerting the maximum muscle force production immediately following WBV. If this is the case, then it might explain why significant improvement in force production is reported in those studies with athletes as the subjects' population (Cochrane and Stannard, 2005; Cochrane et al., 2010; Mcbride et al., 2010), and not in the sedentary or untrained adults (Bagheri et al., 2012; De Ruiter et al., 2003). Even if this is the case, what mechanisms possibly contributed to the enhancement of muscle peak torque? In studies that show acute increase in muscular performance and also simultaneously measure the reflex potentiation effect, Cochrane et al. (2010) state that the improvement of muscle force results from a myogenic response, as opposed to the neural-mediated effect. They suggest that muscle force improvement after the WBV is due to the increased sensitivity of the actin and myosin to the same intracellular Ca+ signal. Similarly, Mcbride et al. (2010) also show significant increase in peak torque but not H-reflex and suggest the changes might be related to myosin light chain phosphorylation as the possible mechanism that facilitates the increase in force production. However, myosin light chain phosphorylation was not measured in our investigation, and we could not determine whether WBV enhances myosin chain phosphorylation. Nonetheless, in the present investigation, acute exposure of WBV device that produced vertical oscillation with a higher frequency (ie > 30 Hz) and low amplitude (< 1 mm) did not induce potentiating effects to the stretch reflex possibly mediated by enhancement of muscle spindle sensitivity. Acute WBV also did not improve the isokinetic peak torque knee extensors performance in healthy young adults.

Conclusion

WBV exercise has been suggested as a strategy for athletes to improve their muscular performance prior to training or competition. Our investigation indicated that a single session of WBV exposure has no potentiation effect on the stretch induced reflex and peak torque performance in healthy young adults.

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Key points

- There is no acute potentiation of stretch reflex right after whole body vibration.
- Acute whole body vibration does not improve muscle peak torque performance in healthy young adults.

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