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The Knee

Effects of whole-body vibration exercise on muscular strength and power, functional mobility and self-reported knee function in middle-aged and older Japanese women with knee pain

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ABSTRACT

Background: Whole-body vibration training using vertical-vibration machines is called "acceleration training" (AT). The purpose of this study was to elucidate the effect of AT on lower-limb muscular strength and power, functional mobility and self-reported knee function in middle-aged and older Japanese women with knee pain.
Methods: Thirty-eight middle-aged and older Japanese women (aged 50–73 years) with knee pain were divided into two groups: (1) the AT group (n = 29) engaged in AT three times per week for eight weeks, and (2) the control group (C group, n = 9). The AT program consisted of flexibility training, strength training of mainly the quadriceps and surrounding muscles and cool-down exercises. The C group was encouraged to perform the same or similar exercises at home without vibratory stimulus. We evaluated knee strength and power, functional mobility (timed up and go: TUG) and self-reported knee function (Japanese Knee Osteoarthritis Measure: JKOM).
Results: No one in the AT group dropped out during the program. All JKOM categories except degree of pain improved significantly post intervention indicating improved knee function, and TUG was significantly shorter in these participants. All knee strength and power parameters except isometric knee extension peak torque improved significantly. The degree of change in JKOM total score and TUG was significantly different between the two groups.
Conclusion: Vibratory stimulus during an eight week AT programme can promote participation and safely improve functional mobility and self-reported knee function better than exercise without vibratory stimulus in middle-aged and older Japanese women with knee pain.
Level of evidence: level 2.

1. Background

As the Japanese population rapidly ages, age-associated diseases of the musculoskeletal system have also increased. Frequent problems include degenerative changes in the knee and the resulting pain. Approximately 60% to 70% of middle-aged and older Japanese women have degenerative arthritis in their knees and approximately 30% to 40% of them experience knee pain [1]. These figures are roughly double the rates experienced by men of the same age [1]. Knee pain has a direct influence on these women's ability to walk, stand up from a chair, ascend and descend stairways and perform other common activities of daily living [2]. Because knee pain is one of the factors that limits physical activity, middle-aged and older women have an urgent need for some way to deal with this problem.

Strength training focused on strengthening the quadriceps muscle has been shown to be an effective, conservative therapy for middle-aged and older women who suffer from knee pain associated with knee osteoarthritis (OA) [3,4]. Recently, whole-body vibration (WBV) has been gaining attention as a new strength training technique that is both safe and effective. WBV training does not rely upon heavy weights or dynamic movements for its effectiveness as a strength training technique. Rather, the participant mounts a platform and statically applies his or her own body weight onto the target site of the body. One major principal behind this technique is the acceleration created by the rapid oscillation of the platform which creates a gravitational field that surpasses gravitational acceleration (9.8 m/s^2). The second major principal is the reflexive mechanism known as the tonic vibration reflex which creates involuntary and sustained muscle contractions [5].

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We are aware of three studies that examine the effectiveness of WBV training on knee OA [6–8]. All of them reported significant improvement in objective assessments such as muscular strength and functional mobility performance. However, while two studies [7,8] concluded that WBV improved self-reported knee function (decreased WOMAC pain, stiffness and/or function score), the third study [6] reported no improvement, which illustrates that there is no consistent view on this issue. One reason for these contradictory results might be the difference in training volume (twice a week for eight weeks [6] vs. three times per week for 12 weeks [7,8]). Trans et al. [6] suggested that the applied program may not have the potential to alter physiological mechanisms to an extent that influences self-reported disease status. By increasing training frequency and improving the training exercises, participants may feel improvement in knee function during a limited eight week period. The exercise programs in previous studies [6–8] only included strength training with squat-type exercises. A recent systematic review [9] of exercise interventions for patients with knee OA found that incorporating strength training plus flexibility exercises improved participants' self-reported knee function more than strength training alone (standardized mean difference = −0.73 and −0.46, respectively). For WBV training, this combination also might be more effective for improving knee function.

The equipment used for WBV training can be divided into two types: the rotational vibration (RV) machine and the vertical-vibration (VV) machine [10]. RV machines have a vibrating platform mounted on a central axis so that the platform can rock right and left (like a seesaw). VV machines have a platform in the shape of a slab that can vibrate in all three spatial dimensions. The difference in the effectiveness of these two types of machines has not been established, but it is easier for users to maintain the correct training posture [10] when using VV machines rather than RV machines. This makes the VV machines well-suited to middle-aged and older persons suffering from knee pain. In recent years, training methods using the VV machines, which can produce vibrations in all three spatial dimensions, have come to be called "acceleration training" (AT) [5].

The objective of this study was to elucidate the effect AT with strength and flexibility exercises has on lower-limb muscular strength and power, functional mobility and self-reported knee function when used by middle-aged and older Japanese women who suffer from knee pain. A secondary objective was to investigate the effectiveness of AT on deformities as categorized by severity. This study hypothesized that AT can improve all aspects of knee function for all levels of severity.

2. Methods

2.1. Participants

The study was a single-blind, prospective, controlled study. A flowchart showing the progress of participants from recruitment and selection to the end of the study is shown in Fig. 1. The power analysis with settings at $\alpha = 0.05$, power $(1 - \beta) = 0.80$ and effect size = 0.58 [3] showed that a group of 26 participants was the required sample size in the AT group. Participants were recruited via advertisements placed in local information magazines with responses handled over the telephone. Inclusion criteria were 1. Post-menopausal women, 2. Age between 50 and 75 and 3. Suffering from knee pain. We received 80 responses. The exclusion criteria were 1. Use of a pacemaker, 2. In the acute phase of a disease, 3. Suffering from severe diabetes, 4. Suffering from rheumatic disease, 5. Unable to walk without support, 6. Being seen regularly at a hospital due to knee pain, 7. Engaging in strength training three or more times per week and 8. Unable to attend the study briefing or continuously attend the training.

There were 47 women interested in participating who fit the criteria: 32 were chosen for the three times per week AT training (AT group) and 15 were placed in the control group (C group) in which they would perform an exercise protocol at their homes. However, after these 47 women were examined by a physician, only 29 women in the AT group and nine women in the C group were found to be free of rheumatic disease and able to participate in the training. Table 1 shows their descriptive data. There were no significant differences in any category between the AT group and C group at the time baseline measurements were taken. This study was conducted with the approval of the ethics committee of the University of Tsukuba. All participants received both oral and written explanations of this study and their written consent was obtained. The nine participants in the C group were given the same post-study program as the participants in the AT group.

2.2. Study protocol

One month before participating in this study, participants were examined by an orthopedic surgeon, and one week before participating, we evaluated their lower-limb muscular strength and power, functional mobility and self-reported knee function. We also obtained radiographs on the 29 participants in the AT group to assess the degree of knee degeneration. One week after the study ended, all of the above tests were repeated.

Participants in the AT group participated in their training program three days per week with at least one day between each session for eight weeks (total of 24 times) (January 16, 2012 to March 9, 2012). Each session was 50 min long which included a 10-minute warm-up and flexibility training period, a 25-minute period of strength training with participants using their own weight and a 15-minute cool-down period. All exercises were performed on VV machines (POWER PLATE, POWER PLATE International, London, UK). The training program is detailed in Table 2 and Fig. 2. Six types of flexibility exercises and four types of cool-down exercises were performed in each session. The strength training exercises were designed to strengthen mainly the quadriceps (e.g. squats and lunge exercises) and surrounding muscles. The numbers of sets and exercises were gradually increased as the program progressed. Exercises were performed at a frequency of 30 Hz, vibration amplitude of 2.5 mm and for 30 s/set, which was well below the WBV training level (30 Hz, 4.0 mm, 10 min/day) suggested by Abercromby et al. [11] as the level which could pose physical danger to the participant. Except for the up-and-down exercise, all exercises were muscular-exertion types involving isometric muscular contractions. Each part of the up-and-down exercise was performed for 4 s in the following order: hip flexion, knee extension, knee flexion and hip extension.

During the eight weeks of the AT group's intervention, the participants in the C group were encouraged to perform exercises at home. Explanatory materials containing instructions on how to perform the exercises were distributed after the pre-test (week 0) and at the end of week 4. The goal was to perform exercises which were the same or similar to those performed by the AT group (Fig. 2) for the same amount of time and number of sets while standing, lying down and seated. Participants in the C group kept a record of their exercises which was submitted to the researchers after the study ended.

2.3. Outcomes

2.3.1. Muscular strength and power

A Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) was used to test the isometric (0 deg/s) knee extension peak torque and isokinetic (60 deg/s) knee extension/flexion peak torque and average power. Participant positioning for the knee extension and flexion trials has been described previously [12]. Participants performed maximal isometric knee extensions of 3-s duration at a knee joint angle of 120 deg (180 deg = full knee extension) [13]. Isokinetic knee extension and flexion trials were performed separately with angle of the knee joint ranging from approximately 90 deg to 180 deg. For each trial, participants performed two submaximal and two maximal contractions before testing. They then performed three maximal voluntary contractions each separated by a 5-s pause. A rest

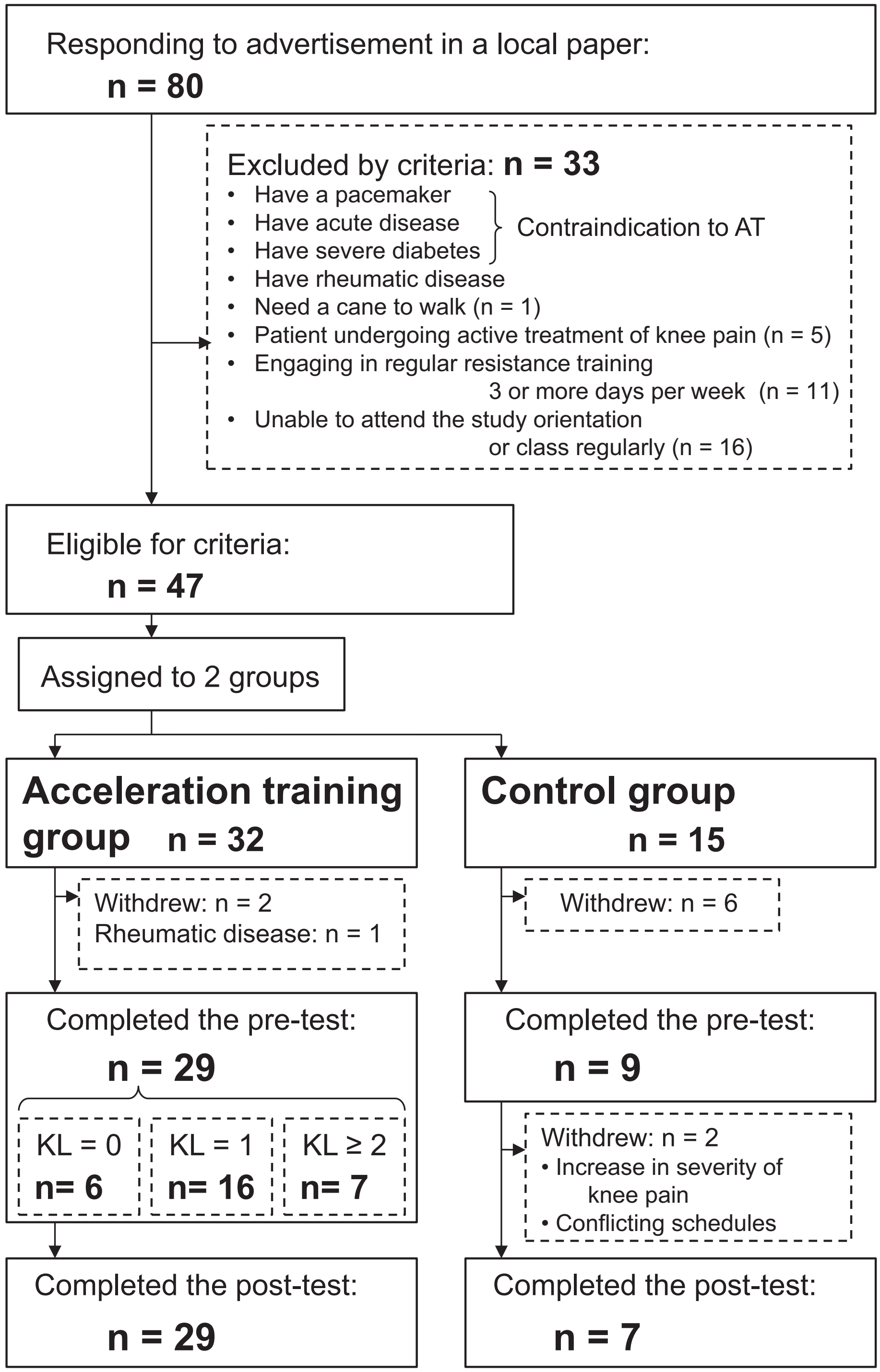

Fig. 1. Flow of subjects through trial. KL: Kellgren–Lawrence grading scale.

period of at least 5 min was allowed between each trial to exclude the effect of fatigue. Peak torque and average power were calculated by the Biodex System 3 Advantage software (version 3.03) and the highest value from each trial was recorded. Torque and power data were normalized per kilogram of body weight (Nm/kg and W/kg, respectively).

2.3.2. Functional mobility

The timed up and go test (TUG) was used to determine functional mobility [14], which is closely linked to lower-extremity muscle function. We measured the time a subject took to rise from a chair (40 cm height), walk 3 m, turn around and sit down again as fast as possible. The participants performed the test two times, and the faster time was recorded.

2.3.3. Self-reported knee function

We compiled information using the Japanese Knee Osteoarthritis Measure (JKOM) [15], which is a subjectively reported assessment criterion for knee function. The JKOM is an assessment criterion based on the Western Ontario and McMaster Universities Arthritis Index (WOMAC) [16] and the MOS short form 36 (SF-36) [17,18], which was created to reflect the lifestyle and environment particular to Japanese people. It includes 25 questions divided into the following four categories: pain and

Table 1
Descriptive data of subjects.

Participants		Control	AT	$P^{\dagger}$	AT (KL = 0)	AT (KL = 1)	AT (KL ≥ 2)	$P^{\ddagger}$
		n = 9	n = 29		n = 6	n = 16	n = 7	
Age	years	60.9 ± 4.6	62.1 ± 5.5	0.56	61.5 ± 3.7	60.8 ± 6.3	65.6 ± 3.4	0.15
Height	cm	154.2 ± 4.3	153.9 ± 5.8	0.87	152.7 ± 7.0	155.3 ± 5.4	151.6 ± 5.6	0.32
Body weight	kg	54.8 ± 6.8	56.2 ± 10.0	0.70	49.5 ± 1.8	57.2 ± 11.3	59.8 ± 8.8	0.15
Body mass index	kg/m^2	23.5 ± 2.9	24.2 ± 3.8	0.63	21.8 ± 2.3	24.1 ± 4.3	26.4 ± 2.4	0.09
Affected side	Bilateral (%)	2 (22.2%)	15 (51.7%)	0.12	3 (50.0%)	8 (50.0%)	4 (57.1%)	0.95
Self-reported knee function (JKOM)								
Total score	(25–125)	41.0 ± 17.1	42.3 ± 12.1	0.80	39.8 ± 4.0	39.5 ± 8.1	50.9 ± 19.8	0.10
Degree of pain (visual analogue scale)	(0–100)	27.2 ± 25.0	24.8 ± 23.1	0.79	27.0 ± 26.4	19.9 ± 16.3	34.0 ± 32.9	0.41
Pain and stiffness in knees	(8–40)	15.2 ± 5.3	15.3 ± 5.2	0.95	14.8 ± 1.9	13.9 ± 3.6	19.0 ± 8.3	0.09
Condition in daily life	(10–50)	14.1 ± 7.2	14.1 ± 4.3	0.98	12.7 ± 1.2	13.3 ± 3.0	17.1 ± 7.1	0.09
General activities	(5–25)	7.1 ± 3.5	8.3 ± 2.7	0.30	8.0 ± 1.8	7.5 ± 2.3	10.3 ± 3.5	0.07
Health condition	(2–10)	4.6 ± 1.7	4.6 ± 1.5	0.91	4.3 ± 1.0	4.8 ± 1.4	4.4 ± 2.1	0.75
Functional mobility								
Timed up and go		5.39 ± 0.76	5.77 ± 0.70	0.16	5.78 ± 0.69	5.64 ± 0.62	6.09 ± 0.86	0.38
Target knee joint		n = 11	n = 44		n = 12	n = 21	n = 11	
Intra articular injection experience	Yes (%)	2 (18.2%)	13 (29.5%)	0.45	2 (16.7%)	7 (33.3%)	4 (36.4%)	0.51
Puncture and drainage experience	Yes (%)	2 (18.2%)	4 (9.1%)	0.39	0 (0.0%)	1 (4.8%)	3 (27.3%)	0.048
Knee strength and power								
Isometric extension peak torque	Nm/kg	1.53 ± 0.37	1.44 ± 0.52	0.60	1.25 ± 0.46	1.54 ± 0.61	1.44 ± 0.35	0.32
Isokinetic extension peak torque	Nm/kg	1.15 ± 0.30[a]	1.16 ± 0.45	0.96	1.02 ± 0.48	1.29 ± 0.47	1.05 ± 0.32	0.16
Isokinetic extension average power	W/kg	0.67 ± 0.19[a]	0.64 ± 0.28	0.75	0.55 ± 0.28	0.73 ± 0.30	0.55 ± 0.18	0.11
Isokinetic flexion peak torque	Nm/kg	0.66 ± 0.13[b]	0.53 ± 0.23	0.11	0.46 ± 0.20	0.59 ± 0.25	0.49 ± 0.22	0.25
Isokinetic flexion average power	W/kg	0.45 ± 0.11[b]	0.36 ± 0.17	0.10	0.31 ± 0.14	0.40 ± 0.18	0.33 ± 0.16	0.29

a: n = 9, b: n = 10.
AT: acceleration training, KL: Kellgren–Lawrence grade, JKOM: Japanese Knee Osteoarthritis Measure.
† *P* value from Student's *t*-test.
‡ *P* value from 1-way ANOVA.

stiffness in knees, condition in daily life, general activities and health conditions. Subjects answer questions using a 5-point Likert scale. Each answer is scored with points ranging from 1 (absent or mild symptoms) to 5 (most severe symptoms) with total assessments ranging from 25 points (best) to 125 points (worst). The degree of knee pain is assessed using a 100 mm Visual Analogue Scale (VAS). Akai et al. [15] have confirmed that none of the questions have floor and ceiling effects and there is satisfactory internal consistency (Cronbach's $\alpha = 0.91$). In addition, concurrency for reproducibility and external criteria (SF-36 and WOMAC) via retesting was satisfactory.

Table 2
Characteristics of the acceleration training program.

Week		Measurement items				
0	Pre-test	Self-reported knee function Lower-limb muscle strength and power				
9	Post-test	Body morphology Radiographic testing (only at pre-test)				
Week	Exercise category	Exercise	Position (Fig. 2)	Frequency (Hz)	s/set	Number of set(s)
1, 2	Flexibility (six exercises)	Hamstring stretch	W1	30	30	1 (each leg)
		Calf stretch	W2	30	30	1 (each leg)
		Side stretch	W3	30	30	1 (each side)
		Quadriceps stretch	W4	30	30	1 (each leg)
		Back relaxer	W5	30	30	1
		Hip stretch	W6	30	30	1 (each side)
	Resistance training (four exercises)	Squat	R1	30	30	1 (1st week) → 2 (2nd week)
		Calves	R2	30	30	1 → 2
		Sit-up	R3	30	30	1 → 2
		Up and down	R4	30	30	1 (each leg) → 2
	Cool-down (three exercises)	Calf massage	C1	40	60	1
		Hamstring massage	C2	40	60	1
		Quadriceps massage	C3	40	60	1
		Back massage	C4	40	60	1
3, 4	Flexibility	(The same six exercises as the 1st and 2nd weeks.)				
	Resistance training (five exercises)	(The same four exercises as the 2nd week.)				
		+ Pelvic bridge	R5	30	30	1 (3rd week) → 2 (4th week)
	Cool-down	(The same four exercises as the 1st and 2nd weeks.)				
5 → 8	Flexibility	(The same six exercises as the 1st and 2nd weeks.)				
	Resistance training (six exercises)	(The same five exercises as the 4th week.)				
		+ Front lunge	R6	30	30	1 (each leg) (5th week) → 2 (6–8th weeks)
	Cool-down	(The same four exercises as the 1st and 2nd weeks.)				

The vibration amplitudes of all exercise programs were set to low (2.5 mm).

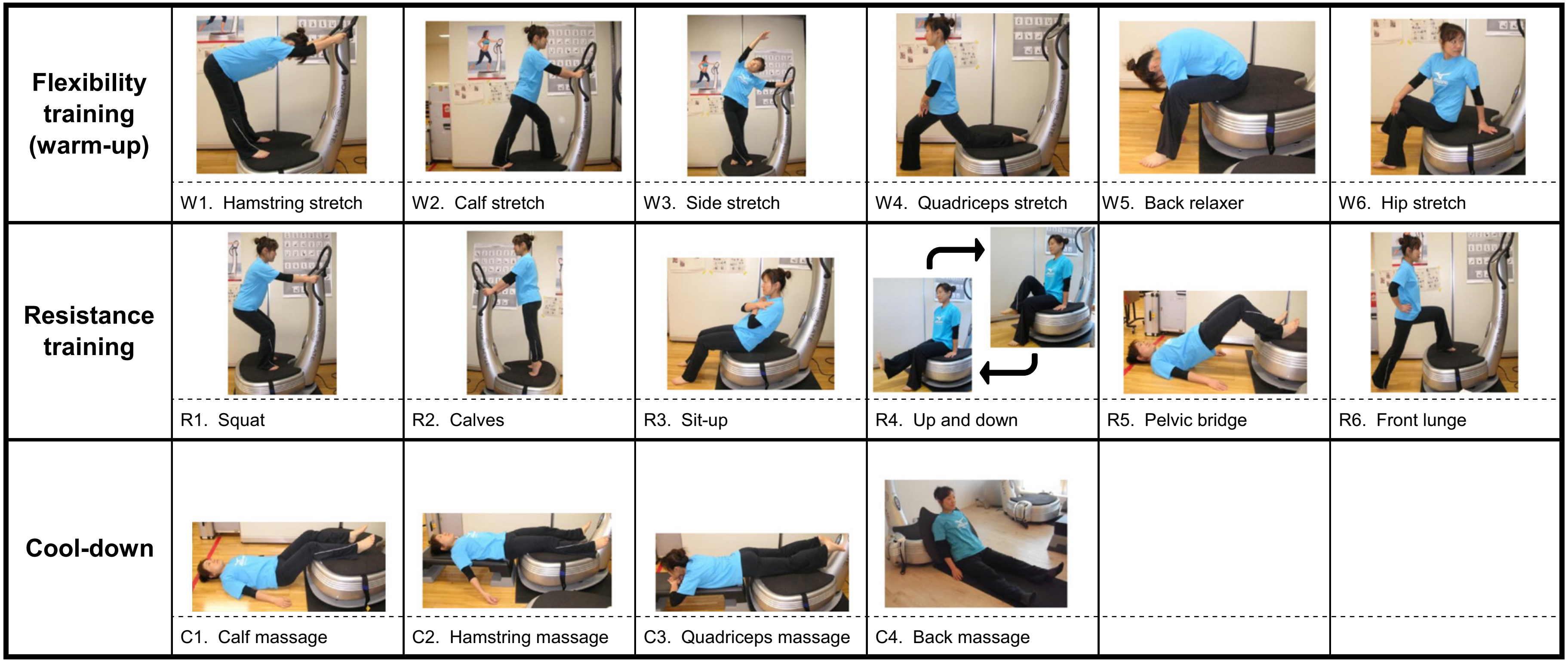

Fig. 2. Acceleration training position of each exercise.

2.3.4. Radiological severity of OA

Plain frontal radiographic views were taken of subjects' knees in the AT group, and the severity of OA was assessed using the Kellgren–Lawrence (KL) scale [19]. To assess the training program's benefits to the AT group, we evaluated severity of knee deformation by dividing the participants into three groups, 0 (none), 1 (doubtful) and 2 to 4 (minimal to severe), based on the KL categories. Since assessment of individual joints is impossible using the JKOM, participants were divided into three groups based on joints with severe pain levels. There were no significant differences in any category between these three groups except for pre-test puncture and drainage experience (Table 1).

2.4. Statistical analysis

We used G*Power 3.1.3 to perform the power analysis for the supposed sample size. As with the JKOM, the result for lower-limb muscular strength and power is shown as mean ± SD. We used the Student's t-test, 1-way ANOVA and chi-squared test to make comparisons at baseline. Comparisons of all groups both before and after training were done using the paired t-test. Differences in effect size due to differences in the training programs (AT group and C group) were determined by calculating the degree of change from pre- to post-training using the Student's t-test. The pre- and post-training effect sizes (Cohen's d) were determined by calculating the average change and excluding the pre-test standard deviation. Effect size (d) standards were as follows: small ($d = 0.2$), medium ($d = 0.5$) and large ($d = 0.8$) [20]. We used intention-to-treat (ITT) analyses to make all pre- and post-training comparisons. Except for the power analysis, all statistical processing was done using PASW Statistics 17.0 for Windows (SPSS, Inc., Chicago, IL, US). Statistical significance was set at 5%.

3. Results

3.1. Participation rate and dropouts

All 29 participants in the AT group continued in the study until and including the post-test with no dropouts. The training participation rate was 95.3%. This was calculated by determining the number of participant-training sessions actually utilized by participants, i.e. 663 (29 participants × 24 training sessions − number of missed training sessions) and dividing that by the total number of available participant training sessions, i.e. 696 (29 participants × 24 training sessions). Compliance with the home exercise program among the C group participants was 75.0%. This was calculated by dividing the number of participant-weeks in which participants exercised at least three times per week, i.e. 54 (nine participants × eight weeks − number of weeks not fully completed), by the total number of participant-weeks available, i.e. 72 (nine participants × eight weeks). One participant in the C group discontinued the exercises in week 2 due to worsening symptoms. One other participant in the C group did not complete the post-test due to scheduling problems. Thus, seven participants in the C group completed the study up to and including the post-test stage. We performed ITT analysis on the two participants who did not complete the post-test stage by using their pre-test results. During the C group pre-tests, however, one participant canceled the isokinetic knee extension & flexion, and another canceled the isokinetic knee extension trial. Thus, we excluded from analysis those pre-test variables for those participants.

3.2. AT effectiveness

The degrees of change between pre- and post-training for the AT group and the C group are shown in Table 3. In the AT group, the point scores of all JKOM categories except degree of pain decreased significantly indicating improved function. There were also significant reductions in TUG and significant improvements in all items of the lower-limb muscular strength and power category except for isometric knee extension peak torque. The only items that changed significantly in the C group were isometric knee extension peak torque and average power. Effect size (d) was small to large ($d = 0.21$–0.98) in the AT group, but medium or below ($d = 0.00$–0.65) in the C group. Comparing the degree of change in the groups revealed significant differences for JKOM total score, condition in daily life and TUG.

3.3. Comparison of OA severity

The degrees of change between pre- and post-training for three groups based on OA severity are shown in Table 3. There were significant decreases in the JKOM total score in the KL = 0 and 1 groups, but no significant change in the KL ≥ 2 group. The KL = 0 group had a significant change in TUG. The effect size (d) was $d = 0.65$–1.17 for all groups

Table 3
Amount of changes in self-reported knee function, functional mobility and knee strength and power measurements by groups.

		Control n = 9			AT n = 29			P‡	AT (KL = 0) n = 6			AT (KL = 1) n = 16			AT (KL ≥ 2) n = 7		
Self-reported knee function (JKOM)		Mean ± SD	P†	d	Mean ± SD	P†	d		Mean ± SD	P†	d	Mean ± SD	P†	d	Mean ± SD	P†	d
ΔTotal score	point	1.1 ± 8.6	0.71	0.06	−4.8 ± 7.1	<0.01	0.40	0.04	−7.7 ± 6.3	0.03	1.91	−4.6 ± 8.2	0.04	0.57	−2.9 ± 4.3	0.13	0.14
ΔDegree of pain (visual analogue scale)	mm	0.7 ± 20.5	0.93	0.03	−4.9 ± 20.3	0.20	0.21	0.48	−16.5 ± 19.6	0.10	0.63	−2.5 ± 19.3	0.61	0.15	−0.6 ± 22.3	0.95	0.02
ΔPain and stiffness in knees	point	−0.2 ± 3.2	0.84	0.04	−1.9 ± 3.3	<0.01	0.37	0.18	−3.7 ± 2.7	0.02	1.89	−1.3 ± 3.9	0.19	0.37	−1.9 ± 2.2	0.07	0.22
ΔCondition in daily life	point	1.0 ± 3.0	0.35	0.14	−1.2 ± 2.4	0.01	0.27	0.03	−1.8 ± 1.2	0.01	1.51	−1.5 ± 2.9	0.06	0.51	0.1 ± 1.6	0.82	0.02
ΔGeneral activities	point	0.0 ± 1.7	1.00	<0.01	−1.0 ± 1.8	<0.01	0.38	0.14	−1.2 ± 2.5	0.30	0.65	−0.9 ± 1.8	0.05	0.41	−1.1 ± 1.7	0.12	0.33
ΔHealth condition	point	0.3 ± 1.5	0.52	0.20	−0.7 ± 1.4	0.01	0.47	0.06	−1.0 ± 1.5	0.18	0.97	−0.9 ± 1.4	0.02	0.64	0.0 ± 1.2	1.00	0.00
Functional mobility																	
ΔTimed up and go		−0.12 ± 0.51	0.51	0.15	−0.68 ± 0.54	<0.01	0.98	0.01	−0.73 ± 0.73	0.06	1.06	−0.72 ± 0.54	<0.01	1.17	−0.56 ± 0.40	<0.01	0.65
Knee strength and power		n = 11			n = 44				n = 12			n = 21			n = 11		
ΔIsometric extension peak torque	Nm/kg	0.20 ± 0.29	0.06	0.54	0.31 ± 0.44	<0.01	0.61	0.43	0.42 ± 0.38	<0.01	0.91	0.38 ± 0.53	<0.01	0.63	0.07 ± 0.11	0.06	0.21
ΔIsokinetic extension peak torque	Nm/kg	0.05 ± 0.17[a]	0.43	0.16	0.10 ± 0.35	0.06	0.23	0.67	0.29 ± 0.43	0.035	0.62	0.04 ± 0.35	0.64	0.08	0.02 ± 0.13	0.58	0.07
ΔIsokinetic extension average power	W/kg	0.04 ± 0.07[a]	0.19	0.19	0.13 ± 0.20	<0.01	0.48	0.18	0.27 ± 0.22	<0.01	0.94	0.09 ± 0.20	0.06	0.30	0.08 ± 0.09	0.01	0.42
ΔIsokinetic flexion peak torque	Nm/kg	0.08 ± 0.08[b]	0.03	0.58	0.15 ± 0.17	<0.01	0.63	0.22	0.22 ± 0.21	<0.01	1.13	0.13 ± 0.15	<0.01	0.52	0.10 ± 0.13	0.03	0.43
ΔIsokinetic flexion average power	W/kg	0.07 ± 0.07[b]	0.01	0.65	0.12 ± 0.12	<0.01	0.72	0.24	0.17 ± 0.14	<0.01	1.18	0.11 ± 0.11	<0.01	0.63	0.08 ± 0.10	0.03	0.48

a: n = 9, b: n = 10.
AT: acceleration training, KL: Kellgren–Lawrence grade, JKOM: Japanese Knee Osteoarthritis Measure.
† P value from paired t-test (pre- vs. post-test).
‡ P value from Student's t-test (Con vs. AT).

at medium and above. In the muscular strength and power category, all groups improved significantly in a majority of the items. The effect size (d) for the KL = 0 group was medium and above (d = 0.62–1.18).

4. Discussion

We confirmed that an eight week, three times per week AT program significantly improved both functional mobility as assessed by performance tests and self-reported knee function better than home-exercise without vibratory stimulus. Avelar et al. [7] showed that knee OA patients (average age 75 years) experienced significant improvement in functional mobility (TUG, chair stand test, 6-minute walk test) as a result of a 12-week, three times per week squat training program using WBV machines. Bautmans et al. [21] used the same type of WBV machines as we used in this study and showed that elderly people living in facilities who participated in a six week, three times per week program improved their TUG results. In addition, the research groups of Avelar et al. [7] and Simão et al. [8] reported notable improvement in all WOMAC categories after a 12-week, three times per week WBV squat training, but Trans et al. [6] did not see improvement with this same training after eight weeks at twice a week.

In this study, despite a duration of only eight weeks, we confirmed significant improvement in self-reported knee function due to an increased frequency of three times per week. Furthermore, we provided not only strength training but also flexibility training. Evidence on the effectiveness of combining both types of training for patients with knee OA has already been established with the systematic review by Uthman et al. [9]. One of the important factors for improving both self-reported knee function and functional mobility might be the improvement in the strength of muscles surrounding the knee. However, the relationship between change in muscular strength, power, JKOM total score and TUG was weaker than expected ($|r| = 0.01–0.27$, data not shown). It is hoped that combining strength and flexibility exercises in an AT program will improve not only muscular strength and power but also flexibility, proprioceptive sensibility and balance [5]. This study did not investigate this aspect of AT, but improvements in self-reported knee function and functional mobility probably run in tandem with improvements in muscular strength and power.

The improvement in lower-limb muscular strength and power we observed in this study is supported by previous studies of healthy middle-aged and older persons. Roelants et al. [22] showed that when women aged 58 to 74 participated in a 24-week AT program three times per week using the same VV machines that were used in this study, both isometric and isokinetic knee extension torques improved approximately 12%. Although the WBV machines used by Trans et al. [6] were different than the WBV machines in our study, they showed in their study that knee OA patients improved their isometric knee extension muscular strength after an eight week, twice a week WBV training course. The basis of WBV training programs such as AT is the acceleration caused by vibrations of the platform. The force (F) exerted during strength training depends on mass (m) and acceleration (a), which is expressed as $F = ma$. In conventional strength training programs, force (F) is adjusted by changing the mass (m). However, in AT, force is adjusted by altering acceleration via the frequency (Hz) and amplitude (mm) of vibrations.

This study is the first to investigate the effect that WBV training has on varying degrees of knee OA severity. There was significant improvement in several categories for all degrees of knee OA severity suggesting that AT is effective on OA of any severity. In the KL = 0 group in particular, many of the test categories showed a large effect size and a trend indicating more notable improvements. The need for a study investigating the effect of strength training on all degrees of severity has been mentioned in the past [3], but there has not yet been a sufficient study on either conventional or WBV training. Patel et al. [23] reported significant improvement in all categories of self-reported scores (WOMAC and Oxford Knee Score) in their investigation of the effect on all KL categories of an eight week training program that included strength training and aerobic exercise plus an education program. However, they did not find a consistent trend in effect size for each degree of severity.

It should be noted that there were no dropouts in the AT group in our study and that the rate of participation was extremely high. On the other hand, compliance in the C group with the at-home exercise program was low, and this limited the results obtained in this study. The participation rates suggest that for middle-aged and older women with knee pain, AT is a training method that is easy to perform and maintain.

This study had several limitations. First, since the primary objective of our study was to detect statistical significance in the AT group, we placed a larger number of participants in the AT group, and this study could not be conducted as a randomized, controlled trial. Furthermore, there were few participants in each of the groups due to the fact that the secondary objective was to investigate the effectiveness relative to OA severity. Although there was a large effect size, some of the cases were not statistically significant. Thus, future studies will have to include larger number of participants. Secondly, we could not discuss in detail whether combining strength and flexibility training is better than separate programs of strength and flexibility because we did not have strength-only or flexibility-only training groups. In addition to this, the effect of flexibility training itself was unclear since we did not measure variables directly related to flexibility such as range of motion. Lastly, since only one kind of vibration machine was used in this study, and the participation protocol was different from previous studies, it is impossible to comment on differences that may emerge when different types of machines are used.

An eight week, three times per week AT program containing strength and flexibility training was shown to be safe while eliciting a high participation rate in middle-aged and older Japanese women with knee pain. In addition, our data suggest that such a program can improve functional mobility and self-reported knee function. These AT results exceeded those obtained via weight-bearing resistance training without vibratory stimulus. The results also suggest that AT is an effective training program for all degrees of OA severity.

Conflict of interest

There is no conflict of interest.

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