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Original Article

Virtual Reality-Based Wii Fit Training in Improving Muscle Strength, Sensory Integration Ability, and Walking Abilities in Patients with Parkinson's Disease: A Randomized Control Trial☆

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SUMMARY

Background: Virtual reality (VR) systems have been proven to increase motor performance in stroke and elderly patients. However, the effects have not been established in patients with Parkinson's disease (PD). The aim of this study was to examine the effects of VR-based training in improving muscle strength, sensory integration ability, and walking abilities in patients with PD through a randomized controlled trial.
Methods: Thirty-six individuals who have been diagnosed with PD were randomly assigned to one of three groups ($n = 12$ for each group). Participants performed VR-based Wii Fit exercise (VRWii group) or traditional exercise (TE group) for 45 minutes, followed by treadmill training for another 15 minutes for 12 sessions in 6 weeks. Participants in the control group did not undergo the structured exercise program, but received fall-prevention education instead. The study outcomes included lower extremity muscle strength, sensory integration ability, walking velocity, stride length, and functional gait assessment. All outcomes were assessed at baseline, after training, and at 1 month follow-up.
Results: Both the VRWii and TE groups showed more improvement in level walking velocity, stride length, functional gait assessment, muscle strength, and vestibular system integration compared with the control group after training and at 1 month follow-up. The VRWii training, but not the TE training, resulted in greater improvement in visual system integration than the control.
Conclusion: VRWii training is as beneficial as TE in improving walking abilities, sensory integration ability, and muscle strength in patients with PD, and such improvements persisted for at least for 1 month. VRWii training is thus suggested to be implemented in patients with PD.

1. Introduction

With the progression of Parkinson's disease (PD), patients may develop a festinating gait with decreased gait speed and stride length in level walking. The slow walking speed and reduced stride length limit the independence and quality of life of these patients. In addition, PD patients also showed impairments in functional walking tasks such as turning, obstacle crossing, and stair climbing. The impairments in level walking and functional walking can lead to a fall. It has been reported that more than two-thirds of community-dwelling individuals with PD experience falls once per year[1]. Therefore, improvement of walking abilities is recognized as an important goal of treatment. Previous studies stated that muscle strength correlated with gait velocity, stride length, and functional ambulation ability[2]. Reduced muscle power is associated with slower walking velocity and falls[3]. In addition to muscle strength, impaired central integration of vision, somatosensation, and vestibular systems are reported in patients with PD[4]. These deficits in integrating sensory inputs contribute to postural instability and decreased gait performance[5]. Previous studies further stated that deficit in sensory integration ability correlated with freezing of gait, turning deficit, and unstable obstacle crossing performance[6].

☆ Conflicts of interest: The authors have no conflicts of interest to declare.

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Traditional exercises (TEs), such as stretching, strengthening, balance exercise, and treadmill training, are found to improve muscle strength, balance, gait performance, and motor function in patients with PD[7,8]. Virtual reality (VR) training has been used in elderly and stroke patients to improve postural control and mobility because of the interaction with a computer-generated scenario[9,10]. Recently, the gaming industry has developed a variety of affordable and accessible VR systems such as Wii Fit. Wii Fit balance board detects the user's body movements to transform a specific action in the game, thus providing a visual feedback to the user in real time. Some studies reported that Wii Fit training can exert beneficial effects on functional activities, balance, quality of life, and Unified Parkinson's Disease Rating Scale in PD patients[11]. However, whether such training can also exert beneficial effects in muscle strength, sensory integration ability, and walking ability in patients with PD is not immediately known.

Therefore, the purpose of this study was to establish the effects of VR-based Wii Fit exercise (VRWii) on improving muscle strength, sensory integration ability, and walking abilities by comparing the TE and the control groups. Our results can provide suggestions for the possible use of VRWii training for patients with PD.

2. Materials and methods

2.1. Participants

Participants were recruited from medical centers in Taiwan and were diagnosed with idiopathic PD by a neurologist. The diagnostic criteria were as follows: (1) at least two of the following features were present: resting tremor, bradykinesia, rigidity, and asymmetric onset; and (2) at least one feature was tremor or bradykinesia. All participants met the following inclusion criteria: (1) Hoehn and Yahr Stages I—III, (2) ability to walk independently without any walking aids, (3) stable medication usage, (4) with or without deep brain stimulation, and (5) a score of 24 or higher in the Mini-Mental State Examination. The exclusion criteria were as follows: (1) unstable medical condition; (2) history of other neurological, cardiopulmonary, or orthopedic diseases known to interfere with the study; and (3) use of cardiac pacemaker. A total of 43 individuals were identified as potential participants for this study. Of these, 36 participants provided informed consent. This study was approved by the Institutional Human Research Ethics Committee of Chang Gung Medical Foundation, Linkou, Taiwan (Figure 1).

2.2. Experimental design

This study was designed as a single-blinded, stratified, randomized controlled trial. The participants were stratified using the Hoehn and Yahr scale: Stages 1—1.5, Stages 2—2.5, and Stage 3. An individual independent of the study selected one of a set of sealed envelopes to assign participants to the VRWii group, TE group, or control group prior to the intervention. Participants in the VRWii group performed 45 minutes of VRWii exercise followed by 15 minutes of treadmill training. Participants in the TE group performed 45 minutes of TE followed by 15 minutes of treadmill training. Participants in the control group, who did not undergo a structured exercise program, received fall-prevention education. The exercise programs were administered for a total 12 sessions (2 sessions per week) over a 6-week period. All outcomes were measured the day prior to the intervention (pre), the day after completing the intervention (post), and the 30th day after completing the intervention (follow-up) by a physical therapist blinded to the group assignment. The measurement and intervention were conducted with the patients in the "on" state when they were moving freely and easily without excessive rigidity or tremor.

2.3. Sample size and power calculation

GPower 3.1 was used to calculate the sample size and statistical power. Sample size was calculated by a given α error (0.05), power ($1 - \beta$ error $= 0.8$), and effect size (calculated by mean and standard deviation of the variables). Statistical power was calculated by effect size, α error, and sample size.

2.4. Interventions

2.4.1. VRWii exercise

The Wii Fit Plus gaming system and Wii Fit balance board (Nintendo Phuten Co., Ltd, Taipei, Taiwan) were used for VRWii exercise. The Wii Fit balance board is a novel system that tracks changes in the center of pressure during an exercise game. A virtual environment was displayed on a 230-cm (width and height) screen in front of the participant. Through avatar technology, images were projected on the screen through a projector. The virtual character provides instantaneous visual or auditory feedback. Participants can initiate the virtual character and adjust their own movements according to the feedback in real time. At the end of the game, the Wii Fit system also provides the total score on the screen. In each Wii Fit exercise session, participants underwent 10 minutes of yoga exercise, 15 minutes strengthening exercise, and 20 minutes of balance game.

(1) *Yoga exercises*. The yoga exercises were a combination of stretching, strengthening, and balance exercises. The yoga program includes sun-salutation modified lunges, chair pose, tree pose, and table top in standing position.
(2) *Strengthening exercises*. This exercise program was similar to that in the TE group but set in a VR-based environment. Ankle weights for each leg were also used, starting from 1 kg and gradually increased to 2 kg for each leg.
(3) *Balance games*. The balance games included the football game, marble balance, ski slalom, and balance bubble. When performing these games, participants needed to shift their COM as quickly and accurately as possible to hit the football, make the rolling marble in the hole, ski without hitting the obstacles, and navigate the bubble through the maze without popping it.

2.4.2. TE

The TE program included 10 minutes of stretching exercises, 15 minutes of strengthening exercises, and 20 minutes of balance exercise training in each session.

(1) *Stretching exercises*. The stretching exercise focused on the upper body and the upper and lower extremities with gentle joint extension and flexion and trunk rotation in a standing position. Deep breathing was emphasized during the exercise.
(2) *Strengthening exercises*. The strengthening exercise focused on the lower extremity muscles that are important for posture, balance, and gait. Participants performed exercises including bilateral alternate: (i) hip and knee flexion/extension, (ii) forward/sideward steps, (iii) heel and toe raises, and (iv) squatting. Participants performed three sets of 10—15 repetitions for each activity. Ankle weights for each leg started from 1 kg and gradually increased to 2 kg for each leg. Natural breathing was emphasized during the exercise.

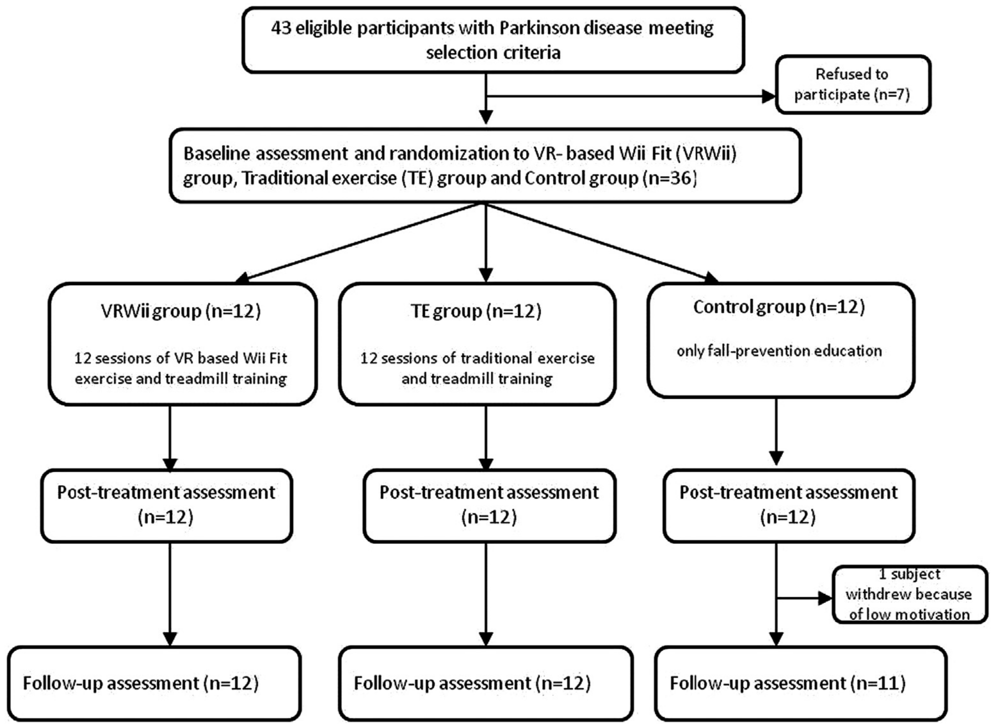

Figure 1. Flowchart of participants recruited in this study.

(3) *Balance exercises*. The balance exercises were a combination of dynamic balance training and sensory integration training. The protocols were (i) symmetric weight shifting with slow and fast speed, (ii) catching balls throw by therapist, (iii) multidirectional stepping in a standing position, (iv) single-leg stance with eye open/close, and (v) standing on a foam with eye open/close.

2.4.3. Treadmill training

Participants in both exercise groups received treadmill training (Biodex, Shirley, NY, USA) after the above-mentioned exercise training for 15 minutes each time. The treadmill speed was set at 80% of the individual's overground comfortable walking speed and increased by an increment of 0.2 km/h per 5 minutes as tolerated.

2.5. Outcome measures

2.5.1. Walking ability

(1) *Level walking performance*. The GAITRite system (CIR Systems, Peekskill, NY 10566, USA) was used to measure the spatial temporal gait variables during level walking. It is a 3.66-m-long and 0.61-m-wide electronic walkway with 13,824 sensors encapsulated in a rollup carpet to identify footfall contacts. During the test, the GAITRite walkway was placed in the middle of the 10-m hallway to minimize the effect of acceleration and deceleration. Participants in the study were asked to walk at a comfortable speed without walking aids for three times. The data from three trials of walking were averaged. The spatiotemporal variables recorded and analyzed in this study were gait velocity and stride length.

(2) *Functional gait performance*. Functional gait assessment (FGA) was used to evaluate the participant's ability to modify gait in response to changing task demands. The FGA comprises 10 items: (i) gait level surface, (ii) change in gait speed, (iii) gait with horizontal head turns, (iv) gait with vertical head turns, (v) gait and pivot turn, (vi) step over obstacle, (vii) gait with narrow base of support, (viii) gait with eyes closed, (ix) ambulating backward, and (x) steps. Each item is scored from 0 to 3, leading to a maximum total score of 30. A higher score indicates better functional gait performance. The validity and reliability of the FGA were reported in a previous study[12].

2.5.2. Muscle strength

The maximal isometric muscle strength was evaluated using a handheld dynamometer (PowerTrack II; JTech Medical, Midvale, UT 84047, USA). The muscle groups measured included hip flexors, hip extensors, knee flexors, knee extensors, ankle dorsiflexors, and ankle plantarflexors. The testing position for the hip flexors and knee extensors was sitting with the hips and knees flexed at 90°. The testing position for the hip extensors and knee flexors was the prone position with the knee flexed at 90°. The testing position for the ankle dorsiflexors was the supine position with the hip and knee straight, and the supine position with the hip and knee flexed at 90° supported by a wooden block for the ankle plantarflexors. The participants exerted a maximum force for 5 seconds. Three trials were obtained with a 15-second rest between trials. The average of three trials was used for data analysis.

2.5.3. Sensory integration ability

The sensory integration ability expressed as the sensory ratios was assessed using the sensory organization test (SOT) of the Balance Master system. During the test, the participants were instructed to stand as still as possible with their arms at their sides and eyes looking forward. Through the sway of the visual surround and support surfaces, inaccurate information was delivered to the

Table 1
Demographic characteristics of included participants.

	Control ($n = 12$)	TE ($n = 12$)	VRWii ($n = 12$)
Age (y)	64.6 ± 8.6	65.1 ± 6.7	67.3 ± 7.1
Sex (male/female)	5/7	6/6	6/6
Disease duration (y)	6.4 ± 3.0	6.9 ± 2.8	7.9 ± 2.7
Hoehr and Yahr stage	1.9 ± 0.8	2.0 ± 0.8	2.0 ± 0.7
1−1.5	5	6	5
2−2.5	4	3	4
3	3	3	3
MMSE	29.7 ± 0.6	29.8 ± 0.3	29.5 ± 0.7
BMI (weight/height^2)	21.5 ± 1.5	22.8 ± 3.3	23.0 ± 1.3

Data are presented as n or mean ± standard deviation.
BMI = body mass index; MMSE = Mini-Mental State Examination; TE = traditional exercise; VRWii = virtual reality-based Wii Fit exercise.

somatosensory, visual, and vestibular systems under each of six sensory conditions (from SOT 1 to SOT 6). The somatosensory (SOT 2/SOT 1), visual (SOT 4/SOT 1), and vestibular (SOT 5/SOT 1) integration ability represent the patient's ability to use inputs from these sensory systems for postural control and balance maintenance. These can also identify impairments of individual sensory systems[13].

2.6. Statistical analysis

Descriptive statistics were generated for all variables, and distributions of variables were expressed as mean ± standard deviation. Intergroup differences among baseline characteristics were evaluated using one-way analysis of variance or Chi-square analysis. Change values were calculated by subtracting the baseline data from the posttraining data, or by subtracting the baseline data from the follow-up data. To analyze intergroup improvement, the changes values were analyzed using one-way analysis of variance with group as a factor, followed by Tukey *post hoc* test. The statistical significance was set at $p < 0.05$.

3. Results

A total of 36 participants participated in this study and were randomly assigned to the control group, TE group, or VRWii group ($n = 12$ for each group). None of the participants reported any adverse events. Only one participant in the control group withdrew during the follow-up stage owing to low motivation. There were no significant differences in baseline demographic characteristics among the groups (Table 1). Similarly, there were no significant differences in all the preintervention-related outcome measures (Tables 2−4).

3.1. Walking abilities

The results for walking abilities are shown in Table 2. Both the VRWii and TE groups showed significant improvements in stride length, velocity, and FGA compared to the control group after the training and at 1 month follow-up. However, there was no significant difference between the VRWii and the TE groups.

3.2. Muscle strength

The results for muscle strength are shown in Table 3. Both the VRWii and TE groups showed significant improvements in hip flexors, knee flexors/extensors, and ankle dorsiflexors/plantarflexors compared to the control group after the training and at 1 month follow-up. However, there was no significant difference between the VRWii group and the TE group.

3.3. Sensory integration ability

The results for SOT are shown in Table 4. Both the VRWii and TE groups showed significant improvements in vestibular integration ability compared to the control group after the training and at 1 month follow-up. The VRWii group also showed significant improvements in visual integration ability compared to the control group after the training and at 1 month follow-up.

4. Discussion

In this study, we demonstrated that VRWii exercise is equally effective as TE in improving the walking abilities of patients with PD. These improvements in walking abilities were also accompanied with concurrent increases in muscle strength and sensory integration ability. Furthermore, such improvements can persist for at least 1 month.

A previous study stated that resistance training induced gains in neuromuscular function, which may lead to an adaptive increase in lower extremity muscle size or change the intrinsic contractile characteristics of muscle[14]. In our results, VRWii and TE demonstrated a similar training effect in muscle strength. Therefore, VRWii training might also have exerted its effect through the same mechanism as TE for the improved muscle strength. The relationships between muscle strength and gait velocity, stride length[5], and functional ambulation ability[2] have been established previously. In our present study, both the VRWii and TE groups received repetitive resistance training such as heel raise, squatting, and stepping. These programs were task-oriented and were observed to significantly improve hip, knee, and ankle strength[7]. From our results, we

Table 2
Comparison of walking abilities.

	Control ($n = 12$)			TE ($n = 12$)			VRWii ($n = 12$)		
	Pre	Post	Follow-up[b]	Pre	Post	Follow-up	Pre	Post	Follow-up
Level walking									
Velocity (cm/s)	87.53 ± 8.28	85.73 ± 12.74	87.23 ± 17.35	84.35 ± 22.10	95.88 ± 18.05	94.16 ± 23.78	84.20 ± 21.68	101.42 ± 16.71	100.1 ± 22.04
Change values[a]		−1.80 ± 7.01	−0.30 ± 13.36		11.53 ± 8.74*	9.81 ± 8.11*		17.21 ± 7.52*	15.98 ± 10.84*
Stride length (cm)	95.96 ± 17.20	94.22 ± 19.43	91.98 ± 23.55	95.00 ± 20.63	107.58 ± 15.39	105.18 ± 21.12	92.96 ± 19.06	108.43 ± 16.33	107.39 ± 18.68
Change values[a]		−1.73 ± 6.60	−3.97 ± 9.95		12.58 ± 7.02*	10.18 ± 4.66*		15.46 ± 10.52*	14.42 ± 12.19*
FGA	19.66 ± 4.27	19.33 ± 4.18	19.41 ± 4.25	18.33 ± 3.14	22.66 ± 3.49	22.50 ± 3.60	18.66 ± 3.25	24.08 ± 2.81	24.00 ± 2.76
Change values[a]		−0.33 ± 1.07	−0.25 ± 1.05		4.33 ± 1.15*	4.16 ± 1.19*		5.41 ± 1.37*	5.33 ± 1.37*

Data are presented as mean ± standard deviation.
*$p < 0.05$ versus control.
FGA = functional gait assessment; TE = traditional exercise; VRWii = virtual reality-based Wii Fit exercise.
[a] Change values were calculated by subtracting the baseline data from the posttraining data (post) or by subtracting the baseline data from the follow-up data (follow-up).
[b] Control ($n = 11$).

Table 3
Comparison of muscle strength.

	Control (n = 12)			TE (n = 12)			VRWii (n = 12)		
	Pre	Post	Follow-up[b]	Pre	Post	Follow-up	Pre	Post	Follow-up
Hip flexors (N)	132.9 ± 30.5	130.9 ± 28.0	126.6 ± 18.2	129.1 ± 26.2	150.5 ± 21.3	153.5 ± 24.2	125.9 ± 36.2	146.2 ± 30.4	143.1 ± 38.6
change values[a]		−1.9 ± 12.3	−6.3 ± 22.9		21.3 ± 17.4*	24.4 ± 20.9*		20.3 ± 15.2*	17.1 ± 14.4*
Hip extensors (N)	81.8 ± 22.46	78.8 ± 24.9	81.4 ± 25.5	82.3 ± 36.1	100.0 ± 34.0	97.9 ± 32.8	77.4 ± 25.7	102.7 ± 27.7	93.9 ± 18.0
change values[a]		−2.9 ± 24.8	−0.3 ± 24.6		17.6 ± 10.5*	15.5 ± 12.4		25.2 ± 16.6*	16.4 ± 20.5
Knee flexors (N)	109.3 ± 16.1	111.0 ± 17.9	110.5 ± 19.4	105.9 ± 31.7	135.1 ± 31.0	135.8 ± 31.7	102.4 ± 32.9	126.2 ± 34.6	125.1 ± 38.4
change values[a]		1.6 ± 9.6	1.1 ± 13.9		29.2 ± 22.3*	29.8 ± 20.4*		23.7 ± 27.7*	22.6 ± 27.0*
Knee extensors (N)	140.1 ± 38.0	136.7 ± 8.4	136.0 ± 24.3	137.0 ± 45.5	170.1 ± 40.4	164.3 ± 44.2	134.6 ± 34.3	166.5 ± 29.0	164.1 ± 41.0
change values[a]		−3.7 ± 29.2	−4.4 ± 25.5		33.0 ± 24.4*	27.3 ± 24.5*		31.9 ± 27.2*	29.5 ± 29.6*
Ankle dorsiflexors (N)	109.2 ± 21.4	107.7 ± 20.8	101.9 ± 23.4	98.2 ± 32.1	137.5 ± 27.0	125.8 ± 27.9	104.7 ± 28.6	142.3 ± 39.5	139.4 ± 40.6
change values[a]		−1.4 ± 13.5	−7.3 ± 13.1		39.2 ± 29.3*	27.5 ± 28.5*		37.5 ± 48.5*	34.6 ± 34.4*
Ankle plantarflexors (N)	128.7 ± 33.6	133.1 ± 32.9	129.6 ± 27.0	120.5 ± 36.7	156.0 ± 32.0	149.2 ± 37.8	117.2 ± 26.8	157.0 ± 32.1	155.1 ± 41.9
change values[a]		4.4 ± 30.7	0.9 ± 35.1		35.5 ± 19.8*	28.7 ± 13.6*		39.7 ± 22.3*	37.9 ± 25.3*

Data are presented as mean ± standard deviation.
*$p < 0.05$ versus control.
TE = traditional exercise; VRWii = virtual reality-based Wii Fit exercise.
[a] Change values were calculated by subtracting the baseline data from the posttraining data (post) or by subtracting the baseline data from the follow-up data (follow-up).
[b] Control (n = 11).

further demonstrated that improved muscle strength can translate to improved walking abilities.

The somatosensory, visual, and vestibular integration ability represent the use of different sensory systems in maintaining postural control, which directly influences balance and gait. In this study, we noted that both VR-based Wii exercise and TE can improve the sensory integration ability, especially the vestibular system. In our treatment program, patients in both exercise groups are required to change in direction of body weight and move their head to gaze. A previous study stated that an increase in the weighting of vestibular inputs is required to prepare for the ensuing change in direction[15]. As such, improved utilization of vestibular feedback would be expected to result in better postural control leading to improved walking abilities as demonstrated in our study. Furthermore, the VR-based Wii training also exerted beneficial effects on vision sensory integration, which was not seen after TE. The possible reasons for such improvements may be attributable to the massive optical flow in the virtual environment with visual feedback during the VR-based Wii training. A previous study stated that PD patients relied on visual feedback for task execution and postural control[16]. However, even with improved visual integration ability in our study, gait performance was not significantly better in the VRWii group as compared with the TE group, although a trend was noted. Therefore, these 12 sessions of training in 6 weeks may not be enough to document the augmented effect of VR for patients with PD.

In this study, we not only measured the stride length and velocity in level walking, but also the functional gait performance to indicate the walking ability. During the FGA, tasks such as gait with horizontal/vertical head turns, gait and pivot turn, step over obstacle, and gait with eyes closed are balance challenging and involve complex integration of multiple sensory systems and motor output. According to our study, both VR-based Wii exercise and TE resulted in significant improvements in functional gait performance possibly because of the improved sensory integration ability and muscle strength of lower extremities.

There are several limitations in this study. First, the estimated sample size is only 20 for each group; therefore, a larger randomized controlled trial is suggested to validate the benefits of the VR intervention documented in the present study. Despite the relatively small sample size, the statistical power is strong in our outcomes (gait velocity, 0.89). Second, the training therapist was not blinded, which may introduce biases in the results. Third, the VRWii group received 15 minutes of treadmill training. Even though the intensity is relatively low, the effect in the exercise groups may be attributed to the treadmill training. Fourth, the 4-point scale of FGA may not be sensitive enough to reflect the small quality changes in gait performance.

In summary, VR-based Wii exercise is as beneficial as TE. Both exercise programs (for 12 sessions) can significantly improve walking ability, sensory integration ability, and lower extremity

Table 4
Comparisons of sensory organization ability.

	Control (n = 12)			TE (n = 12)			VRWii (n = 12)		
	Pre	Post	Follow-up[b]	Pre	Post	Follow-up	Pre	Post	Follow-up
Somatosensory	96.6 ± 3.5	96.4 ± 3.3	95.9 ± 2.9	96.4 ± 2.7	96.5 ± 1.3	97.4 ± 2.3	95.2 ± 3.9	96.8 ± 2.0	96.6 ± 2.2
Change values[a]		−0.2 ± 3.6	−0.7 ± 3.1		0.1 ± 2.3	0.9 ± 3.0		1.5 ± 3.9	1.3 ± 4.1
Vision	83.9 ± 7.0	83.3 ± 9.5	83.2 ± 14.0	83.9 ± 9.6	89.2 ± 4.6	89.3 ± 2.8	83.9 ± 8.1	91.8 ± 3.6	92.0 ± 4.7
Change values[a]		−0.6 ± 7.0	−1.1 ± 9.0		5.3 ± 8.2	5.4 ± 9.1		7.9 ± 7.5*	8.1 ± 7.7*
Vestibular	47.6 ± 15.9	46.1 ± 20.8	48.9 ± 16.4	47.3 ± 19.2	62.3 ± 17.3	61.6 ± 14.4	45.8 ± 15.0	5.4 ± 9.0	67.9 ± 14.3
Change values[a]		−1.4 ± 13.3	1.5 ± 8.2		15.0 ± 15.1*	14.3 ± 9.3*		19.6 ± 10.7*	22.0 ± 12.3*

Data are presented as mean ± standard deviation.
*$p < 0.05$ versus control.
TE = traditional exercise; VRWii = virtual reality-based Wii Fit exercise.
[a] Change values were calculated by subtracting the baseline data from the posttraining data (post) or by subtracting the baseline data from the follow-up data (follow-up).
[b] Control (n = 11).

strength, and such beneficial effects can persist for at least 1 month. In the clinic, VRWii training can be another choice of treatment for patients with PD.

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