J. Phys. Ther. Sci. 28: 20–26, 2016

The Journal of Physical Therapy Science

Original Article

Efficacy of virtual reality-based balance training versus the Biodex balance system training on the body balance of adults

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Abstract. [Purpose] This study investigated efficacy of virtual reality (VR)-based balance training on enhancing balance and postural reactions of adults as a low-cost new modality compared to the established Biodex Balance System (BBS). [Subjects] Thirty normal adults of both genders were divided randomly into two equal-sized experimental groups of 15: BBS balance training and VR balance training. [Methods] The training programmes were conducted in 12 sessions, three 15-min sessions per week. The Nintendo® Wii Fit Plus (NWFP) and its balance board were used to train of the VR group. Each participant answered a questionnaire concerning usability, enjoyment, balance improvement, and fatigue at the end of the training programs. [Results] The study found a significant increase the measure of mean overall balance (OLB) in both groups. No significant difference was found between the groups, but a significant decrease in the mean balance-test time was found for both groups, with no significant difference between the two training methods. The VR programme was rated highly enjoyable by 81.8% of the group. [Conclusion] The Wii Fit Plus system with the balance board as a new VR balance-training technique, can be considered an effective and enjoyable tool for the training of adults' body balance.

Key words: Virtual reality, Biodex balance training, Adults

(This article was submitted Aug. 17, 2015, and was accepted Oct. 5, 2015)

INTRODUCTION

Balance is a complex process involving coordination of multiple sensory, motor, and biomechanical components. An individual senses the position of his or her body in relation to gravity and the surroundings by combining visual, vestibular, and somatosensory inputs[1)]. Balance movements also involve motions of the ankle, knee, and hip joints, which are controlled by coordinated actions along the kinetic chain[2)]. Body balance and postural reactions are essential components of a healthy life and precise interaction with the surrounding environment. Balance performance decreases continuously with age, starting from the age of 45. As a consequence, the risk of being injured in a fall is higher among older people. Retaining body fitness as we age is vital if we want to continue to be active and mobile[3)]. But with the advancement of age, even in healthy adults, the capacity to perform certain physical tasks reduces[4)].

Sometimes traditional training programmes are not engaging to participants, for several reasons: e.g., rote, mechanical movements, and exposure to group training. On the other hand, the recently developed exercise-based virtual-reality (VR) training offers enjoyable and attractive options for exercise, even for seniors[5)]. Virtual reality (VR) can be defined as an artificial world that consists of images and sounds created by a computer, which is affected by the actions of the person experiencing it[6)]. VR can similarly be referred to as immersive multimedia or computer-simulated life, replicating an environment that simulates physical presence in places in the real world or imagined worlds. Virtual reality can recreate sensory experiences, including virtual taste, sight, smell, sound, and touch[7)]. Virtual-reality-based therapy is considered one of the

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most innovative recent developments in rehabilitation technology[8, 9]. The Biodex Balance System (BBS) has proven to be a reliable and objective tool for balance assessment and training[10]. Previous studies have evaluated balance improvements achieved by the VR technique using manual balance-testing methods[3, 5, 11–17]. No comparison has been made between BBS as an objective instrument of balance assessment and training and VR-based balance training.

Therefore, the purpose of this study was to test the efficacy of VR-based balance exercises at improving body balance and postural reactions in comparison with the established BBS instrument. Using the BBS as an objective assessment and training tool for balance is a novel procedure in the testing of the efficacy of the Nintendo® Wii Fit Plus (NWFP) and its balance board in the enhance of fitness and body balance. Comparing the balance achievements of the BBS and the NWFP could supply indications about which is preferable for the enhancement of balance. The lower cost and higher level of enjoyment attached to the Nintendo® Wii device, a new tool in physical rehabilitation, provided a second motivation for conducting this study. Thus, the research question of this study was: What is the effect of the Nintendo® Wii Fit Plus (NWFP) as a virtual-reality (VR) training method in comparison with that of the Biodex Balance System (BBS) on the enhancements of the adults' balance?

SUBJECTS AND METHODS

Thirty healthy adults participated in this study. The sample was divided into two experimental groups of 15. Both males and females were included in the study. The participants were randomly and equally assigned to a Biodex Balance Group (BBSG: six males, nine females) and a virtual-reality group (VRG: eight males, seven females). The BBSG was trained using the BBS (Biodex, Inc., Shirley, NY, USA) and the VRG was trained using the Nintendo® Wii Fit Plus and its balance board as an innovative virtual-reality-based technique. The participants were selected from among the employees of the Faculty of Physical Therapy, Cairo University. The experimental procedure was explained to all of them and all tests and training exercises were conducted at the biomechanics lab of the Faculty.

The inclusion criteria were: age from 35 to 55 years, and no musculoskeletal, vestibular or neurological disorders. The mean ± standard deviation (SD) age, weight and height of the BBSG were 44.4 (±7.3) years, 84.1 (±17.4) kg and 164.8 (±10.4) cm. The mean ± standard deviation (SD) age, weight and height of the VRG were 39.1 (±6.4) years, 78.4 (±8.6) kg and 168.5 (±5.8) cm (Table 1). The study was approved by the university's institutional review board, and all of the participants provided their written informed consent prior to their participation in the study, in accordance with the ethical principles of the Declarations of Helsinki.

The overall balance (OLB) of all participants was measured using the BBS to establish the initial balance level before the balance-training programmes. The time taken to accomplish the dynamic limit-of-stability balance test (DLOS) was also measured by the BBS. Both groups were trained three times a week for four weeks. Re-evaluation of balance was conducted after completion of the training period. The study adopted a pre-test/post-test group design. Each participant answered a close-ended questionnaire concerning the usability, enjoyment, balance improvement and fatigue of each balance-training method at the end of the training sessions.

The balance tests were carried out at the level-6 stability protocol, which allows a moderate inclination of the BBS footplate in the horizontal plane in all directions. The difficulty level was "easy" (= 50% LOS) and both sides were exercised, (selectetion through the LOS Training Setup screen). The OLB of each participant was calculated by the BBS software based on a percentage scale of 100. The time taken to accomplish the test was measured in minutes. The DLOS screen was used for the balance assessment. It is designed to challenge the participant to follow the rapid movement of a cursor to a blinking target by using their body to move the movable plate of the BBS. The test challenges the participants to move and control their centre of gravity within their base of support. The test is a good indicator of dynamic control within a normalized sway envelope. Only one trial was recorded from each participant to eliminate the learning effect and to avoid muscle exhaustion.

The BBSG was trained using the Dynamic Balance Training (DBT) screen. The training stressed the ability of the participant to maintain balance on the movable, unstable footplate of the BBS. The training period lasted 15 minutes. The VRG participants were trained using specific virtual balance games. In the games a character on the computer screen responds to the participant's movement on the Wii balance board. The training session lasted for 15 minutes starting with 5 minutes

Table 1. General characteristics of the participants in the Biodex balance system group (BBSG) and the virtual reality group (VRG)

	BBSG n = 15	VRG n = 15
Age (yrs)	44.4±7.3	39.1±6.4
Weight (kg)	84.1±17.4	78.4±8.6
Height (cm)	164.8±10.4	168.5±5.8
Gender (M/ F)	6/9	8/7

stretching exercises for the waist muscles using the Half-Moon stretching exercise. This exercise was chosen from the yoga activity software of the NWFP. Each participant played five games for two minutes each, a total training time of fifteen minutes.

The five selected games were:

1. Tight-rope walks: the participant tries to maintain balance while walking on a rope extended between two edges without falling.

2. Balance Bubble: the participant was inside a soap bubble being carried down a river. If the bubble touched the river-bank the bubble would burst.

3. Soccer Headers: the participant tries to head a ball that is thrown to him/her. While also trying to avoid heading other harmful objects.

4. Penguin Slide: the participant drives a penguin's motion on a piece of ice, maintaining balance while trying to catch fish in the water without sliding in.

5. Table Tilt: the participant moves his/her body to direct a ball to a hole in a tilting table.

After the completion of the four weeks of balance-training procedures, the DLOS balance test of the BBS system was repeated. The testing procedures carried out during pre-training were repeated during re-evaluation. The OLB and the time taken to accomplish the targets of the DLOS test were measured. The OLB percentage up to 100 was calculated for each participant. The higher the percentage, the better the balance of the participant. The percentage was calculated by the comprehensive BBS software. The software also measured the time taken to accomplish the DLOS test in minutes.

A closed-end questionnaire was constructed evaluating the subjective feelings of enjoyment, usability, balance improvement and fatigue of the two training methods. After completion of the 12 balance-training sessions the questionnaire was given to each participant. Each participant expressed his or her opinion regarding each training method. Participants from both groups chose one of four answers—no effect, low effect, intermediate effect or high effect—regarding the two training methods for each assessment attribute. Then, the data were collected and analysed to obtain percentages of each answer in relation to the total number of the participants in each group.

The collected data were compared and analysed by the mixed analysis-of-variance (MANOVA) statistical test to measure the between-subjects and within-subject variations. All data were analysed using the IBM Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA), version 20. The significance of differences between the two groups and within each group were accepted for values $p< 0.05$. The responses of the participants in each training group regarding enjoyment, usability, balance improvement and fatigue were counted and divided by 15, the sample number of each group. The result was then multiplied by 100% to obtain the percentage value for each of the questionnaire response.

RESULTS

The mean pre-test OLB VRG was 9.67 ± 3.1% while the post-test mean was 15.2 ± 5.1%. The overall balance increased by 5.53%. The post-test mean increased by 63.6% from the pre-test mean. There was a substantial main effect of training time on subject's overall body balance: Wilks' Lambda = 0. 4, F (1, 28) = 41.4, (p <0 0.05), partial eta squared = 0.6. These results indicate a very large effect size of the VRG on enhancing body balance, and there was a significant increase in OLB values between the two time periods. The DLOS balance-test reaction time was measured of all the participants in both groups' before and after performance of the two different balance-training programmes. The participants tried to complete the test in as little time as possible, and longer times suggest poorer control of body balance. The mean pre-test test time was 3.5 ± 0.8 min while the post-test mean was 2.37 ± 0.4 min. The mean test time of VRG decreased by 1.1 min, to 68.6% of the pre-test value (Table 2). There was also a substantial main effect of the balance-training period on subjects' postural reactions: Wilks' Lambda = 0. 26, F (1, 28) = 82.8, $p < 0.05$, partial eta squared (η_p^2) = 0.75. These results indicate a very large effect size of VRG and there was a significant decrease in test time values between the two time periods (pre- and post-test) ($p<0.05$).

About 81.8% of the group trained on the VR programme found the programme highly enjoyable. One hundred per cent of the trainees found that the VR instrument had a high level of usability. They found that it was very easy to use and responded to the game requisites of the VR instrument. About half of the participants (45.5%) who trained on the VR instrument reported a high level of improvement in their balance, while the other half (54.5%) reported an intermediate level of balance

Table 2. Comparison of the mean changes in the OLB and DLOS test times of the training groups

	BBSG			VRG		
	pre	post	Gain score	pre	post	Gain score
OLB (%)	9.87±3.05	14.6±7.7*	5*	9.67±3.1	15.2±5.1*	5.53*
DLOS test time (min)	3.98±1.05	2.8±0.80*	−1.17*	3.5±0.8	2.37±0.4*	−1.1*

*Significant difference within group, $p<0.05$. VRG: virtual reality group; BBSG: Biodex balance system group; OLB: overall balance; DLOS: dynamic limit of stability

improvement in their practical life; 81.8% reported no fatigue during the training on the Wii balance board, while the remaining 18.2% found that VR training elicited a low level of muscular and general fatigue. The remaining questionnaire results are summarized in Table 3.

The Levene's Test of Equality of Error Variance between the VRG and BBSG was non-significant, $p > 0.05$, indicating the homogeneity of variance in both groups. There was no significant interaction between programme type and time: Wilks' Lambda = 0.99, $F(1, 28) = 0.25$, $p = 0.62$ ($p>0.05$), partial eta squared (η_p^2) = 0.009. These results indicate a very small effect size of interaction which means that the improvements in OLB and postural reactions in both groups were only elicited by the balance programme not the time factor. The main effect of the two types of intervention was not significant: ($p> 0.05$), $F(1, 28) = 0.016$, $p = 0.9$, partial eta squared (η_p^2) = 0.001. This suggests there was no difference in the effectiveness of the two balance-training methods regarding overall balance improvement. The main effect of the two types of intervention effect on the DLOS test time was not significant: ($p> 0.05$), $F(1, 28) = 1.9$, $p = 0.18$, partial eta squared (η_p^2) = 0.07. Again, this suggests there was no difference in the effectiveness of the two balance-training methods in decreasing the time taken to accomplish the balance test.

For the statistical comparison of BBSG and VRG questionnaire responses, the non-parametric Mann-Whitney U test was used. There was a significant difference between the groups in the enjoyment attribute ($p< 0.05$), with higher enjoyment reported by the VRG. The usability of the BBS and NWFP did not differ significantly ($p>0.05$), but there was a tendency of preference towards the VRG. The sense of balance improvement also did not differ significantly between the groups ($p>0.05$), but the VRG group had the higher mean rank. There was a significant difference between the groups regarding the participants' sense of fatigue after the training session ($p< 0.05$) with higher fatigue reported by of the BBSG. The results of the Mann-Whitney test are summarized in Table 4.

The χ^2 statistical comparison between the VRG and BBSG of the questionnaire response in relation to the physical characteristics of both groups revealed that there was a significant difference in the usability reported by the male of both groups ($p<0.05$), with the VRG usability ratings being higher. Females' responses showed no significant difference between the groups ($p>0.05$). There was a significant difference in males' enjoyment levels between the groups ($p<0.05$), with higher enjoyment ratings reported by the VRG. There was no significant difference between the groups in females' enjoyment levels during the training sessions ($p>0.05$). The sense of balance improvement reported by males and females in the BBSG and VRG did not differ significantly ($p>0.05$). On the other hand, there was a significant difference in fatigue levels reported by both males and females in both groups ($p<0.05$), with higher fatigue reported of the BBSG participants.

There was no significant difference in the enjoyment levels of age category one (AG1) (32–42 years) and age category two (AG2) (43–53 years). The effect of age on the usability of the two training instruments was not significant ($p>0.05$) in either group. Also the sense of balance improvement of the two age categories didn't differ significantly ($p>0.05$) between the training groups. On the other hand, both age categories showed a significant difference ($p<0.05$) between the BBS and VRG regarding the sense of fatigue: the "no fatigue" percentage of AG1 of VRG and the "intermediate fatigue" of AG2 of BBSG being higher.

Weight category one (WC1) (60–85 kg) showed a significant difference ($p<0.05$) in reported enjoyment levels between

Table 3. Participants' questionnaire responses regarding enjoyment, usability, sense of balance improvement (BI) and fatigue

	Enjoyment		Usability		Sense of BI		Fatigue	
Effect grades	BBSG	VRG	BBSG	VRG	BBSG	VRG	BBSG	VRG
No effect (%)	0	0	0	0	11	0	0	81.81
Mild effect (%)	22.2	0	22.2	0	11	0	11	18.19
Intermediate effect (%)	44.5	18.20	44.4	0	22.3	54.5	78	0
High effect (%)	33.3	81.8	33.4	100	55.7	45.5	11	0

BBSG: Biodex balance system group; VRG: virtual reality group

Table 4. Mann-Whitney statistical comparison of the BBSG and VRG subjects' questionnaire responses

	BBSG mean rank	VRG mean rank
Enjoyment	10.3	20.8*
Usability	12.4	18.6*
Sense of BI	14.4	16.6
Fatigue	22.8*	8.5

*Significant difference between BBSG and VRG mean rank, $p<0.05$. VRG: virtual reality group; BBSG: Biodex balance system group; Sense of BI: sense of balance improvement

the training groups with higher enjoyment reported by VRG, while weight category two (WC2) (86–111 kg) showed no significant difference ($p>0.05$) between the training groups. No significant difference ($p>0.05$) was found between BBSG and VRG in either WC1 or WC2 concerning the usability and sense of balance improvement items of the questionnaire. A significant difference ($p<0.05$) in the fatigue levels of WC1 was found between the training groups with WC1 reporting "no fatigue" more often in VRG? There was also a significant difference ($p<0.05$) inWC2 levels of fatigue between the training groups.

No significant difference ($p>0.05$) was found between BBSG and VRG in height category one (HC1) (140–160 cm) regarding the enjoyment levels, whereas height category two (HC2) (161–181 cm) showed a significant difference ($p<0.05$) with higher enjoyment reported by VRG. Usability showed no significant difference ($p>0.05$) between BBSG and VRG in HC1, whereas there was a significant difference ($p<0.05$) between the training groups in HC2 usability levels, with higher usability reported by VRG. Significant differences ($p>0.05$) were not found between BBSG and VRG regarding balance improvements in both HC1 and HC2. A significant difference ($p>0.05$) was not found between BBSG and VRG in the fatigue level reported by HC1, whereas there was significant difference ($p<0.05$) between the training groups in the fatigue reported by HC2 after the training programme with more reports of no fatigue in VRG. The χ^2 results of these items are summarized in Table 5.

DISCUSSION

The current study was conducted to investigate the efficacy of the recently developed VR-based training instrument, NWFP, in the enhancement of body balance. To the knowledge of the authors, no previous study has compared the VR Wii training system with an objective and reliable instrument like the BBS. The questionnaire was introduced to support the objective evaluation of the BBS by considering the subjective feelings of each participant. The attractive virtual games induced enthusiasm in the VRG, which encouraged them to make maximum effort in the training without getting bored or exhausted.

Males responded better to the new VR tool reporting higher enjoyment and usability; however, females' response did not differ between the training methods. Both males and females reported significant fatigue differences between BBS and NWFP training. The two different age categories didn't report significant differences between BBS and VR training in the questionnaire except for fatigue. This may be due to the age category ranges having been close to each other. More disparate age categories might result in different questionnaire responses. The lighter weight group reported greater enjoyment in VR training. This may be due to the fast postural reactions which are required for the body responses to the NWFP virtual games being more easily performed by low body weight subjects.WC1 also reported less fatigue in VR than in BBSG training which might also be explained by high speed reaction tasks being more easily performed by the lower weight group. The taller subjects of HC2 in VRG reported significantly greater enjoyment, better usability and less fatigue than in BBSG towards the VR training which might be attributable to a better ability to perform the fast reactions of taller subjects which required by NWFP virtual games.

The improvement of OLB reflects the efficacy of both balance-training methods at enhancing balance. There was no significant difference between the two training methods. The OLB of both groups increased by nearly the same value, which proves that the VR training programme of the Wii Fit Plus is as effective as the BBS at improving body postural reactions and body COG control. About 81% of the participants found that the VR training was a highly enjoyable training method. All the participants indicated the VR programme was easy to use.

The decrease of DLOS test time might be attributable to the new Wii Fit Plus system enhancing the postural reactions of the participants. Therefore, the new interactive VR balance-training method could be used to replace the traditional BBS training to improve the speed of postural reactions of senior adults. VR training is a low-cost instrument that can be used by a wide range of participants home, and it is especially practical for older people who cannot go out every day. Previous studies[2, 4, 6, 8] compared the effects of the NWFP with those of traditional exercises, and concluded that the Wii system was better. In the present study, the VR system was compared to an established method (BBS) of balance training and assessment.

Table 5. Chi-Square statistical comparison of the BBSG and VRG questionnaire responses in relation to the physical characteristics (gender, age, weight, height) of subjects

		Gender		Age		Weight		Height	
Quest. attribute		Male	Female	AG1	AG2	WC1	WC2	HC1	HC2
Enjoyment	Pearson Chi-Square	11.78*	3.75	0.53	14*	10.77*	2.4	0.37	13.73*
Usability	Pearson Chi-Square	5.54	1.36	2.70	2.86	4.02	2.40	0.75	9.45*
Sense of BI	Pearson Chi-Square	1.44	3.95	1.4	1.6	4.30	1.2	2.62	0.26
Fatigue	Pearson Chi-square	10.9*	10.8*	8.89*	14*	18.51*	6.00*	3.75	17.95*

*Significant difference between BBSG and VRG, $p<0.05$. Sense of BI: sense of balance improvement; AG1: age group 1 (32–42 years); AG2: age group 2 (43–53years), WC1: weight category 1 (60–85 Kg); WC2: weight category 2 (86–111 Kg); HC1: height category 1 (140–160 cm); HC2: height category 2 (161–181 cm)

The BBS system has been reported by many previous studies to enhance body balance and to help neuromuscular training to prevent falls by adults[18–20].

The results of the present study are supported by the study conducted by Kliem and Wiemeyer[3] to compare the effect of a traditional exercise method with that of a virtual reality-based balance-training programme on body balance. That study found that the virtual reality-based balance training with the NWFP was suitable for the rehabilitation of adults. In another study, carried out by Meldrum et al.[12] the usability of the NWFP in the treatment of balance impairment in vestibular and other neurological diseases was investigated. The participants in that study reported that the NWFP was enjoyable, less fatiguing, and easier to use for the improvement of balance in real life. Both studies concluded that the NWFP is an efficient modality for balance rehabilitation and for motivation, more so than traditional balance rehabilitation methods.

The feasibility and benefits of physical therapy based on task-oriented approaches were examined by Sztum et al[13]. The results of their study agree with those of the present study, that balance was improved significantly by the virtual reality-based exercises, which supports the results reported in the current study. Balance improvement was measured in this study by the Biodex Balance System, while the balance scales and sensory tests were used by Sztum et al. The results of both studies suggest that the use of an interactive simulation balance-training tool is very effective in balance training.

Similar results were obtained by Abdel Rahman[5], who examined the effect of virtual reality-based therapy on the balance of children with Down's syndrome. That study showed that the use of the NWFP virtual reality system was effective at improving the balance. Nitz et al.[14] conducted a study to determine the feasibility of the NWFP for improving the balance, strength, flexibility and fitness of healthy women aged between 30 and 60 years. They concluded that the activity fostered by the NWFP showed an immediate effect on balance and strength.

Rendon et al.[15] conducted a study comparing the effect of virtual reality gaming on the dynamic balance of older adults with a control group that did not receive any balance training. Their results show that virtual-reality gaming provides clinicians with a useful tool for improving the dynamic balance and balance confidence of older adults. The potential effectiveness of utilizing the NWFP as a therapeutic agent in occupational therapy practice was also suggested by Williams et al.[16], who conducted a study explore the effect of the NWFP on the balance of a pilot group of elderly people. Bainbridge et al.[17] studied the effect of the NWFP on community-dwelling adults with perceived balance deficits. Their findings suggest that an intervention programme including the Wii technology may be an effective rehabilitation option for older adults with perceived balance deficits. The findings of the present study are supported by the results obtained by Desalvo[21]. Who studied the influence of a Wii Fit Plus exercise protocol on lower-extremity strength and balance in the adult population, utilizing the same balance games used in this study. There was greater improvement of balance in the VR group after eight weeks training on the NWFP.

Virtual reality-based balance training significantly improved the balance ability and the psychological state of stroke patients[22]. Rehabilitation with the use of functionally effective virtual reality was considered a satisfying and convenient new physical therapy rehabilitation tool[23]. Virtual reality treadmill training significantly improved balance and the balance self-efficacy of stroke patients[24]. Similarly, the augmented virtual reality-based exercises improved the balance and falls efficacy of elderly women[25]. Based on the results of these and the present study, the new Nintendo Wii Fit Plus system with its balance board is a VR technique which is highly effective and enjoyable in training body balance in comparison to the BBS.

This study was limited to healthy adults who had no balance deficits and lasted for only four weeks. Further studies should be carried with older participants to evaluate their responses to this new technology. Also, larger samples with wider age categories would be valuable for determining the responses of different age categories to the VR training. Subjects with balance deficits should be evaluated in future research. It is recommended to extend the training period beyond one month as it may elicit more significant effects.

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