

# Comparison of whole-body vibration training, strength training and health education on physical function and neuromuscular function of individuals with knee osteoarthritis: a randomized clinical trial

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## Research article

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# Abstract

*Background* Knee osteoarthritis (KOA) is one of the leading causes of global disability which causes knee pain, stiffness, and swelling. Impaired neuromuscular function contributes to the development and/or progression of KOA. As a new modality to treat KOA, whole-body vibration (WBV) training is considered to improve pain and physical function effectively. However, limited numbers of studies were designed to investigate the effect of WBV on neuromuscular function in KOA.

*Methods* 81 eligible participants with KOA were randomly allocated to WBV, strength training (ST) and health education (HE) groups. Each group of participants was encouraged to perform the WBV training, similar strength training and health education program, respectively. These supervised interventions were performed three times per week for 8 consecutive weeks. Neuromuscular function was measured with isokinetic muscle strength and proprioception. Physical function was assessed with Timed Up and Go (TUG) and 6-min Walk Distance tests.

*Results* Physical function and neuromuscular function did not show significant difference between three groups ( $p > 0.05$ ). However, post-hoc test showed that isokinetic knee muscle strength of WBV group (peak torque of extensor at  $180^\circ/\text{s}$ , peak torque of flexors at  $180^\circ/\text{s}$ , peak work of extensor at  $180^\circ/\text{s}$ , and peak work of flexor at  $90^\circ/\text{s}$ , all  $p < 0.05$ ) increased significantly compared with HE group. Similarly, compared with ST group, muscle strength of WBV group (peak torque of extensor at  $180^\circ/\text{s}$  and peak work of extensor at  $180^\circ/\text{s}$ ,  $p < 0.05$ ) improved significantly.

*Conclusion* The current study showed that the advantage of WBV training on muscle strength gain in patients with KOA compared with similar strength training without vibration and health education.

*Trial registration* It was registered at Chinese Clinical Trial Registry a priori as a clinical trial (ID: ChiCTR-IOR-16009234). Registered 21 September 2016.

## 1. Background

Knee osteoarthritis (KOA) is a degenerative, non-infectious knee joint disease and one of the leading causes of global disability [(1)]. Patients with KOA often suffer from arthralgia, stiffness, swelling, decreased muscle strength, impaired proprioceptive function and physical foundational limitation [(2-4)]. In US, it was reported that the prevalence of KOA has increased to 33.6%, thereby affecting most adults aged 65 years old and above [(5)]. Considering the improving longevity and the increasing prevalence of obesity and joint injury, the prevalence of KOA may continue to increase in future decades; therefore, there is an increasing need to address KOA.

As far as we know, no cure for KOA exists. As suggested by several international guidelines, non-pharmacological and pharmacological modalities (even surgical treatment) should be combined to manage KOA [(6-8)]. Among these treatments, exercise is recommended for effective treatment; examples

of exercises are aerobic and/or resistance land-based exercise, aquatic exercise, and Tai Chi [(6)]. Strength exercises are considered as the foundation of non-pharmacological treatments [(9)].

Several studies have shown that the impaired neuromuscular function, such as proprioception and muscle strength of the affected knee joint, might play a detrimental role in KOA [(4, 10, 11)]. The weakness of muscle strength around the knee would contribute to joint instability, which would change the alignment and stress of the knee, thereby accelerating knee OA progression [(12)]. Meanwhile, the proprioception of the affected joint has been reportedly impaired significantly in KOA compared with the age-matched controls [(4)] even compared with the non-symptomatic knee [(13)].

With the lower load on the affected joint, whole-body vibration (WBV) training was proposed as an effective and potentially feasible neuromuscular modality to treat several musculoskeletal system diseases, such as low back pain, osteoporosis and chronic achilles tendonitis [(14, 15)] even in patients with neurological disorders [(16)].

Recently, treatment of KOA has been evaluated, particularly in the aspects of pain relief and physical function improvement [(17-19)]. Several systematic reviews and meta-analyses affirmed the therapeutic effects of WBV training on pain and function in individuals with KOA [(20, 21)].

However, limited studies have evaluated the effect of WBV training on neuromuscular function in individuals with KOA, which was associated with symptoms, prevalence and progression. Segal et al. [(22)] conducted a randomised controlled study to determine the effect of exercise on the vibration platform on proprioception, muscle strength and power in the women with KOA risk factors. However, there was no significant improvement in the outcome measures compared to the matched exercise group without vibration. In the study of Park et al. [(23)], the similar effect of WBV in quadriceps muscle strength gain was found compared with the control group. On the contrary, several studies have reported the positive effects of WBV training on neuromuscular function. Trans et al. [(24)] found that two kinds of WBV training regime with different vibration platforms promoted the strength of knee extensors and proprioception in women with KOA separately, which was consistent with the studies of Osugi et al. [(25)], Wang et al. [(26)], and Bokaeian et al. [(18)]. These inconsistent results of previous studies hinder the validation of the effects of WBV training on neuromuscular function of patients with KOA.

Therefore, the present study aimed to investigate the effect of WBV training on the neuromuscular function of patients with KOA. We conducted a single-blind randomised controlled trial to determine the efficacy of an 8-week WBV training program compared with lower extremity strength training and health education on muscle strength and knee proprioception in individuals with KOA. We hypothesised that WBV training would significantly induce muscle strength gain and proprioception improvement of KOA.

## 2. Methods

This study was a single-centre, single-blind randomised controlled trial with blinded outcome assessment, which was conducted at the Sport Medicine and Rehabilitation Centre, Shanghai University of Sport. It

was approved by the Ethics Committee of the Shanghai University of Sport (Ref. No.: 2016-016) and registered at Chinese Clinical Trial Registry a priori as a clinical trial (ID: ChiCTR-IOR-16009234). In addition, this study adhered to CONSORT guidelines.

## 2.1 Participants

With settings of  $\alpha = 0.05$ , power  $(1 - \beta) = 0.80$  and effect size = 0.25, power analysis showed that three groups of 81 participants in total were the required sample size. The effect size (0.25) of the extensors' peak torque was used to estimate the sample size. Considering the progression of disease and drop-out, 30 subjects in each group were recruited for this study.

The voluntary participation of KOA patients was requested via posters on community centres in Yangpu District, Shanghai, China from July 2017 to September 2018. The diagnosis of KOA was performed by an orthopaedic surgeon based on the patients' medical history, X-ray imaging and physical assessment. Based on the classification criteria of the American Rheumatism Association for KOA [(27)], the inclusion criteria were as follows: (1) men or women with radiographic diagnostic criteria of definite KOA (unilateral or bilateral) and who reported pain symptoms for at least 3 months; (2) mild-to-moderate KOA (Lequesne Knee Score = 1 to 7); (3) aged 50–70 years old; (4) medication not expected to change during the study period; and (5) available three times a week for over 3 months. The exclusion criteria were as follows: (1) had undergone knee surgery in the past 6 months; (2) had acute symptomatic KOA; (3) had muscular, joint or neurological conditions that affect lower limb function; (4) underwent a structured exercise program specifically for KOA; (5) unable to understand the study's procedure; and (6) had motor neuron disorders, such as Alzheimer's and Parkinson's diseases [(19)]. The research designer (LZ) took charge of contacting the eligible participants, confirming their willingness to complete the trial and arranging the baseline assessment of outcomes.

After screening, 81 eligible participants were informed about the study procedures and given written informed consent before enrolled in the study. These participants were randomly divided into WBV, strength training (ST) and health education (HE) groups using computer-generated randomisation by the main research designer (WL). The group randomisation was separated into opaque envelopes which was kept by the main research designer (WL).

## 2.2 Outcome measures

All outcome assessments were conducted by the independent research assessor who was blind with group allocation at pre-intervention and post-intervention. For the bilateral KOA, the affected side was defined as the worse side.

Before the intervention, the demographic questionnaire was collected, including participants characteristics (sex, age, Body Mass Index, Lequesne Knee Score and affected side). After intervention, all

participants were requested to return to the laboratory within 2 days and complete the post-intervention assessment.

## Primary Outcome

### 2.2.1 Isokinetic muscle strength

Knee extensor and flexor strength of the affected side were measured using an isokinetic dynamometer (Physiomed, CON-TREX, TP 1000, Germany). Before the formal test, the participants were informed about the test procedure and performed a 5 min warm-up. At first, the assessor secured them to the dynamometer at the upper chest, pelvis and distal femur on the tested side with straps. Then, the participants were instructed to familiarise themselves with the procedure through three submaximal contractions. In the formal test, the maximal concentric knee extension–flexion contractions were performed at angular velocities of 90°/s and 180°/s. The work of each trial was recorded from 80° to 10° of the knee moving angle, and 0° was considered as the full extension. During the test, the assessor verbally encouraged participants to move as forcefully as possible. The peak torque and peak work (PT and PW; Nm/kg and W/kg, respectively) normalised by body mass were recorded for analysis. This study performed strength training focused on the knee extensors. Therefore, the peak torque of knee extensor was considered as the main outcome of muscle strength which was powered for sample size.

### 2.2.2 Proprioception of knee

The proprioception of knee was observed as the threshold for the detection of passive movement (TDPM) and was measured using a reliable method [(28)]. The participants were informed about the proprioception test procedure. In a sound-attenuated room, the participants were isolated to reduce any auditory or visual interference. TDPM was tested using an electrically driven movable frame. The participants were instructed to sit on an adjustable chair, which helped them place foot lightly on the plane. During the test, the plane moved the shank forward or backward at a velocity of 0.4°/s. The angle of the knee joint was adjusted to 120° by a goniometer. The patients would press the handheld stop button immediately when they perceived the movement of the knee, then report the direction. The rotation angles of the frame were determined as the threshold for the detection of flexion and extension. The mean value of three successful trials in each direction was used for analysis.

## Secondary Outcome

### 2.2.3 Self-reported knee pain

The 10 cm visual analogue scale (VAS) was used to assess the knee pain of the affected side over the last week. The number 0 indicated no pain, whereas 10 represented maximal pain.

## 2.2.4 Physical function

The Timed Up and Go test (TUG) and the 6-min Walking Distance test (6MWD) were administered to determine the function performance of participants. These methods are simple and reliable measurements which have been used in previous studies on KOA [(19, 29)]. In the TUG test, the participants were requested to perform the following tasks on optimal speed to the best of their ability. they were instructed to stand up from a standard chair (40 cm height), walk 3 m, turn around, walk back to the chair and sit down., the completion time was measures by a chronograph in second. The total test was timed by a chronograph (in seconds). As for 6WMD, the participants were asked to walk for 6 min, and the distances were recorded. All participants must finish these tests thrice for the average values to be calculated.

## 2.3 Intervention

The same certified physical therapist supervised the interventions in the WBV, ST and HE group. Each training session comprised a 5 min warm-up and 5 min cool-down in WBV and ST.

### 2.3.1 Whole-body vibration training

Participants in the WBV group performed the training 3 days per week for 8 weeks. WBV training was conducted on a vibration device (i-vib5050; Sport Platform, China). During the training, the participants performed static squat barefoot on the platform with bent knee (30° and 60°). The distance between their feet was consistent with the shoulders. the physical therapist adjusted the angle of knee flexion throughout each session, timed the duration time and prevented the participants from falling. As showed in Table 1, the duration time, sets and total time were increased progressively over the 8-week training period. The parameters of WBV were set at the frequency of 20 Hz and amplitude of 2 mm.

### 2.3.2 Strength training

The ST group undertook three training sessions per week for 8 weeks the same as the WBV group. Likewise, all sessions were under the supervision of the same physical therapist in the WBV group. However, the participants performed static squat on flat ground. The protocol of ST, including the duration time and the angle of the bent knee, was parallel with WBV except for the vibration exposure (Table 1).

(Insert Table 1)

### 2.3.3 Health education

The participants in the HE group received 8 weeks of health education. They attended one 60-min group session per week. Each session consisted of a 30-min lecture and a 30-min discussion. The session was facilitated by the same physical therapist in the WBV and ST groups. The lectures were focused on health-related topics, such as OA, aging and nutrition. Furthermore, the participants in the HE group were required to maintain their previous lifestyle and not to attend any other regular rehabilitation programs during the study period.

## 2.4 Statistical analysis

The SPSS statistical software program (IBM, Chicago, IL, USA) was used for statistical analysis. The data were included for analysis of all participants and Intention-To-Treat (ITT) analysis was utilized. All data were expressed as means  $\pm$  SD. To evaluate the normality of these data, the Shapiro–Wilk test was used. The one-way analysis of variance (ANOVA) and the chi-squared test were performed to determine the difference of demographic characteristics among the WBV, ST and HE groups. Then, the two-way repeated measurements ANOVA was used to determine the difference in outcomes among the three groups. The effect size of between-group effect was calculated by partial eta-square. For post hoc test, the difference of each index relative to baseline was calculated, and the one-way repeated measurements ANOVA was used for pairwise comparison. Significance was set at  $p < 0.05$ .

## 3. Results

### 3.1 Participation

In this study, 81 participants were included for data analysis with 27 in each group. In addition, there were 17 participants dropped out the interventions (5 in WBV group, 4 in ST group, and 8 in HE group). Furthermore, the main reasons for leaving were: 1) loss of interest; 2) long distance to the rehabilitation centre; 3) other diseases not related to intervention in this study.

The demographic characteristics of the participants are shown in Table 2. There was no significant difference among these three groups regarding demographic and anthropometric data, such as age, gender, height, weight and Body Mass Index (BMI). No significant differences were found in the data collected prior to intervention between groups, thereby confirming the baseline homogeneity of these groups.

### 3.2 Isokinetic muscle strength

Isokinetic strength of knee extensor and flexor were measured at the angular velocities of 90°/s and 180°/s. As shown in Fig. 1 and Table 3, no significant main effect of these variables among three groups was found ( $p > 0.05$ ). Furthermore, at 90°/s, a significant interaction effect in peak work of knee flexors of

three different groups was found ( $p < 0.05$ ,  $\eta^2 = 0.09$ ). After the post hoc test, the peak work of knee flexors significantly improved in WBV group compared with HE group ( $p < 0.05$ , 95% = 0.02 – 0.42).

As for the outcomes at 180°/s, no main effect was detected for isokinetic muscle strength ( $p > 0.05$ ) (Fig. 2 and Table 3). Similarly, at 180°/s, significant interaction effect was found in peak torque of extensors ( $p < 0.01$ ,  $\eta^2 = 0.276$ ), peak torque of flexors ( $p < 0.05$ ,  $\eta^2 = 0.112$ ), and peak work of extensors ( $p < 0.05$ ,  $\eta^2 = 0.151$ ). Moreover, the results of post hoc test showed that these three outcomes significantly increased in WBV group compared with HE group (peak torque of extensors,  $p < 0.01$ , 95% = 0.11 – 0.33; peak torque of flexors,  $p < 0.05$ , 95% = 0.02 – 0.19; peak work of extensors,  $p < 0.05$ , 95% = 0.12 – 0.75). Compared with ST group, the peak torque and peak work of knee extensors were also significantly improved in WBV group (peak torque of extensors,  $p < 0.01$ , 95% = 0.10 – 0.32; peak work of extensors,  $p < 0.01$ , 95% = 0.09 – 0.71).

### 3.3 Proprioception of knee

Fig. 3 and Table 4 shows the differences in TDPMs of knee flexion and extension in three groups. Regarding the proprioception of knee joint, no significant change was found on flexion and extension among HE, ST and WBV groups ( $p > 0.05$ ).

### 3.4 Self-reported knee pain and physical function

As illustrated in Table 4, there was no significant difference in the pain relief and function improvement caused by WBV, ST and HE ( $p > 0.05$ ).

## 4. Discussion

Along with pain and stiffness, patients with KOA experienced decreased muscle strength, impaired neuromuscular function and limited physical function [(30)]. As a type of strength exercise, WBV training has been proposed for the treatment of KOA. However, several systematic reviews about the effect of WBV for KOA were explored, thereby leading to dispersed results [(20, 21, 31, 32)]. These studies failed to indicate the superiority of WBV compared with a control group or a similar strength training group. Thus, this study attempted to determine the effects of 8-week WBV training on pain, physical function and neuromuscular function in individuals with KOA.

In this study, the participants were randomly assigned to WBV, ST, and HE group and performed corresponding intervention for 8 weeks. The results showed that the 8-week WBV training effectively increased isokinetic strength of knee extensors compared with ST or HE, while these three interventions didn't promote the knee passive motion sense. As for the self-reported pain intensity and physical function, WBV, ST, and HE led to a similar effect in these clinical outcomes, although the pain and the time of TUG test improved significantly after 8 weeks of all three interventions. Generally speaking, the

finding of this study demonstrated that compared with similar training and health education, whole body vibration intervention could significantly promote the increment in knee extensors strength and have a similar effect on knee pain relief and physical function improvement.

## 4.1 Muscle strength

The main finding of this study is the significant improvement in muscle strength (peak torque and peak work) in the WBV group compared with similar strength training. As reported in previous studies, the improvements in muscle strength and power might be the results of several neural factors [(33)] and biochemical factors [(34)]. Several factors were speculated to be involved in the possible mechanism underlying the effect of WBV training on strength gains, such as increased recruitment, synchronisation, muscular coordination and proprioception [(30)]. However, the results of proprioception in our study showed that the WBV training did not promote the improvement of proprioception. Considering the lack of electromyography data, whether the recruitment, synchronisation and coordination of the muscles around knee joint were enhanced after 8 weeks of WBV training cannot be confirmed.

There are several reasons that can explain the increased effect of training on muscle strength. Firstly, during vibration training, the length of the muscle-tendon complex in skeletal muscle changed, and vibration elicited the “tonic vibration reflex,” which is one kind of muscle response produced by the activation of muscle spindles, mediation of Ia afferents and activation of muscle fibres [(23)]. Furthermore, during the ST, the force depended on the mass and the gravity acceleration. However, for the participants in the WBV group, the acceleration was changed by platform’s vibration, which adjusted the resistance during training sessions. Another possibility might be that the WBV training stimulated growth hormone secretion, which was beneficial to the gain of muscle strength.

Currently, there is no consensus on the effect of WBV training on muscle strength in patients with KOA [(18, 23, 35, 36)]. Several researchers have affirmed the advantage of WBV training on muscle strength in KOA, which was consistent with our result [(24, 25, 36)]. Due to the absence of guidelines for optimal protocol, previous studies employed different parameters, such as frequency, amplitude, duration, posture of WBV training, and even the vibration device. As mentioned previously, mechanical vibrations provoke a reflexive muscle contraction, which is referred to as tonic vibration reflex [(37)]. The magnitude of provoked tonic vibration reflex is related to vibration frequency, vibration displacement, initial position applied in WBV training, vibration type and the training protocol [(38)]. The difference between these parameters employed might be responsible for the inconsistent conclusions.

## 4.2 Proprioception

It has been generally accepted that impaired knee proprioception played an important role in the onset and progression of KOA as a local factor [(4, 39)]. Compared with age-matched healthy controls, the patients with KOA showed significant impairment in position sense or motion sense [(40, 41)]. WBV

exposure is a neuromuscular training in the management of several neurological disorders and musculoskeletal disease. It was speculated that WBV training could help improve muscle strength and proprioception and neuromuscular responses [(42)]. However, the result of our study showed that WBV training did not improve proprioception in participants with KOA. Currently, limited studies have been designed to investigate the effect of WBV training on proprioception in KOA. Trans et al. [(24)] compared the effects of two different vibration trainings on KOA and found that the TDPM was improved in WBV in the balance-vibration group but not in the conventional stable-vibration group. The stable WBV device (vertical platform) was applied to this study, and the difference in the device might have contributed to the ineffectiveness in proprioception. Segal collected the vibration perception threshold of the lower extremities [(22)], and similar to our experiment, positive results were not found.

## 4.3 Pain

Compared with the baseline, the knee pain decreased significantly in the HE and WBV groups, and knee relief tendency was found in the ST group, although no significant intergroup effect was found. The results of the pain state are consistent with those in previous studies. For example, in Tsuji's study [(17)], the participants with knee pain underwent WBV training 3 times a week for 8 weeks. However, no significant effect of WBV training on pain was found in comparison with the control group, which performed a similar exercise without the vibration stimulus. Similar to our results, Wang [(19)], Trans [(24)] and Bokaeian [(18)] found that the WBV training did not help relieve the pain of KOA patients more effectively. Furthermore, a systematic review and meta-analysis showed that vibration training does not have an additional effective effect on knee pain [(31)].

## 4.4 Physical function

The TUG and 6MWD tests were used to determine the ability to perform daily activities, as commonly reported in related studies [(17, 30)]. Compared with other groups, the physical function did not improve more effectively in the WBV group, whereas the TUG and 6MWD results were enhanced after 8 weeks of WBV training and ST. During the physical function test, several factors would affect the test outcomes, such as the function of balance, mobility, muscle strength, etc. Although the WBV training obviously promoted the increase of knee muscle, other multiple factors might contribute to undifferentiated results of physical function. Besides, similar to our results, several studies failed to verify the superior effect of WBV on physical function [(17, 22, 43)]. However, after WBV training with longer or more frequent interventions, the physical function of patients improved significantly compared with those that underwent a similar training, as reported by Wang et al. [(19)], Simao et al. [(43)] and Osugi et al. [(25)]. Therefore, we speculate that prolonged WBV training might promote functional improvement.

This study had several limitations. Firstly, we did not address the factors that might affect the effect of WBV, such as the vibration frequency, displacement and type. Secondly, all the participants were measured at a single centre, and this might have skewed the clinical outcomes. In addition, the

participants with mild and moderate KOA were included in this study. Considering the eligibility criteria, the results have limited generalisability and are difficult to apply to patients with severe KOA. In this study, the pain intensity, physical function and neuromuscular function were addressed to determine the efficacy of WBV training. A full exploration of the effects of WBV training on KOA patients was not possible due to the lack of analysis of disease-related biochemical indicators and neuromuscular response.

## **5. Conclusion**

The current study showed that the advantage of WBV training on muscle strength gain in patients with KOA compared with similar strength training without vibration and health education. Thrice a week for 8 weeks under this protocol didn't result in the alleviation of pain, the improvement of physical function and proprioception. More research is needed in the future to help develop the optimal treatments for KOA.

## **Declarations**

### ***Ethics approval and consent to participate***

This study was approved by the Ethics Committee of the Shanghai University of Sport (Ref. No.: 2016-016). A certificate of approval has been provided. Additionally, all participants were informed about the study procedures, and gave the written informed consent before enrolling in the study.

### ***Consent for publication***

Not applicable.

### ***Availability of data and materials***

All data generated or analyzed during this study are available from the first author & corresponding author.

### ***Competing interests***

The authors declare that they have no competing interests.

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## ***Authors' contributions***

ZL and LW contributed to the conception and design of the trial and drafted the manuscript. ZL, SL and YC participated in trial registration and communication. The authors read and approved the final version of the manuscript.

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## **Abbreviations**

BMI: Body Mass Index; HE: Health Education; KOA: Knee Osteoarthritis; OA: Osteoarthritis; PT: Peak Torque; PW: Peak Work; ST: Strength Training; TDPM: The Threshold For The Detection Of Passive Movement; TUG: The Timed Up And Go Test; VAS: Visual Analogue Scale; WBV: Whole Body Vibration; 6MWD: The 6-Min Walking Distance Test.

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## Tables

Table 1 The protocol of training in WBV and ST group

Weeks	Angle of bent knee	Training time	Rest time	Sets	Total time
1	30°	30s	30s	6	12 min
	60°	30s	30s	6	
2	30°	40s	40s	6	14 min
	60°	30s	30s	6	
3	30°	40s	40s	7	17 min
	60°	40s	40s	6	
4	30°	50s	50s	7	21 min
	60°	40s	40s	7	
5	30°	50s	50s	8	25 min
	60°	50s	50s	7	
6	30°	60s	60s	8	29 min
	60°	50s	50s	8	
7	30°	60s	60s	9	34 min
	60°	60s	60s	8	
8	30°	70s	70s	9	39 min
	60°	60s	60s	9	

ST, strength training; WBV, whole body vibration.

Table 2 Demographic characteristics of participants before intervention

Variable	HE (n=27)	ST (n=27)	WBV (n=27)	P-value
Age (y)	63.67±4.84	64.81±4.04	63.52±4.98	0.535
Height (cm)	157.76±5.10	158.89±6.06	160.16±7.66	0.389
Weight (kg)	58.25±7.02	58.36±8.60	62.32±8.48	0.114
BMI (kg/m <sup>2</sup> )	23.45±2.99	23.08±2.91	24.28±2.70	0.292
Sex, M/F, (n)	4/23	2/25	5/22	0.479
Affected side, L/R, (n)	8/19	6/21	8/19	0.779
Lequesne & Mery index #	16/11/0/0/0	19/8/0/0/0	18/9/0/0/0	0.682

HE, health education; ST, strength training; WBV, whole body vibration;  
 #, Disease severity: mild/ moderate/ severe/very severe/ extremely severe.

All the data were expressed as means ± SD.

Table 3 Amount of changes in proprioception and isokinetic muscle strength by groups.

		HE (n=20)	ST (n=18)	WBV (n=19)	P value of difference between groups	Effect size
TDPM of Knee Flexion (°)	Pre- intervention	2.51±1.83	3.13±2.38	2.35±1.64	0.537	0.016
	Post- intervention	1.94±0.73	2.12±0.74	2.37±1.85		
TDPMs of Knee Extension (°)	Pre- intervention	2.90±1.69	2.94±1.58	2.29±1.08	0.698	0.009
	Post- intervention	2.49±1.08	2.39±1.15	2.60±1.55		
PT (Nm/kg), Extension, 90°/s	Pre- intervention	0.81±0.24	0.73±0.25	0.80±0.31	0.474	0.019
	Post- intervention	0.78±0.24	0.73±0.24	0.80±0.23		
PT (Nm/kg), Flexion, 90°/s	Pre- intervention	-0.44±0.17	-0.40±0.15	-0.43±0.16	0.603	0.013
	Post- intervention	-0.42±0.18	-0.39±0.23	-0.46±0.18		
PW (Nm/kg), Extension, 90°/s	Pre- intervention	1.25±0.36	1.15±0.40	1.27±0.49	0.149	0.048
	Post- intervention	1.22±0.37	1.16±0.39	1.46±0.66		
PW (Nm/kg), Flexion, 90°/s	Pre- intervention	0.73±0.24	0.65±0.24	0.68±0.25	0.259	0.034
	Post- intervention	0.70±0.26	0.68±0.24	0.88±0.48		
PT (Nm/kg), Extension, 180°/s	Pre- intervention	0.59±0.18	0.54±0.16	0.51±0.23	0.312	0.030
	Post- intervention	0.56±0.20	0.51±0.17	0.69±0.28		
PT (Nm/kg), Flexion, 180°/s	Pre- intervention	-0.31±0.13	-0.31±0.11	-0.31±0.17	0.278	0.033
	Post- intervention	-0.30±0.12	-0.33±0.16	-0.41±0.20		
PW (Nm/kg), Extension, 180°/s	Pre- intervention	1.81±0.52	1.66±0.55	1.59±0.73	0.600	0.013
	Post- intervention	1.69±0.57	1.57±0.54	1.91±0.79		
PW	Pre- intervention	0.99±0.36	0.95±0.36	0.96±0.53		

(Nm/kg), Flexion, 180°/s	intervention Post- intervention	0.97±0.31	1.02±0.48	1.16±0.50	0.719	0.009
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All the data were expressed as means ± SD.

HE, health education group; ST, strength training group; WBV, whole body vibration group; TDPM, the threshold for the detection of passive movement; PT, peak torque; PW, peak work.

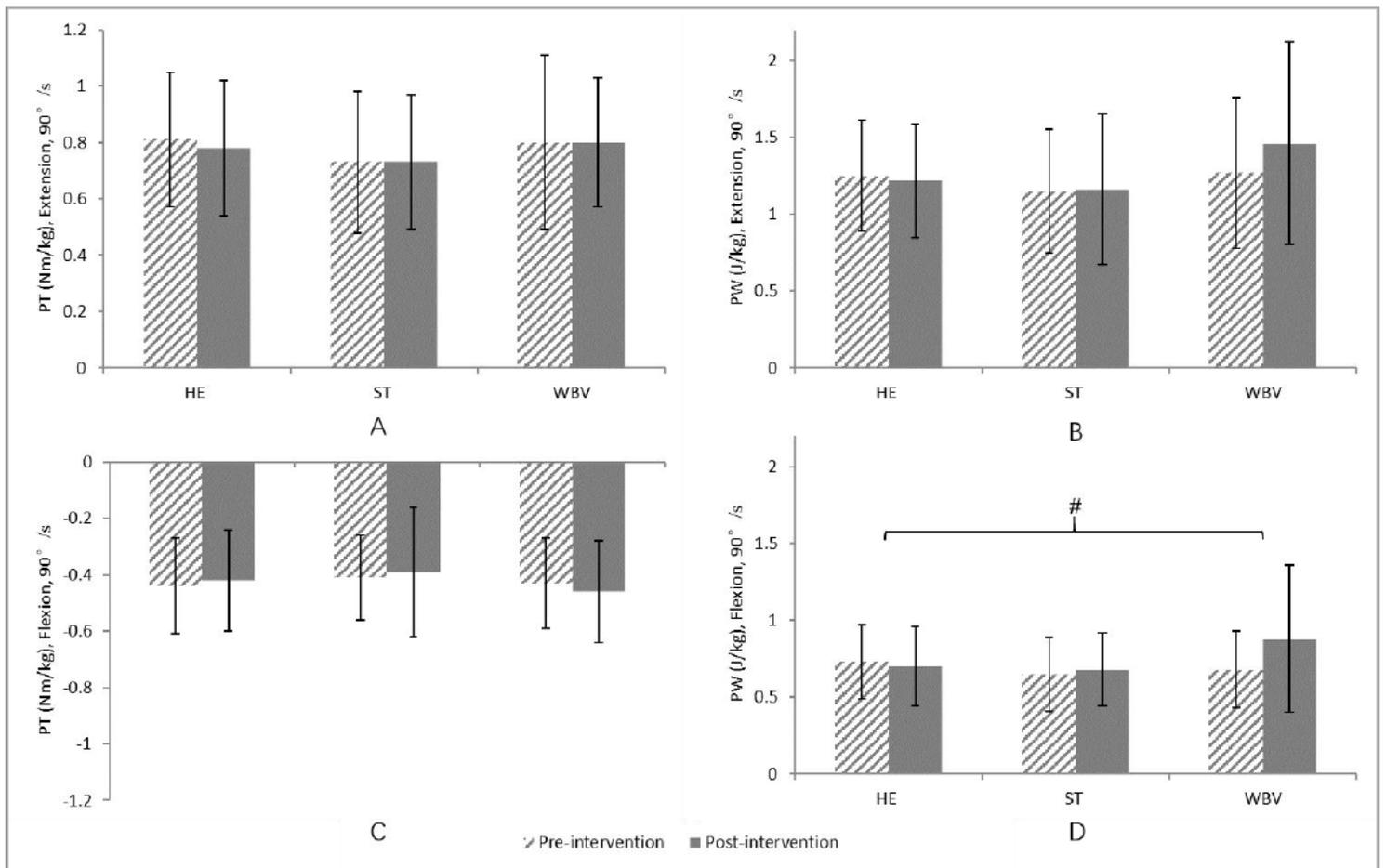
Table 4 Amount of changes in self-reported knee pain and physical function measurements by groups.

		HE (n=27)	ST (n=27)	WBV (n=27)	P value of difference between groups	Effect size
VAS	Pre-intervention	3.52±2.26	3.26±2.43	3.85±2.52	0.777	0.006
	Post-intervention	2.74±2.16	2.41±2.10	2.59±2.39		
TUG (second)	Pre-intervention	6.88±0.58	6.92±0.68	7.15±0.69	0.890	0.003
	Post-intervention	6.50±0.68	6.56±0.79	6.41±0.96		
6MWD (meter)	Pre-intervention	548.56±79.41	533.11±55.94	515.48±58.42	0.386	0.024
	Post-intervention	532.44±71.68	570.74±94.36	543.89±68.16		

All the data were expressed as means ± SD.

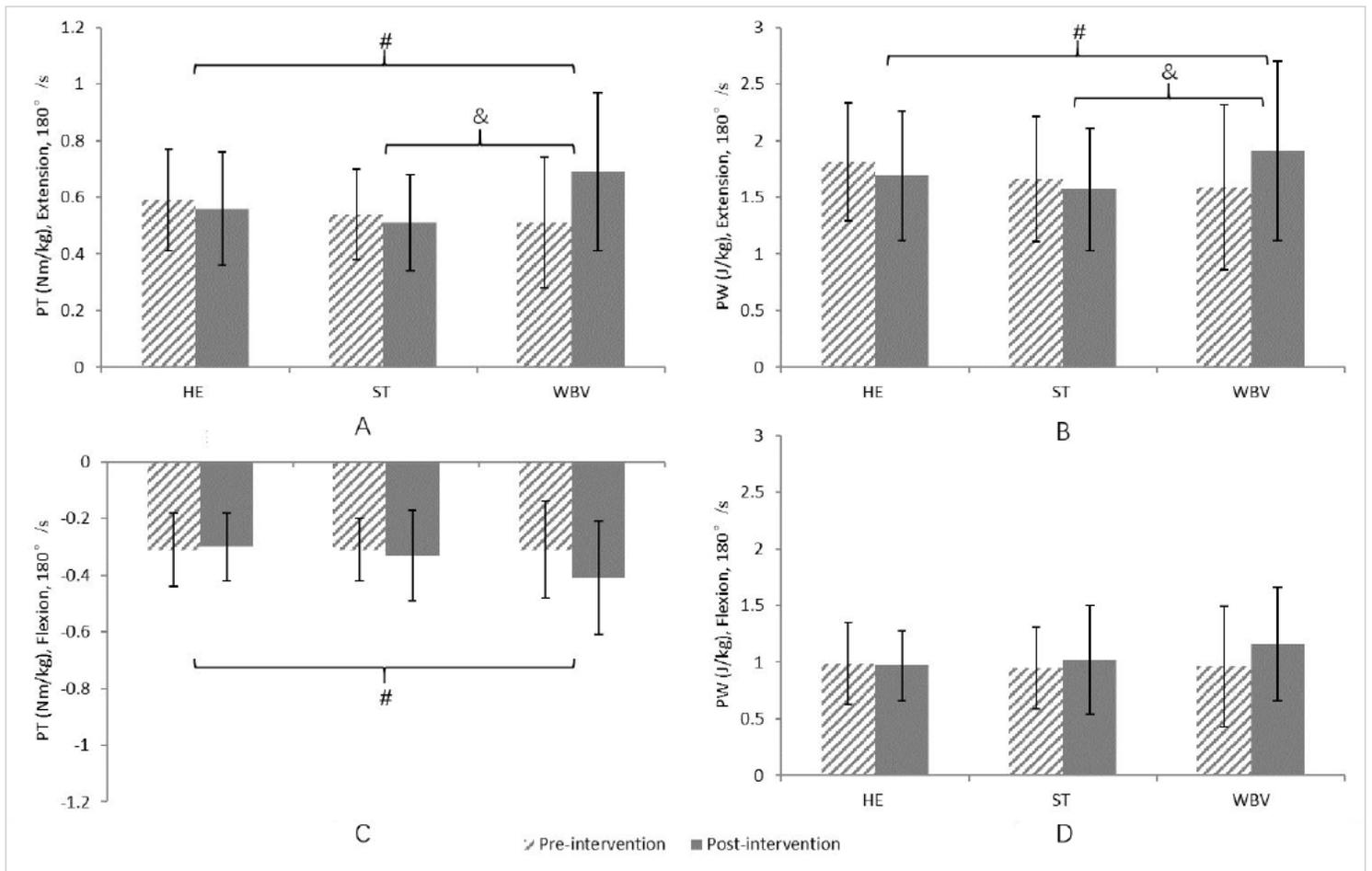
HE, health education group; ST, strength training group; WBV, whole body vibration group.

## Figures



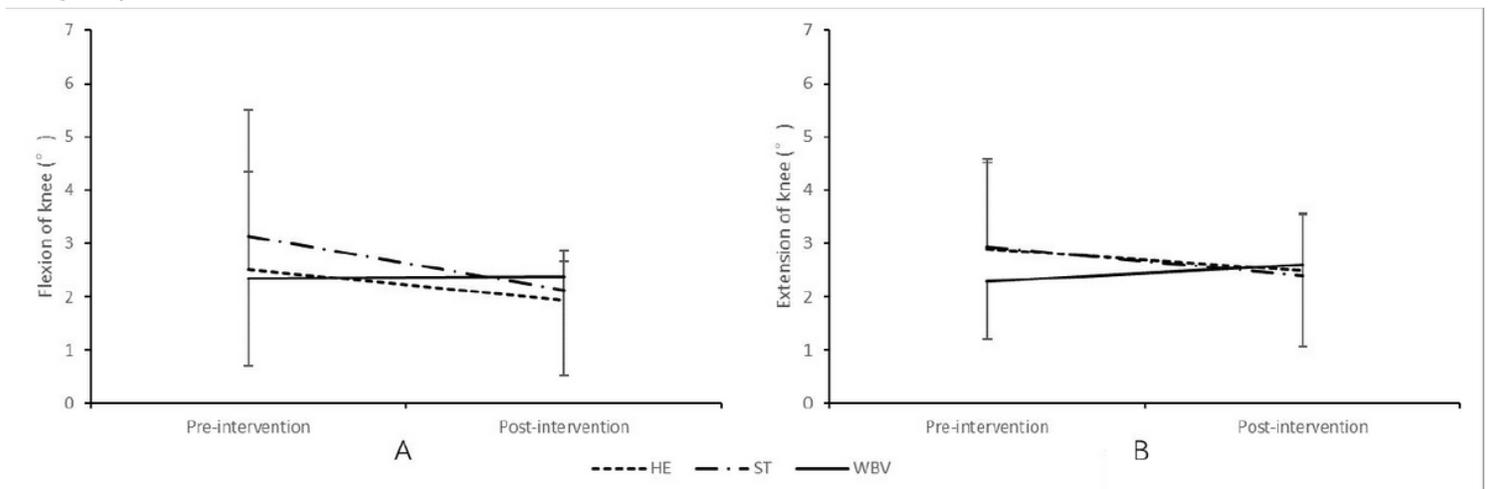
**Figure 1**

Changes in isokinetic muscle strength parameters at an angular velocity of 90°/s. The changes of the peak torque of knee extensor (A), the peak work of knee extensor (B), the peak torque of knee flexor (C) and the peak work of knee flexor (D) among groups. HE, health education group; ST, strength training group; WBV, whole body vibration group; PT, peak torque; PW, peak power; #,  $p < 0.05$ , changed significantly compared with the HE group in the WBV group.



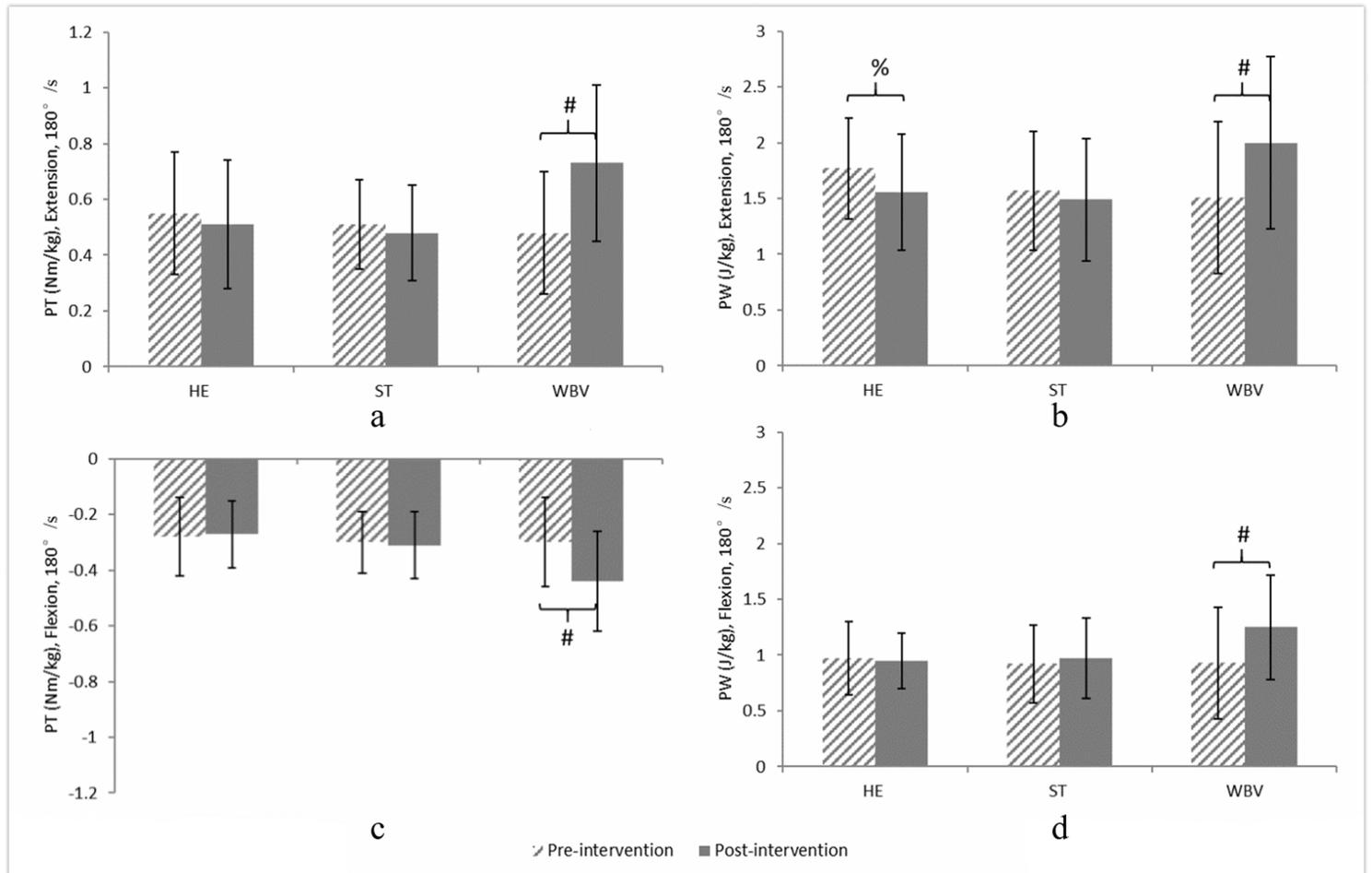
**Figure 2**

Changes in isokinetic muscle strength parameters at angular velocity of 180°/s. The changes of the peak torque of knee extensor (A), the peak work of knee extensor (B), the peak torque of knee flexor (C) and the peak work of knee flexor (D) among groups. HE, health education group; ST, strength training group; WBV, whole body vibration group; PT, peak torque; PW, peak power; #,  $p < 0.05$ , changed significantly compared with the HE group in the WBV group; &,  $p < 0.05$ , changed significantly compared with the ST group in the HE group.



**Figure 3**

Comparison of passive motion sense of knee joint among the three groups A, the passive motion sense of knee flexion among three groups; B, the passive motion sense of knee extension among three groups; HE, health education group; ST, strength training group; WBV, whole body vibration group.



**Figure 4**

Changes in isokinetic muscle strength parameters at angular velocity of 180°/s. The changes of the peak torque of knee extensor (a), the peak work of knee extensor (b), the peak torque of knee flexor (c) and the peak work of knee flexor (d) among groups. HE, health education group; ST, strength training group; WBV, whole body vibration group; PT, peak torque; PW, peak power; #,  $p < 0.05$ , changed significantly compared with the baseline in the WBV group; %,  $p < 0.05$ , changed significantly compared with the baseline in the HE group.

## Supplementary Files

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