

Electromyographic activity of back muscles during stochastic whole body vibration

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Abstract

Objectives: Stochastic resonance whole body vibrations (SR-WBV) may reduce and prevent musculoskeletal problems (MSP). The aim of this study was to evaluate how activities of the lumbar erector spinae (ES) and of the ascending and descending trapezius (TA, TD) change in upright standing position during SR-WBV. **Methods:** Nineteen female subjects completed 12 series of 10 seconds of SR-WBV at six different frequencies (2, 4, 6, 8, 10, 12Hz) and two types of “noise”-applications. An assessment at rest had been executed beforehand. Muscle activities were measured with EMG and normalized to the maximum voluntary contraction (MVC%). For statistical testing a three-factorial analysis of variation (ANOVA) was applied. **Results:** The maximum activity of the respective muscles was 14.5 MVC% for the ES, 4.6 MVC% for the TA (12Hz with “noise” both), and 7.4 MVC% for the TD (10Hz without “noise”). Furthermore, all muscles varied significantly at 6Hz and above ($p \leq 0.047$) compared to the situation at rest. No significant differences were found at SR-WBV with or without “noise”. **Conclusions:** In general, muscle activity during SR-WBV is reasonably low and comparable to core strength stability exercises, sensorimotor training and “abdominal hollowing” in water. SR-WBV may be a therapeutic option for the relief of MSP.

Keywords: Torso, Muscle Contraction, Pilot Study, Young Adult, Back Muscles

Introduction

There are a range of whole body vibration (WBV) platforms available which fall into two categories: sinusoidal (S-WBV) and stochastic resonance whole body vibration (SR-WBV). Technical properties and physiological effects differ between S-WBV and SR-WBV devices^{1,2}. At the physiological level the neural system reacts differently to sinusoidal than to stochastic stimuli. At the same basic amplitude the reversal potential of a nerve cell is reached sooner with stochastic than with sinusoidal stimuli, meaning that action potential is generated earlier³. However, there are few published studies comparing SR-WBV and S-WBV directly^{4,5}. These studies found higher muscle activity in the pelvic floor⁵ and the erector

spinae (ES)¹ during SR-WBV. Furthermore SR-WBV may reduce and prevent musculoskeletal problems (MSP)^{6,7} as well as functional limitations caused by pain⁶.

In a study of elderly people Dittrich and colleagues found a significant increase in flexion and extension of isometric muscle strength in the trunk after a three-month exercise intervention on an SR-WBV device⁸. Baumgartner and Neuenschwander⁴ observed significant high muscle response of the ES at the fourth lumbar vertebrae during SR-WBV compared to “at rest”. However, to date there is no evidence that back muscle activation goes higher than the fourth lumbar vertebrae during SR-WBV. Since the transmitted vibrations decrease from caudal to cranial⁹ it would be beneficial to examine different muscles at different positions up and down the back. Another study¹⁰ demonstrated an increase of muscle activity with higher frequency. Therefore the aims of this pilot study were to examine electromyographic activity of the ES at the fourth lumbar (L4) and of the descending (TD) and ascending (TA) trapezius muscles at different frequencies during SR-WBV. The influence of the application of “noise”, which will be described in detail in section “Materials and methods”, shall be examined.

The authors have no conflict of interest.

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Material and methods

This study was executed in accordance to the Declaration of Helsinki (2008)¹¹. All participants gave written informed consent. According to an agreement with the local ethics committee there was no need for an ethical examination if the following criteria had been met: the planned study concerns a relevant examination in physical therapy with a low risk for the participants, and the study subject matter is part of the training curriculum for physiotherapy students.

Participants

All subjects in this study were female students of a Swiss University of Applied Sciences. Potential participants were contacted by e-mail and received oral and written study information after expressing interest in the study. All subjects had to fulfill the inclusion criteria (anamnestic healthy female students, age between 18 and 35 years, body mass index (BMI) between 19 and 26) and were excluded if one or more exclusion criteria were met (back trauma or surgery, acute musculoskeletal problems (headache or back pain e.g.), thrombosis, infections, tissue injury, new fractures or surgery, disturbed or decreased sensibility, diseases like epilepsy, migraine, tumors, diabetes mellitus, metallic or synthetic implants (cardiac pacemaker e.g.), competitive athletes (≥ 3 exercise sessions per week)).

The sample size for this pilot study was set at 15-20 participants.

In this pilot study 21 female subjects were recruited. One woman had to be excluded due to a too low BMI (17.2); all other 20 female subjects were included. One participant's data set exhibited measurement recording errors and was not analyzed. Table 1 shows minimum, maximum and mean values as well as standard deviations (SD) in relation to age, height, body weight and BMI.

Equipment and measurements

SR-WBV platform

The SR-WBV platform used in this study was the SRT Zep-tor[®] medical plus noise (SR-Therapy Systems GmbH & Co, Lifescience KG). Stochastic vibrations are generated by coupled oscillators and are applied to the upright standing person through two independent platforms. Besides the major vertical movements the platforms also allow passively medial and lateral tilting which leads to a pluridimensional movement. A stochastic "noise" signal (steps 0-5; 0="no noise", 5="noise" maximum) can be added to the frequency range (1-12-Hz). Haas¹² described "noise" as stochastic elements which interfere in addition to already stochastically generated vibrations leading to an even more stochastic signal, but the ideal mix between basic signal and part of "noise" is still unclear¹³. Unfortunately, the manufacturer does not provide more details regarding "noise".

Liu and coworkers used sinusoidal waves at 30-Hz and overlaid mechanical "noise". In their study elderly people, stroke patients and patients with neuropathic diabetes could feel the vibrations at fingertips and toes better with "noise" applied than without¹⁴.

n=19	Minimum	Maximum	Mean	SD
Age [years]	19.0	26.0	22.4	2.2
Height [m]	1.6	1.9	1.7	0.1
Body weight [kg]	46.9	72.1	61.0	7.4
BMI [kg/m ²]	18.5	25.3	21.8	2.0

Abbreviations: kg= kilogram; kg/m²= kilogram per square meter; m= meter; n= number of participants; SD= standard deviation.

Table 1. Anthropometric data of all participants (n=19) with minimum, maximum, mean values and standard deviation.

Electromyography

Muscle activity of the ES was analyzed at L4, TA and TD using surface electromyography (EMG). EMG signals were captured with single use surface electrodes (Nicolet Disposable Center Snap Rectangular Silver/Silver Chloride Electrode, REF: 019-767700) at a sampling rate of 1-kHz. All myoelectric signals were filtered by a pre-amplifier (Input impedance >100 MegaOhm, common mode rejection ratio >100dB, Base gain=500, Bandpass 10-500 Hz), then transferred to a transmitter (TeleMyo[™] 2400T G2 Transmitter, Noraxon INC., Velamed medical technics & biomedical concepts GmbH) and finally transduced to a receiver (TeleMyo[™] 2400T G2 Receiver, Noraxon INC., Velamed medical technics & biomedical concepts GmbH). The data obtained was displayed and analyzed with the "analog signal caption and analysis" program (ADS, uk-labs).

Reliability of the EMG data obtained from the ES (root mean square [RMS]) (Intra-class correlation coefficient [ICC]=0.977) and the trapezius (ICC=0.627) during jogging was rated as good¹⁴. The validity of EMG during WBV is a matter of some debate, recently Ritzmann et al.¹⁶ showed that the EMG signals obtained during vibration do not contain artifacts but genuine myoelectric data and therefore the data does not have to be filtered again.

Force plate

The force plate used for this study will not be described in detail as no force measurements were done. The force plate only served as "sham device" to distract subjects and blind for EMG measurements of back muscles at rest (see also chapter "Muscle activity at rest").

Data collection

The single-use electrodes were applied following the SENIAM standards¹⁷ (Figure 1) [SENIAM project, n.d.]. Skin impedance was classified as acceptable if less than 10kOhm were obtained. If the measured value for resistance exceeded this threshold, electrodes were removed, the skin was prepared again and new electrodes were applied. Before recording, validity and quality of the EMG signals were checked.

Application and palpation of muscles was always done by

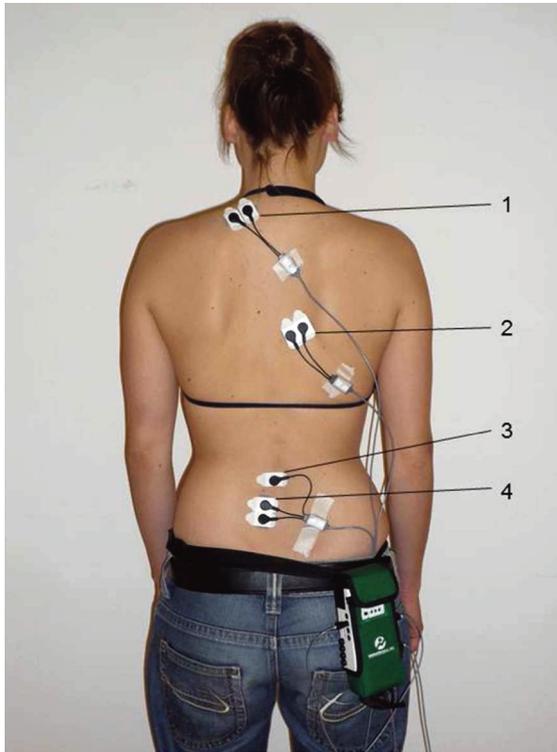


Figure 1. Application of electrodes: 1) M. trapezius descending part (TD), 2) M. trapezius ascending part (TA), 4) M. erector spinae (ES), 3) reference electrode on spinous process of an upper lumbar vertebrae.

the same assessor. Placement of electrodes followed international standards^{17,18}. Localization of the spinous process of the fourth lumbar vertebrae was determined by height of the iliac crest¹⁹. Choice of either left or right side of the spine when applying electrodes was randomized for every subject and every muscle to control for measurement errors due to asymmetrically developed back muscles. One neutral reference electrode was attached to an electrically unaffected but nearby area, here on the spinous process of one of the upper lumbar vertebrae.

Maximum voluntary contraction

To compare muscle activities of different subjects, muscles or modalities, an isometric maximum voluntary contraction (MVC) had to be done prior to the test trials for data normalization of EMG (MVC%). MVC samples (3-5 seconds per muscle, break of 15 sec between two series) were based on muscle tests²⁰.

Muscle activity at rest

The first trial was executed in standing position on the force plate, which served as “sham device”. The subject was asked to focus on a black dot (5 m away, at eye level) in order to avoid any unwanted head movements which could falsify the results. All instructions were given by the same assessor and



Figure 2. Starting position on the SR-WBV device.

included the following: make a few steps on the spot, stay in an upright standing position with knees slightly bent, look at this black point and do not move.

Muscle activity was recorded during 15 sec. The same procedure was repeated on the SR-WBV platform without applying any vibration or “noise”.

Muscle activity during vibration

To have equal foot positions for every subject (Figure 2), the center of the two vibrating platforms was marked with tape. In addition to the above mentioned instructions the subjects were informed that there would be a total of 12 series, each with 10 sec of intervention and a 30 sec break, that they should place the feet onto the tape, that they should stand as still as possible and let their arms hang freely during the vibration. The end of the break was announced with “3, 2, 1, go”, afterwards the subjects should stand still again. During the breaks they were allowed to move freely.

Six series of 10 sec at a frequency of 2, 4, 6, 8, 10 and 12-Hz, once with “noise”= level 5 and once without “noise”= level 0, were recorded. The order of the series had been randomized beforehand. Each subject was not informed of the order of the series in order to eliminate factors such as voluntary muscular tension or different starting positions.

Data analysis

To analyze EMG data of MVC the signals were averaged by applying root mean squares (RMS) (time interval 500 ms).

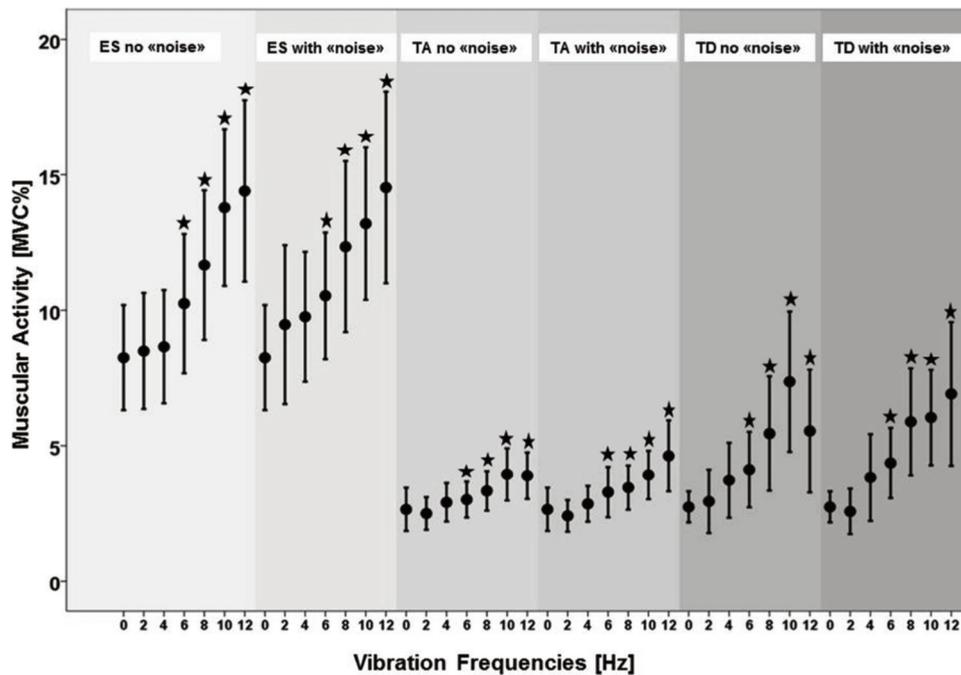


Figure 3. Mean values and 95% confidence intervals of muscle activity normalized to the maximum voluntary contraction (MVC%) of the erector spinae (ES), the ascending (TA) and descending (TD) part of the trapezius muscle during SR-WBV at different vibration frequencies with and without “noise”. 0Hz equals the measurements on the SR-WBV device while standing still. Significant values are marked with a *.

Then the maxima of the RMS from the two MVC measurements were taken, averaged and considered to be 100 MVC%. The mean RMS-value (moving average, 200 ms) over a time window of 10 sec muscle activity was calculated for each of the 12 series of SR-WBV (6 frequencies, 2 noise modalities) and the two trials at rest (upright standing on the SR-WBV platform and the force plate). Out of the absolute values the relative values (MVC%) were calculated for every trial with Excel (Microsoft® Excel 2010, Microsoft Corporation).

Statistical analysis

A difference in baseline muscle activities between the two measurement set-ups at rest (standing still on the SR-WBV platform and force plate) was determined by applying paired t-tests. Prior to data analysis, all parameters (7 frequencies: 0, 2, 4, 6, 8, 10, 12-Hz; 3 muscles: ES, TA, TD; 2 “noise”-modalities: “noise”= level 5 and level 0) were tested for normal distribution with the Shapiro-Wilk-Test.

A three-factorial analysis of variance (ANOVA) with repeated measurements on every parameter was executed if there was a significant difference within one group (frequency, muscle, “noise”). The first step was to test the sphericity of the three group variables with the Mauchly's Sphericity test, if necessary a Greenhouse-Geisser-correction was applied. A post-hoc test was done to see if there was a significant difference detected within a group. Power ($1-\beta > 0.8$) and effect size (eta square $\eta^2=0.1$ =small effect; $\eta^2=0.25$ =medium effect;

$\eta^2=0.4$ =big effect) were calculated using ANOVA²¹.

The level of significance was set at $p \leq 0.05$ (one-sided).

For statistical analysis of the data SPSS version 20 (IBM SPSS Statistics) was used.

Results

As all measurements for upright standing on the force plate compared to upright standing on the vibration platform were not significant (p-values of 0.530 for ES, 0.126 for TA and 0.809 for TD) only the data set (standing still) of the vibration platform was used for further statistical analysis.

Figure 3 illustrates muscle activity in relation to activation during MVC (MVC%) according to vibration frequencies, “noise”-applications and muscles. The following section summarizes the results of the measurements at rest compared to the peak mean value with the 95% confidence interval during SR-WBV for every tested muscle: The ES was active with 8.3 MVC% [6.3, 10.2] when standing still. The ES highest activation, 14.5 MVC% [11.0, 18.1], was recorded at 12Hz with “noise”. Furthermore, TA activity at rest was 2.6 MVC% [1.9, 3.4]. At a frequency of 12Hz with “noise” the activity increased to 4.6 MVC% [3.3, 5.9]. The TD was active with 2.7 MVC% [2.2, 3.3] when standing still. The highest value, 7.4 MVC% [4.8, 10.0], was reached with 10Hz without “noise”.

“Frequency” exhibited significant difference after applying the Greenhouse-Geisser-correction ($F(2.803; 53.251)=30.844$,

$p \leq 0.001$, $\eta^2 = 0.619$, $1 - \beta = 1.000$). At 6 Hz and above MVC% differed significantly during SR-WBV compared to the values at rest. The p-values of the post-hoc-tests were 0.027 at 6 Hz, and from 8-Hz and higher p was ≤ 0.001 (one-sided).

A significant difference in “muscle” MVC% after correcting using the Greenhouse-Geisser-method was found: $F(1.216; 23.099) = 33.553$, $p \leq 0.001$, $\eta^2 = 0.638$, $1 - \beta = 1.000$. All 13 ES MVC% values (at rest and 12 series of SR-WBV) differed significantly from the TA and TD measurements (both with p-values ≤ 0.001). As figure 3 illustrates values for the TD MVC% of showed a tendency to be higher than those of the TA. A p-value of 0.047 suggests that they differ significantly (one-sided).

No significant differences were found for the factor “noise” in relation to MVC% ($F(1.000; 19.000) = 0.651$, $p = 0.430$, $\eta^2 = 0.033$, $1 - \beta = 0.120$).

With higher frequencies also muscle activity tends to increase independently of muscle and use of “noise”. Figure 3 shows some variations, for instance a decrease of MVC% for the muscles TA and TD at rest compared to 2-Hz. The increase of muscle activity from one frequency level to the next is statistically significant between 6 and 8-Hz ($p = 0.005$) as well as between 8 and 10-Hz ($p = 0.035$).

Discussion

The aim of this study was to evaluate the activity of back muscles (ES, TA and TD) with EMG during SR-WBV whilst applying different frequencies (2-12Hz) and two modalities of “noise” (with and without “noise”).

The muscle activity significantly increased during SR-WBV compared to standing still. At 6Hz without “noise” the back muscles measured were active between 3 and 10 MVC%, which was the same order as those obtained in Baumgartner and Neuenschwander⁴. The muscle activity of the ES reached 10.3 MVC% at the first lumbar vertebrae and 6.0 MVC% at the fourth lumbar vertebrae during SR-WBV (5-Hz). At 10, 12 Hz respectively, ES, TA and TD showed a maximum activity between 4.6 and 14.5 MVC%. Recent studies report similar results for the back with S-WBV, Wirth et al.¹⁰ recorded a maximum activity of 18 MVC% for ES and multifidii muscles with subjects standing in a partial squat position with a knee angle of 60°. Lauper et al.⁵ examined healthy participants and recorded mean activity of 63.9 MVC% at 12-Hz in their pelvic floor muscles. Compared to muscle activity of the pelvic diaphragm the activity measured in the three back muscles exhibit comparably low strain (3-15 MVC%) and can presumably be classified as aerobic activation of back muscles²². Despite low activity and load intensity, Dittrich et al.⁸ described a significant increase in isometric muscle strength of the trunk after a three-month intervention on a SR-WBV device.

Muscle activity during SR-WBV is comparable to core strength stability exercises and “abdominal hollowing” in water. Bressel et al.²³ measured ES muscle activity of 10.7 MVC% during “abdominal hollowing” exercises, 14.2 MVC% during “stationary marching” and 14.6 MVC% during “mediolateral pelvic tilts” muscle activity. Attention should be paid to the fact, that

most trunk muscles have lower EMG activity in water compared to the same exercise on land²⁴. Exercises in water have been used for many years and are a common treatment strategy for patients with MSP including low back pain to relax, reduce pain and increase mobility^{25,26}. Likewise, SR-WBV may not only serve as suitable treatment and preventative intervention for patients with MSP but also help them to relax^{6,7,27,28}. It has yet to be explained why MSP decreases after an intervention with SR-WBV. One possible explanation is the higher muscle activity (higher metabolism, increased blood flow, etc.) during SR-WBV²⁹. Additionally, a study with young healthy females²⁸ showed that muscular relaxation increased after SR-WBV which could also have a positive influence on MSP.

Muscle activity did not constantly decrease from caudal to cranial. As shown in Figure 3, activation of the ES is higher than the TA and TD, but those of the TA are significantly lower ($p = 0.047$) than those of the TD. Baumgartner and Neuenschwander⁴, however, observed higher muscle activity of the ES during SR-WBV (5-Hz) at the first lumbar vertebrae compared to the fourth. Pollock et al. found⁹, that there is no discernable pattern in a muscle’s activity level and its distance to the vibration platform. The graphs of this study show that the muscles of the lower leg are more active than thigh muscles. However, muscles of the buttocks have a higher activity compared to the thighs but a lower activity than the muscles of the lower leg. Therefore further studies are needed to show conclusively whether muscle activity decreases from caudal to cranial. The higher TD activity compared to the TA ($p = 0.047$) at rest and during SR-WBV can be explained as follows: The center of mass of the head lies close to the sella turcica, anterior to the plumb line of the body in an upright standing position. Therefore, the neck extensors are working constantly against gravity³⁰.

Our results did not show any significant difference between measurements with or without the application of “noise” during SR-WBV. A possible explanation could be that the human body serves as a low pass filter and therefore extracts the “noisy” parts of the signal (with small amplitude and high frequency), so that they do not reach the back. This explanation is similar to the damping effect of muscles, described by Wakeling and colleagues³¹.

Due to the small power ($1 - \beta = 0.120$) and small effect ($\eta^2 = 0.033$) after applying the Greenhouse-Geisser-correction for the difference in muscle activity for the factor “noise” ($p = 0.430$) it can be concluded that the effect of activation of back muscles was very small. The application of “noise” does not influence the activity, but it seems to be unclear which effect the application of “noise” has on activation of neural cells, inter- and intramuscular coordination as well as perception. This should be investigated within further studies.

With higher vibration frequency only a tendency was seen towards higher muscle activity. Pollock et al.⁹ found that increased activity of the lower leg muscles and the biceps femoris varied according to frequency (S-WBV, 5-30-Hz, amplitude: 2.5 and 5.5 mm). Depending on muscle and amplitude the authors describe a moderate or low correlation. These findings are consistent with those of Lauper et al.⁵, whose study

found that pelvic floor muscle activity was higher with increased frequency during SR-WBV in both healthy females and women with poor postnatal pelvic diaphragm function. However, it remains unclear as to whether these results can be transferred to back muscles.

There can be found another possible explanation for the frequency-dependent increase in activation in physiology: The more stimuli are applied the bigger the reaction of the neural system will be. The reason for this bigger reaction lies in the generation of action potentials, because one action potential will be generated per stimulus above threshold³².

Strengths and weaknesses of the study

The whole measuring procedure worked successfully and the tasks were easily understandable for all participants, but the starting position of the subjects with regard to the knee flexion angle was not sufficiently standardized (knees slightly bent). During the measurement the subjects spontaneously increased the angle of knee flexion with higher frequencies. Abercromby et al.³³ showed that the acceleration of the head decreased with knees more bent (S-WBV, 30-Hz, 4 mm). Therefore, the acceleration of the back muscles probably also depends on knee flexion. Ritzmann and colleagues demonstrated that joint kinematics but also body posture both affect the mechanical transmission of the vibrations¹⁶. Furthermore the acceleration of one part of the body is closely related to the applied frequency and in turn the frequency has an influence on muscle activation⁹. As in the current study the authors did not control for posture and knee flexion, it is not sure that the observations made are based on the effect of the applied vibration frequency. Therefore, it is recommended that further studies standardize the knee flexion angle with the aid of a goniometer and keep track of the projected angle on a monitor. Moreover, it also would be beneficial to investigate muscle activity during different articular angles and starting positions.

The higher activity of the TD compared to the TA is possibly attributable to its retaining function of the head. Therefore the hypothesis that higher vibration frequencies generate muscle activity at a higher anatomical level could not be definitively answered. For further studies the ES instead of the TD should be examined at the sixth cervical vertebrae. However, this is not possible using surface electrode as the TD overlies the ES.

Another limitation concerning the execution of the study is the inter-electrode resistance as skin impedance was classified as acceptable if less than 10 kOhm were obtained. As Ritzmann et al. showed EMG signals during WBV were free of artifacts with an inter-electrode resistance below 2 kOhm¹⁶.

Despite a small sample size of this pilot study, the results were supported by a high power ($1-\beta=1.000$) and a big effect (at Greenhouse-Geisser-correction for “frequency” $\eta^2=0.619$ and “muscle” $\eta^2=0.638$).

Conclusion

This study evaluated the electromyographic activity of three back muscles at and above the fourth lumbar spine during SR-

WBV. The ES, TA and TD activity measured was rather low but also comparable to core strength stability exercises and “abdominal hollowing” in water²³. SR-WBV can serve as treatment and preventional option for people with MSP but also have a relaxing effect^{6,7,27,28}. Further studies are needed to ascertain the influence of muscle activity on MSP and to explore how SR-WBV can be used as low intensity core stabilization training or sensorimotor exercise for the back.

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