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Virtual Reality Exercise Improves Balance of Elderly Persons with Type 2 Diabetes: a Randomized Controlled Trial

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Abstract. [Purpose] The purpose of this study was to investigate the effects of a virtual reality exercise program on the balance of elderly persons with type 2 diabetes. [Subjects] Participants were randomly allocated to two groups: a VR-based exercise group (n=27) and a control group (28). [Methods] The VR group performed a VR-based exercise program for 50 minutes twice a week for 10 weeks, and the control group received only diabetes education without exercise activity. Balance was measured as postural sway using a force plate. [Results] Postural sway significantly decreased after the VR-based exercise. [Conclusion] The VR-based exercise program improved balance. These results suggest that VR-based exercise programs are suitable and effective preventing falls by elderly persons with type 2 diabetes.
Key words: Type 2 diabetes, Virtual reality, Postural balance

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INTRODUCTION

Older people have increased risk of falls because of changes in the musculoskeletal system and impaired balance caused by a decline in the performance of vision, a vestibular organ, proprioceptive function, and muscle strength of the lower limbs[1)]. A third of community-dwelling old adults over 65 years old experience falls every year, and 10–15% of them experience severe accidents leading to fracture or head injury[2)].

The experience of falls itself is not only stressful for the elderly, but also cause various problems such as losing the ability to walk due to injury and being put in a nursing home if independent activities of daily living become impossible[3)].

Elderly people with underlying conditions such as chronic disease tend to suffer from more serious complications and damage. In particular, the complications of diabetes include peripheral neuropathy, diminished vision, weakened kidney function, hypoglycemia, etc. These will eventually result in physical and psychotic difficulty or limitation[4)].

The vestibular system, the cerebellum, supporting ability of the musculoskeletal system, and the sensorimotor system work together to keep balance. Diabetes patients' complications, especially peripheral neuropathy, lead to increased postural instability and body sway[5)]. Diabetes patients show diminished proprioception due to peripheral neuropathic complication. Moreover, there is a greater chance of losing balance on uneven ground and the risk factor of falls will increase with delayed recovery time of balance[6, 7)].

The fall incidence rates of the elderly with and without diabetes mellitus are 78% and 30%[8)]. Morrison et al.[9)] also compared the elderly with diabetes and the healthy elderly, and found that the elderly with diabetes had greater postural sway and slower reaction times than the healthy elderly, indicating that they had a significant decrease in balance. Slow reaction time means that the elderly with diabetes have delayed responses to sudden changes in posture, instead of a timely proper response, ultimately raising the risk of falls.

Adequate exercise is needed to improve the balance of older adults, and regular exercise is reported to enhance the ability to maintain balance by reducing postural sway, increasing flexibility, and strengthening lower-body muscle strength[2)]. As a result, of exercise, it was reported that the ability to perform simple activities like walking, climbing the stairs, and rising faster from a chair as well as complex activities such as bathing and preparing meals showed improvements[10)].

Most previous researches of the elderly with diabetes has focused on improving glycemic control and lowering the risk of cardiovascular diseases through exercise intervention[11–16)], and only a few studies have dealt with enhancing balance. Therefore a systematic study of the effects of exercise on the balance of old adults with diabetes is needed[17)].

Recent advances in information and science technologies have introduced new ways to achieve the benefits of exercise by performing various challenges in virtual reality using a computer.

Virtual Reality (VR) refers to an interactive simulation

Table 1. Subject characteristics

Group	N	Sex (male/female)	Age (years)	Height (cm)	Weight (kg)	Experience of falls (yes/no)	Duration of diabetes	Treatment (Oral/Insulin)
Experimental	27	7/20	73.8 (4.77)	153.8 (8.6)	58.5 (7.4)	13/14	10.07 (7.6)	19/2
Control	28	9/19	74.3 (5.20)	155.4 (8.4)	58.1 (8.8)	11/17	9.04 (7.7)	21/1

NOTE: Values are freguency or mean (SD)

created by computer hardware and software which provides users with an environment where they can see and feel objects and incidents similar to those in real life[18]. VR allows users to interact with those virtual objects by offering environments similar to the real world that stimulate respond to the various senses (sight, hearing, touch). In VR, the users can use and move virtual objects and challenges. In VR they receive the same feedback as 'those in reality'[19].

EyeToy of PlayStation 2 has the advantages of easily creating VR using a motion-tracking camera and a monitor maximizing the effects of exercise by triggering users' interest in a game which encourages them to participate in the activity inducing users to participate together and compete; and encouraging active movement through visual stimulation while playing games[20, 21].

A VR-based exercise program is useful for improving posture or balance and motor skills. When performed by patients with stroke, it restored damaged physical functions[22], enhanced the level of activities of daily living, and increased their quality of life by promoting interactions with family or society through the game activities[23].

Therefore, this study aimed to identify the effects of a VR-based exercise program on the elderly with diabetes with impaired balance caused by damaged physical functions and underlying conditions.

SUBJECTS AND METHODS

Fifty-five subjects with type 2 diabetes diagnosed by a physician were recruited and randomly assigned to two groups: experimental exercise group with 27 subjects and a control group with 28 subjects. Exclusion criteria for all subjects were any musculoskeletal impairment, such as inability to walk independently (stroke, serious arthritis), and intellectual disabilities. Individuals who participated in less than 80% of exercise program and who were unable to perform follow-up tests were also excluded.

As shown in Table 1, there were no significant differences in sex, age, height, weight, experience of falls, duration of diabetes between the two groups.

The purpose and procedure of the study were explained to all subjects who signed a consent form to participation in the research.

Subjects in the experimental group subject in participated in the VR-based exercise program for 50 minutes twice a week for 10 weeks, and the control group received health education on diabetes management without the exercise activity.

A total of 8 sets − each set consisted of PlayStation 2 (SCPH-75001, Sony, Japan), USB-connected motion-tracking camera (Logitech, Japan), and 25 inchLCD monitor display − were prepared for the VR-based exercise program. EyeToy™, Play 1, 2, 3 (Sony Computer Entertainment, Japan) were used in this program.

If a user bends forward in front of the camera, the motion-tracking camera captures the movement and display the movement images on the monitor in real time. The VR environment changes depending on the type of exercise program to give different challenges, and the objects on the screen are controlled and moved by following the movements of the user. The VR environment also delivers sound effects (e.g., the sounds of bowling pins struck, glass window washed, and words of command, etc.), creating illusion of playing the screen. Ten-minute warm-up exercises including stretching all muscles and massaging with a ball to improve blood circulation and relax muscles were performed. During the exercise session, participants were instructed to play games such as 'Wishi Washi: window washing', 'Keep Ups: heading game', 'bowling', 'bubble pop', 'boot camp' and 'Kung foo'. Each game takes 3–5 minutes to do and a total 35 minutes to complete all of the games. Lastly, stretching and deep breathing were performed for five minutes to cool down.

Participants played the games on a mat spread on the floor with their shoes off. They worked in pairs in front of the monitor. One research assistant was assigned to one pair. The assistant explained how to play the game, gave a demonstration, and helped the participants to practice a few times and to perform the challenges safely. Individual scores of each game were rated according to the level of performance and aggregated by research assistants to decide the highest-scoring winner who was then presented with a small gift.

The health education on diabetes management was given twice and pre- and post-tests were carried out in the control group as in the experimental group, Education was given regarding the symptoms and complications of diabetes, foot care, diet, exercise, medication, fall prevention, and diabetes management guidelines.

Postural sway was measured using a force plate (PDM Multifunction Force Measuring Plate, Zebris, Germany, 2004). The force plate is an instrument that measures static and dynamic balance by analyzing static and dynamic pressure distribution under the feet when standing and walking. The rectangular-shaped force plate has 1,504 sensors one per square centimeter, arranged in a 32 × 47 cm matrix. Each sensor measures the pressure independently.

The extent of sway was measured by the path made by the center of pressure generated on the force plate by gravity acting on the center of the body. The anterior-posterior postural sway path length, medial-lateral postural sway path length, and total postural sway path length were measured. The sub-

Table 2. Comparison of Postural Sway within Groups and Between Groups

			Experimental (n=27) M ± SD	Control (n=28) M ± SD	t^b
EO	AP (cm)	Pre	39.73 ± 8.92	39.82 ± 8.17	0.037
		Post	26.84 ± 6.28	40.08 ± 7.72	
		Pre-Post	12.90 ± 6.55	-0.26 ± 1.93	10.185*
		t^a	10.231*	0.716	
	ML (cm)	Pre	36.75 ± 8.06	35.22 ± 6.91	0.751
		Post	23.10 ± 4.93	34.11 ± 7.49	
		Pre-Post	13.64 ± 4.98	1.11 ± 3.88	10.433*
		t^a	14.228*	1.517	
	Total (cm)	Pre	61.61 ± 12.39	59.63 ± 12.40	0.594
		Post	38.76 ± 6.97	59.04 ± 12.21	
		Pre-Post	22.85 ± 8.31	0.59 ± 3.72	12.902*
		t^a	14.293*	0.839	
EC	AP (cm)	Pre	47.60 ± 11.59	45.27 ± 9.60	0.816
		Post	32.97 ± 7.63	45.17 ± 9.40	
		Pre-Post	14.63 ± 8.89	0.10 ± 1.94	8.442*
		t^a	8.547*	0.270	
	ML (cm)	Pre	40.15 ± 11.14	43.45 ± 10.63	1.123
		Post	24.62 ± 4.05	43.81 ± 10.75	
		Pre-Post	15.53 ± 12.12	-0.36 ± 2.12	6.833*
		t^a	6.658*	0.902	
	Total (cm)	Pre	69.18 ± 15.75	66.35 ± 16.04	0.660
		Post	46.25 ± 9.20	66.96 ± 16.46	
		Pre-Post	22.93 ± 12.71	-0.61 ± 2.80	9.567*
		t^a	9.375*	1.161	

^{a}: paired t-test, ^{b}independent t-test, EO: eye open, EC: eye close, AP: anterioposterior path length, ML: mediolateral path length.

jects stood comfortably on the platform without shoes with their arms at their sides for 30 seconds. They were instructed to open their eyes and keep their feet parallel separated by a distance of approximately 10 cm between them, and look straight ahead at the 15 cm dot in diameter on the spot 3 cm from 15° off center[24, 25]. Sway was also measured with subjects' eyes closed. With their eyes closed, subjects were also asked to wear an eye patch to exclude light and earplugs for better concentration. Data were gathered three times to calculate the mean score, which was expressed in centimeters. Higher scores represent sway and worse balance. Statistical analyses were performed using SPSS version 18.0. After confirming the normality of the data the Shapiro-Wilks test, the independent t test and χ^2 test were used to test the homogeneity of the two groups. Pre and post-intervention data were examined with the paired t-test within each groups and the independent t-test to compare between groups.

The level of significance was $p < 0.05$.

RESULTS

There was a significant difference in the exercise group between pre- and post- intervention for all parameters under both conditions (eyes open anterior-posterior, medial-lateral, total body sway; eyes closed anterior-posterior, medial-lateral, total body sway) (p=0.001). In the control group, however, there were no significant differences between pre- and post- intervention (Table 2).

DISCUSSION

Balance is the ability to maintain the center of gravity (COG) on the base of support (BOS) and serves a pivotal role in basic movements of the human body as well as a variety of physical and daily activities[25]. Balance is kept when afferent information obtained from vestibular system, visual system, and somatosensory system are integrated in the brain and adjusted, resulting in reflexive adjustment of the eyeballs and muscles invoking movement of the four limbs[26].

Therefore, both conditions of blocked and unblocked visual information, by closing and opening the eyes were measured and compared. Generally, the eyes-closed condition induces larger postural sway of diminished balance.

Our present study assessed A-P postural sway path length, M-L postural sway path length, and total postural sway path the of the participants who stood on the force plate, both with their eyes closed and opened, to identify their ability to maintain balance.

Preceding studies of postural sway using force plates have used different units or methods to measure and express the postural sway, so it is hard to directly compare the results. For instance, the results of postural sway path length have been expressed in centimeters, postural sway area or speed calculated, or the results scored. Therefore, a study to verify the various methods and recommend a unified method and outcome variables is needed in the future.

Tinetti[1)] reported that older people with experience of falls showed larger postural sway when standing, and Lajoie and Gallagher,[27)] who studied community-dwelling elderly reported that elderly people with experience of falls showed significant increases in both A-P and M-L postural sway path lengths compared to those without fall experience. These findings suggest that increased postural sway raises the risk of falls.

Our present study found that the post-intervention in A-P postural sway path length of the experimental group had decreased by 32% and 31% with eyes open and closed, respectively, and the M-L postural sway path length was reduced by 37% and 39% with eyes open and closed, respectively. Given that M-L postural sway length is associated more with fall events than A-P postural sway length[28)], the VR-based exercise program conducted in this study was shown to have had positive effects on reducing the risk of falls by significantly decreasing the M-L postural sway path length.

Many studies have conducted various exercise methods for old adults and found improvement in their balance. It has been reported that the elderly with diabetes who practiced walking and balance keeping exercises for 12 weeks showed a decrease in postural sway length of 31%[29)]; those who practiced balance keeping exercise for 3 months showed a significant decrease in A-P postural sway path length[30)]; and those who practiced a combined exercise program, including aerobic exercises such as weight training and fast walking, stretching, and jumping, for 6 weeks showed significant decreases in A-P postural sway path length and M-L postural sway path length of 32.5% and 35%, respectively[31)]. Those findings are consistent with the results of the present study. Also, Morrison[9)] reported that the balance of the elderly with diabetes who practiced a balance keeping exercise for 6 weeks was enhanced as the postural sway decreased, compared to a control group.

The subjects of the present study not only practiced jumping during the games such as army recruit and king header, but also practiced maintaining the same posture and stretching out their arms when engaging in games, such as bowling and window washing. These stretching and weight bearing activities were effective reinforcing muscle strength.

In virtual reality, weight bearing tasks, such as turning, moving, walking, and running, improve balance[31)]. In the real world, subjects may underestimate their abilities and fear falling, but in a virtual world, they can perform the tasks without such worries or fears[32)].

Jumping and balancing on a beam in the boot camp game were tasks participants were unable to do in the real world, but they could follow the motions in a free and safe way in the virtual world.

One of the biggest advantages of the VR-based programs was to maximize the effects of exercise by triggering players' interest in being fully immersed in the games, compared to other exercise programs[33)]. Moreover, as the game continued, the score was displayed to give instant feedback, which fostered an interest in competing for a better score. This increase interest and immersion in the new program, ultimately promoting the overall performance of the participants.

The VR-based exercise program reported in this study was shown to be an effective intervention for improving the balance of the elderly with diabetes, who experience impaired balance caused by underlying conditions, and we expect this program will be used in more clinical trials in the future.

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