Acute Neuromuscular Modulation Enhances Postural Control after Whole-Body Vibration

**Summary**

The postural movement control determines performance of almost any kind of human movement. The current study aimed to investigate whether a short bout of whole-body vibration (WBV) can improve postural control. Effects were compared to a conventional balance training (BAL).

During an unstable one-legged stance, postural control was assessed in 22 healthy subjects before and after 2-min bouts of either WBV or BAL. Postural sway, antagonist co-contraction of selected lower limb muscles (soleus, gastrocnemius medialis, tibialis anterior, rectus femoris, biceps femoris) and soleus spinal excitability (H-reflexes) were recorded by means of posturography and electromyography, respectively.

Postural sway was significantly reduced after WBV (p<.05). After both interventions, a reduction of H-reflexes (WBV: -31%, BAL: -14%, p<.05), M-waves (WBV: -22%, BAL: -19%, p<.05) as well as shank muscle co-contraction was observed (WBV up to -18%, BAL up to -20%, p<.05). Thigh muscle co-contraction was only diminished after BAL (-17%, p<.05). Postural sway changes correlated positively with reflex amplitude changes (p<.05).

Thus, greater inhibition in spinal excitability (after WBV), but not diminished thigh muscle co-contraction (after BAL) are accompanied by postural sway reduction. With the benefit of being task-unspecific and easy to apply, WBV represents a possible intervention to improve postural control.

**KEY WORDS:**
Balance, H-Reflex, Co-Contraction, Centre of Pressure

**Zusammenfassung**

Die posturale Bewegungskontrolle bestimmt nahezu jede menschliche Bewegung die motorische Leistung. Das Ziel der vorliegenden Studie war die Erfassung, inwiefern eine Einheit Ganzkörpervibration (WBV) die posturale Kontrolle verbessern kann. Die Effekte wurden mit einem klassischen Gleichgewichtstraining (BAL) verglichen.

Die posturale Kontrolle wurde im monopedalem Stand bei 22 gesunden Proband*innen vor und nach 2-min Einheiten WBV oder BAL erhoben. Der posturale Schwankweg, die antagonistische Co-Kontraktion ausgewählter Muskeln der unteren Extremität (soleus, gastrocnemius medialis, tibialis anterior, rectus femoris, biceps femoris) und die spinale Erregbarkeit des Soleusmuskels (H-Reflex) wurden mittels Posturographie und Elektromyographie aufgezeichnet.

Der Schwankweg war nach WBV signifikant reduziert (p<.05). Nach beiden Interventionen konnte eine Reduktion des H-Reflexes (WBV: -31%, BAL: -14%, p<.05), der M-Welle (WBV: -22%, BAL: -19%, p<.05) und der Co-Kontraktion im Unterschenkel beobachtet werden (WBV bis -18%, BAL bis -20%, p<.05). Die Co-Kontraktion im Oberschenkel war lediglich nach BAL reduziert (-17%, p<.05). Die Änderung des Schwankwegs korrelierte positiv mit den Änderungen der Reflexamplitude (p<.05).

Demnach ging lediglich die stärkere Hemmung der spinalen Erregbarkeit (nach WBV), nicht jedoch die reduzierte muskuläre Co-Kontraktion des Oberschenkels (nach BAL) mit der Schwankwegreduktion einher. Mit dem Vorteil, dass die Modulationen (aufgaben-)unspezifisch und einfach zu applizieren waren, stellt WBV ein mögliches Interventionsgerät dar, mit dem die posturale Kontrolle verbessert werden kann.

**SCHLÜSSELWÖRTER:**
Gleichgewicht, H-Reflex, Co-Kontraktion, Schwankweg

**Introduction**

For any kind of human movement, the maintenance or acute restoration of postural control is of fundamental necessity (24). Balance training, which is known to improve postural performance (22), is therefore of particular relevance for sub-populations, who manifest deficits in motor control due to degeneration (e.g. elderly) or neurological disorders. In this regard, whole-body vibration (WBV) training has moved into the focus of scientific research, because it may enhance postural stability (28). 1) High-frequent mechanical oscillations of the platform cause perturbations applied to the body by means of instability (29), and thus 2) cause the muscle-tendon complex to dampen those forces transmitted to the body (5). This training modality makes WBV unique among...
traditional balance training (BAL) methods. Characterized by a time-efficient and easy usage, especially patients who suffer from movement disorders might benefit from WBV (1). Nonetheless, evidence about the acute effects on postural control after WBV is still inconsistent and a conclusive statement is missing (4, 10).

From a neurophysiological point of view, postural control requires a complex interaction between sensory perception, central integration and motor execution (24). Therefore, excitability can be transferred via pathways which are originated from cortical structures of the central nervous system and are known to enhance motor control (corticospinal) as well as via pathways which are relevant in reflex motor responses (spinal). This neuromuscular interaction is highly adaptable, as could be demonstrated by conventional balance training: Reduced excitability via spinal pathways (37), enhanced input via corticospinal pathways (38) and an efficient intermuscular coordination of antagonists and agonists were observed (26). Acutely, the inhibition of spinal excitability correlates positively with enhanced postural stability; but modulations are only task-specific (25, 39). After vibration, similar modulations can be observed: exposure induces reduced muscle spindle sensitivity (30) and concomitant with the tonic vibration reflex (9) diminishes excitability via spinal (16, 33) and increases input via corticospinal pathways to the muscle (21). However, regardless of the resembling neuromuscular modulations after WBV compared to BAL, the impact of those neurophysiological correlates on postural control is vague.

From a mechanical point of view, WBV has an impact on neuromuscular control by applying sinusoidal forces to the body through the mechanical oscillation of the device (5). This occurs rather independent from the component inter-linked to the postural demand (40). In comparison, balance training-induced improvements depend on the attributes of the performed balance exercise, i.e. degrees of movement and trajectory (14). Even though resembling modulation of Ia afferent pathways can be observed after both short-term interventions, neuromuscular effects are elicited by differing stimuli: The external (mechanical) stimulus of WBV can be opposed to the self-induced (physiological) stimulation of BAL.

Thus, the main purpose of the current study was to investigate, if acute neuromuscular modulation has an effect on postural control during a postural challenging task after WBV. We aimed to identify if the training stimulus acts on spinal reflex activity and antagonistic muscle co-contraction and whether these neuromuscular modulations attribute to changes of postural sway.

In addition, we aimed to test the dependency of results from the stimulus itself. Therefore, we also conducted a conventional balance task which is known to improve postural control in a task-specific manner. Thus, based on the strong mechanical stimulus, changes in postural control were expected to be greater after WBV compared to BAL.

| Table 1 |
| Control parameters of test-retest reliability. Presented are angular excursions with goniometric recordings (Gonio [°]), for the ankle joint (AJ) and knee joint (KJ) and muscular background activation with electromyography (iEMG [%]). Cronbach’s α are listed in the last column; values were compared to baseline values. |

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Methods

Participants

Twenty-two young, healthy subjects (17 females/5 males, 25±2 years of age, 169±8 cm height, 62±12 kg body mass) participated in this investigation. Inclusion criteria comprised the ability to balance on a wooden wobble board in a one-legged stance. Participants were excluded in case of acute or chronic orthopaedic injuries or neurological disorders. All participants gave written informed consent to the experimental procedure, which was in accordance with the latest revision of the Declaration of Helsinki and approved by the ethics committee of the University of Freiburg (197/17).

Experimental Design

In a repeated-measures cross-sectional study design, parameters of postural control were tested prior and after 2-min short-term interventions of either WBV or BAL in a randomized order (Fig. 1). Assessment of postural control was conducted while balancing in a one-legged stance on the wobble board (37). Postural sway, agonist-antagonist muscular responses (co-contraction) and spinal excitability were recorded. The duration of one trial lasted 40s with the application of ten electrical H-reflex stimulations. Participants were instructed to stand as still as possible in an upright position (14). Head and eyes faced in forwards position, the contralateral leg was flexed at 90° in the knee, but extended in the hip (14). They trained prior to the first assessment to exclude habituation effects (14). For test-retest reliability, authors supervised standardized body position at all times and the exact same assessment was conducted twice prior to the first intervention (control assessment, CON) (21). In case of balance loss, the trial was repeated. Due to an unreliable body position characterized by differences in ankle joint position measured by electrical potentiometers, one participant was excluded from data analysis.

Short-Term Interventions

Participants balanced either on a vertical side-alternating vibration platform (Galileo Sport, Novotec Medical, Pforzheim, Germany) or on the wobble boards (14, 39) for two minutes intermittently (5, 36; see Fig. 1). Each trial was repeated twice with short breaks in-between to prevent fatigue. Identical to the assessment, participants stood in an upright one-legged position. Training protocols were matched to exclude confounding effects due to volume, duration or body position, with the only exception of a nearly extended knee and slightly lifted heel to reduce vibratory stimuli to the upper body according to previous results (21) (4mm peak-to-peak displacement, 11cm from rotation axis, peak acceleration 7.2g).

Data Collection

Postural sway. Three-dimensional forces and torques were recorded with a force plate (Novotec Medical GmbH, Pforzheim, Germany) located under the wobble board with a frequency of 50Hz. Centre of pressure displacements in anterior-posterior (COPap) and medio-lateral direction (COPml) were assessed in addition to the total displacement (COP).

Kinematics. Angular position in the ankle and knee joint in the sagittal plane was assessed with custom-designed electrogoniometers (Biometrics®, Gwent, UK). The rotary potentiometers (Megatron, Munich, Germany) were fixed over the respective joint with rotation axes and movable endplates in line with the longitudinal body axes (33). Neutral position for the ankle joint was set at 90° between the endplates and for the knee joint at 180°. Data were recorded with a sampling frequency of 1kHz.

Electromyographic recordings. Muscular responses of five selected lower limb muscles (SOL–soleus, GM–gastrocnemius medialis, TA–tibialis anterior, RF–rectus femoris, BF–biceps femoris) were recorded with surface electromyography (EMG) according to SENIAM (17). Hair over the muscle belly was shaved, skin slightly emerised and degreased. Bipolar Ag/AgCl surface electrodes (Ambu Blue Sensor P, Ballerup, Denmark; diameter 9mm, centre-to-centre distance 25mm) were placed in line with the muscle fibres and over the tibia (reference electrode) with an interelectrode resistance below 2.5kΩ. Data were transferred to the amplifier (sampling frequency of 1000Hz) and band-pass filtered (10Hz-1kHz).

Prior to the experimental session, trials to assess the maximal isometric voluntary contraction (MVC) were conducted to establish each muscles’ maximal activation intensities based on Daniels and Worthingham (8). Maximum contractions of three seconds were used for normalization. Body position and antagonistic muscle activity were standardized and controlled strictly.

Spinal excitability. With the technique of Peripheral Nerve Stimulation, muscular responses were elicited with 10 electrical stimulation of the tibial nerve (Digitimer D57, Digitimer, Welwyn Garden City, UK) and recorded with EMG electrodes over the SOL. A cathode (10x5cm dispersal pad) was placed over the tibial nerve in the popliteal fossa and an anode below the patella (2cm diameter). Squared-wave pulses of 1ms were applied with 4s interstimulus intervals. With the exception of CON, which was conducted for reliability reasons, each protocol was conducted twice resulting in 20 stimuli for each condition.

Figure 1

Study design of 2-min bouts of whole-body vibration (WBV) or a conventional balance task (BAL). Two pre-measurements (PRE/ t0, CON/ t1) were conducted to test for test-retest reliability. At each assessment point, the outcome measures centre of pressure (COP), spinal excitability (H-reflexes, HR) and co-contraction (co-contraction index, CCI) were recorded during 40s of a balance task.
Stimulus intensity of 25% of the individual maximal muscle response (6) was assessed with an H/M-recruitment curve during bipedal stance prior to the first measurement (33).

Data Processing
For all outcome measures, mean values and standard deviations were calculated.

Postural Sway
Total COP path length (COP) was calculated according to the Pythagoras theorem with COP anterior-posterior axis and COP medio-lateral axis in a time window of 20s: 

$$\text{COP}_t = \sum \sqrt{(\text{Displacement in anterior-posterior axis})^2 + (\text{Displacement in medio-lateral axis})^2}$$

for each sample point (32).

Electromyographic recordings
MVC values were analyzed in a time window of 50ms after maximal EMG amplitude. Background activity was assessed 100ms prior to each electrical stimulus. Raw EMG values were rectified and integrated (iEMG[mVs]).

For the quantification of co-contraction, data were analyzed starting at the first H-reflex stimulus and with a time window of 20s while balancing on the wobble board. After normalization to MVC values, co-contraction indices (CCI) of the antagonist muscle pairs CCI SOL_TA, CCI GM_TA and CCI IRF_BF were calculated as follows: 

$$\text{CCI} = \frac{\text{EMG}_{\text{lower activated muscle}}}{\text{EMG}_{\text{higher activated muscle}}} \times (\text{EMG}_{\text{lower activated muscle}} + \text{EMG}_{\text{higher activated muscle}})$$

for each sample point (23).

Spinal Excitability
Peak-to-peak SOL M-wave and H-reflex amplitudes were evaluated between the initial deflection of the EMG signal from baseline to the second crossing of the baseline as described previously (33). We summarized the differences between maximum peak of $H_{\text{BAL-HWBV}}$ ($\Delta 1$) and between minimum peak of $H_{\text{BAL-HWBV}}$ ($\Delta 2$) to calculate total amplitude differences ($H_{\Delta}$; Fig. 2).

Statistics
Changes over time were analyzed with two dependent variables (pre vs. post): Normal distribution was determined with Shapiro-Wilk test. Based on those results, either Student’s paired t-test or the non-parametric Wilcoxon Rank-test were calculated. Data were corrected for multiple testing based on Benjamini and Yekutieli (3). Effect sizes over time were analyzed with Glass’ Δ. Additionally, either Pearson or Spearman’s rank correlation coefficient were calculated for the comparison of COP and H-reflex pre-post-differences. Reliable background activity and joint position were ensured with Cronbach’s $\alpha$ values (12).
Results

Cronbach’s α estimates yielded excellent values for the ankle and knee joint position (.90-.98) and good to acceptable values for muscular background activity (.78-.98; Table 1) indicating a reliable body position and neuromuscular activation throughout the measurement. Neither functional (postural sway, Glass’ Δ=.19-.23) nor neuromuscular outcome measures (antagonistic co-contraction Glass’ Δ=.06-.08, spinal excitability Glass’ Δ=.08-.13) changed over time when no training was applied (CON; Table 2).

In line with CON, postural sway did not change after BAL (p=.29, Glass’ Δ=.21), but was significantly reduced after WBV for COPap (p<.05, Glass’ Δ=.40).

In contrast to CON, effects for co-contraction (cf. Table 2) were observed after both training modalities: CCI_SOL_TA values ranged between -17±19% (p<.01, Glass’ Δ=.62) and -20±15% (p<.01, Glass’ Δ=.62), CCI_TA values between -18±17% (p<.01, Glass’ Δ=.43) and -14±23% (p<.05, Glass’ Δ=.32) for WBV and BAL, respectively. In addition, co-contraction in thigh muscles (CCI_RF_BT) was diminished by -17±26% after BAL, only (p<.05, Glass’ Δ=.21; Table 2). For spinal excitability, significant effects were observed in comparison to CON as well: H-reflexes were diminished by -31±30% after WBV (p<.01, Glass’ Δ=.71) with greater effect sizes than after BAL with a reduction of -14±25% (p<.05, Glass’ Δ=.40; Fig. 2). Additionally, M-waves were diminished as well; values of -22±34% after WBV (p<.05, Glass’ Δ=.29) and -19±36% after BAL were assessed (p<.05, Glass’ Δ=.29; Table 2).

Comparing WBV to BAL, reduced H-reflexes correlated significantly with diminished COPap (r=.472, p<.05; Fig. 3) and COPml (r=.538, p<.01).

Discussion

The aim of the current study was to investigate acute effects of WBV on postural control by means of neuromuscular parameters and functional effects on postural sway. In comparison to conventional balance training, we demonstrated for the first time that neuromuscular control during a postural challenging task was modulated after both, a short 2-min bout of WBV and BAL. However, differences in motor control resulted just partly in a verification of our hypotheses:

1) After WBV, a reduced postural sway in anterior-posterior direction was accompanied by a decline in spinal excitability and co-contraction in the shank muscles. After BAL, there were no changes in postural sway, but antagonist co-contraction in shank and thigh muscles declined. 2) Comparing the selected interventions, greater effect sizes were reached for changes in postural sway and spinal excitability after WBV and in muscular thigh co-contraction after BAL. The electrophysiological findings correlate with COP displacement indicating an interrelationship between balance performance and neuromuscular function.

Task-Specificity

First, the reduction of postural sway following a short bout of WBV is in accordance with previous results and might indicate enhanced postural control (35). In the current study, sway in anterior-posterior direction moves into focus. Even though it could be assumed that side-alternating vibration might induce a lateral stimulus, and thus modulation of COPml, previous investigations have shown that muscles which are involved in the anterior-posterior sway (SOL, GM and TA) are activated to a greater degree compared to synchronous vibration (34). By decreasing muscular activation in those specific muscles around the ankle joint, self-induced perturbation might be reduced, and thus COPap sway decreased as well.

In addition, this observed outcome of postural sway after WBV was connected to neuromuscular effects for the first time: As introduced earlier, both, WBV and BAL elicit stretch reflexes via the Ia afferent circuitry, either via the external (mechanical) vibration-induced or the self-induced (physiological) task-specific stimulus. While the reflex reduction after BAL is in accordance with previous investigations (39).
Acute exposure to WBV has a positive impact on postural control in anterior-posterior direction beyond the effects of BAL. With a major contribution of diminished spinal excitability and shank muscle co-contraction, WBV can be used to acutely modulate neuromuscular control during postural demanding tasks. Especially populations suffering from postural instability based on enhanced co-contraction and spinal hyper-excitability might benefit from those acute modulations.

However, further evidence is needed to investigate the transfer into everyday life tasks. Therefore, the modulation during dynamic postural control and the maintenance of those acute modulations might be of great relevance. While previous investigations point towards sustaining...
neuromuscular effects for 10-15min following WBV, the application of WBV training immediately prior to postural unstable situations might be of great relevance for long-term fall prevention.

Acknowledgements

This work was supported by a scholarship as per the State Law on Graduate Funding (LGFG) of the state Baden-Württemberg as part of an announcement at the University of Freiburg.

Conflict of Interest

The authors have no conflict of interest.

References


Posturale Kontrolle nach Ganzkörpervibration


