Hong Kong Physiotherapy Journal (2011) **29**, 12—19

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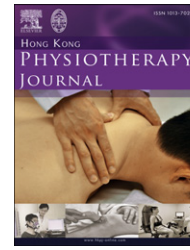

RESEARCH REPORT

Leg muscle activity level and rate of perceived exertion with different whole-body vibration frequencies in multiple sclerosis patients: An exploratory approach

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KEYWORDS
electromyography;
multiple sclerosis;
perceived exertion;
whole-body vibration

Abstract This study aimed to determine the whole-body vibration (WBV) frequencies that cause the highest average electromyogram (EMG) output in four different muscles, in relation to patients suffering from multiple sclerosis (MS), and to what extent the loads were acceptable. In a series of measures using different WBV frequencies applied to five MS patients, the effects on EMG output (in μV) and the rate of perceived exertion (RPE; scale, 6—20) were studied. All measurements were performed on two different WBV devices: the ZeptorMed™ and the Galileo2000®. The physical loads were well accepted, with a highest average rate of perceived exertion of 12.8 during the 29-Hz application. With the Galileo2000®, the highest EMG results were obtained at 29 Hz in the vastus medialis and lumbar muscles, at 25 Hz in the gastrocnemius medialis, and at 19 Hz in the tibialis anterior muscle. The results with the ZeptorMed™ were more consistent at 11 Hz and 12 Hz, but the EMG output was lower. In conclusion, the physical loads of WBV were well accepted by the MS patients. However, the most effective frequencies are device specific and should be determined for each subject and for each individual muscle or muscle group.

Introduction

Multiple sclerosis (MS; encephalomyelitis disseminata) has a substantial physical and physiological impact on those suffering from this disease. The incidence rate in Switzerland is approximately four new diagnosed cases of MS per 100,000 inhabitants per year, with a total of 10,000 patients in Switzerland and around 2.5 million worldwide [1].

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doi:10.1016/j.hkpj.2011.02.002

MS is a chronic autoimmune disease, which mainly, but not exclusively, affects the central nervous system. Primary demyelination has also been found in the peripheral nervous system [1]. For example, in all of the cases of "acute multiple sclerosis" described by Marburg [2], thorough investigation of the patients revealed outbreaks of the disease in the peripheral and central nervous system.

Although the disease was first described as a clinical entity ("Histologie de la sclerose en plaques") [3] in 1868 by Jean-Martin Charcot (1825–1893), its cause remains unknown. So-called slow viruses [1], genetic predisposition [4], and recently presented chronic cerebrospinal venous insufficiency [5] are the possible causes of this disease.

There are two main classifications of MS: progressive (primary and secondary) and relapsing remitting MS (RRMS). After about 10 years, approximately 50% of people with RRMS go on to develop secondary progressive MS (SPMS). Many new drug therapies have been successful in treating the symptoms of people with RRMS [6]. However, studies have indicated that SPMS does not respond so well, if at all, to the medications used to treat RRMS [7].

The lack of effective drug therapies for people with SPMS increases the need to discover successful treatments to improve their quality of life. In relation to rehabilitation and research, the effects of resistance training and, more recently, whole-body vibration (WBV), on neurological patients, have been emerging areas, though WBV is not a new application. In 1892, Jean-Martin Charcot presented a study [8] in which he stated that vibrations applied to the skin, joints, or the whole body could be useful in ameliorating a number of neurological disorders. Charcot mainly focused on the treatment of people with Parkinson's disease (PD), based on anecdotal reports from patients suffering from this disease who claimed to have experienced "great relief from prolonged journeys by railroad and carriage." To simulate the rocking of the carriage cars, he devised a vibrating armchair, known as the "Fauteuil Trepidant."

Although the exact parameters used by Charcot are not known, he described giving his patients daily sessions in the vibration chair lasting 30 minutes and with varying intensities depending on individual tolerance. Charcot was able to modify the frequency, direction, and intensity of the vibrations and was sensitive to the responses of his patients, stating that "... PD patients react individually and, therefore, it is essential to tailor the treatment according to each subject" [8].

Charcot reported demonstrable improvements after five or six sessions. Although this treatment was supposed to be a therapy for shaking palsy, the tremor itself was not greatly influenced. However, patients reported feelings of greater lightness, less stiffness, and improved walking, as well as improvements in parkinsonian nocturnal symptoms, discomfort, and sleep impairment.

After Charcot's death in 1893, his younger colleague, Gilles de la Tourette, continued to pursue the vibratory therapy. However, he moved away from WBV and, instead, developed a motorised helmet to produce brain vibrations. As Tourettes's career did not last very long, vibratory therapy ostensibly disappeared after the death of Charcot.

WBV therapy was rediscovered in the early 1990s and has since made a remarkable comeback as an additional training tool for both healthy and impaired subjects. Research in this area is now widespread and popular, not in the least because of a bed rest study carried out in Berlin [9,10], which studied the effects of WBV in situations of sub-gravity. The Berlin study mainly focused on mineral bone density, muscle strength, and power, as these physiological properties are heavily threatened during long-term spaceflight and a two-year flight to mars, which is planned for the near future.

In general, the beneficial effects of WBV training are widely accepted and recognised in sports and in rehabilitation [11–13]. Although the therapeutic effects of WBV on elderly, postmenopausal women and neurological patients are very promising, research in these areas specific to neurological patients is lacking [14]. Several researchers [15–20] have focused mainly on patients with PD. However, studies with MS patients are very rare. Schuhfried et al [21], in 2005, and Biland et al [22] and Schyns et al [23], in 2009, reported promising results, but the numbers of participants were small and the dropout rates were high. Another problem in this area is the lack of prescriptions for WBV training. Schuhfried et al [21], Haas et al [16], Turbanski et al [19,24], and Biland et al [22] used the same type of vibration device (the ZeptorMed™) [25], which has a frequency range of 1–12 Hz, an amplitude of 3 mm, and 1- to 90-second intervention time. These studies used low frequencies of around 3 Hz during five bouts of 60-second WBV, with 1-minute rest between bouts. The decision regarding which frequency was used was primarily based on the patients' subjective reports. The intervention time (of around 60 seconds) and the amplitude (around 3 mm) were chosen by the researchers.

Schyns et al [23] used the VibroGym® [26] with a frequency range of 30–50 Hz, 2- to 4-mm amplitude, and an intervention period of 30–60 seconds, which started and ended with 60-second warm-up and cool-down, respectively, at 50-Hz frequency and 2-mm amplitude. The exercise bout consisted of one 30-second bout with 40-Hz frequency and 2-mm amplitude. No rest periods were provided between the different bouts.

Several studies with healthy subjects [27,28] tried to determine the most effective frequencies for activating individual muscles or muscle groups with WBV. Jackson [29] compared two different vibration frequencies (2 Hz and 26 Hz) to determine which parameter had the maximum effect on isometric strength in MS patients. They used the Maxuvibe® [30], which is based on the same principles as the Galileo devices (5–30 Hz, alternating tilting plate and 0- to 5.2-mm amplitude) [31]. Although not significant, they found a consistent trend of higher torque values for the quadriceps and hamstring muscles after the 26-Hz intervention and compared with the 2-Hz condition.

The muscles tested in the foregoing studies were mainly the vastus medialis, erector truncae, tibialis anterior, and gastrocnemius medialis. These muscles play an important role in extension activities, such as standing up and walking. In medical and physiotherapeutic treatments for MS patients, the ability to maintain extension activities is the most important rehabilitation goal.

As our study focused on the muscular benefits of WBV, the most effective frequency was defined as the frequency that caused the highest electromyogram (EMG) output measures (in μV). It is thought that this frequency may

Table 1 Specifications of the wireless EMG device (KinePro) according to the manufacturer (www.kine.is)

Specifications of the KinePro EMG device	
Transmitter output power	0.1—10 mW
Radio bandwidth per channel	100 kHz
Transmission frequency	433.05—434.79 MHz ISM band
Number of channels	1—12
Radio range	50 m
Sampling frequency	1562.5 Hz
Signal bandwidth	10—500 Hz
Input impedance	10 GO
Sensitivity	4 mV
Output format digital	RS232
Electrode placement	Triode with electrodes 20 mm apart

EMG = electromyogram; ISM Band = industrial, scientific and medical band.

cause an increase of maximum force and/or power in that particular muscle or muscle group, triggered by stretch reflexes. This may not necessarily be the only goal of a therapeutic vibration intervention, as very low frequencies also have muscular effects because of other mechanisms, such as the triggering of the otoliths [28].

The main goal of this research was to determine the most effective WBV frequencies of two different vibration platforms and the rate of perceived exertion (RPE) of four different muscles, the vastus medialis, erector truncae, tibialis anterior, and the gastrocnemius medialis. It is generally accepted that the application of WBV is responsible for additional muscular activity. Therefore, we hypothesised that higher frequencies would cause higher levels of muscular activity.

Although amplitude and resonance are also variables to be considered in rehabilitation and in future studies, in this study, we focused exclusively on frequency and on the RPE using the Borg Scale (range, 6—20). Although finding the frequency with the highest EMG output was the main goal of our research, ethical and health reasons led us to decide to make the RPE, as reported by the MS patients, the first limitation criterion to be considered in our research, as well as in future rehabilitation settings.

Furthermore, we hypothesised that the most effective levels of vibration will vary between and within individuals because the intensity and effectiveness of vibrations depend on the mass, stiffness, and other properties of the tissues, the distance of the tissues from the vibrating plate, and the ability of the participant to activate damping mechanisms [32—34].

If these hypotheses are true, this would imply that the optimal parameters of WBV need to be determined not only for each subject individually, but also for each muscle or muscle group.

Methods

Subjects

Five patients with MS participated voluntarily in this study. They were informed in detail about the study and the study goals and signed an informed consent. All measures were conducted in accordance with the declaration of Helsinki. All of the participants were current patients in the outpatient neurological and geriatric physiotherapy department of the University Hospital Basel in Basel (Switzerland) and were familiar with and currently undergoing WBV as a physiotherapeutic intervention. Therefore, no ethical approval was required.

Besides a history of MS, all participants were required to be able to stand on the vibration platform without assistance. To gain an indication of the participants' functional abilities, two functional tests, "timed up and go" (TUG) [35] and the "chair rising test" [36], were performed before the first vibration application. These tests are often used to monitor therapeutic effects and the course of neurological patients [35,37,38]. The participants started and finished the tests sitting on a chair (sitting height, 43 cm) with armrests and with their back against the back of the chair. Both tests were performed without assistance and had to be executed as fast as possible. Walking aids were allowed. In the TUG, the participants stood up, walked 3 m, turned around, walked back, and sat back again. The use of the armrest was allowed. In the "chair rising test," the participants stood up until the knees were fully extended and then sat down again five times, without using the armrest.

Devices

The two different WBV devices used in this study were the ZeptorMed™ (http://www.sr-therapiesysteme.eu/121.html), which is described as a "stochastic resonance

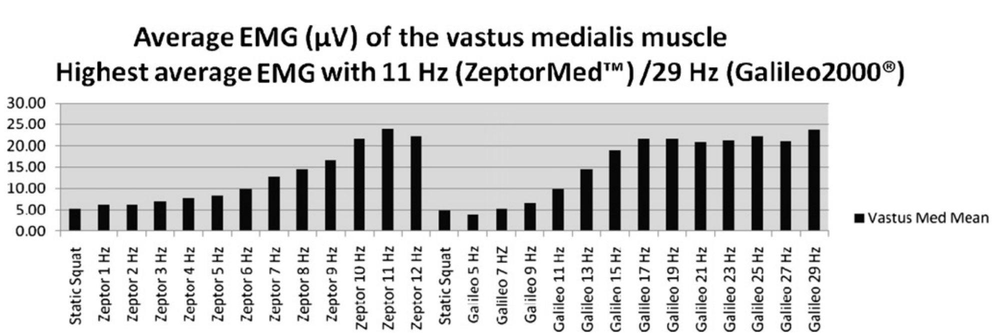

Figure 1 Average EMG values of the vastus medialis muscle at all frequencies on two different devices. EMG = electromyogram.

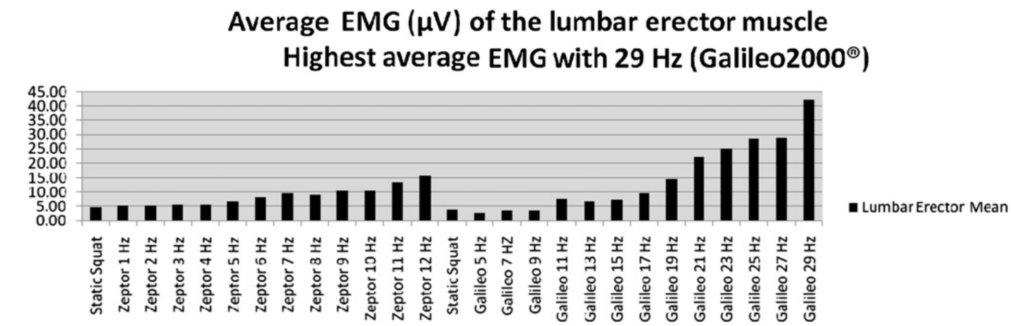

Figure 2 Average EMG values of the lumbar erector muscle at all frequencies on two different devices. EMG = electromyogram.

training" device, and the Galileo2000® (Novotec Medical, http://www.galileo-training.com/de-deutsch/start.html). The ZeptorMed™ has two separately vibrating plates, with 3-mm amplitude and a frequency range of 1–12 Hz. The Galileo2000® has one plate that alternates around a mid-axis. The amplitude of the Galileo2000® depends on the distance of the feet from the mid-axis, which results in an amplitude range of 1–7 mm. The vibration frequency has a 25-Hz range (5–30 Hz).

The "KinePro Wireless EMG-Device" (http://hitechtherapy.ipcoweb.com/kine_pro), which has an effective measuring distance of 50 m, was used to measure muscular activity. This allows participants to move freely without disturbance and being distracted by connection cables. The KinePro Wireless EMG device measures and records EMG output every 70 milliseconds, which means that around 140 measures are recorded during a 10-second application phase. To prevent error, the EMG signal is digitised within 5 mm from the skin surface. Technical specifications of this device are provided in Table 1.

Recording procedures

All participants were measured on two occasions at the same time of the day (4 PM) with 1 week between measures. The triodes (triple electrodes with a 20-mm space) of the wireless EMG device were placed on four different muscles [vastus medialis, erector truncae (L3–L4), tibialis anterior, and gastrocnemius medialis], using the guidelines of Konrad [39] and those recommended by the manufacturer of the EMG device.

Before applying the WBV, each participant performed a static squat with knees slightly bent at a 20° angle to record a baseline value and to become familiarised with the correct body posture. To maintain this position during the application of the vibration, the participants stood facing a wall on which a marker indicated their eye level. This was done to ensure a correct, consistent, and reproducible body position. To provide optimum recovery and minimum extra load, the participants were asked to sit down during the one-minute rest period between the 10-second applications.

During the first session, each frequency (1–12 Hz) of the ZeptorMed™ was applied for 10 seconds, starting with the lowest frequency possible, with 60-second rest between applications. In total, 12 ten-second applications were conducted. After each application, the participant rated the physical load (RPE).

During the second session, the same procedure was used with the Galileo2000®. As this device has a 25-Hz range, only every second frequency was applied, starting with the lowest frequency (5 Hz) and ending with 29 Hz. In total, 13 ten-second applications were conducted, which closely equates with the number of tests during the first session.

The EMG recording began 0.5 seconds after the start of the vibration and was stopped around 0.5 seconds before the application concluded. After each application, the participants rated the physical load during the vibration application using the Borg Scale, where 6 is the lowest and 20 is the highest rate possible. In addition, after each vibration application, the participants were asked if they wanted to continue to the next higher level. Despite the possibility of sequence effects, it was decided to start with the lowest frequency and to increase the rate successively, rather than applying each frequency in a random order. This setting enabled the participants to better estimate the load during the next higher level. Thus, unexpected high

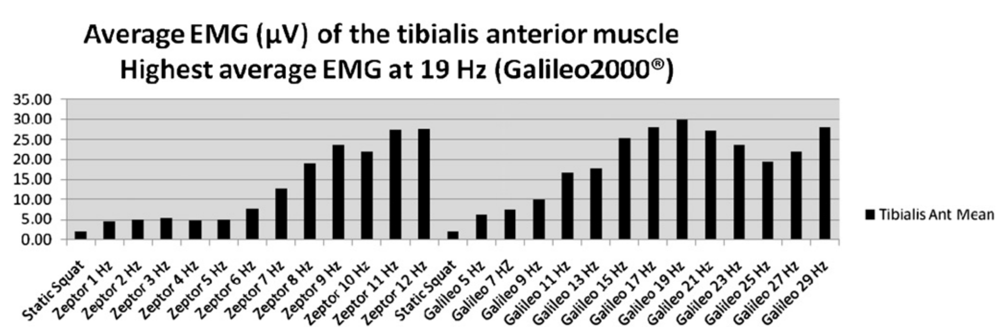

Figure 3 Average EMG values of the lumbar erector muscle at all frequencies on two different devices. EMG = electromyogram.

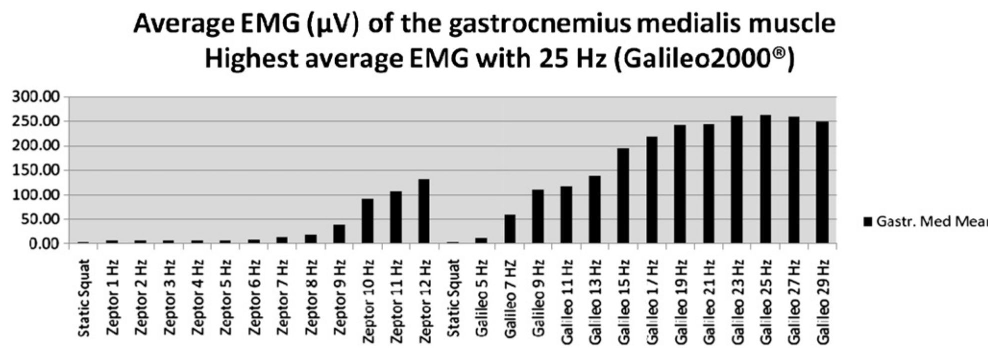

Figure 4 Average EMG values of the gastrocnemius medialis muscle at all frequencies on two different devices. EMG = electromyogram.

loads and, subsequently, the risk of possible physical harm were reduced to a minimum.

Data analysis

After each measurement, the results were converted into an excel file. The mean and maximum EMG outputs in μVolts as well as the time to maximum output were calculated for each muscle and each vibration frequency in each participant. The data of all participants were averaged, which resulted in an EMG average for each muscle at each frequency.

All of the averaged EMG data as well as the RPE with the ZeptorMed™ and Galileo2000® were then listed and are presented in graph form, as shown in Figs. 1—4.

Results

Subjects

Five MS patients [3 women and 2 men; age average, 41.4 years (±16.95)] of the outpatient department of the University Hospital physiotherapy centre in Basel (Switzerland) volunteered to participate in this study. On average, they had suffered from MS for 16.8 (±12.03) years. Two patients used walking aids. The participants' functional abilities differed substantially, as represented by their "TUG" and "chair rising test" results (Table 2).

WBV and rate of perceived exertion

All participants finished all applications. Although the RPE on the Galileo2000® was higher than that on the ZeptorMed™ (average, 9.06 against 8.90), all participants preferred the vibration applications on this device. Only one patient reported a feeling of discomfort immediately after the research sessions, but this lasted only for about 30 minutes. After that, the participant stated that he felt more comfortable and relaxed, and this lasted for around the next 4 days. The application with 29 Hz on the Galileo2000® was rated the highest RPE (average, 12.8) (Fig. 5). The highest rate on the ZeptorMed™ was on average 11.4 with 12 Hz. Although one participant rated up to 20, he reported that this was bearable.

WBV and frequency

In this study, four different muscles were measured (Figs. 1—4). It appeared that every muscle had its own optimum frequency and, as both devices produced different types of vibrations with possibly different effects, the highest results were determined for each device and each muscle individually.

Overall, the Galileo2000® had the highest EMG outputs on the vastus medialis and erector truncae muscles with 29 Hz, on the tibialis anterior muscle with 19 Hz, and on the gastrocnemius medialis muscle with 25 Hz. The highest results obtained with the ZeptorMed™ were with 11 Hz on

Table 2 Overview of the participants (age and MS history in years) and the results of the CRtest and the TUG and the RPE during each performance, as an indication of the participants' functional and physical abilities

Participants	Age (yr)	Walking aids	MS history (yr)	CRtest (s)	RPE CRtest	TUG (s)	RPE TUG
P1	35	2 Canes	22	53.6	10	40.5	9
P2	23	None	6	15.9	8	7.4	9
P3	68	1 Cane	35	32.2	7	24.9	7
P4	35	None	14	12.7	7	7.8	6
P5	46	None	7	7.9	7	5.6	6
Mean	41.40		16.80	24.46	7.80	17.24	7.40
Standard deviation	16.95		12.03	18.67	1.30	15.18	1.52

CRtest = "time of chair rising test"; MS = multiple sclerosis; RPE = rate of perceived exertion; TUG = "timed up and go."

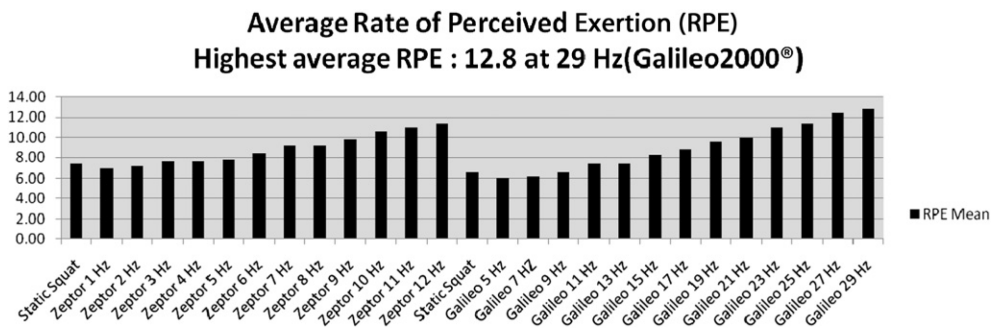

Figure 5 RPE during vibration applications and static squat without vibration. RPE = rate of perceived exertion.

the vastus medialis muscle (equal to the output with 29 Hz on the Galileo2000®), and with 12 Hz on all other muscles. Although these results showed a clear tendency, the differences between and within subjects should not be ignored (Tables 3 and 4).

ZeptorMed™

In 10 out of 20 cases, 12 Hz was the most effective frequency with the ZeptorMed™, whereas 11 Hz was the most effective in seven cases. For the vastus medialis muscle, 11 Hz was the most effective frequency (in four out of five cases). In general, it can be stated that 11—12 Hz was the most effective frequency, though in two out of 20 cases, 7 Hz was the most effective one, and in another case, it was 9 Hz.

Galileo2000®

With the Galileo2000®, the most effective frequencies varied considerably. On the lumbar erector muscle, the higher frequencies (range, 23—29 Hz) caused the highest outcomes. In all other three muscles, a greater range of frequency variation was found, with a tendency towards lower frequencies from around 20 Hz. The vastus medialis muscle showed the largest variation (17—29 Hz).

Discussion

Although the frequencies varied greatly, with the ZeptorMed™, the frequencies of 11 Hz and 12 Hz were clearly the most effective. Below 7 Hz, the effects of the ZeptorMed™ were limited. It would be interesting to see the effects with higher frequencies on this device, but 12 Hz is the highest frequency possible.

With the Galileo2000®, the range between 21 Hz and 29 Hz was found to be the most effective, which was also the case in several other studies [11,23]. The results with this device lend support to the conclusion that each muscle has its own optimum frequency. Although the lumbar muscles tended to show optimum reactions more consistently toward the higher frequencies (greater than 25 Hz), the reactions of the leg muscles varied considerably. On the Galieo2000®, frequencies of 17 Hz and above appeared to be most effective.

In physiotherapeutic settings, WBV devices should be used with caution. The choice of device and the target muscle groups depend on the aim of the therapeutic treatment. The vibration frequency should be adapted to the individual patient and the intensities tailored to his or her physical capacity, although the vibration loads were well accepted in this study. With the Galileo2000® in particular, the frequency should be determined for each individual subject and his or her individual muscle groups, especially as it appears that the EMG results had reached their maximum level for the frequency range of this device.

The aim of this study was to determine the most effective vibration load for four separate muscles. The author is aware of the fact that the number of participants does not ensure concrete conclusions. Nevertheless, although it is clear that a single most effective frequency does not exist, the conclusion that higher (25 Hz and higher), though not the highest, frequencies cause higher EMG output appears to be justified to some extent.

The reported RPE indicated that the load of WBV was within the physical and physiological limits of the participants. However, this does not mean that WBV is suitable for every MS sufferer. We, therefore, recommend including the RPE in every WBV application when used for impaired subjects.

WBV is an exciting area in the field of exercise and medical science. To enable experts in this field to use this application more efficiently and more effectively, the

Table 3 ZeptorMed™ frequencies (Hz) with the highest electromyogram output

Participants	Vastus medialis	Lumbar erector	Tibialis anterior	Gastrocnemius medialis
P1	7	7	11	11
P2	11	12	9	12
P3	11	12	12	12
P4	11	12	12	12
P5	11	12	11	12

Table 4 Galileo2000® frequency (Hz) with the highest electromyogram output

Participants	Vastus medialis	Lumbar erector	Tibialis anterior	Gastrocnemius medialis
P1	29	29	29	29
P2	25	23	23	23
P3	17	25	19	29
P4	27 and 29	29	21	23
P5	19	29	19	19

effects of different amplitudes and different application times on muscular output should be the aim of future studies.

Acknowledgement

The author would like to thank the patients who participated in this study and the Department of Physiotherapy of the Basel University Hospital for use of the WBV and EMG equipments and for helping him recruit the participants for this study.

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