



# The effect of six week virtual reality training on the improvement of functional balance in women with type-I osteoporosis: A preliminary study

Mohammad Kazem Rezaei<sup>1</sup> · Giti Torkaman<sup>2</sup> · Fariba Bahrami<sup>3</sup> · Noushin Bayat<sup>4</sup>

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## Abstract

**Purpose** This preliminary study aimed to investigate the effects of exergames in a virtual reality environment to improve functional balance during goal-directed functional tasks in postmenopausal women with osteoporosis.

**Methods** Twelve volunteer postmenopausal women with osteoporosis were randomly assigned to virtual reality (VRT,  $n=6$ ) and conventional multimodal (CMT,  $n=6$ ) training groups. The exercise was performed for 6 weeks, 3 days weekly, and 18 sessions. Using a force platform, functional balance assessments were made through four dynamic tasks, including performance-based limits of stability (LOS), curve tracking (CT), sit-to-stand (STS), and turning before and after 18 sessions of treatment. Each task's time-dependent center of pressure (COP) variables was separately calculated via Kistler-Mars software.

**Results** The COP variables of LOS and CT tasks were significantly improved after 6 weeks of CMT and VRT ( $P \leq 0.05$ ). In the VRT group, the rising index ( $P < 0.00$ ), COP sway velocity in STS, and Turn sway were significantly reduced ( $P < 0.05$ ). Following the VRT, the mean difference of forwarding maximum COP excursion increased ( $P = 0.03$ ), and errors in CT ( $P = 0.03$ ) significantly decreased.

**Conclusion** The VRT and CMT improved the COP sway parameters during weight-shifting tasks. The VRT was more effective than CMT in increasing the ability to control weight-shifting and dynamic functional tasks in postmenopausal women with osteoporosis. This approach in training has suitable potential to provide convenient error feedback learning.

**Keywords** Virtual reality training · Conventional multimodal training · Postmenopausal · Osteoporosis · COP sway · Weight shift · Dynamic balance

✉ Giti Torkaman  
torkamg@modares.ac.ir

Mohammad Kazem Rezaei  
m-rezaee@modares.ac.ir

Fariba Bahrami  
fbahrami@ut.ac.ir

Noushin Bayat  
nobayat@yahoo.com

<sup>1</sup> Physical Therapy Department, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran

<sup>2</sup> Physical Therapy Department, Faculty of Medical Sciences, Tarbiat Modares University, Ale-Ahmad Ave, P. O. Box: 141171311, Tehran, Iran

<sup>3</sup> Human Motor Control and Computational Neuroscience Lab, School of Electrical and Computer Engineering, College of Engineering, University of Tehran, Tehran, Iran

<sup>4</sup> Exercise Physiology Research Center, Department of Rheumatology, Lifestyle Institute, Baqiyatallah University of Medical Sciences, Tehran, Iran

## Introduction

Primary osteoporosis is a metabolic and systemic disease characterized by decreased bone density and increased bone fragility due to estrogen deficiency [1]. The fall-related fractures threaten the lives of osteoporotic women [2]. Poor postural balance is one of the most critical intrinsic risk factors for falls and fractures [3]. Postural control is more challenging on dynamic tasks. Maintaining an effective relationship between the center of mass and the base of support during dynamic tasks depends on good interaction between somatosensory, central predictive sets, and musculoskeletal systems [4, 5].

The earlier studies have revealed the positive effects of applying conventional balance training protocols on static/dynamic postural balance and quality of life in osteoporotic women [6]. These conventional training programs have limited impacts on reversing the adverse effects of osteoporosis

on the motor control system. They cannot easily develop multi-component training plans that simultaneously use all the impressive components of balance behavior, such as muscular, cognitive, and neural subunits. Also, there is a limited capacity of the translational values obtained from conventional multimodal training to functional activities of daily living due to reinforcement of the internal instead of external focus. High-speed, multi-component motion exercise combined with simulated functional tasks promises to improve functional outcomes [7], so exergames seem to have the potential to be a good alternative or supplement to conventional training protocols. Exergame refers to performing some dynamic and goal-specific tasks instructed by video games. In this way, more attention is paid to the goal of the task, so the external focus is augmented; consequently, motor skills will easily advance to the high levels of the rehabilitation pyramid [8].

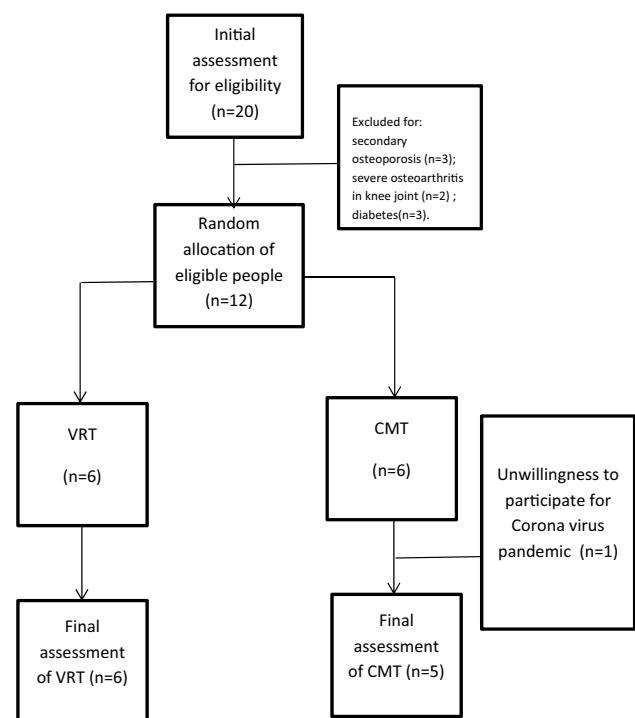
Specificity, adaptability, reproducibility, accurate assessment of skill, and the safety of therapeutic practice in virtual environments [9] may be superior to conventional therapeutic exercises. The effects of virtual reality training (VRT) on balance variables have been studied in elderly or neurologically impaired people [10, 11]; however, the results are contrasting [12, 13]. Some of these conflicting results are related to the methods used to assess treatment outcomes. From a biomechanical point of view, force plates can show more optimized movement aspects than other functional tests, such as the timed up-and-go test (TUG) [14] and the Berg balance scale (BBS). The force platform is sensitive enough to detect time-coordinated discrepancy of the center of pressure (COP) through dynamic and functional tasks, such as weight-shifting, chair rising, and turning [15]. Therefore, this preliminary study investigated whether exergames in a virtual reality environment improve functional balance on goal-directed functional tasks more than traditional exercise. For this purpose, dynamic balance control and related fluctuations in COP were monitored during functional tasks, including weight shifts, sit-to-stand, and turning. We hypothesized that virtual reality training might improve the ability to control postural balance during dynamic and functional tasks more than conventional multimodal balance training in osteoporotic women.

## Methods

This study is a preliminary single-blind, randomized controlled trial. The study was approved by the medical ethics committee of Tarbiat Modares University and was registered with the Iranian Registry of Clinical Trials as IRCT20101017004952N7.

The sample size was estimated according to Toulotte et al. [16], which examined the effect of virtual reality-based

exercise programs on balance improvement in senior older adults. The calculation was based on the mean deference of the position of the center of gravity in virtual reality ( $-8.1 \pm 2.3$ ) and adapted physical activity ( $-0.9 \pm 0.8$ ) groups, the effect size of 1.87, the alpha of 5%, and power of 80%. Twenty volunteers were recruited from individuals admitted to Baqiyatallah public bone densitometry clinic in Tehran, Iran. The inclusion criteria were: menopause for at least 1 year,  $T$  score  $\leq -2.5$  at the femoral neck or lumbar regions by world health organization criteria, age 48–65 years, body mass index 22–30 kg/m<sup>2</sup>, not participating in a regular exercise program (at less 30 min, 2–3 days/week for at least later six months) and femoral neck or lumbar  $T$  score  $\leq -2.5$ . Participants didn't suffer from visual, vestibular, or major neuromuscular disorders that affect postural balance. The exclusion criteria were unwillingness to participate or cooperate. The training methods and objectives of the study have been fully explained to participants, and they provided written informed consent before entering the study. Figure 1 shows the consort of the allocation procedure. Eight people were excluded for secondary osteoporosis ( $n=3$ ), severe osteoarthritis in the knee joint ( $n=2$ ), and diabetes ( $n=3$ ). Twelve osteoporotic women were randomly enrolled in the conventional multimodal training (CMT,  $n=6$ ) and virtual reality (VRT,  $n=6$ ) groups. An independent person converted allocation and assignment by



**Fig. 1** Consort plot to show participant enrollment and retention throughout the study. CMT conventional multimodal training, VRT virtual reality training

blocking randomization using sealed, opaque, and stapled envelopes. One person in the CMT group was reluctant to participate in the study due to the coronavirus pandemic, and she was excluded from the study. The CMT and VRT performed exercises 3 days per week for 6 weeks (18 sessions) under the supervision of a trained physiotherapist. The COP sway was evaluated using the dynamic and weight-shifting tasks before and after training. These tasks included a performance-based limit of stability (LOS), mediolateral tracking curve (CT), sit-to-stand (STS), and turning in level walking (Turn) that were done on the force plate.

### Assessment of dynamic and weight-shifting tasks

A computerized force plate recorded the COP sway parameters (9286B, Kistler Co., Winterthur, Switzerland). Pre–post tests were assessed before and after 6 weeks of intervention by an assessor blinded to grouping. The Kistler-Mars software, which supports the Kistler data acquisition system, was used to correctly analyze the characteristics of the postural balance in the tasks. Before the data acquisition, each participant was familiar with the test procedure. Then, each functional task was repeated thrice with one-minute rest in between and 5 min between the assorted tasks in the following order: LOS, CT, STS, and Turn. The test subject's preferred foot positions in LOS, CT, and STS were the same for all three repetitions and were based on the shoulder width while standing during the first test, controlled by recording the foot position on an enclosed special sheet. The examiner stayed close to the participants to protect them from falling.

At the LOS, the participant tried to shift her weight in four completely different directions (forward, backward, right, and left). The test stopped if the trunk flexed, stretched, leaned, or extended shoulders substituted the movement. The reaction time (RT), the COP sway velocity ( $COP_{vel}$ ), COP directional control ( $COP_{dc}$ ), COP maximum excursion ( $COP_{exc}$ ), and maximum body lean ( $COP_{lean}$ ) were measured [17].

The subject was asked to track a sinusoidal pattern within the CT task. The COP was displayed on the LCD screen to guide the execution of the task. Mean absolute errors (mm), standard deviation (mm), and the area between the reference pattern and the actual COP signal (calculated as the integral of the absolute deviations between the two curves (mm\*s)) were determined following tracking the sinusoidal curve.

In the STS examination, the subject performed a vertical upward movement from a bench-adjusted height to keep the hip and knee joints at 90/90. The participant was not allowed to use her hands for support. The weight transfer time (s), rising index (RI), and the average COP sway velocity (mm/s) were scored during STS.

In Turn, the participant was instructed to start walking at least two paces from the force plate, then approach the force

plate and perform the 180° rotation on a force plate with the dominant leg. The test ended when the subject returned to the starting point. The time required to complete the 180° Turn in place(s) and the average velocity of the COP sway during the turn time, the turn sway (mm/s), were recorded separately.

### Training protocol

Exercises were held one by one in the physiotherapy clinic of Tarbiat Modares University. The duration of training in both groups was set to sixty minutes, 3 days weekly for 6 weeks, and 18 sessions. The training program was established on different days, so the participants in each group were blinded to the training mode of the other group. The exercises in both groups began with five minutes of stretching to warm up. Interval periods were taken into account between activities to avoid declining performance. Both groups followed regular daily activity, nutrition, and medication regimen. The intensity and difficulty of the exercises gradually increased in both groups. In the first 2 weeks, it was done at an easy level; in the second two weeks, it was moderate; in the third 2 weeks, it was done at an advanced level. In the CMT group, the exercise difficulty was adjusted through accessory devices and combined movements, which are explained in Table 1. In the VRT group, the exercise intensity was adjusted by choosing each game's easy, moderate, and advanced levels.

In both groups, we also measured the 10-point Borg rating of the perceived exertion scale (Borg) which individuals subjectively rate their level of exertion during exercise. In the first 2 weeks of training, we determined the scale of 2–3 for light intensity; in the second 2 weeks, 4–5 for moderate intensity; and in the third two weeks, 6–7 for hard intensity.

### Virtual reality training

At the VRT group, the strength balancing exercises were carried out with the help of Xbox 360 games and a Kinect camera (Microsoft, Redmond, WA, USA). The Kinect tracks the participant's body position and provides feedback if they properly do the task. Eighteen minutes of Your shape: fitness evolved, Kinect sport one, and Kinect Adventures games were selected in which the muscles of the lower extremities, upper limbs, and torso were more involved, in parallel with increasing the difficulty of the task in the game (Fig. 2a). For safety, activity was monitored, but no physical assistance was given. Monitor, Xbox console, and Kinect sensor were set at a 2 m height from the ground and away from the participant's gesture. Verbal commands for the video games had been supplied earlier than the training beginning. Once every six sessions, the difficulty level increased according to the software's instructions.

**Table 1** The protocol of conventional multimodal training for postmenopausal osteoporotic women in the CMT group

Level Position	Easy	Intermediate	Advance
Sitting on the Swiss ball	<ol style="list-style-type: none"> <li>Grabbing the bar, moving the Swiss ball in four different directions (2 min)</li> <li>Flexion/abduction of the hips while grasping the bar (2 min)</li> <li>Knee extension grasping the bar (2 min)</li> <li>Bringing the opposite arm and leg, hands to the bar (2 min)</li> <li>Pressing 20 cm balls against the wall (2 min)</li> <li>Rotating the torso to both sides by holding the bar by the hands (2 min)</li> <li>Throwing a 20 cm ball ten times while grasping the bar</li> </ol>	Exercises at the intermediate level were followed as easy but without taking the bar	At the advanced level, free weights and elastic bands and throwing the one-kilogram medicine ball were used for progression based on the subject's ability
Standing	<ol style="list-style-type: none"> <li>Standing on the foam with/without grasping the bar (1 min for each one)</li> <li>Standing on one foot with/without holding the bar (30 s for each one)</li> <li>Standing on both feet and then one foot on the BOSU ball (1 min for each one)</li> <li>Standing on both feet, then one foot, and perform a calf raise (15 times for each repetition)</li> <li>Standing on BUSO on two legs and doing w to v overhead reaching without weight (2 min)</li> <li>Standing on 2 feet and moving hands bolted in PNF patterns (D1 and D2) (2 min)</li> <li>Pulling the arm back (shoulder extension and shoulder retraction) (2 min)</li> </ol>	The exercises followed in the second 2 weeks proportional to the capacity of the subject, which adds oscillation of the body blade	The exercises were improved in the third 2 weeks, depending on individual ability, by throwing the ball/adding half a kilogram of weight and light elastic bands
Walking	<ol style="list-style-type: none"> <li>Walking back and forth (2 min)</li> <li>Fast walking left and right (2 min)</li> <li>Tandem walking (2 min)</li> <li>Spiral walking (2 min)</li> <li>Walking inside the ladder spaces to the front-back and left-right (2 min each)</li> </ol>	The subject was asked to gently rock the light body blade at each stage of the easy level	The subject was asked to walk inside the ladder with a weighted vest up to 10% of the body weight or using elastic bands attached to the ankle

**Fig. 2** The site of the monitor, Xbox kinect, and console and samples of body motions in *VRT*, the movement of the dominant upper limb during discus throw (a); the samples of body motion in standing at the *CMT* (b). Note the similar movement patterns in the *CMT* with those that occurred on discus throw in the *VRT*



GYM Games exercises were selected in your shape, including virtual smash, light race, and stack 'em up. Each stage was repeated four times in a 2 min trial. At virtual smash, the displayed boxes were accidentally destroyed. In the light race, the participant was asked to bring the feet toward the highlights on the anterior, posterior, left, and right sides by the closer foot. In stack 'em up, the subject was asked to empty the boxes assembled on the board according to the software instructions by shifting and tilting the upper limb into the highlight chambers. The foam was used under the feet in the stack 'em up at the third stage.

In Kinect Sport 1, the subjects were done bowling, bump bash (shift position to avoid collision with things thrown), soccer sets (to simulate foot and hand movement in the proprioceptive neuromuscular facilitation (PNF) patterns), sprinting in place (hip and knee flexion movements on the swing leg and balance maintenance on the standing leg as well as continuous reciprocal upper limbs movements), and discus throw (movement of the upper extremity of the dominant arm and the rotational movements of the trunk to simulate the motion of the throw).

Finally, in the Kinect adventure game and at the free play section, the participants completed three parts of this game: reflex ridge, rally ball, and 20,000 leaks.

#### Conventional multimodal training protocol

In the *CMT* group, conventional strength-balance exercises were considered the same duration as *VRT* in three positions: sitting, standing, and walking. The time required for sustaining a position was two minutes, and a break of 30 s between each task. Two sets of 10 repetitions were adjusted separately for the left and right sides. The free weights, elastic bands, body blade, SWISS ball (75 cm in diameter), Swedish wall bar, Buso ball, foams, and weighted vests were used for exercise progression. According to the subject's tolerance, these elements were gradually absorbed in the advanced sessions. The exercises in the first 2 weeks were defined as an easy level, the second fourteen days as an intermediate level, and the third fourteen days as an advanced level (Table 1). A sample of movement patterns in *CMT* at standing (advanced stage) was provided (Fig. 2b).

## Statistical analysis

After confirming the data distribution normality using the Shapiro–Wilk test, each group used the paired *t*-test for pre–post evaluation. The independent sample *t*-test was performed to compare the difference of changes in the variables between the two training groups. Statistical analysis was performed by SPSS version 19 (IBM, Armonk, NY, USA), and the significance level was set at  $P \leq 0.050$ .

## Results

The personal characteristics, including age, height, weight, BMI, and femoral neck /lumbar BMD, showed no significant difference between the groups ( $P > 0.05$ ) (Table 2).

The effect of two types of exercise on the LOS is illustrated in Table 3. After 18 sessions of CMT, the forward RT was 0.52 s less than the before treatment, which was statistically significant ( $P = 0.014$ , effect size = 2.06). In the right direction, the  $COP_{exc}$ ,  $COP_{dc}$ , and  $COP_{lean}$  were 22.26 mm, 12.24°, and 1.36°, significantly higher than the baseline values ( $P = 0.033$ , effect size = 1.41;  $P < 0.001$ , effect size = 4.6;  $P = 0.035$ , effect size = 1.46; respectively). In the left direction, the  $COP_{vel}$ ,  $COP_{exc}$ , and  $COP_{lean}$  were 17.48 mm/s, 15.83 mm, and 1.25° C, respectively. They showed a significant increase relative to baseline values ( $P = 0.028$ , effect size = 1.59;  $P < 0.001$ , effect size = 2.2;  $P = 0.019$ , effect size = 1.87; respectively). After 6 weeks of intervention in the VRT group, the forward RT was decreased by 2.3 s ( $P < 0.001$ , effect size = 2.1), and the forward  $COP_{vel}$  increased by about 4.80 mm/s ( $P < 0.001$ , effect size = 1.38). The backward  $COP_{dc}$  was 13.26 degrees greater than before treatment ( $P = 0.021$ , effect size = 1.24). In the right and left directions,  $COP_{exc}$  ( $P_{right} = 0.022$ , effect size = 1.57,  $P_{left} = 0.016$ , effect size = 1.37),  $COP_{dc}$  ( $P_{right} = 0.001$ , effect size = 2.02,  $P_{left} = 0.001$ , effect size = 2.60) and  $COP_{lean}$  ( $P_{right} = 0.044$ , effect size = 1.06,  $P_{left} = 0.010$ , effect size = 1.60) were significantly intensified

compared to baseline values. The independent *t*-test showed that the mean difference of the forward RT was 0.52 in CMT and 0.23 in VRT, and this difference between the two groups was significant ( $P = 0.028$ , effect size = 1.56) (Fig. 3a). The mean difference of the  $COP_{exc}$  in the VRT group indicates an improvement of 10.75 mm, and the difference between the two groups was significant ( $P = 0.034$ , effect size = 1.53) (Fig. 3b). The mean difference of forwarding  $COP_{dc}$  was 7.5 degrees higher in the VRT group and – 7.6 degrees lower in the CMT group from each baseline value. This difference was also significant between the two groups ( $P = 0.038$ , effect size = 1.53) (Fig. 3c).

After 18 sessions of intervention, in the curve tracking via mediolateral weight-shifting, the CMT group showed a decrease in the values of the SD of the absolute error from  $44.4 \pm 6.1$  to  $32.66 \pm 4.8$  mm, which was significant ( $P < 0.001$ , effect size = 1.38; Table 3 and Fig. 3d). After the VRT training, the mean/SD of absolute errors ( $P < 0.001$ , effect size = 1.06 and 1.75, respectively) and the area ( $P = 0.016$ , effect size = 1.60) significantly decreased compared to the baseline value (Table 3 and Fig. 3d, e). CMT showed a difference of – 4.5 mm in the mean of absolute error, while VRT training had a difference of – 24.61 compared to the baseline value. This difference was significant between the two groups ( $P = 0.022$ , effect size = 2.47). The area in the CMT group decreased by – 127.99 mm\*s, while in the VRT group, it decreased by about – 448.59 mm\*s, which was a statistically significant difference between groups ( $P = 0.045$ , effect size = 1.60).

In the VRT group during STS (Table 3), the RI significantly decreased from  $66.41 \pm 2.13$  to  $56.55 \pm 4.89\%$  of body weight ( $P < 0.001$ , effect size = 1.70). The COP sway velocity after VRT was markedly reduced from  $183.16 \pm 6.82$  to  $146.59 \pm 30.86$  mm/s ( $P = 0.010$ , effect size = 1.46). Regardless of the greater effect of VRT on the quantified parameters, the independent *t*-test indicated that neither of the two methods had a greater impact on COP-dependent parameters in this task ( $P > 0.05$ ).

In the Turn task and after training by the VRT, the mean COP sway velocity at the moment of 180 degrees of turning on the dominant leg decreased significantly from  $166.64 \pm 20.63$  to  $125.9 \pm 21.93$  ( $P = 0.012$ , effect size = 1.57). Still, this difference was not significant compared to the CMT group (Table 3).

**Table 2** Anthropometric characteristics and *T* score value for the two groups, mean  $\pm$  SD

Variables	CMT ( <i>n</i> =5)	VRT ( <i>n</i> =6)	<i>P</i> value
Age [year]	57.60 $\pm$ 5.5	58.33 $\pm$ 2.7	0.794
Height [centimeter]	160.60 $\pm$ 4.50	159.16 $\pm$ 5.03	0.634
Weight [kilogram]	69.90 $\pm$ 3.50	70.16 $\pm$ 4.44	0.799
BMI [kg/m <sup>2</sup> ]	27.16 $\pm$ 1.22	27.55 $\pm$ 1.19	0.465
<i>T</i> score lumbar	– 2.92 $\pm$ 0.16	– 3.01 $\pm$ 0.27	0.162
<i>T</i> score femoral neck	– 2.89 $\pm$ 0.20	– 2.83 $\pm$ 0.32	0.730

BMI body mass index, CMT conventional multimodal training, VRT virtual reality training

## Discussion

This preliminary study aimed to evaluate the practical outcomes of performing active exercises in a virtual reality platform (VRT group) on the balance parameters and simultaneously compare these results with conventional multimodal balance training (CMT group) in osteoporotic women.

**Table 3** The values of the COP sway parameters in LOS, CT, STS, and Turn, mean ± SD

LOS task	CMT ( <i>n</i> = 5)			VRT ( <i>n</i> = 6)		
	Before	After	<i>P</i> value	Before	After	<i>P</i> value
<b>Reaction time (s)</b>						
Forward	1.31 ± 0.14	0.79 ± 0.25	<0.001 <sup>a</sup>	1.18 ± 0.11	0.95 ± 0.20	<0.001 <sup>a</sup>
Backward	1.14 ± 0.39	1.43 ± 0.29	0.228	1.01 ± 0.22	1.11 ± 0.19	0.531
Right	1.48 ± 0.26	1.20 ± 0.27	0.461	1.05 ± 0.24	1.12 ± 0.33	0.836
Left	1.50 ± 0.31	1.39 ± 0.32	0.770	1.02 ± 0.18	0.76 ± 0.28	0.301
<b>COP<sub>exc</sub> (mm)</b>						
Forward	58.34 ± 13.07	51.66 ± 11.53	0.186	63.22 ± 17.16	73.97 ± 16.65	0.091
Backward	57.63 ± 6.25	64.54 ± 10.22	0.178	55.36 ± 10.02	56.25 ± 4.39	0.434
Right	50.62 ± 10.26	72.86 ± 11.18	0.050 <sup>a</sup>	54.21 ± 15.63	75.24 ± 15.60	0.022 <sup>a</sup>
Left	46.02 ± 13.77	61.85 ± 11.87	<0.001 <sup>a</sup>	61.87 ± 14.47	85.48 ± 11.73	0.016 <sup>a</sup>
<b>COP<sub>vel</sub> (mm/s)</b>						
Forward	10.38 ± 2.98	15.18 ± 5.91	0.211	14.59 ± 4.39	19.39 ± 5.81	<0.001 <sup>a</sup>
Backward	20.21 ± 7.15	26.76 ± 14.81	0.473	30.12 ± 15.47	27.31 ± 13.93	0.888
Right	15.78 ± 2.80	24.81 ± 11.63	0.118	21.25 ± 2.34	25.57 ± 11.19	0.391
Left	10.54 ± 3.90	28.03 ± 11.84	0.028 <sup>a</sup>	28.53 ± 15.99	36.78 ± 6.58	0.256
<b>COP<sub>dc</sub> (°)</b>						
Forward	76.34 ± 8.67	68.66 ± 16.30	0.152	66.83 ± 4.45	74.42 ± 8.97	0.121
Backward	75.01 ± 8.22	75.64 ± 4.92	0.909	67.82 ± 6.09	81.08 ± 5.17	0.021 <sup>a</sup>
Right	61.52 ± 6.25	73.76 ± 5.88	<0.001 <sup>a</sup>	67.00 ± 6.43	81.87 ± 4.31	<0.001 <sup>a</sup>
Left	72.76 ± 6.12	73.59 ± 11.08	0.899	65.40 ± 7.76	72.12 ± 6.58	<0.001 <sup>a</sup>
<b>COP<sub>lean</sub> (°)</b>						
Forward	3.98 ± .90	4.15 ± 1.29	0.521	4.46 ± 1.14	4.90 ± .87	0.215
Backward	4.13 ± 0.10	4.22 ± 0.53	0.742	3.81 ± 0.59	3.84 ± 0.30	0.932
Right	3.39 ± 0.52	4.75 ± 0.90	0.035 <sup>a</sup>	3.84 ± 1.20	4.97 ± 0.58	0.044 <sup>a</sup>
Left	3.21 ± 0.94	4.46 ± 0.71	0.019 <sup>a</sup>	4.52 ± 0.74	6.09 ± 0.71	0.010 <sup>a</sup>
<b>Curve tracking</b>						
Mean absolute error (mm)	60.05 ± 9.80	55.54 ± 9.27	0.500	75.01 ± 9.80	50.40 ± 16.73	<0.001 <sup>a</sup>
SD of absolute error (mm)	44.41 ± 6.10	32.66 ± 4.89	<0.001 <sup>a</sup>	46.16 ± 3.12	33.47 ± 10.10	<0.001 <sup>a</sup>
Area (mm*s)	1158.81 ± 185.8	1030.82 ± 145.3	0.106	1489.11 ± 44.1	1040.52 ± 307.7	0.015 <sup>a</sup>
<b>Sit to stand</b>						
Weight transfer time (s)	1.52 ± 0.26	1.47 ± .17	0.753	1.65 ± 0.30	1.49 ± .029	0.149
RI (%BW)	65.87 ± 3.55	60.82 ± 3.87	0.134	66.41 ± 2.1	56.55 ± 4.8	<0.001 <sup>a</sup>
COP sway velocity (mm/s)	189.10 ± 7.90	167.00 ± 37.96	0.262	183.16 ± 6.82	146.59 ± 30.86	0.010 <sup>a</sup>
<b>Turn</b>						
Turn time (s)	1.67 ± 0.39	1.53 ± 0.36	0.637	1.69 ± 0.36	1.52 ± 0.28	0.308
Turn sway velocity (mm/s)	200.97 ± 57.54	160.03 ± 11.49	0.195	166.64 ± 20.63	125.09 ± 21.93	0.012 <sup>a</sup>

LOS: limits of stability, RT: reaction time, the time among the motion instructions till the incidence of the primary motion, COP<sub>exc</sub> the maximum distance reached by the test subject, COP<sub>vel</sub> the average velocity of the COP movement, COP<sub>dc</sub> the directional control reveals the movement in the desired direction (toward the target) in proportion to the unexpected direction (away from the target), COP<sub>lean</sub> the maximum body lean, CT: Curve tracking, STS: sit to stand, RI: rising index, the sum of constraints that the legs apply on the constrain gage plate while standing, BW: body weight, CMT: conventional multimodal training, VRT: virtual reality training

<sup>a</sup>A significant difference than the baseline value (*P* < 0.05)

Based on the study outcome, at the LOS task, both training modes improved the degree of freedom about COP fluctuations by improving COP<sub>vel</sub> at forward (VRT) and left (CMT) directions, COP<sub>dc</sub> at backward (CMT), right (CMT and VRT), and left (VRT) directions. After training, both groups' SD of the absolute error reduction revealed better

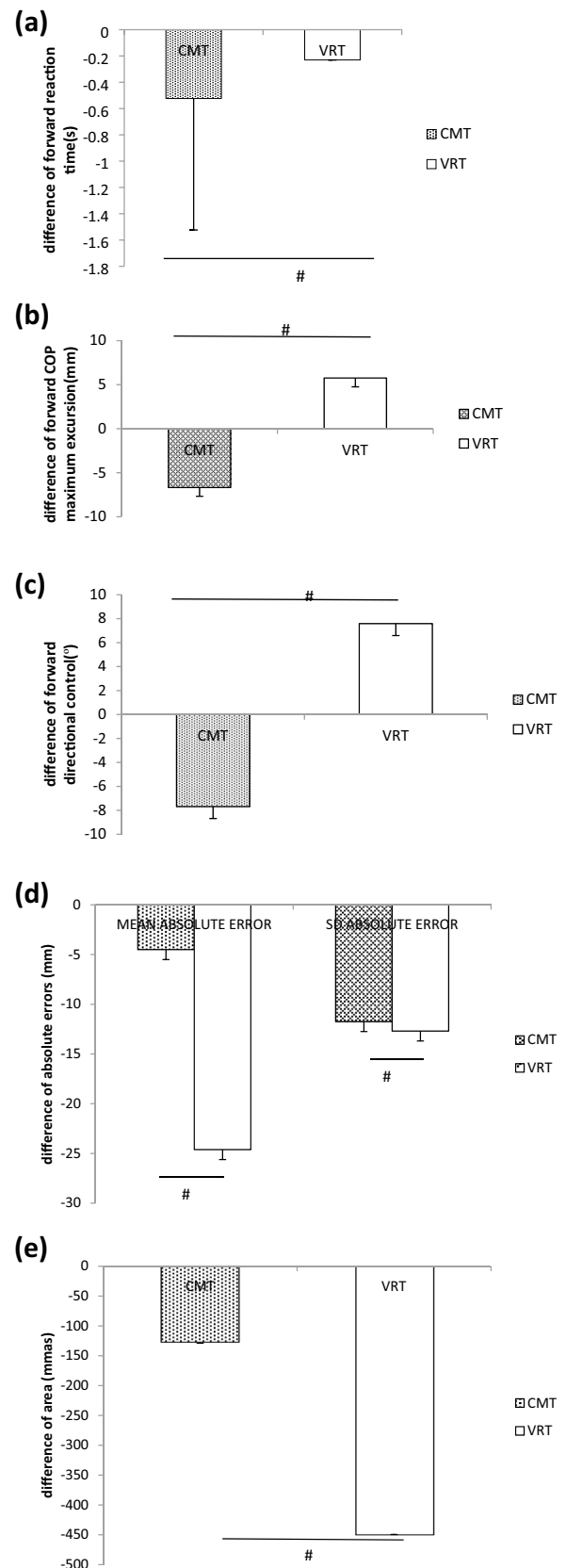
control of the COP displacements around the reference line. The RI and COP sway velocity in STS and the sway velocity in Turn were significantly changed only in the VRT group. These parameters didn't reach a significant level after CMT. Decreasing the values of RI after VRT could reflect the lesser forward bending of the trunk after training.

**Fig. 3** The mean differences of forwarding reaction time (a), maximum excursion (b), directional control (c) at LOS task, and absolute errors (d) and area of error (e) at sinusoidal curve tracking task between two groups. CMT: Conventional multimodal training. VRT: Virtual reality training # significant difference between two groups

Although the results of this study should be cautiously generalized due to the small sample size, VR training seems more effective than CMT in improving the balance status during weight shifts to forward and lateral directions. The improvement of the forward  $COP_{exc}$  and  $COP_{dc}$  indicates that VRT had helped osteoporosis women move the COP with greater freedom to the anterior edges of the stability area. Regarding the RT values, the CMT decreased the time interval between the onset of the motor reaction and the issuance of a motor command in the same direction. The results of the CT indicated that the participants in the VRT group could control the voluntary displacement of COP more consistently with the reference curve than the CMT. It was determined by reducing the mean of absolute error and area more than the values illustrated after CMT. Forming the proper error feedback learning provided in the VRT significantly affected the subject's performance in the functional tests.

Both training protocols potentially improved the quality of time-dependent COP dispersions at weight-shifting tasks. In dynamic tasks, STS and Turn, the osteoporotic women in the VRT group seem to have attained the proper synergistic ability to control COP fluctuations on the functional base of support to float the position of body segments more exquisitely. These physiological changes in motor control behavior were expected following the motor learning process [18] and adaptability [19].

Adaptability and trainability in the locomotor system provide the capability to the motor control system to accommodate different exercise therapy protocols to optimize motor responses that may cause to decrease the risk of falling in functional activities. The factors that inform the appropriate motor commands are muscle strength and somatosensory functions [20]. Proper neuromuscular coordination [21] and cognitive factors affect predictive sets within the central nervous system [22]. Although both types of protocols have effectively improved COP-related parameters, VRT has been more effective due to rehabilitation codes defined in the motion complexity model and the simultaneous use of several subsystems involved in balance control [8]. This effectiveness could be due to the similarity of VRT with real functional activities and their greater attractiveness to participants. Various visual, auditory, and motivating feedback from VRT directs attention to the intended execution of the functional movement in a suitable manner, which is usually not well-formed in conventional methods. During VRT, the user interacts with the game scenario, and the sensory,





cognitive, psychological, and motor functions are stimulated [23–25]. It will be more challenging to acquire functional motor skills in traditional exercises where the internal focus is reinforced than in the goal of the task.

In contrast, targeted functional exercises such as VRT use rehabilitation codes, such as cognition, being active, feedback, repetition, and learning more appropriately to reinforce the external focus further, making goal achievement easier for skills [26]. Due to the simulation of the real environment, these exercises can effectively learn and control movements and ultimately transfer motor experiences to new environmental challenges [27]. In addition, the user training of these games at home must be mentioned. Tele-physiotherapy and purposeful training programs can be applied in critical situations like corona pandemic [28, 29]. In line with the present study, Duque et al. revealed that after 6 weeks of exercises in virtual reality environments, LOS was significantly increased in 30 elderly volunteers in the age range of 78 compared with age-matched controls [13]. In a pilot study, Pluchino et al. showed that virtual reality balance training (Wii fit balance) had ameliorated COP fluctuations in the frontal and sagittal planes but had no significant superior outcome to other training modes [30].

In Bieryla's pilot study, 3 weeks of Xbox Kinect motion-based exercise modified Berg balance and the Fullerton advanced balance scale in ten seniors with an average age of 70 [31]. Babadi and Daneshmandi compared the effects of 9 weeks of VRT with conventional balance training in 36 older adults. In their study and using functional reach test, single leg stance with open/closed eyes, Fullerton advance balance test, and TUG, the same results were recorded after both types of interventions when comparison was made with controls [32].

Visual feedback provided to the participant in the assessment (LOS and CT) and practice methods (VRT) used in this study may impact the results. According to Gold–Berg's theory, motor pathways, such as the cerebellum, peritoneal lobe of the brain, and the external pre-motor cortex, will dominate when voluntary human movements are directed according to external commands [33]. In contrast, well-learned and self-generated movements in humans cause dominant activity in other parts of the central nerves, such as the basal ganglia and supplementary motor area [34, 35]. STS and Turn tasks are more self-generating movements. There was no visual feedback for the guidance of movement; in this way, the COP-related parameters of these two tasks didn't reach a significant level at this period of intervention, so neither method was superior to the other.

To comply with ethical principles, this study selected the control group as the CMT group. Perhaps one of the most important limitations in this study is related to restrictions on the degree of freedom in head and neck movements imposed by the nature of the exergames. In virtual reality training,

subjects should limit their gaze on the monitor to provide proper visual and auditory feedback, so the somatosensory inputs from head-neck and vestibular systems are confined to excursions on frontal plane. Conversely, the freedom of movement at the head-neck and eyes provided in CMT had a substantial role in forming good righting reflexes at dynamic postural control. So it is suggested that the efficacy of VRT and CMT is examined on the vestibular system via a sensory organization test to clarify better their possible effects on righting reflexes, especially at levels 5 and 6 of this test. A larger sample size and a follow-up assessment are required to enhance external validity. It is suggested that future studies follow the results at least one month later to compare the consistency of the interventions performed on balance factors of functional motor skills. Evaluation of muscle synergy and co-contraction by electromyography can effectively recognize the motor control changes following VRT, which is recommended in future studies.

## Conclusion

Both conventional multimodal exercise therapy and VR training effectively improved functional motor skills. The COP sway results showed that the 18 virtual reality training sessions were comparable to CMT in improving postural control during weight-shifting on a fixed support surface. This conclusion is especially significant when transferring weight to the front and lateral edges of the base of support.

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**Author contributions** Study conception and design: GT, MKR. Acquisition of data: GT, MKR, NB. Analysis and interpretation of data: GT, MKR, FB. Drafting of the manuscript: GT, MKR, FB, NB. Critical revision: GT, MKR.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical statement and Informed consent** The study was approved by the Tarbiat Modares University Research Ethics Board (Project number: IR.MODARES.REC.1397.050) and was conducted in compliance with the standards set by the Declaration of Helsinki. All participants provided informed written consent prior to their participation in the study.

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