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Research article

Acute Effects of Whole-Body Vibration on Trunk and Neck Muscle Activity in Consideration of Different Vibration Loads

Dennis Perchthaler [1]✉, Simon Hauser [1], Hans-Christian Heitkamp [1], Tobias Hein [2] and Stefan Grau [2]
[1]Department of Sports Medicine, Medical Clinic, University of Tuebingen, Germany
[2]Department of Food and Nutrition, and Sport Science, Biomechanics, University of Gothenburg, Sweden

Abstract
The intention of this study was to systematically analyze the impact of biomechanical parameters in terms of different peak-to-peak displacements and knee angles on trunk and neck muscle activity during whole-body vibration (WBV). 28 healthy men and women (age 23 ± 3 years) performed four static squat positions (2 peak-to-peak displacements x 2 knee angles) on a side alternating vibration platform with and without vibration stimulus. Surface electromyography (EMG) was used to record the neuromuscular activity of the erector spinae muscle, the rectus abdominis muscle, and of the splenius muscle. EMG levels normalized to maximal voluntary contractions ranged between 3.2 – 27.2 % MVC during WBV. The increase in muscle activity caused by WBV was significant, particularly for the back muscles, which was up to 19.0 % MVC. The impact of the factor 'condition' (F-values ranged from 13.4 to 132.0, $p \leq 0.001$) and of the factor 'peak-to-peak displacement' (F-values ranged from 6.4 to 69.0 and p-values from < 0.001 to 0.01) were statistically significant for each muscle tested. However, the factor 'knee angle' only affected the back muscles (F-value 10.3 and 7.3, $p \leq 0.01$). The results of this study should give more information for developing effective and safe training protocols for WBV treatment of the upper body.

Key words: Vibration, electromyography, torso, paraspinal muscles.

Introduction

Whole-body vibration (WBV) training has become a popular exercise method for athletes and patients over the last decade. It is used as a training form in prophylaxis and medical rehabilitation, as well as in standard strength training (Nordlund and Thorstensson, 2007; Rittweger, 2010). WBV exercises are performed while standing on a motor driven oscillating platform device. Hereby, a distinction is drawn between side alternating vibration platform devices, which reciprocate vertical displacements on the left and right side of a fulcrum, and synchronous vibration platform devices, where the whole plate oscillates uniformly up and down (Cardinale and Wakeling, 2005; Rauch et al., 2010; Rittweger, 2010). The mechanical vibration stimulus applied to the muscles and tendons during WBV exercise is characterized by a cyclic transition between eccentric and concentric muscle contractions and leads to a neuromuscular response (Rittweger, 2010). Thus, WBV exercise acutely enhances the pattern of the neuromuscular system due to the physiological mechanism called "tonic vibration reflex" (TVR), where muscle spindle reflexes facilitate the activation of Ia-motoneurons, leading to muscle contractions (Hagbarth and Eklund, 1966; Lance et al., 1973). Monosynaptic and polysynaptic pathways have been shown to mediate TVR (Desmedt and Godeaux, 1980; Luo et al., 2005).

Previous studies have shown that WBV has an effect on muscle strength parameters (Delecluse et al., 2003; Issurin et al., 1994; Luo et al., 2005; Schlumberger et al., 2001; Torvinen et al., 2002), performance (Lamont et al., 2009; Wyon et al., 2010) and postural control, especially in older adults (Bruyere et al., 2005; Gómez-Cabello et al., 2013; Kawanabe et al., 2007; Runge et al., 2000). Most of these studies focused on leg muscles and only few studies were found that investigated the effects of WBV exposure on trunk and neck muscles. According to this, it has been reported that WBV training reduces back pain by relaxing the back muscles (Iwamoto et al., 2005; Rittweger et al., 2002). Furthermore, Osawa and Oguma (2013) showed a significant increase in the muscle strength of the back muscles after 13 weeks of WBV training with a synchronous vibrating platform compared to conventional strength training (+51.5 ± 34.1%, $p < 0.001$ and +26.4 ± 17.5%, $p < 0.001$). Both training groups significantly increased the number of sit-ups performed with respect to time ($p < 0.001$). However, a small number of studies are known which specifically investigated the neuromuscular activity of the back muscles during WBV exposure. In this context, Wirth et al. (2011) showed significant increases in muscle activity (measured with surface EMG) in abdominal and back muscles by adding WBV stimuli in different gymnastic exercises on a synchronous vibrating platform, whereas the level of activation correlated with the exercise. There is still a lack of published information about WBV influence on neuromuscular activity of the neck muscles, although it is suggested that the neck muscles are also capable of being influenced by the vibration stimulus (Abercromby, 2007b).

During WBV exposure, the magnitude of EMG levels of a specific muscle depends on the vibration load determined by the biomechanical parameters (vibration frequency, peak-to-peak displacement, and joint angle), the exercise parameters (side alternating or synchronous vibration platform devices, acute vs. chronic effects, exercise position) (Abercromby et al., 2007a; 2007b; Krol et al., 2011; Perchthaler et al., 2013; Petit et al., 2010; Roelants et al., 2006), and the anatomical localization of the muscle (Hug, 2011). There are no studies investigating the influence of the combination of these parameters to

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achieve the highest neuromuscular activity of the trunk and neck muscles. In particular, the acute effect of the variation of peak-to-peak displacement on the neuromuscular response of these muscles has not been investigated. Furthermore, vibrations could be potentially harmful to the soft tissue organs within the head (Rittweger, 2010), and therefore the selection of the biomechanical parameters should be well-considered. In this context, Abercromby et al. (2007b) quantified head accelerations by performing slow dynamic squats with knee angles 10-35° during WBV and comparing them to ISO 2631-1:1997 standards for potentially harmful vibration exposure. They suggest that potentially harmful vibration transmission to the head is minimized when using a side alternating vibration platform rather than a synchronous device and by squatting with a knee angle of 26-30°. In addition, Caryn et al. (2014) investigated how changes in WBV frequency and knee angle affect acceleration transmission to the head on a synchronous vibration device. These authors reported that frequencies below 30 Hz combined with knee angles less than 40° should be avoided to reduce the risk of injury to structures of the head during vibration exercise. Although both studies recommend a vibration frequency of 30 Hz, there are differences in the peak-to-peak displacement of 4 mm (Abercromby, 2007b) and 1-2 mm (Caryn, 2014), respectively. The main contrast between the studies by Abercromby (2007b) and Caryn (2014), however, is a significant discrepancy relating to the recommendations for knee angles (26°-30° vs. > 40°) to avoid harmful head accelerations. In respect to the recommended parameters of these two studies, knee angles of 30° and 45° at a frequency of 30 Hz were assumed as biomechanical parameters in the present study. In addition, low and high peak-to-peak displacements (2.6 and 7.8 mm) were included.

The aim of this study was to examine the combination of peak-to-peak displacement and knee angle, which achieves the highest level of activity of the trunk and neck muscles during WBV. We hypothesized that the biomechanical parameters affect the level of neuromuscular activity in different dimensions. We first examined to what extent these muscles were active during WBV. Next, we observed the differences between muscle activity with (WBV) and without (CON) a vibration stimulus of 30 Hz frequency. Finally, we investigated how the level of activation was affected by the biomechanical parameters. These steps were important to provide effective and safe recommendations for WBV training protocols for trunk and neck muscles.

Methods

Study design

To test the hypothesis, measurements were done to analyze the neuromuscular activity of the trunk and neck muscles during WBV exposure. Trunk muscles analyzed in previous studies addressing acute (Wirth et al., 2011) and chronic (Osawa and Oguma, 2013) effects of WBV were selected for the present trial. In addition, one neck muscle was also included, as data about EMG analyzes of the neck muscles during WBV is lacking in current literature. Therefore, surface EMG was used to record the signals from the upper and lower rectus abdominis muscles, upper and lower erector spinae muscles and from the splenius muscle in different conditions of WBV and without vibration stimulus. The neuromuscular activation levels of the trunk and neck muscles were the dependent variables. The independent variables were the vibration condition (vibration stimulus with a vibration frequency of 30 Hz and no vibration), two peak-to-peak displacements (2.6 and 7.8 mm) and knee angles at 30° and 45°. To normalize EMG, muscle activation was recorded during isolated and isometric maximal voluntary contractions (MVC). EMG treatment procedure and data analysis were performed according to Merletti (1999).

Participants

Twenty-eight healthy and physically active men (n = 14) and women (n = 14) (age 23 ± 3 years, height 1.73 ± 0.17 m, weight 65.5 ± 19.5 kg, BMI 21.8 ± 4.2 $kg \cdot m^{-2}$) volunteered to participate in the present study. Exclusion criteria were fresh fractures, all types of diseases related to gallstones and kidney stones, and acute back pain. No one had to be excluded on the basis of these criteria. All participants gave written informed consent to participate in the experiment. The study was approved by the Human Ethics Committee of the university according to the Declaration of Helsinki.

EMG analyses

Surface EMG (Noraxon Telemyo 2400T V2, Scottsdale, AZ) was recorded from the upper (UES) and lower (LES) part of the erector spinae muscle, upper (URA) and lower (LRA) part of the rectus abdominis muscle, and from the splenius muscle (SPL) of a randomized side of the body. Skin was prepared by removing the hair and cleaning the muscle area with fine sand paper and alcohol. Bipolar surface electrodes (Ag/AgCl, 3M Health Care, St. Paul, MN) were applied over the muscle belly using SENIAM recommendations for UES and LES (Hermens et al., 1999), whereby these were not available, e.g. for URA, LRA SPL, referring to literature data (Lehman and McGill, 2001; Konrad, 2005; Wirth et al., 2011). The electrodes were placed with an interelectrode distance of 20 mm on the UES (2 fingers' width lateral from the L1 spinous process), on LES (2–3 cm from the midline at the level of L5, placed on and aligned with a line from the caudal tip of the posterior spina iliaca superior to the interspace between L1 and L2), on URA (2–3 cm lateral from the midline on the second segment of the muscle), on LRA (2–3 cm lateral from the midline, on the fourth segment of the muscles or 2 cm inferior to the umbilicus if the fourth segment could not be palpated), and on SPL (2-3 cm from the midline at the level of C4). A ground electrode was placed over the dorsal process of the seventh cervical vertebra. The preamplified EMG signals were amplified (x1000), bandpass-filtered at 10-500 Hz ± 2 % cut-off (Butterworth/Bessels), and sampled at 1500 Hz. MyoResearch XP software (Noraxon, Scottsdale, AZ) was used to collect and store the data for subsequent analysis. EMG cables were properly fixed on the skin with tape to prevent the cables from swinging and to avoid-movement artifacts.

Treatment protocol

After attaching the electrodes, MVC was performed to measure the maximum possible EMG level of the muscle. These MVC were performed on special training devices (DAVID 110, 130, and 140, David Health Solutions Ltd., Helsinki), which allow valid and reliable isolated isometric contractions of the muscles tested (Denner, 1997). All aspects of these MVC test procedures (rater's behavior, familiarization procedures, test position, fixation, and content of test instructions) to recruit erector spinae muscle (DAVID 110), rectus abdominis muscle (DAVID 130), and splenius muscle (DAVID 140) were standardized to enhance objectivity and have been extensively described elsewhere (Denner, 1998).

The participants were exposed to WBV using a side alternating vibration platform (Galileo Fitness, Novotec Medical GmbH, Pforzheim). Such a vibration device reciprocates vertical displacements on the left and right side of a fulcrum. Thus, the peak-to-peak displacements on a side alternating platform depend on the width of the foot position (Rittweger, 2010). Therefore, muscle activity was recorded during four different static squat positions: two different foot positions (innately marked 5.7 and 17.1 cm from the central axis of rotation by the manufacturer), which determined the peak-to-peak displacements of 2.6 mm and 7.8 mm , performed at knee angles of 30° and 45°, respectively. Each different position was measured in two conditions: with (WBV) and without (CON) a vibration stimulus of 30 Hz. Hereby, the root mean squared acceleration (a_{RMS}) at a peak-to-peak displacement of 2.6 mm and 7.8 mm represents 3.33 *g* and 9.99 *g* (where $g = 9.81\ m{\cdot}s^{-2}$), respectively. The participants were asked to stand barefoot in the relevant squat position with the center of the heel on a marker for the particular foot position while their hands were kept on their waists. Knee angles were monitored simultaneously and recorded with EMG signals using a flexible axis goniometer (Noraxon 2D-Goniometer, Scottsdale, AZ) connected to the EMG device. The goniometer was properly fixed to the skin with tape on the lateral line of the tibiofemoral joint of the leg, with its center placed over the joint space on the same side of the body as the EMG electrodes. Zero offset calibration was performed at a knee angle of 0°, and additionally monitored with a manual goniometer. A straight back and an upright body were required during all test positions. Posture was permanently monitored visually during all measurements. Before starting the measurements, participants were able to familiarize themselves with the selected vibration stimulus during a warm-up period of 60 seconds.

The EMG signals were recorded for about 25 seconds once the subjects had taken up the correct position on the vibration platform. Each of the four test positions were measured two times during WBV and CON conditions. The order of the different measurements was randomized. To unload the muscles, subjects paused for 60 seconds before the next measurement started. All measurements were conducted by the same investigator.

Data analysis

The EMG raw signals were rectified and smoothed. Root mean square calculation (RMS) was applied as a digital smoothing algorithm in a defined moving time window (400 ms) for the whole 25 seconds trial. A time window of four seconds in which the knee angle was stable (below 0.5° deviation of the aimed target knee angle) was chosen for further analyses. Then the EMG_{RMS} signals were MVC-normalized according to the isolated MVCs done prior to the WBV trials. Subsequently, muscle activity of the measurements was expressed as a percentage of the muscle activity during the measured MVC (100 %). Muscle activity of the UES, LES and SPL was expressed relative to muscle activity during maximal isometric trunk and neck extension. Muscle activity of the URA and LRA was expressed relative to muscle activity during maximal isometric trunk flexion. Data were reported as mean ± *SE*.

Statistical analysis

Statistical analyses were performed using the software package SPSS, Version 21 (IBM, Armonk, NY). An ANOVA for repeated measurements (2 [condition] x 2 [knee angle] x 2 [peak peak-to-peak displacement]) was performed to analyze differences in $EMG_{\%MVC}$. A Bonferroni correction was used to adjust the *p* value related to the number of conditions that were performed. Significance level was set at $p \leq 0.05$.

Results

Upper part of the erector spinae muscle

The muscle activity of the UES varied during WBV between 15.4 and 27.2 % MVC, whereby the highest level was found at a peak-to-peak displacement of 7.8 mm and a knee angle of 30°.

In addition, we found that the magnitude of $EMG_{\%MVC}$ was always higher in the WBV condition compared with the CON condition and there was a statistically significant main effect of 'condition' ($F (1.26) = 113.239$, $p < 0.001$). The highest increase in activity was also found at a peak-to-peak displacement of 7.8 mm combined with a knee angle of 30° (see Table 1). Furthermore, there was a statistically significant 'condition x peak-to-peak displacement' interaction effect ($F (1.26) = 78.001$, $p < 0.001$). The interaction effect of condition and knee angle was statistically significant ($F (1.26) = 9.361$, $p < 0.01$). The 'condition x peak-to-peak displacement x knee angle' interaction effect was also statistically significant ($F (1.26) = 7.770$, $p < 0.01$).

The biomechanical parameters had different effects on the muscle activity of the UES. Our results show that there was a statistically significant main effect of the peak-to-peak displacements tested ($F (1.26) = 63.726$, $p < 0.001$). The main effect of 'knee angle' was also statistically significant ($F (1.26) = 10.281$, $p < 0.01$). No statistically significant 'peak-to-peak displacement x knee angle' interaction effect ($F (1.26) = 1.104$, $p > 0.05$) was found. This indicates that some combinations of the biomechanical parameters have similar effects on muscle activity.

Lower part of the erector spinae muscle

Normalized EMG activity of the LES during WBV ranged between 16.1 and 27.0 % MVC. The highest activation level was detected at a peak-to-peak displacement of 7.8 mm and a knee angle of 30° (see Table 1).

We also found a statistically significant main effect of the 'condition' ($F(1.26) = 131.975$, $p < 0.001$), whereby the $EMG_{\%MVC}$ level was always higher during WBV compared to the CON condition. In addition, statistically significant interaction effects were found for both 'condition x peak-to-peak displacement' ($F(1.26) = 123.569$, $p < 0.001$) and 'condition x knee angle' ($F(1.26) = 13.238$, $p < 0.001$). In contrast, no statistically significant interaction effect was found for 'condition x peak-to-peak displacement x knee angle' ($F(1.26) = 2.181$, $p > 0.05$).

Furthermore, we can show that the level of activation was affected by the biomechanical variables in different ways. A statistically significant main effect of the peak-to-peak displacement was found ($F(1.26) = 69.003$, $p < 0.001$), as well as statistically significant differences in $EMG_{\%MVC}$ levels between the two knee angles tested ($F(1.26) = 7.279$, $p < 0.05$). However, the muscle activity remained similar at both peak-to-peak displacements when the knee angles changed and there was no statistically significant interaction effect of 'peak-to-peak displacement x knee angles' detected ($F(1.26) = 2.197$, $p > 0.05$). This also indicates that some of the biomechanical variable combinations have similar effects on the muscle activity of LES.

Upper part of the rectus abdominis muscle

The EMG of URA varied during WBV between 3.6 and 6.0 % MVC, and the highest level was found at a peak-to-peak displacement of 7.8 mm and a knee angle of 30°. Furthermore, the neuromuscular activation was always higher in the WBV condition compared to the CON condition, ($F(1.26) = 47.993$, $p < 0.001$). The highest increase in $EMG_{\%MVC}$ was also found at a peak-to-peak displacement of 7.8 mm combined with a knee angle of 30° (see Table 1). In addition, there was a statistically significant interaction effect for 'condition x peak-to-peak displacement' ($F(1.26) = 5.293$, $p < 0.05$). A statistically significant interaction effect between condition, peak-to-peak displacement and knee angle ($F(1.26) = 5.887$, $p < 0.05$) was also found. However, there was no statistically significant interaction effect for 'condition x knee angle' ($F(1.26) = 1.104$, $p > 0.05$).

Finally, our results show that there was a statistically significant main effect of the peak-to-peak displacements tested ($F(1.26) = 36.532$, $p < 0.001$). However, neither the main effect 'knee angle' ($F(1.26) = 0.114$, $p > 0.05$) nor the 'knee angle x vibration condition' interaction effect ($F(1.26) = 1.104$, $p > 0.05$) was statistically significant, and thus indicates that some combinations of the biomechanical parameters have similar effects on URA activity.

Lower part of the rectus abdominis muscle

Normalized EMG activity of the LRA during WBV ranged between 3.2 and 5.8 % MVC, whereby the maximum activation level was found at a peak-to-peak displacement of 7.8 mm and a knee angle of 45° (see Table 1).

Moreover, we found a statistically significant main effect of the 'condition' ($F(1.26) = 23.555$, $p < 0.001$), whereas the muscle activation level was always higher during vibration stimulus compared to the CON condition. The highest increase of activity was also registered at a peak-to-peak displacement of 7.8 mm combined with a knee angle of 45°. Additionally, we can report a statistically significant interaction effect of the condition and the peak-to-peak displacements tested ($F(1.26) = 34.072$, $p < 0.001$). However, no statistically significant interaction effects were found for 'condition x knee angle' ($F(1.26) = 0.011$, $p > 0.05$) or 'condition x peak-to-peak displacement x knee angle' ($F(1.26) = 0.075$, $p > 0.05$).

Furthermore, statistical analyses confirmed a main effect of the peak-to-peak displacement ($F(1.26) = 28.892$, $p < 0.001$). However, some combinations of the biomechanical parameters appear to have similar effects on LRA muscle activity, as the EMG levels remained similar at both knee angles ($F(1.26) = 0.014$, $p > 0.05$)

Table 1. Muscle activity of the upper (UES) and lower (LES) part of the erector spinae muscle, upper (URA) and lower (LRA) part of the rectus abdominis muscle, and splenius muscle (SPL) with different vibration peak amplitudes (1.3 mm and 3.9 mm) and knee angles (30° and 45°) during whole-body vibration (WBV) and without vibration stimulus (CON). In addition, the increase in $EMG_{\%MVC}$ level (DIF) between WBV and CON condition is shown. Values are presented as a percentage of the muscle activity during an isolated MVC (100%). Values are mean (± SE).

		1.3 mm		3.9 mm	
		30°	45°	30°	45°
UES	CON	8.6 (1.4)	12.5 (1.5)	8.1 (1.2)	13.0 (1.7)
	WBV	15.4 (1.6)	17.7 (1.7)	27.2 (2.0)	26.3 (2.2)
	DIF	+6.8 *	+5.2 *	+19.1 *	+13.3 *
LES	CON	9.0 (1.2)	12.9 (1.5)	8.8 (1.1)	12.7 (1.5)
	WBV	16.1 (1.3)	17.6 (1.6)	27.0 (1.6)	25.8 (2.4)
	DIF	+7.1 *	+4.7 *	+18.2*	+13.1*
URA	CON	2.9 (0.8)	3.0 (0.9)	3.0 (0.9)	3.1 (1.0)
	WBV	3.6 (1.0)	3.8 (1.0)	6.0 (1.1)	5.6 (1.0)
	DIF	+0.7 *	+0.8 *	+3.0 *	+2.5 *
LRA	CON	2.2 (0.3)	2.3 (0.4)	2.2 (0.4)	2.2 (0.3)
	WBV	3.3 (0.6)	3.2 (0.5)	5.7 (1.0)	5.8 (0.9)
	DIF	+1.1 *	+0.9 *	+3.5 *	+3.6 *
SPL	CON	3.6 (0.4)	4.2 (0.4)	3.8 (0.4)	3.7 (0.4)
	WBV	4.8 (0.5)	5.4 (0.7)	8.5 (1.6)	7.9 (1.4)
	DIF	+1.2 *	+1.2 *	+4.7 *	+4.2 *

* Significant increase in muscle activity WBV-CON ($p \leq 0.05$).

and no statistically significant interaction effect of ‘peak-to-peak displacement x knee angles’ (F (1.26) = 0.003, $p > 0.05$) was found.

Splenius muscle

The highest EMG level of the SPL was found at a peak-to-peak displacement of 7.8 mm and a knee angle of 30°, and the muscle activity varied between 4.8 and 8.5 % MVC during WBV.

Based on a statistically significant main effect of the ‘condition’ (F (1.26) = 13.426, p = 0.001), we found that the muscle always showed higher activity during WBV compared with CON condition. Thus, the highest increase in activity was also found at a peak-to-peak displacement of 7.8 mm combined with a knee angle of 30° (see Table 1). Furthermore, a statistically significant interaction effect was detected between the condition and the peak-to-peak displacements tested (F (1.26) = 7,884, $p < 0.01$). In addition, there was no interaction effect found for ‘condition x knee angle’ (F (1.26) = 0.212, $p < 0.05$) or ‘condition x peak-to-peak displacement x knee angle’ (F (1.26) = 0.445, $p < 0.05$).

Finally, we found that the biomechanical parameters had different effects on SPL activity. There was a statistically significant main effect of ‘peak-to-peak displacement’ (F (1.26) = 6.419, $p < 0.05$). In addition, the interaction effect of ‘peak-to-peak displacement x knee angle’ was also statistically significant (F (1.26) = 4.888, $p < 0.05$), whereby no statistically significant main effect of the knee angle was detected (F (1.26) = 0.514, $p < 0.05$).

There were no gender-specific differences concerning the main effects or the interaction effects in all muscles tested.

Discussion

This is the first study examining how different combinations of biomechanical parameters (peak-to-peak displacements and knee angles) with and without a vibration stimulus of 30 Hz have an acute effect on trunk and neck muscles activity. The results of the present study show that these tested parameters affect the activity of these muscles in different ways when exposed to vibration stimulus from a side alternating platform, thus confirming our hypothesis.

To date, only one published study has also investigated the acute effects of WBV on neuromuscular activity levels of the trunk muscles (Wirth et al., 2011). The authors measured the muscle activity of trunk muscles in different static exercise positions on a vertical vibrating platform (synchronous device) at a vibration frequency of 30 Hz and peak-to-peak displacement of 4 mm. They reported a maximum activation level of 25.6 % MVC for the multifidius muscle during WBV, which is similar to our findings (27.2 % MVC for the UES and 27.0 % MVC for the LES). Furthermore, these authors found an activation maximum with vibration for the rectus abdominis muscle of 46.4 % MVC, which was much higher than the maximum activity level measured for the abdominal muscles in the present study (6.0 % MVC for the URA). However, Wirth et al. (2011) measured the highest activation of the rectus abdominis muscle during a sit-up position which may have led to a much higher preactivation of the muscle, and might explain the larger activation maximum in this study. In this context, it has been reported that an increased preactivation of a muscle leads to better effects due to vibration exposure (Hopkins et al., 2009; Mester et al., 1999; Ritzmann et al., 2013) caused by an increased muscle spindle sensitivity through alpha-gamma coactivation (Burke et al., 1976), whereas muscles closer to the vibration inducing system were more receptive to vibration stimulus (Nigg, 2010; Roelants et al., 2006). However, we found no studies investigating acute effects of WBV on the neuromuscular activity of the splenius muscle. Similar to the other muscles tested, a main effect of the condition was also detected for that muscle in the present study, and we can presume that the vibration stimulus reaches the head. This is in line with Abercromby et al. (2007b), who reported head acceleration while subjects performed a slow dynamic squatting movement during WBV exercises with similar conditions as used in the present study.

Another factor clarified in the present study is the WBV-induced increase (DIF) in trunk muscle $EMG_{\%MVC}$. In this context, Wirth et al. (2011) reported that an additional vibration stimulus led to lower effects for the back muscles (WBV-induced increase of +1.6 % MVC) than for the abdominal muscles (WBV-induced increase of +7.2 % MVC). On the contrary, our results show that the vibration effect on the back muscles (maximum DIF +19.1 % MVC) was higher than on the abdominal muscles (maximum DIF +3.6 % MVC) at similar vibration peak peak-to-peak displacements compared to Wirth (3.9 mm vs. 4 mm). These differences in vibration effect may be caused by differences in study design with regard to body position (almost upright stand vs. different gymnastic exercises, e.g. in seated positions), and vibration platform type (side alternating vs. synchronous), whereas the vibration frequency was identical at 30 Hz. Noticeable in our results are the great differences of DIF among the tested muscles. For both peak-to-peak displacements and both knee angles, the highest vibration effect was measured for the back muscles (DIF +4.7 % MVC - +19.1 % MVC), followed by the neck muscle (DIF +1.2 % MVC - +4.7 % MVC), and the abdominal muscles (DIF +0.7 % MVC - +3.6 % MVC). Hence, we have to consider that the amount of vibration stimulus transmitted through the body depends on posture, stiffness and damping (Nigg, 2010; Rittweger, 2010). Due to the human anatomy, vibration transmission occurs segmentally from the vibration source to the feet, then to the calves, up to the thighs, and from the trunk through the neck to the head. Therefore, as mentioned before, muscles closer to the vibration inducing system were more receptive to vibration stimulus (Nigg, 2010; Roelants et al., 2006). In this context, Pel et al. (2009) reported that side alternating vibration devices transmit 85 % of the induced a_{RMS} to the ankle, 8 % to the knee, and only 2 % to the hip, respectively. This indicates that the storage of vibration energy is limited from the lower to the upper part of the human body. That could explain the higher DIF magnitudes in back muscles than in the neck muscles in the present study. However, comparing the results of the abdominal muscles with the results of the lower back muscles shows discrepancies between our results and the distance and transmission factor. Although both muscle groups were similar distances from the vibration platform and the transmission characteristic of the trunk is constant for frequencies between 5 and 50 Hz (Griffin, 1990; Mester et al., 2003), we detected a large difference between the gained WBV effects for the muscles. To explain these discrepancies, we hypothesize that the back muscles have a higher impact on upright stance and the stabilization of the lumbar spine than the abdominal muscles and therewith a higher preactivation, which would explain the larger DIF of the back muscles. Another explanation for the differences in neuromuscular preactivation between the mentioned muscles reflects that muscle tuning (Nigg, 2010) as a postural control strategy is adopted during WBV rather than myotatic reflex contractions.

In answer to our third research question, the different biomechanical parameters affect neuromuscular muscle activation in different ways. The present study is the first study to investigate the impact of peak-to-peak displacement and knee angle on EMG magnitude of the trunk and neck muscles. First, we found that peak-to-peak displacement appears to have an important effect on these muscles, as the $EMG_{\%MVC}$ increased with the higher peak-to-peak displacement. These finding agree with the results of Krol et al. (2011), and a previous study done in our lab (Perchthaler et al., 2013), which investigated the influence of peak amplitudes on muscles of the lower limbs. Both measured a higher neuromuscular response of the leg muscles by increasing the vibration peak amplitude in different vibration frequencies and body positions. This amplitude impact on the muscles associated with faster and greater stretching of the muscle (Cochrane et al., 2004) due to WBV exercise is characterized by cyclic transmission between eccentric and concentric muscle contractions (Rittweger, 2010). This could mean that the magnitude of vibration-related acceleration of the lumbar spine depends on the knee angle (Rubin et al., 2003). For all other muscles tested, the extent of neuromuscular activity for both knee angles (30° and 45°) was similar. Therefore, we support the suggestions of Caryn et al. (2014) and Abercromby et al. (2007b), who recommend knee angles greater than 40° and 26°-30° at a vibration frequency of 30 Hz for safe vibration transmission to the head, respectively. Abercromby also reported that head acceleration was significantly lower when using a side alternating vibration platform and increasing the knee angle. However, it can be questioned whether head acceleration caused by vibrations can be put on the same level with neuromuscular activation of the neck muscles caused by WBV training. To clarify the correlation between head acceleration and neuromuscular response of the neck muscles, further studies are necessary to measure these factors simultaneously. Nevertheless, WBV stimulus to the head should be considered critically, because strong vibrations generated in the head can lead to eye and ear diseases, as reported in occupational medicine (Bochnia et al., 2005; Moussavi Najarkola et al., 2013; Soliman et al., 2003). Thus, there is a need for further studies to investigate any long-term risks of WBV training. Nonetheless, assuming an equitable introduction to the training modality, vibration exercise seems to be an appropriate and safe training method (Rittweger, 2010). In addition, further research is needed to evaluate whether the low-to-moderate muscle activity levels measured in this study between 3.2 and 27.2 % MVC are sufficient strength-training stimuli in practical application to cause acute and chronic effects to improve muscle performance. In this context, Cardinale and Bosco (2003) suggested that the neural adaptations can also improve muscle performance after WBV training, even when muscle activation was rather low to moderate.

A limitation of the present study is the aspect of test position and posture on the WBV platform device during EMG measurements. During EMG trials in this study only knee angle was controlled using an electronically goniometer. However, ankle and hip joint angles may also affect the muscular activity (Roelants et al., 2006). As nearly no comparable parameters according to ankle, knee, and hip joint in EMG measurement during WBV exposure are available (Abercromby et al., 2007a; Cardinale and Lim, 2003; Krol et al. 2011), a standardized test position was determined and visually monitored in the present study. This point has to be considered, and the results should be interpreted in the context of its design.

Conclusion

WBV exercise has been shown to have a positive influence on back pain (Iwamoto et al., 2005; Rittweger et al., 2002), but it has also been reported that WBV exposure could be potentially harmful (e.g. Abercromby, 2007b; Rittweger, 2010). There is still a lack of knowledge about effective and safe WBV training procedures for the upper body. The current study is the first with results leading toward detecting the best recommendations for combining biomechanical parameters (according to low-risk peak-to-peak displacements and knee angles, and frequency considered in literature) to produce the highest vibration load during WBV exposure to 30 Hz for trunk and neck muscles on a side alternating platform. Currently, a maximized vibration load could be achieved at a high peak-to-peak displacement of about 4 mm, whereby WBV leads to a higher $EMG_{\%MVC}$ level of the lower back muscles than of the abdominal muscles. Both applied knee angles of 30° and 45° have similar effects on the vibration load and according to literature represent a safe position to prevent harm (Abercromby, 2007b; Caryn, 2014). Thus, the results of acute WBV effects should be able to help physical therapists, coaches, and athletes in diverse sectors to activate the trunk and neck muscles most effectively during a WBV session. Because of the low requirements on the patients during WBV training (Runge, 2006), this training form could be used by patients who cannot participate in traditional training programs. However, the effect of WBV on strength and power development depends on the biomechanical parameters, as well as on the exercise protocols. Further studies are necessary to develop and evaluate effective and safe training procedures and protocols for the trunk and neck muscles. In consideration of the potential harm of WBV to the head, further research should focus on finding specific body positions and stabilizers which reduce the vibration impact to the head and examine long-term effects.

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AUTHORS BIOGRAPHY

Dennis PERCHTHALER

Employment

Department of Sports Medicine, Medical Clinic, University of Tuebingen, Germany

Degree

Dipl.-Sportwiss.

Research interests

Influence of Whole-Body Vibration in men, clinical biomechanics, physical therapy

E-mail: sportmed@gmx.net

Simon HAUSER

Employment

Department of Sports Medicine, Medical Clinic, University of Tuebingen, Germany

Degree

MD student

Research interests

Influence of Whole-Body Vibration in men, clinical biomechanics

E-mail: simon.hauser@student.uni-tuebingen.de

Hans-Christian HEITKAMP

Employment

Prof., Department of Sports Medicine, Medical Clinic, University of Tuebingen, Germany

Degree

MD

Research interests

Influence of Whole-Body Vibration in men, sport intervention, physical therapy

E-mail: hans-christian.heitkamp@med.uni-tuebingen.de

Tobias HEIN

Employment

University of Gothenburg, Department of Food and Nutrition, and Sport Science, Biomechanics, Goeteborg, Sweden

Degree

PhD

Research interests

Clinical biomechanics, overused injuries, footwear biomechanics

E-mail: tobias.hein@gu.se

Stefan GRAU

Employment

Prof., University of Gothenburg, Department of Food and Nutrition, and Sport Science, Biomechanics, Goeteborg, Sweden

Degree

PhD

Research interests

Clinical biomechanics, overused injuries, footwear biomechanics

E-mail: stefan.grau@gu.se

Key points

- The maximum levels of muscle activity were significantly reached at high amplitudes at a vibration frequency of 30 Hz.
- WBV leads to a higher muscle activation of the lower back muscles than of the abdominal muscles.
- Both knee angles of 30° and 45° have similar effects on the vibration load and represent safe positions to prevent any actual harm.
- Certain combinations of the biomechanical variables have similar effects on the level of muscle activity.

✉ **Dennis Perchthaler**

Hoppe-Seyler-Str. 6, 72076 Tuebingen, Germany