Effect of a Whole-Body Vibration Session on Knee Stability

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Key words
- single whole-body vibration
- short latency response
- medium latency response
- anterior tibial translation
- hamstring muscles

Abstract

The aim of the study was to investigate the effect of WBV on stretch reflexes involved in knee joint control. We evoked stretch reflexes of the hamstring muscles by inducing an anterior tibial translation during standing in 23 healthy subjects which were divided into a control and an intervention group. WBV with a frequency of 30 Hz and a vertical amplitude of 4 mm was induced by an uniformly oscillating platform. The WBV session lasted 60 seconds and was repeated twice. Short (SLR) and medium latency responses (MLR) of the hamstring muscles and maximum tibia translation were assessed using surface EMG and linear potentiometers. While there were no significant changes in latency, the size of the lateral and medial hamstring SLR was significantly increased after WBV ($p = 0.039$ and $p = 0.043$, respectively). No significant differences were found for the hamstring MLR size after WBV. Maximum tibial translation was significantly decreased after WBV ($p = 0.031$). Our results suggest that single WBV exposure has a positive effect on knee joint stability as a short-term adaptation on neuromuscular level. This appears to be directly associated with an increase of hamstring SLR size in response to the anterior tibial movement which may cause the decrease in anterior tibial translation.

Introduction

Whole-body vibration (WBV), which represents an unspecific vibration stimulus to the human wobbling masses (i.e., soft tissues) and their receptors [35], is increasingly used in addition to other training modalities in order to enhance physical fitness and to prevent or rehabilitate injuries [9]. Conflicting results regarding the effects of WBV have been reported in the literature. Several studies found that acute effects of WBV training [4,5] and long-term WBV training [13, 39] led to a significant increase in knee extension strength, countermovement jump height and movement velocity. In contrast, there are also results suggesting that directly after WBV training [15], short [15] as well as long-term WBV training [14,45] have no or even adverse effects on force production and jump height. Apart from the aforementioned different observations, knowledge of the effectiveness of WBV on sensorimotor function in terms of joint stabilisation is rare. Therefore, a comprehensive understanding of WBV effects on neuromuscular control of the knee joint is particularly important for the most serious sports-related injuries, the anterior cruciate ligament (ACL) ruptures, and their prevention [25].

In previous studies, the existence of a direct reflex arc between the anterior cruciate ligament and the hamstring muscles was demonstrated intraoperatively [18,20]. It has been suggested that the hamstring muscle activity restrains anterior tibial translation and has, therefore, a protective function for the ACL [26,32,44]. Results of Melnyk and Gollhofer [34] and also Wojtys et al. [47] supported this assumption. In both studies, fatigue of the hamstring muscles was found to be associated with an increase of the anterior tibial translation and therefore a potential ACL injury risk caused by hamstrings fatigue was suggested. Further studies indicated the existence of an at least indirect reflex pathway and that there is an altered control of hamstring activity after ACL rupture [1, 8]. Recently, Friemert et al. [20] showed, in healthy subjects, that during standing, the hamstring muscle reflex response after anterior tibia translation consists of a monosynaptic and a polysynaptic component, which are at least partly mediated via muscle spindle afferents [22].

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Muscle or tendon vibration leads to a rhythmic activation of the muscle spindle, which is associated with an inadequate afferent output for the respective movement task [7,22,36]. Consequently, Verschueren et al. [46] showed that the application of muscle vibration changed the control of the hamstring muscles and caused a significant increase in walking velocity. Although the unspecific WBV stimulus is not directly comparable with direct muscle or tendon vibration, a potential effect on muscle spindles cannot be excluded. Therefore, one may argue that WBV affects the reflex activity of the hamstring muscles which are suspected to act as synergists to the anterior cruciate ligament [44] and thus the neuromuscular control of the knee joint. The aim of our study was to investigate whether a single session of WBV exposure influences the reflex activity of the hamstring muscles during mechanically induced posterior-anterior tibial translation. We hypothesise that a WBV exposure results in a decrease of muscle reflex activity which may in turn affect neuromuscular knee stabilisation.

Material and Methods

Subjects

A total of 23 healthy subjects (control group – age: 25 ± 2.1 years; height: 176.1 ± 8.8 cm; mass: 69.5 ± 9.3 kg; intervention group – age: 25 ± 2.7 years; height: 174.8 ± 9.5 cm; mass: 66.3 ± 10.7 kg) with no history of orthopaedic or neurological disorders participated in the study. They were randomly divided into an intervention group (n = 13) and a control group (n = 10). All subjects gave written informed consent prior to the tests. The study was carried out in accordance with the Declaration of Helsinki.

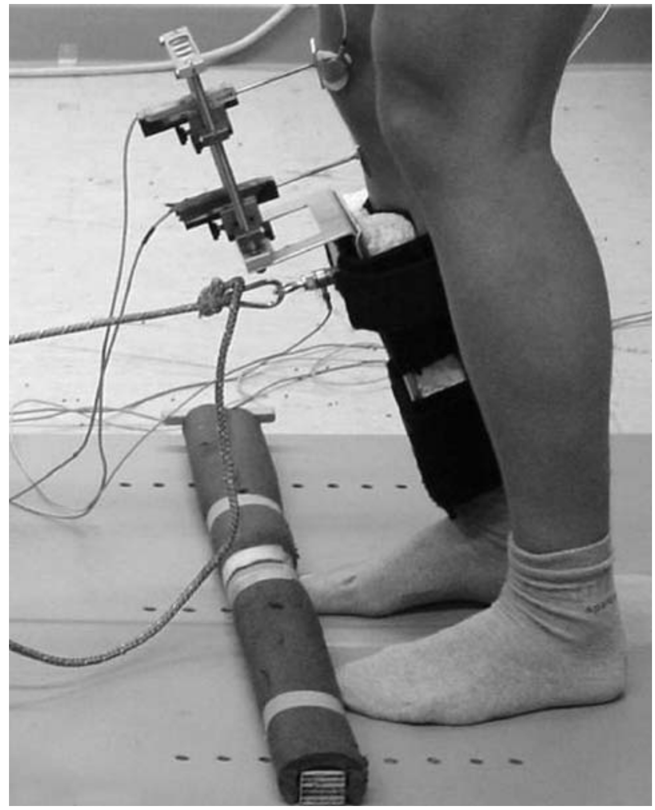

Fig. 1 The subjects were asked to stand in 30° knee flexion. The transmitted force applied to the calf evoked the anterior tibia displacement. The way of tibial motion was quantified by two potentiometers placed at the patella and the tibial tuberosity.

Experimental setup

In both control and intervention groups, the measurements were conducted at intervals of eight minutes. The subjects were examined during bipedal stance with a knee flexion of 30 degrees (0° represents full extension, **Fig. 1**) which was supervised by the investigator. In order to minimise potential measurement errors, all subjects were familiarised in up to 10 pre-tests to the standing condition, measurement device and the feeling of force transmission. Posterior-anterior tibial translation was induced by a pulley system that applied a predetermined impulse to the lower right leg, parallel to the tibial plateau. A stabilising device was attached to the tibia to secure two linear potentiometers (measuring accuracy: < 0.01 mm, linearity: ± 0.7 %, type CLR13–50, Megatron, Putzbrunn, Germany) that were placed on the patella and the tibial tuberosity. This procedure allows the detection of tibia movements relative to the femur. The placement of both potentiometers was marked in order to ensure the same position before and after WBV exposure. The onset of tibial movement was used as a trigger signal for the measurement of reflex latencies. A force transducer (measuring range: 0 to 5000 N, linearity: ± 0.2 to 0.3 %, sensitivity: 3.44 pC/N, Kistler, Winterthur, Switzerland) was used in order to control the force applied (325 ± 25 N for the intervention group; 329 ± 38 N for the control group). A series of 15 measurements was performed for each subject and lasted two minutes. Measurements were performed before and eight minutes after the end of the vibration including the return from the vibration plate to the place of measurement and a careful subject preparation. It is unlikely that this time delay, in the present study, substantially influenced the muscle spindle excitability because Shinohara et al. [42] still found a significant increase of the short latency component 20 minutes after vibration of a hand muscle.

Electromyography (EMG)

The reflex activity of the hamstring muscles was assessed by surface EMG. Self-adhesive bipolar surface electrodes (diameter: 1.5 cm, interelectrode distance: 3 cm, Blue Sensor, Medicotest A/S, Olstykke, Denmark) were attached longitudinally over the muscle bellies of the lateral hamstring (m. biceps femoris) and the medial hamstrings (m. semitendinosus/semimembranosus) of the right leg. The reference electrode was placed over the patella. The skin was shaved and cleaned with alcohol before the electrodes were attached. The EMG signals were sampled at 2 kHz, amplified (× 1250) and band-pass filtered (10 Hz to 1 kHz). In order to assess latencies and to calculate reflex sizes, the EMG signals were rectified and averaged over trials by specifically designed EMG analysis software (Lab View, National Instruments, Austin, TX, USA).

Whole-body vibration protocol

The subjects of the intervention group were instructed to stand upright on both legs on a vibration platform oscillating uniformly up and down (Power Plate, Power Plate International, Frankfurt, Germany). The knees were flexed at 30 degrees with an outer rotation of the feet of approximately 5 degrees. WBV stimulus was induced to the plantar surfaces of the feet at a frequency of 30 Hz with vertical amplitude of 4 mm. One vibration trial lasted 60 seconds and was repeated twice with 30 seconds of rest between two trials. The control group was briefed to per-

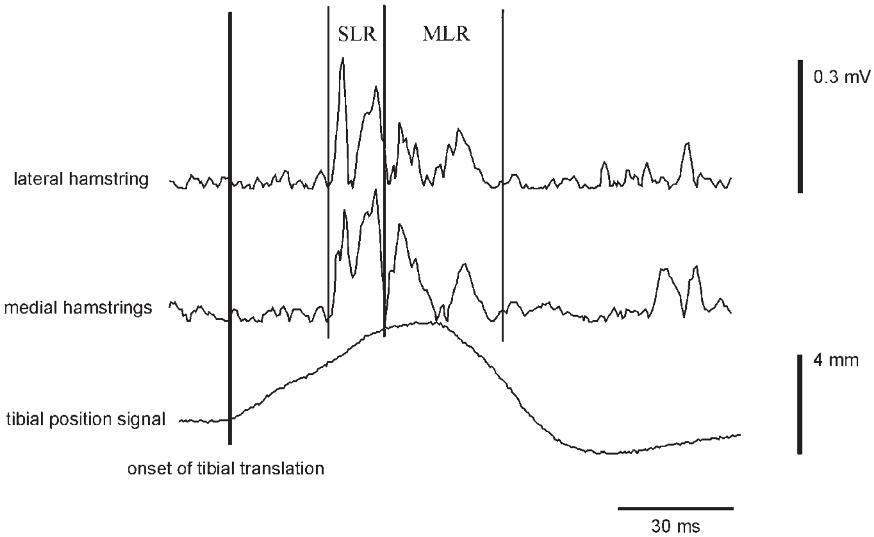

Fig. 2 From data recording, latencies and integrals as well as the anterior tibial translation were determined. The figure displays a typical graph of the tibial translation and the rectified and averaged hamstring response consisting of two reflex components, short latency response (SLR) and medium latency response (MLR). The onset of tibia translation was used as a trigger for the latency determination.

form their normal daily activities without participating in WBV training.

Data analysis

Before and eight minutes after WBV, onset latencies and size in terms of integrated (i)EMGs of the hamstring reflex responses were assessed semiautomatically by visual inspection on the computer using two cursors (**Fig. 2**). The onset latency of the first response was defined as the time from the onset of tibial translation to the first significant muscular activity. This deflection in the EMG curve was determined as the averaged amplitude EMG value plus five SDs of the preloading baseline activity of the 100 ms prior to stimulation. In all subjects an early muscle response with an onset latency that is compatible with a short latency response (SLR) was observed. The within-subject variability of these SLR latency scores over trials was found to be low in a pilot study of an earlier study [34]. The longer latency of the second reflex response suggests a polysynaptic pathway which was labelled as medium latency response (MLR, [22,41]). In case of superimposed signal configuration of SLR and MLR, we used our evaluation algorithm to differentiate MLR from SLR [21]. According to the algorithm, the duration of the SLR can be estimated quite accurately by multiplying the time between the onset of the SLR and the first peak with the empiric factor of 3.28 as shown in detail in a previous paper [21]. The duration from the onset to the first part of the SLR is used in case of partly superimposed signal configuration. This first part of the SLR is not contaminated by the MLR and highly reliable in all SLR responses. In superimposed signals the end of the SLR was taken as the onset of the MLR. The end of the MLR was generally defined 30 ms after its onset. The size of the SLR was assessed as the integral of the rectified and averaged EMG activity over trials from the onset until the calculated end of the SLR, which corresponds to the mean amplitude of EMG during this time window. Correspondingly, the size of the MLR was assessed as the integral of the 30-ms time window following the onset of the MLR. In order to ensure interindividual comparability the iEMG values measured after WBV were expressed as a percentage of the values obtained before WBV. Maximum tibial translation was determined on the basis of the curves for anterior tibial displacement.

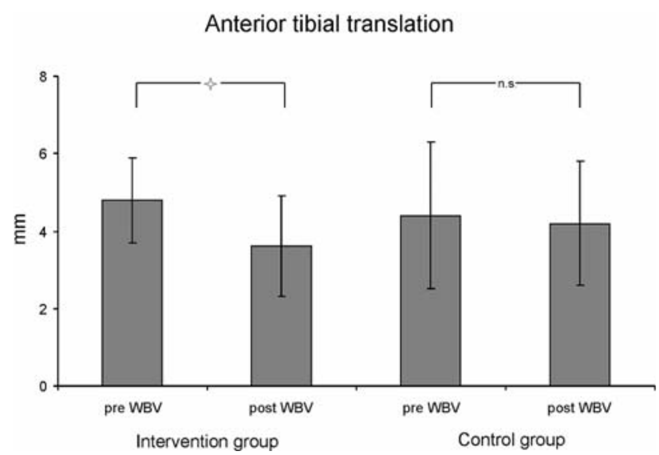

Fig. 3 Knee joint stability assessed as anterior tibial translation was significantly increased after whole vibration exposure. Tibial translation decreased from 4.8 to 3.6 mm. No changes were found in the control group. Values are presented as means ± SD.

Statistical analysis

The data represent means and the standard deviations (SD). Possible statistical differences between both the intervention and the control and pre- and post-vibration results were analysed using a repeated-measures two-way ANOVA (group × measurement time). When there were statistical differences in tendency between pre- and post-values within the intervention group, paired Student's *t*-tests were additionally conducted. A p value of less than 0.05 was considered statistically significant.

Results

None of the subjects reported discomfort during WBV exposure. In the WBV group a significant effect on posterior-anterior tibial translation was found. A decrease in anterior tibial displacement from 4.8 ± 1.1 mm to 3.6 ± 1.3 mm ($p = 0.031$, Student's *t*-test) after a single session of WBV (**Fig. 3**) was observed, whereas no significant change was found in the control group (4.4 ± 1.9 to 4.3 ± 1.7 mm; $p = 0.493$, Student's *t*-test). Two-way ANOVA

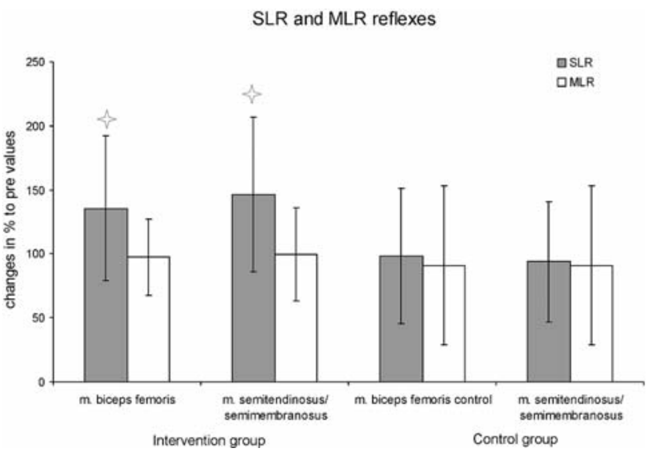

Fig. 4 Effects of a single WBV exposure on the SLR and MLR size of the lateral hamstring and the medial hamstrings. A significant increase in motor activity of SLR was observed in both muscles. The control group revealed no significant differences in SLR and MLR in both muscles. Data are displayed as means ± SD. Values are normalised to the precondition.

testing revealed no significant differences in respect to anterior tibia translation (p = 0.161).

EMG analysis showed no significant differences in the latencies of the SLR or the MLR components of the lateral (p = 0.748 and 0.313, respectively) and medial hamstring muscles (p = 0.549 and p = 0.893, respectively) comparing groups and measurement time. Before WBV, the onset of the SLR was found after 23.5 ± 1.6 ms followed by the MLR onset after 38.8 ± 1.2 ms in the medial hamstrings and in the lateral hamstrings (SLR: 23.6 ± 1.8 ms, MLR: 37.8 ± 1.4 ms), respectively. After WBV, the latencies in the SLR component were unchanged (medial: 23.7 ± 1.4 ms, lateral: 23.2 ± 1.4 ms) as well as for the MLR component (medial: 38.2 ± 1.6 ms, lateral: 38.4 ± 1.5 ms). Similar latency responses were assessed in the control group.

In respect to the observed integrals of both reflex components, SLR sizes showed a statistically significant increase of 35% (p = 0.039, Student's *t*-test) for the lateral hamstring and 46% (p = 0.043, Student's *t*-test) for the medial hamstrings after WBV compared to pre-intervention values. In contrast, MLR sizes of both the lateral and medial hamstring muscles were not significantly affected by WBV normalised to pretraining data (97 ± 37%, p = 0.434 and 99 ± 30%, p = 0.847; ▶ **Fig. 4**). In the control group, lateral hamstring activity showed neither for the SLR (98 ± 53%) nor for the MLR (91 ± 62%) significant differences in relation to the data of the first measurement. The SLR and MLR of the medial hamstrings were also unchanged between the two trials (94 ± 47% and 91 ± 62%, respectively). However, no significant differences in the lateral (SLR: p = 0.067, MLR: p = 0.576) and also medial hamstring muscles (SLR: p = 0.241, MLR: p = 0.443) were found for the comparison between groups and measurement times.

Discussion

The objective of our study was to investigate the effect of a single WBV exposure on the reflex activity of the hamstring muscles and on functional knee stability. Our results suggest that a single session of WBV results in a decrease in anterior tibial translation. Within the intervention group an increase in the integrated EMGs for the hamstring SLRs was observed but no changes in the iEMGs for the hamstring MLRs were found. WBV showed no effect on the latencies of the SLR and MLR components. In conclusion, hamstring SLR-size rather than latency appears to be a factor for restraining posterior-anterior tibial translation and thus for functional knee stability.

Previous studies showed that reflex activity in the hamstring muscles in response to a perturbation of the knee may play an important role in stabilising the knee. It was demonstrated that the stretch reflex of the quadriceps muscle group contributes substantially to the total torque around the knee joint [37]. Likewise, Shultz et al. [43] were able to show a close correlation between knee joint laxity and reflex activity. They found that test subjects with above-average knee laxity showed a greater delay in the m. biceps femoris reflex than subjects with normal knee laxity. This result suggests a direct relationship between reflex activity and knee stability. Wojtys et al. [47] reported that fatigue of the thigh musculature caused an increase in anterior tibial translation. Two recent studies [16,17] also showed that reflex activation of the thigh muscles considerably enhanced joint stabilisation under valgus loading conditions. The muscle reflex activity induced by valgus stress of the knee joint was found after 70 ms and therefore suspected to be mediated by receptors from the periarticular tissue of the knee joint and not from the muscle spindles themselves. Our results support previous findings that the reflex activity of the thigh muscles is likely to contribute to functional knee stability [16,17,47]. On the basis of the present data, the hamstring SLR which is mediated via muscle spindles appears to play a key role in maintaining knee stability during posterior-anterior movements of the tibia relative to the femur. Regarding the potential role of the SLR to knee joint stability, results of Horita et al. [27] support our findings. They investigated the effect of strenuous submaximal stretch-shortening exercise on the relationship between muscle reflex response and stiffness regulation of a joint. Horita et al. [27] observed that immediately after fatiguing exercise, a positive correlation exists between changes in the SLR and the amount of knee joint stiffness during the early braking phase of a drop jump. Due to the fatigue-induced decline in SLR and the reduction of knee joint stiffness, the authors suggested that the SLR component was closely related to the stiffness changes. Although knee joint stiffness is not directly comparable with anterior tibia translation in respect to knee joint stability, one may argue that the SLR may stabilise the knee joint in different motor tasks. As a result of the very short time of 23 ms in the present study from beginning of tibial translation to the SLR excitation and therefore a subsequent development of force, it seems feasible that hamstring reflex activity plays a potential role in knee joint stability and may prevent anterior cruciate ligament rupture.

To our knowledge, no study has assessed the effect of WBV on specific reflex activity so far. The effect of the muscle vibration or tendon vibration on muscle reflex activity has been extensively investigated [2,3,10,24,28,31,38]. However, the underlying mechanism of the WBV regarding muscle reflex excitability is still unclear. In both experimental paradigms, muscle and tendon vibration, the vibration stimulus was directly applied to a specific anatomical structure whereas WBV represents an unspecific vibration stimulus to the human wobbling masses [35], which probably affects not only muscle spindles but also mechanoreceptors in other anatomical structures. Moreover, due to the significant differences in vibration frequencies between the

WBV and the direct muscle or tendon vibration (up to 120 Hz), a comparison of results between both aforementioned vibration applications should be conducted carefully.

The present findings lead to the suggestion that single WBV causes an increase in the SLR activity of the hamstrings and does not influence the MLR activity of the hamstrings. SLR is known to be mediated by group Ia afferents [6,19,44], MLR is at least partly mediated by group II afferents [6,22,41]. For this reason, it is likely that a single WBV does not directly influence group II afferents, whereas group I afferents do respond to a whole vibration stimulus. The increase of SLR after WBV, in the present study, leads to the suggestion that the effect of increased knee stability is rather caused by a modified effectiveness on reflex excitability than direct vibration stimulus. In this context, Bosco et al. [4] and Issurin et al. [29] assumed that WBV led to an increase in force production, which they attributed to more efficient neuromuscular coordination based on an increase in the synchronisation activity of the motor units.

For interpretation of the present results regarding knee joint stability in sports, it has to be considered that due to the experimental setting, we only investigated the sagittal plane under static conditions, which does not reflect real-world situations as sporting movement tasks including landing and cutting manoeuvres with a high impact load on the ACL [12,33]. Furthermore, it was previously demonstrated that muscle fatigue plays a potential role in the incidence of the ACL injuries under static [34] as well as under dynamic situations [11,33]. In the present study the role of muscle fatigue was not investigated. We were focused on the determination of the effectiveness of WBV on joint protection. However, it would be of interest to see if the beneficial results of the present study are also detectable when the joint protecting muscles are in a fatiguing state. This issue should be addressed in future studies. The differences between the range of the force transducer (0 – 5000 N) and the force transmission (around 330 N) may result in a low-level resolution of the force signal which may influence the interpretation of the present data. Finally, the results suggest that WBV enhances knee stability, in this particular case, which may have clinical significance. However, it is finally unclear whether the detected reduced amount of translation has a direct impact on the severity of knee injury.

Conclusions

Our results suggest that a WBV exposure improves knee joint stability at least for eight minutes. This short-term adaptation appears to be caused by an increase of the SLR component in response to the anterior tibial movement which seems to be responsible for the decrease in posterior-anterior tibial translation. However, the effectiveness of the WBV on neuromuscular function and the duration of these effects observed in the present study remain unknown. Before these findings can be integrated into any training or rehabilitation programme, further studies are required to investigate the time course and the duration of these effects. Furthermore, the influence of characteristics like amplitude (i.e., whole plate oscillating uniformly up and down versus reciprocating vertical displacements on the left and right side of a fulcrum [9]) and frequency of the WBV on the effectiveness should be investigated. Finally, due to the fact that the significant values were solely found within the intervention group, the present results should be interpreted very carefully.

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