Neuromuscular Ankle Joint Stabilisation after 4-weeks WBV Training

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Key words
- ankle sprain simulation
- whole-body vibration training
- reflex activation
- ankle musculature
- time of ankle inversion motion

Abstract

Whole body vibration (WBV) training is increasingly implemented in prevention programs as well as in rehabilitation protocols but evidence for beneficial effects of WBV training over several weeks on ankle joint stabilisation is lacking. The purpose of the study was to investigate the effects of 4-weeks WBV training on reflex activity of the long peroneal and tibialis anterior muscles and on the duration of ankle inversion movement in response to an unexpected combined 24° inversion 15° plantar flexion ankle joint motion. Twenty-six healthy subjects were divided into an intervention group (n = 16) and a control group (n = 10). The intervention group trained thrice weekly for 3 min on a unidirectional oscillating vibration platform (30 Hz, 4 mm amplitude). Pre and post intervention reflex activity were measured and the duration of ankle joint movement was calculated by vertical ground reaction forces. After four weeks of WBV training no significant changes were found in latencies and reflex activity in both muscles in response to ankle sprain simulation. Similar results were observed for the time of ankle inversion motion. Based on the present results, it is unlikely that 4-weeks WBV training has beneficial effects on ankle joint stability in the case of an ankle inversion motion.

Introduction

Ligament injuries of joints of the lower extremities frequently occur during sports and exercise. Apart from knee injuries, ankle sprains have the highest incidence of injury particularly in sport disciplines such as volleyball and basketball [4, 25, 35]. Ankle sprain injury can result not only in an alteration of sensorimotor joint control, i.e., increasing response latency at least in the peroneal muscles [22], but can also frequently be caused by a long-lasting effect of disturbed sensorimotor function described as functional instability feeling or 'giving way' [20]. Furthermore, there is evidence that athletes with a former history of ankle injury have a significantly higher incidence of re-injury than healthy athletes [4]. These findings clarify the importance to implement specific injury prevention programs in sports aiming to sufficiently reduce the occurrence of ankle sprains. A small number of recent studies have focused on the improvement of the neuromuscular system as it concerns ankle joint stability and ankle sprain occurrence by exclusively using ankle braces [13] or taping [2, 24]. These prospective studies have found that balance training significantly decreases the incidence of ankle sprains in volleyball, basketball, and soccer players [5, 25, 26].

Whole body vibration (WBV) training is not only a modern training receiving more attention in sports but also shows an increasing implementation in prevention programs as well as in rehabilitation protocols [10]. This kind of training seems to have the potential for increasing muscle strength and jump performance, as well as enhancing muscular activation after long-term intervention [9, 11, 31] the origin of which may be attributed to an enhancement in reflexive muscle activation. Mrachacz-Kersting and Sinkjaer [29] reported a substantial contribution of muscle reflexes to the total amount of torque, at least in the knee joint. Further, Melnyk and Gollhofer [28] showed that a decrease in muscle reflex activity as a result of submaximal muscle fatigue adversely affected knee joint stability. For the ankle joint, a fatigue-induced decline in reflex amplitude in peroneal muscles was assumed to be a potential factor for a higher rate in ankle sprains [36]. For this reason, a higher

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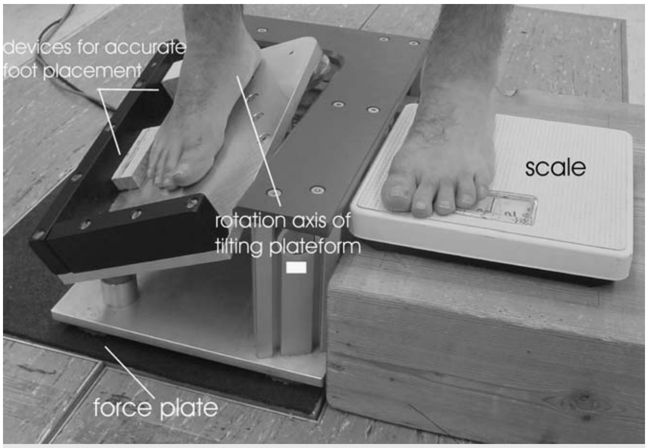

Fig. 1 Experimental set up for ankle sprain simulation during bipedal stance.

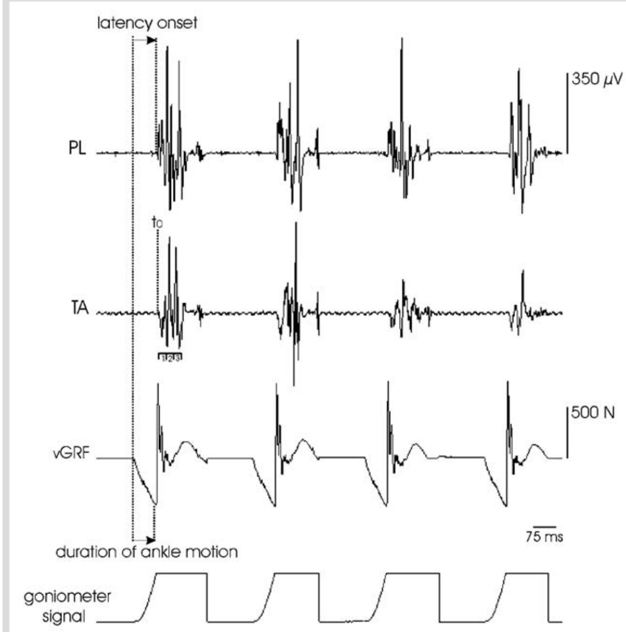

Fig. 2 The figure illustrates an example of a subject measurement consisting of four consecutive trials. The first two traces represent EMG raw data of the muscle reflex activity in response to the sudden release of the tilting platform. The further curves below show the changes in the vertical ground reaction forces (vGRF) and the signal of the electrogoniometer, respectively. Latency determination was performed by calculating the onset the decreasing vGRF (trigger signal) and the first significant increase in EMG activity. Integrated EMGs were determined in three periods (1 = 0–25 ms, 2 = 25–50ms, 3 = 50–75 ms) after the onset of reflex activity (t_O). Duration of ankle joint motion was assessed from deflection to lower point of the vGRF curve.

reflex activity of the stabilising ankle musculature could protect ankle joint from ligament injury. Further, it was recently suggested that reflex activity of the stabilising ankle muscles could substantially reduce ankle joint loading in case of ankle sprain motion [15,30]. However, so far no data exist concerning the preventive effects of several weeks WBV training on reflex activity of the stabilising ankle musculature during induced perturbed ankle inversion.

Therefore, we aimed to quantitatively assess the effects of a 4-week WBV training on reflex activity of the long peroneal and anterior tibialis muscles and the duration of ankle inversion movement. Based on previously reported improvements in neuromuscular performance [9,11,31], and on suggestions that a decline in the reflex activity in ankle joint muscles is a potential factor in ankle joint injuries [36], we hypothesize that WBV training over a period of 4 weeks enhances neuromuscular-induced ankle joint stability.

Methods and Materials

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Study design

Twenty-six physically active subjects without history of neurological disorders or orthopaedic injuries participated in the study. Written informed consent was obtained from all subjects prior to participation and all procedures were approved by the Ethics Committee of the University of Freiburg. The subjects were randomly divided into an intervention (n = 16, 6 males and 10 females, age: 24.1 ± 2.8 years, height: 172.3 ± 8.4 cm, mass: 67.5 ± 11.6 kg) and a control group (n = 10, 5 males and 5 females, age: 25.6 ± 2.5 years, height: 173.3 ± 10.1 cm, mass: 66 ± 10.1 kg). Both groups underwent pre intervention measurements followed by post intervention measurements after a period of four weeks. Subjects of the intervention group were asked to participate in the WBV training and to keep their everyday living activities constant whereas subjects of the control group were instructed to maintain their normal day activity without participating in WBV training.

Experimental setting

Subjects performed a bipedal stance with full knee extension throughout the measurements. Since Benesch et al. [6] found no limb dominance regarding peroneal reflex latencies in healthy subjects, the right leg was generally tested and placed on the surface of a tilting platform (Kistler type 9281 A, Kistler AG, Switzerland). The foot of the left leg was positioned on a scale (◉ **Fig. 1**) which gave direct visual feedback on the load distribution for the subject. Vertical ground reaction forces (vGRF) were recorded for the final analysis in order to determine ankle inversion movement. Instead of using electrogoniometry, this novel methodological approach allows a clear cut determination of the beginning and the end of the inversion movement with vGRF (◉ **Fig. 2**) and an insight into the vertical external loading conditions of the tested leg representing the actual mechanical stimulus for the mechanoreceptors in the capsuloligamentous ankle joint structures at the end of the mechanical induced ankle sprain simulation. Foot placement was carefully adjusted on the tilting platform to ensure subtalar joint axis [18] alignment with the rotation axis of the tilting platform. Ankle sprain simulation was provoked by a sudden release of the tilting platform inducing a combined angle joint motion of 24° inversion and 15° plantar flexion, reflecting a potential injury mechanism [3,12,33]. The position of the foot was marked on the platform surface to accurately reproduce foot placement in case of position loss. In addition, individually adapted fixing devices were placed between the platforms' walls and the foot to ensure a stable foot condition throughout each ankle sprain simulation. We induced the ankle sprain simulation with a loading of 90% body weight to approximately reflect the injury situation regarding ankle motion velocity as previously discussed [15,24,30]. The relatively high ankle joint loading did not correlate with an increase in ankle joint muscle activity. In a pilot study we measured a minor voluntary EMG activity in the gastrocnemius and soleus muscles during the bipedal stance on the tilting platform which represents postural motor patterns to secure the subject from forward fall. In contrast, no EMG activity in the peroneal and tibialis anterior muscles was found during upright stance. Further, under the presented testing condition, e.g. bipedal stance we could secure an extreme stable upright stance which was associated with no voluntary EMG activity in the peroneal and tibialis muscles as well as with a generally high reproducibility of the testing condition. Apart from this point, the stable bipedal stance (with a center of pressure within the base of support) was one more reason for the lack of EMG activity in the tibialis and peroneal muscles because no voluntary EMG activity was necessary to compensate body oscillations in the backward (eliciting tibialis anterior muscle activity) and in the medial direction (eliciting peroneal muscle activity). When the test leg was finally loaded by 90% of body weight ankle sprain simulation was induced by sudden release of the tilting platform. In order to minimize a potential learning effect, each subject was familiarized with the experimental procedure by performing ten trials prior to the measurement recording.

EMG preparation

Changes in the electrophysiological activity were measured with self-adhesive bipolar electrodes (diameter size: 1.5 cm, inter-electrode distance: 2 cm, Blue Sensor, Medicotest A/S, Olstykke, Denmark). The EMG electrodes were placed on the belly of the long peroneal muscle (PL) and anterior tibialis muscle (TA). The osseous aspect of the tibia was chosen for reference electrode placement. All electrode placements were marked on the skin. Prior to electrode placement, the skin was carefully shaved and cleaned with alcohol. In order to ensure similar electrode placement during both pre and post measurements, all subjects remarked the electrode placement on the skin each day.

Data analysis

EMG activity of both muscles was assessed by visual examination on the computer screen using two cursors in order to determine the beginning and the end of the corresponding time window of analysis (**Fig. 2**). EMG signals were band-pass filtered (10 Hz to 1 kHz, Butterworth filter: 3rd order), amplified (x1000) and recorded at a sampling rate of 4 kHz. For data analysis, the EMG signals were rectified and averaged over trails. The latency of each muscle response was defined as the time window from the onset of deflection in the vertical ground reaction force (vGRF) curve to the first significant muscular activity. Motor activity of both PL and TA muscles were determined by the integrated (i)EMGs. For iEMG analysis, the first significant rise in muscle activity was set as zero time point. According to a previous study [24], the reflex response was divided into three time windows of 25 ms each (0–25 ms, 25–50 ms, 50–75 ms after zero time point) in order to obtain a precise insight in the PL and TA reflex activity in response to ankle sprain simulation. For comparison, iEMG values of post measurements were generally normalised to values of the pre condition. The duration of the ankle inversion movement was assessed from the onset of deflection to the minimum in the vGRF-curve. An electrogoniometer (Megatron, Putzbrunn Germany; resistance: 10 k, linear accuracy: 1.5%) was implemented on the tilting platform and detected the onset of the platform movement. Simultaneous signals from the electrogoniometer and vGRFs were recorded and stored on a personal computer at a sampling rate of 4 kHz. In contrast to EMG analysis, no filters were used for the signals of the electrogoniometer and the vGRFs.

Training intervention

The subjects were instructed to stand bilaterally upright on a unidirectional oscillating vibration platform (Power Plate Next Generation, Power Plate International, Frankfurt, Germany), bending their knees at 30° as proposed by Abercromby et al. [1]. According to Cardinale et al. [10] a frequency of 30 Hz was induced to the plantar surface of the feet. Moderate vertical amplitude of 4 mm was chosen considering the recommendation of Mester et al. [27]. Training intervention was performed over a period of four weeks including three training sessions per week. Generally, one day of rest was set at least between two training sessions. Each training session lasted one minute and was repeated two times with a rest of 30 seconds between each WBV exposure. In order to exclude possible acute vibration-induced effects, post intervention measurements were generally performed one day after the last WBV training session.

Statistical analysis

All values are expressed as means and standard deviations. In order to detect potential statistical differences regarding reflex latencies, reflex activity, and the duration of ankle inversion movement, two way ANOVA (groups * measurement time points) was used. Differences were deemed significant using an alpha level of $p < 0.05$.

Results

PL and TA latencies

The sudden release of the tilting platform generally elicited in both TA ad PL muscles distinct EMG bursts. In the intervention group, the EMG responses in the TA muscles were found after 73 ± 7 ms slightly faster than the PL muscle responses of 75 ± 8 ms. Latencies of the TA and PL in the subjects in the control group were not found to be significantly different compared to the intervention group (PL: 74 ± 7 ms; TA: 75 ± 6 ms). After four weeks of WBV training, latency responses were not significantly influenced by WBV. In the intervention group, the onset of TA reflex activity was found after 75 ± 9 ms. Likewise, mean latency of the PL did not significantly differ to the values of pre condition 77 ± 9 ms ms. Statistical analysis showed therefore no significant interactions between groups and measurement times (TA $p = 0.186$, PL $p = 0.863$).

PL and TA integrals

Comparisons between pre and post intervention values revealed no significant changes in either PL and TA muscle reflex activity. More precisely, independent from the calculated time windows iEMGs of intervention group ranged around 90% of the motor activity normalised to pre intervention (**Fig. 3**). IEMGs in the control group were generally found to be approximately 5% higher than values of pre condition. However, based on two-way ANOVA testing no effect of 4-week WBV training could be concluded for the PL iEMGs (0–25 ms: $p = 0.198$, 25–50 ms: $p = 0.734$, 50–75 ms: $p = 0.327$) as well as for the TA iEMGs (0–25 ms: $p = 0.438$, 25–50 ms: $p = 0.799$, 50–75 ms: $p = 0.506$).

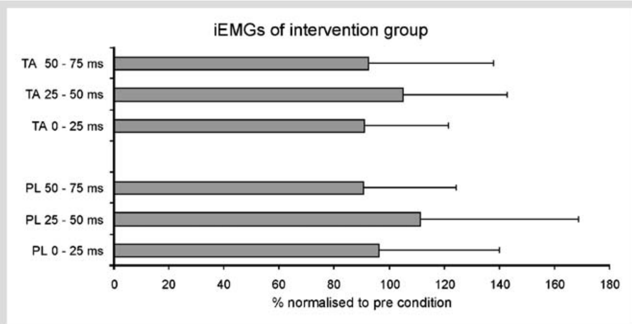

Fig. 3 Results of iEMG determination in the both long peroneal (PL) and tibialis anterior (TA) muscles of the intervention group (n = 16). Data are given as mean and standard deviation. Values are normalised to pre condition.

Time of ankle sprain simulation motion

By means of vGRF determination, the duration of the ankle inversion movement was assessed. Time from beginning of the deflection to the minimum of the loading curve was not significantly altered between intervention and control group and measurement time point (p = 0.313). Prior to training, the ankle joint movement lasted 75 ± 8 ms in the intervention group as compared to 73 ± 6 ms in the control group. After four weeks of WBV training no significant changes were found in the duration of ankle joint movement in either the intervention (73 ± 6 ms) or the control group (73 ± 7 ms).

Discussion

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The present study indicates that a 4-week WBV program has no beneficial effect on either reflex latencies or reflex activity of long peroneal and tibialis anterior muscles. Moreover, the data suggest that the onset of reflex activity of both investigated muscles occurs too late to substantially restrain ankle inversion movements. This can be expressed by the comparison between the end of the ankle inversion movement and the first significant EMG rise of the tibialis anterior and long peroneal muscles.

Coherence between reflex latencies and ankle joint motion

The EMG reflex patterns of the peroneus and tibialis anterior muscles showed to be insufficient to restrain a combined plantar flexion inversion motion of the ankle joint. This present observation corresponds well with previous reports [15, 21, 30] although these studies solely induced unidirectional ankle motion. However, the notion of this methodological difference, i.e. two directional versus unidirectional ankle joint motion, is relevant for discussion of the different onsets of peroneal and anterior tibialis reflex activity. It was shown that unidirectional ankle inversion mainly elicits muscle reflex responses around 45 ms. As a consequence of the onset latency, this reflex activity was assigned to a short latency response (SLR) reflecting a stretch response originating from primary muscle spindle afferents [15, 30]. However, present latencies were observed significantly later than the aforementioned latencies of recent findings [15, 30] indicating a different reflex origin as a SLR. Because the reflex onset was measured around 75 ms in this study, it can be assumed that the present reflex activity is originally mediated by group II and/or group III afferents originating from the mechanoreceptors in the ankle ligaments and/or from the joint capsule [14]. In order to report a potential protective function of the long peroneal and anterior tibialis muscles, the electromechanical delay (EMD), the delay between the observed reflex activity and the development of muscle force, i.e. eversion torque, must be considered. Konradsen et al. [21] estimated an EMD for unidirectional inversion ankle sprain simulations around 72 ms which supports the view of a non-protective function of the peroneal and tibialis anterior reflex activity under the present experimental setting.

Reflex activity

Most previous findings indicated that a long-term WBV training program is associated with increasing muscle strength and an improvement of neuromuscular activity [9, 11, 31]. For these beneficial adaptations of the neuromuscular system, a modulation of the muscle spindle sensitivity due to a higher γ motor neurone input has been assumed [34]. A modulation of the α - γ co-activation may also lead to a more efficient neuromuscular coordination based on an increase in the synchronization activity of the motor units and possibly an increase in motor unit recruitment as previously suggested [7, 19]. Our study, however, did not support these assumptions. We observed no significant changes in the reflex activity in both PL and TA muscles after WBV training as compared to pre/post measurement group intervention. Taking into account that vibration stimuli were shown to enhance muscle spindle sensitivity particularly in the primary muscle spindles [8, 16], the following notes may explain the present results. An explanation could be attributed to the mode of ankle sprain simulation. The combined plantar flexion inversion motion of the ankle joint may not directly stretch the long peroneal and tibialis anterior muscles such as unidirectional ankle inversion motion or a plantar flexion motion, respectively. It therefore cannot be presumed that the present ankle joint simulation may represent an adequate stimulus for the stretch-sensitive muscle spindles in both investigated ankle joint muscles. It is more likely that the present reflex responses are mainly mediated by mechanoreceptors from ligaments and connective tissue of the ankle joint. There is no evidence so far that WBV training which represents a more unspecific stimulus to the neuromuscular system compared to tendon vibration [8] may not significantly influence the function of mechanoreceptors in terms of higher neuromuscular performance, e.g. enhanced reflex activation. Our results support this notion.
The present findings indicate that WBV training over 4 weeks does not have a beneficial effect on ankle stabilisation during unexpected ankle joint inversion. Therefore, an implementation of WBV to prevent ankle sprain is debatable because of its lacking effects on the peroneal reflex activity, which was also undetected in a recent study [17]. It was reported that immediately following a trial of WBV and after 30 min, peroneal reflex activity was not significantly influenced in response to inversion ankle perturbation during gait. Furthermore, the present data do not provide evidence that WBV training leads to a reduction of ankle joint loading due to a higher muscle reflex activity of the long peroneal and anterior tibialis muscles as recently suggested [15, 30].

Methodological limitations of the study

Our study may be limited due to the static testing procedure which lacks a dynamic ankle movement condition comparable to a real ankle sprain situation. Otherwise it could be considered that under dynamic conditions, a much higher velocity of ankle inversion motion could occur and that the reflex latencies of the peroneal muscles and also of the anterior tibialis muscle would probably remain unchanged due to the limited nerve conduction velocity of the specific afferent pathway. Hence, an increased risk of ankle joint injury would be likely in real-world situations. Previous studies have shown that pre-activated muscles efficiently increase ankle joint stiffness [23,32]. Due to the static condition, the role of pre-activation of the ankle joint muscles on the time of ankle joint motion could not be ruled out which limits the conclusion of the study. Moreover, it is still under discussion whether pre-knowledge of a movement task would also alter the muscle reflex activity. At least for ankle inversion motion Gruneberg et al. [15] found no influence of pre-knowledge on muscle activation prior to touchdown and on the first reflex component labelled as SLR in the TA and PL during landing on an inverting and non-inverting platform. We did not investigate the reflex activity of the short peroneal muscle. Based on the consistent results in the PL and TA muscles, it is unlikely that the values of the short peroneal muscle would be significantly different. We considered recommendations for an efficient WBV stimulus from previous literature [1,10,27], but it remains unclear whether a WBV training on reciprocal oscillating vibration platform induced similar results as presented here. In this respect, Abercromby et al. [1] found differences between two modes of WBV application, i.e. unilateral versus reciprocal oscillating vibration platforms. Finally, to our knowledge there is no data available as to how long WBV training as well as the mode of WBV application (traditional as currently performed vs. progressive vs. randomly induced WBV regarding amplitude and frequency) should be conducted to induce beneficial adaptations of the neuromuscular system. Future research should address this important issue. In this study we determined the vGRF in order to precisely describe the time of the ankle inversion motion. But it has to be kept in mind that the curve of the vGRF does not provide an insight into the actual loading condition of the foot and the ankle joint itself. Moreover, it could be assumed that between the two aforementioned time points the subject was falling over following the motion of the tilting platform and therefore only minor loading of the foot occurred. Using EMG analysis comparing reflex activity before and after WBV training we were not able to clearly secure that parameters such as maximal capacity or the EMG cancellation phenomenon at the second measurement time point were similar to the pre measurements. To minimize such effects the subjects were generally (at pre and post measurement) instructed to do similar activities in their daily routine prior to testing. In addition, electrode placement was marked after the first measurement and this placement was remarked every day to ensure similar electrode placement for the second measurement after a period of four weeks. However, this issue should be incorporated regarding the interpretation of the EMG data.

In conclusion, the present results provide evidence that a WBV training program carried out over 4 weeks has no beneficial effect on the PL and TA muscle reflex activity in response to a combined plantar flexion inversion ankle motion. As observed reflex latencies, iEMGs and the duration of ankle motion were not significantly altered by WBV training. However, due to the limited methodology further research is needed to evaluate the effect of WBV training on ankle joint stability during dynamic movement tasks. Thus the question as to whether a WBV program should be implemented in the prevention of ankle sprains remains open.

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