Optimal frequency/time combination of whole body vibration training for improving muscle size and strength of people with age-related muscle loss (sarcopenia): a randomized controlled trial

Ning Wei, MS, Marco Y. C. Pang, PhD, Shamay Ng, PhD, and Gabriel Ng, PhD

Laboratory: Sports training laboratory of Department of Rehabilitation Sciences, The Hong Kong Polytechnic University

Ning Wei*. ST828, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Hong Kong (SAR). Email: 11902302r@connect.polyu.hk; Tel: 852-27664340; Fax: 852-23641031

Marco Y. C. Pang. QT515. Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Hong Kong (SAR). Email: marco.pang@polyu.edu.hk; Tel (fax): 852-27667156; Fax: 852-27745131.

Shamay Ng. ST506. Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Hong Kong (SAR). Email: shamay.ng@polyu.edu.hk; Tel (fax): 852-27664889; Fax: 852-23308656.

Gabriel Ng. QT510a. Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Hong Kong (SAR). Email: gabriel.ng@polyu.edu.hk; Tel (fax): 852-27666704; Fax: 852-27745131.

Correspondence should be sent to Ning Wei.

Gabriel Ng, Shamay Ng and Marco Pang: study design and critical review.

Gabriel Ng: grant acquisition, direct supervision of data collection and manuscript drafting.

Ning Wei: data collection, data analysis and drafting.

Running head: Optimal combination WBV

ABSTRCT

Aim: To determine the optimal combination of frequency and exposure time of whole-body vibration (WBV) training program for improving muscle performance of older people with age-related muscle loss.

Methods: Eighty community dwelling seniors with age-related muscle loss were randomly divided into 4 equal groups, namely, low frequency long duration (LG: 20Hz x 720s), medium frequency medium duration (MG: 40Hz x 360s), high frequency short duration (HG: 60Hz x 240s) and control (CG: no training) for 12-week whole-body vibration training and 12-week follow-up. Assessments were done at baseline, mid-intervention, post-intervention, mid-follow-up, follow-up for cross-sectional area (CSA) of vastus medialis, isometric knee extension strength at 90° and isokinetic knee extension at 60°/s and 180°/s.

Results: There was significant time × group interaction effect in isokinetic knee extension at 180°/s. Significant time effects were found in all muscle strength outcome variables. Group differences in percentage change from baseline were significant between MG and CG on isokinetic knee extension at 180°/s and 60°/s. No changes were found in CSA of vastus medialis.

Conclusions: With the total number of vibrations controlled, the combination of 40 Hz and 360s of WBV exercise has the best outcome among all other combinations tested. The improvements in isokinetic knee extension performance can be maintained for 12 weeks after cessation of WBV training.

Key words: age-related muscle loss, optimal setting, whole-body vibration

INTRODUCTION

Age-related muscle loss (sarcopenia) is considered as one of the most important factors leading to frailty and disability in the elderly.[1] Human muscle strength usually peaks between 20 and 30 years of age and remains stable until the onset of the sixth decade of life. With increasing age, the human skeletal muscle size and function decay and the decrease becomes most evident when one reaches 60 years or older.[2] The constant decrease in lower limb strength in seniors approximates to 1-3 % per year.[3] Poor muscle strength significantly compromised the functional independence in walking, posture and balance control.[4] Seniors with decreased muscle strength have more difficulties with motor tasks and less involvement in physical activities.[5]

In the past decade, a number of researchers had investigated the effects of whole-body vibration (WBV) on muscle mass and size. von Stengel et al. reported no change in lean body mass in elderly women after 18 months of WBV training,[6] whereas Kennis et al. found significant increase in muscle volume in healthy elderly men after one year of training with WBV.[7] For the muscle size, Machado et al. demonstrated significant increase in cross-sectional area of vastus medialis in elderly women after 10 weeks of training which was later echoed by Marin et al. who demonstrated the thickness of rectus femoris and vastus lateralis on the non-paretic limb of seniors with stroke was increased by 15% after 3 months of WBV exercise.[8,9]

There were also studies on the effects of WBV training on muscle strength but the findings were equivocal. Verschueren et al. reported the isometric knee extension in elderly subjects had significantly increased after 24 weeks of WBV training.[10] Machado et al. found that after 10 weeks of WBV training, the isometric hip, knee and ankle extensors strength had all improved in elderly women.[8] However, de Ruiter et al. reported no significant change in isometric strength in the young adults after 11 weeks of WBV[11] and a few others have reported no change in isokinetic knee strength in postmenopausal women after a 32 weeks of WBV training.[12,13]

Frequency, amplitude and exposure time are the main determinants for any WBV training protocol. Two systematic reviews concluded that WBV with higher frequency had a greater effect on muscle strength in both young and old people.[14,15] With the same amplitude and exposure time, higher vibration frequency has been found to result in better strength performance.[16]

Exposure time could also influence the effect of WBV training on muscle performance. If the exposure time is too short, it might not elicit any change in muscle performance.[12] However, if it is too long, it could fatigue the muscles.[17] The exposure time for many previous studies varied between 120s and 600s and the duration for one training set ranged between 30s and 360s.[18,19] Da Silva-Grigoletto et al. advocated the optimal exposure time for one set of WBV exercise should be 60s[18] whereas Stewart et al. suggested 120s per set of exercise was the optimal exposure time.[19]

Hitherto, there is no consensus on the optimal frequency and exposure time for WBV training. The inconsistency in the literature makes it difficult for clinicians to design the WBV exercise protocol. Since frequency * exposure time = dosage (the total number of vibration), it is important to determine the optimal combination of frequency and exposure time under the same dosage. Therefore, the aim of this study was to examine the different combinations of frequency and exposure time of WBV training on muscle performance in seniors with sarcopenia.

METHODS

Participants

This study targeted to recruit community dwelling seniors aged 65 years or above. Suitable subjects without uncontrolled medical conditions attending a local Elderly Health

Center were invited to go through a screening test of bioelectrical impedance measurement to estimate their absolute skeletal mass. An established formula[20] was used to calculate the skeletal mass that:

Skeletal mass = [0.401 ∗ (height2/bio-impedance) + (3.825 ∗ gender index) – (0.071 ∗ age) + 5.102]

Gender index for male = 1; female = 0

The absolute skeletal mass was converted to skeletal mass index by dividing it with the square of body height. Male and female participants with skeletal mass index less than 8.87kg/m^2 and 6.42kg/m^2, respectively, would be classified as sarcopenia[20] and were invited to participate in this study. Subjects with metal implants, severe heart problem, neurodegenerative diseases, peripheral vascular disease, vestibular disorders or severe osteoporosis with fractures within 1 year prior to the study were excluded.

All participants were randomly assigned into 4 groups by a computer program (Research Randomizer Form www.randomizer.org). The 4 groups are (a) low frequency and long exercise time (LG) (20Hz x 720s), (b) medium frequency and medium exercise time (MG) (40Hz x 360s), (c) high frequency and short exercise time (HG) (60Hz x 240s) and (d) no vibration control (CG). In a previous meta-analysis study on participants receiving WBV training, an effect size of 0.43 was reported for strength improvement.[14] The present study adopted this effect size for estimating the sample size. With a power of 0.8, the sample size was calculated to be 16 per group. In order to cater for the possible dropout, the total sample size for the study was 80 participants. The Human Ethics Review Board of the administrating institution reviewed and approved the study and participants gave their written informed consent prior to joining the study.

Interventions

All WBV training sessions were conducted in a sports training laboratory of the administrating institution under the supervision of the same researcher. A total of 36 training sessions were implemented at 3 days/week over a 12-week period. Extra sessions catering for missing appointments were arranged to make sure all subjects would complete the same number of training sessions. The training on each day comprised 14,400 vertical vibrations, which were divided into four sets with each containing 3,600 vibration cycles. The peak-to-peak amplitude was set at 4mm for all training groups.

During training, the participants stood barefoot with knee joint flexed at 60° on the platform of the WBV machine (Fitvibe excel, GymnaUniphy NV, Bilzen, Belgium) and hands holding onto the rail in front for support. A soft mat supplied by the Fitvibe manufacturer was placed on the vibration platform during all training sessions for protection. All participants were advised to keep their lifestyle and physical activity as usual during the study.

Outcome Measurements

The training lasted for 12 weeks but there was another 12 weeks of follow up period and all the participants were assessed at baseline, mid-intervention (week 6), post-intervention (week 12), mid-follow-up (week 18), follow-up (week 24). The assessments included muscle size, isometric and isokinetic knee extension strength measurements.

Muscle Size Assessment

The cross-sectional area (CSA) of vastus medialis (VM) of the dominant leg, which was defined as the leg used to kick a ball, was measured with ultrasound imaging. Participants were positioned supine with a custom-made ankle stabilizer applied at the ankle to keep the leg in neutral alignment. The B-mode of An Aixplorer® ultrasound unit (Supersonic Imaging, Aix-en-Provence, France) was used to capture the CSA of VM at 1/3 of the leg length (the length from anterior superior iliac spine to the medial side of knee joint line space) above the base of patella.[8] Three images were captured for calculating the average CSA of VM.

Muscle Strength Assessment

The dominant knee extension strength was evaluated with an isokinetic dynamometer (Cybex Norm, Henley Healthcare, Nauppauge, NY, USA). Isometric strength was measured at a knee angle of 90° whereas dynamic contraction performance was measured at two angular speeds of 60°/s and 180°/s. Participants were positioned on an isokinetic machine with hip at 80° of flexion and knee joint line aligned with the dynamometer axis of rotation. The trunk and tested leg were firmly secured by straps to the chair. Each participant performed two trials with submaximal effort for familiarization followed by three maximal contractions for the actual data collection. A recovery period of 60s between each testing session was given. The maximum value of peak torque in the three trials was recorded for data analysis.

Test-retest reliability for all the assessments were established with a 7-day interval with 6 age-matched subjects who were not involved in the main study. All the assessments showed good test-retest reliability (ICC3,1=0.84-0.98).

Data Analysis

To compare the baseline characteristics of the four groups, one-way ANOVA tests were conducted. Two-way repeated measures ANOVA (time × group) was used to examine the effects of WBV on muscle performance. If the time effect was significant, one-way repeated ANOVA was used to investigate the within-group difference for each group. Percentage changes from baseline in outcome variables for the five assessments were calculated and between-group differences were tested using one-way ANOVA with Bonferroni post hoc for each assessment. Intention to treat (ITT) analysis was used. The last observation carried forward method (LOCF) was used to handle missing data .due to attrition.

was used for data analysis. Descriptive analyses were reported as means ± standard error.

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SPSS 20.0 (SPSS Inc., Chicago, Illinois, USA) was used for statistical analysis. Significance level was set at $p<0.05$, unless otherwise stated.

RESULTS

Eighty participants were recruited for baseline assessments but 10 withdrew due to personal reasons. Among the 70 who had completed the study, there were 17 in LG, 17 in MG, 18 in HG and 18 in CG (Figure 1). Baseline characteristics of the four groups were summarized in Table 1. There was no significant difference between groups in physical characteristics and outcome variables at baseline ($p>0.05$).

There was significant time × group interaction effect in isokinetic knee extension at 180°/s ($F_{12,304}=2.529$, $p=0.003$). Significant time effects were found in isometric knee extension peak torque ($F_{4,304}=5.150$, $p<0.001$), isokinetic knee extension at 180°/s ($F_{4,304}=10.104$, $p<0.001$) and isokinetic knee extension at 60°/s ($F_{4,304}=7.084$, $p<0.001$). Within-group differences in outcome variables were presented in Table 2a and 2b.

Group differences in percentage change from baseline were significant between MG and CG on isokinetic knee extension at 180°/s (Figure 2) and 60°/s (Figure 3). No significant within-and between-group differences were found in CSA.

DISCUSSION

No previous study had examined the combination of frequency and exercise time of WBV training on muscle performance in people with sarcopenia. The present findings suggested both 20Hz x 720s and 40Hz x 360s had positive effects on muscle performance in people with sarcopenia. Group differences were mainly found between MG (40Hz x 360s) and CG (no vibration), which indicated among the 3 combinations of frequency and exercise time, 40Hz x 360s would be the most effective for improving muscle performance in seniors with sarcopenia.

Mikhael et al. reported the CSA of mid-calf had increased by more than 3cm^2 after 39

WBV training sessions, which is clinically meaningful but not statistically significant.[21] Machado et al. examined the CSA of individual leg muscles and found a significant increase of 8.7% for the CSA of VM and BF after 38 training sessions in healthy older women.[8] In the present study, there was no significant increase in CSA of VM after 36 sessions of WBV training in our subjects. However, we found the CSA of VM had increased in all the 3 training groups after training (LG: 0.4%; MG: 1.5%; HG: 0.5%), but the difference was not statistically significant.

The main difference between our study and the study of Machado et al.[8] was the form of exercise performed by the subjects. In their study, the subjects were to do dynamic exercise on the vibration platform, such as deep squat, wide stance squat and heel raise, whereas in our study, subjects were only required to maintain in a half-squat standing position during the training, which was same as the study of Mikhael et al.[21] It could be that the loading on the muscles with static standing on the platform during WBV exercise was not sufficient to stimulate muscle hypertrophy in the subjects. Furthermore, our subjects were seniors with sarcopenia who are inclined to lose their muscle mass, it would be difficult for CSA of their muscles to have large increase with a relatively short training duration.

Considering the variety of WBV protocol, outcome variables and individual characteristics among the studies, it is difficult to conclude on the effects of WBV training on muscle mass. Meanwhile, subjects in the training groups showed decreases at the 12-week follow-up assessment, which is in line with a study that demonstrated the improvements in muscle volume obtained from a year long WBV training program could not be maintained after cessation of the training.[7]

It is known that seniors with sarcopenia have lower muscle strength, which impairs their physical performance with active daily living.[1] Our findings revealed that MG group had greater improvement than the other groups in isometric knee extension. However, there were equivocal reports on the training effect of WBV on isometric muscle strength. A study using 30Hz of vibration frequency reported no change in isometric strength after 11 weeks of training[11] whereas Roelants et al. used a similar frequency of 35-40Hz had found significant increases in both isometric and isokinetic strength after 12 weeks of WBV training.[22] An explanation for this inconsistency might be with the different training designs. The total duration of one session in the study of Roelants et al. was gradually increased from 3 to 30 minutes[22] while de Ruiter et al. only trained their participants for 8 minutes per session.[11] Also, de Ruiter et al. had incorporated a 2-week rest period into the 11-week WBV training program,[11] while Roelants et al. conducted their training without interruption.[22] Since the exposure time could influence the outcome of WBV training, it may explain why there was no change in muscle strength in the study of de Ruiter et al.[11]

Our findings revealed both LG and MG had improved in isokinetic knee extension performance after the 12-week training program. The peak torques at 180°/s had improved more than at 60°/s. This is in line with the report by Roelants et al.[11] that significant improvements in knee strength were only found in high speed of movement with an external resistance up to 20% of isometric maximum, while the knee strength tested at low speed with 40% and 60% of isometric maximum showed no change.[22] It is speculated that the fast-twitch muscle fibers in the subjects might have been preferentially stimulated with WBV training, which was proved by the study of Pollock et al.[23] that the recruitment threshold of fast-twitch muscle motor units had declined only after a 5-minute WBV training session. If a long-term WBV training program could facilitate the fast-twitch fibers recruitment, it will be extremely important for the management of sarcopenia and frailty in elderly people because fast twitch muscles are significantly weakened with these conditions. Further research is warranted to shed more lights on this issue. Moreover, with the final follow up assessment at 12 weeks after cessation of training, all training groups demonstrated better performance than those at baseline under high-speed of contraction, which is similar to the finding of Kennis et al.[7] at 1-year follow up.

Since no studies had explored the optimal combination of frequency and exposure time of WBV training, comparison with previous studies can only be done on frequency and exposure time separately. Although both the LG and MG have significant increases in muscle performance after 36 sessions of WBV training, only MG showed better performance than CG on isokinetic knee extension. To synthesize our findings, the most effective frequency for muscle performance improvement with WBV training might range between 20Hz and 40Hz, and that the optimal vibration frequency for seniors with sarcopenia was likely to be in the vicinity of 40Hz. Some studies had investigated the optimal frequency of long-term WBV training on muscle performance but no agreement was reached. One study had controlled for the acceleration, and found no difference in muscle performance in young adults between low- (18Hz) and high-frequency (32Hz).[24] Another study only controlled the exposure time and revealed that 50Hz with 4mm was more effective than 30Hz with 2mm.[16] However, Savelberg et al.[25] reported a different finding that frequency of WBV had no effect on muscle strength in young adults with 4 weeks of training.

Despite that the optimal frequency of WBV training was not well investigated, the optimal frequency of acute WBV training was reported in several studies. Turner et al. found the young participants trained with 40Hz would present with better counter-movement jump performance than those trained with lower frequencies of 30Hz and 35Hz when the same amplitude and duration were applied.[26] Another study on young adults found that 30Hz would elicit the highest muscle activity in vastus lateralis.[27] A recent study by Liengard et al.[28] demonstrated young people trained with 40Hz had significantly higher activity in the soleus, and when trained with 35Hz, there was higher activity in vastus lateralis and vastus medialis, while no such change was observed in rectus femoris when frequency increased from 25Hz to 40Hz. Though plenty of studies supported there was an influence of frequency on muscle performance, Duc et al.[29] reported no change in muscle activity of vastus lateralis and rectus femoris in young people when frequency increased from 20Hz to 60Hz, which is the usual frequency range adopted in most WBV studies.

Very few researchers have studied the optimal exposure time of WBV training and there is no consensus on this parameter. In our study, 90s per training set resulted in more benefits than 180s and 60s. Since each session comprised 4 training sets, the optimal exposure time for the entire session would be 360s, which was consistent with the report of Da Silva-Grigoletto et al.[18] that 360s of training per set had resulted in higher jump height than 180s and 540s. However, for the optimal duration in one exercise set, there is no consensus. Da Silva-Grigoletto et al.[18] found the participants with 60s per set increased the height of counter-movement and squat jump, whereas Adams et al.[30] found no difference between the groups with set duration of 30s, 45s and 60s. One the contrary, Stewart et al.[19] suggested 120s should be the optimal duration for one set because they found that longer durations of 240s and 360s were associated with a decrease of 2.7% and 6% in knee extensor strength.

There are a few limitations in this study that need to be considered. First, there was no blinding in this study. However, since no previous studies had investigated the optimal frequency/time combination of WBV on muscle performance in people with sarcopenia, thus no a priori expectation could be established on which frequency/time combination was optimal. Furthermore, all the outcome measurements were from objective data without any subjective assessment elements, therefore the lack of blinding could not have influenced the results. Second, due to practical consideration, only 3 frequency/time combinations were tested thus the findings can only be interpreted as 40Hz x 360s was better than 20Hz x 720s and 60Hz x 240s. We cannot rule out the possibility that some other frequency/time combinations not tested in this study could out-perform the 40Hz/360s combination. Future studies with finer distinctive groups of frequency/time combination are warranted.

Based on our present findings, we conclude that medium frequency of 40Hz combined with medium duration of 360s per session was more effective than 20Hz with 720s and 60Hz with 240s for improving and preserving muscle performance in seniors with sarcopenia.

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DISCLOSURE STATEMENT

No potential conflicts of interest were disclosed.

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FIGURE LEGENDS

Figure 1. Flowchart of Subject Group Assignment for the Study.

Figure 2. Percentage Changes of Isokinetic Knee Extension Peak Torque at 180°/s between Groups. LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; Mid: completion of 18 training sessions; Post: completion all 36 training sessions; Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * $p<0.05$ vs. CG

Figure 3. Percentage Changes of Isokinetic Knee Extension Peak Torque at 60°/s between Groups. LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; Mid: completion of 18 training sessions; Post: completion of 36 training sessions; Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * $p<0.05$ vs. CG