Virtual reality training improves dynamic balance in children with cerebral palsy

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Aims: The purpose of this study was to investigate the effects of Virtual reality training on dynamic balance of children with spastic hemiplegic cerebral palsy (SHCP).
Methods: 20 girls with SHCP (mean age =9.4; SD =1.48) were selected from special schools and divided into the experimental and control groups. Commercially available Kinect dance game (Microsoft Inc., Redmond, WA, U.S.A.) 'Just Dance 3' and Modified star excursion balance test (SEBT) were used for video game based training and dynamic balance tests, respectively. MANCOVA and ANCOVA Tests were performed at $p < 0.05$ to analyze the data.
Results: Based on MANCOVA test results, there was a significant difference between groups at least in one of the dynamic balance variables (anterior, posterolateral, and posteromedial) after controlling for pretest ($F(3, 13) = 41.81$, $p < .005$). Results of ANCOVA test showed a significant difference between the dynamic balance variables in the anterior ($F = 52.80$, $p = 0.001$), posterolateral ($F = 117.86$, $p = 0.001$), and posteromedial ($F = 23.84$, $p = 0.001$) directions in children with cerebral palsy.
Conclusions: This paper proposes that video game based training can successfully guide children with cerebral palsy to improve their balance ability. This virtual system is therefore an interesting tool in the therapies related to the children with cerebral palsy.

Keywords: Spastic Hemiplegic Cerebral Palsy, video game based training, Xbox, balance

Introduction

Balance control is one of the basic prerequisites for motor development in children (De Kegel *et al*. 2010). Maintaining the center of gravity at the supportive level in the positions of standing, moving, and preparing for movement is a complex capability of a person (Overstall 2003). The dynamic balance points to a sense of balance when standing without falling over the movement (Subasi *et al*. 2008). In contrast to the static balance, dynamic balance is a voluntary movement of the center of gravity with the aim of creating motion in the lateral, anterior and posterior directions (Geldhof *et al*. 2006). Dynamic balance training is needed because children must learn to change the center of gravity and anticipate more changing situations (Geldhof *et al*. 2006).

Abnormal body fluctuations are caused by several factors, one of them is cerebral palsy (Miller 2007). Cerebral palsy is a congenital neuromuscular disorder that can occur in the age range of fertilization up to 2 years after birth (Miller 2007). The word 'cerebral' means being related to the brain. The word 'palsy' means having problems with body movement. Cerebral palsy (CP) points to a group of disorders that affect muscle movement (Miller 2007). One of the most common forms of cerebral palsy is spastic hemiplegia due to one-sided injury to the motor cortex or pyramidal pathway. In this particular type of cerebral palsy, muscles in the opposite side of affected brain region have an eclipse state that are reflected in the increase of sensitivity to normal tensile reflections; as a result, movements of the more damaged limbs are often slow and jerky (Miller 2007). CP is characterized by impaired motor control and delayed motor milestones. Defect in balance control is a restrictive factor in motor growth of children with cerebral palsy. Clinical conditions of cerebral palsy include neuromuscular deficits such as lack of selective motor control and changes in muscle tone, leading to an imbalance between the agonist and antagonist muscles, sensory changes and weaknesses (Shumway-Cook et al. 2003).

Researches have shown an increasing fluctuation in static balance of children with motor disorders (Geuze 2003); subsequently, effective interventions have been developed to overcome these problems (Granacher

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et al. 2011). Nevertheless, less attention has been paid to the dynamic balance of these children, despite the fact that they have significant problems in maintaining their dynamic balance (Deconinck *et al*. 2010).

The goal of physiotherapy-related therapies in children with cerebral palsy is to improve motor learning through functional and motor exercises with multiple sensory stimuli (Chagas *et al.* 2004). One of the treatment methods with this feature that has recently been used in the treatment of people with cerebral palsy is Virtual Reality (VR) (Weiss *et al.* 2003, You *et al.* 2005). In virtual environments, all features of activity such as duration, severity, and type of feedback can change based on the purpose of treatment and the ability of individuals. Previous research findings suggest that new treatments such as virtual reality programs and virtual environment-based assignments can be effective (Schultheis and Rizzo 2001, You *et al*. 2005). For example, Morone *et al*. (2014) showed improvement in balance scores after intervention with Wii computer games in 50 patients with acute stroke (Morone *et al.* 2014). Kim *et al*. (1999) reported initial data using a bicycle connected to the virtual environment of healthy adults and suggested the effectiveness of this training system in balance control (Kim *et al*. 1999).

One of the first reports of using VR technology in rehabilitation was to compare the treatment of VR with a traditional approach in a sample of elderly people. Compared to standard rehab program, there were reports of better dynamic balance for a small group of elderly people following the virtual reality program (Cunningham and Krishack 1999). Also, Boroumand and Hassani Merraban (2018) found the effectiveness of virtual reality interventions in the balance of a child with cerebral palsy Some research used a similar approach to a larger research community of people with brain stroke (McComas and Sveistrup 2002, Sveistrup *et al*. 2003, Sveistrup *et al*. 2004). They compared activity-based exercise program (ABE) with VR-based exercise program (VRE). Results showed the benefits of video game based training; In particular, participants in the virtual reality programs showed more passion for training programs and reported more pleasure and self-esteem (McComas and Sveistrup 2002, Sveistrup *et al.* 2003, H Sveistrup *et al*. 2004). Moreover, some neuroimaging studies reported that virtual reality interventions might instigate neural plasticity (Berger *et al*. 2018) and cortical reorganization (Xiao *et al*. 2017). Despite the benefits of video game based training compared to traditional practice mentioned in above studies (see also Boroumand and Hassani Merraban 2018), similar results were suggested in other works (Pluchino *et al.* 2012, Singh *et al*. 2012). Also, Reid's findings did not significantly support the virtual reality interventions (Reid 2002).

Based on the literature, the effectiveness of a VR-based intervention on balance capability of a large group of children with CP is unknown. Our question is that whether a program in the VR environment could improve dynamic balance in this population? Therefore, due to the importance of motor learning and the advantages of virtual technology in rehabilitation programs of these individuals, the purpose of this study was to investigate the effects of a VR intervention on dynamic balance of children with SHCP.

2. Materials and methods

2.1. Participants

Twenty girls ranging from 7 to 12 years (mean = 9.4; SD =1.48) were selected by available sampling method from the exceptional schools and randomly divided into the experimental and control groups. The inclusion criteria were Spastic Hemiplegic Cerebral Palsy (SHCP), levels I and II based on Manual Ability Classification System (MACS), score range from 1 to 3 according to the Gross Motor Function Classification System (GMFCS) (Palisano *et al*. 2000), and able to walk without an assistive device. Children with intellectual disabilities, severe degrees of spasticity (score 4+ based on Modified Ashworth Scale), epilepsy, vestibular problem, and hearing or visual impairment were excluded from the study. The ethnicity of children with cerebral palsy was controlled; they were all Iranian. Participants had no experience with the task and the purpose of the experiments. Children's parents signed informed consent form and authorized their participation in the study. Rehabilitation medicine physicians determined the type of CP. They were also informed that the data gathered in this study would be kept completely private. Ethics approval was obtained from the appropriate institutional ethics review board.

2.2. Apparatus

Xbox 360 Kinect (Microsoft, New York, and United State) was used as a therapeutic device for video game based training. This apparatus provided a real-time visual feedback for children with cerebral palsy, which allowed them to see a representation of their movement projected on the screen and to correct compensatory movement patterns. Kinect is a motion detecting camera that can be used with the Xbox 360. It uses special technology to track the body movements and translate those movements into games. The Xbox system was connected to a 39-in TV screen (89 by 52 cm) with a viewing distance of two meters (equivalent 24 degrees of view).

Commercially available Kinect dance game (Microsoft Inc., Redmond, WA, U.S.A.) 'Just Dance 3' was used as video game based training for children with Spastic Hemiplegic Cerebral Palsy (SHCP) (Subramaniam and Bhatt 2015).

Figure 1 Y-Balance Test (YBT) was used to measure the dynamic balance in children with cerebral palsy. Participants were asked to perform the balance task in each direction (anterior, posterolateral, and posteromedial)

Modified star excursion balance test (SEBT) was used to assess the dynamic balance in children with cerebral palsy (Figure 1.). Limb length was measured before starting SEBT Test. It was measured in centimeters from the bottom edge of the anterior superior iliac spine to the distal edge of the medial malleolus. Reach distances were also normalized to each participant's leg length by dividing the reach distance by limb length and then multiplying by 100 to obtain the score for each child and eliminate the impact of foot length on the performance (Gribble and Hertel 2003).

Procedure

The experiment performed individually in a quiet room. General Health Questionnaire (GHQ) was used to assess the general health of participants at baseline (Goldberg and Hillier 1979). Before starting the intervention, barefooted participants conducted 1 practice trials in each direction (anterior, posterolateral, and posteromedial) by Modified star excursion balance test (SEBT). Children with cerebral palsy were asked to stand on one leg in the middle of three directions, while hanging their arms beside the body. Participants placed their healthy foot at the center and attempted to reach at the furthest point in each three direction with their affected foot and then return to the starting point while maintaining their balance on the stance limb. The average of 3 formal trials in each direction was considered as maximum reach distance and was used for the analysis in both pre-test and post-test phases.

Children in the experimental group conducted VR-based dance rehabilitation for 6 weeks by using 'Just Dance 3' game (Microsoft Inc., Redmond, WA, U.S.A.). A high-intensity tapering method was used with 5 sessions per week in the first two weeks, 3 sessions per week in the next two weeks, and 2 sessions per week for the last two weeks (20 sessions in total). (Fabre *et al*. 2002, Hackney and Earhart 2009). 10 minutes stretching exercises were considered to prepare participants for the training period and reduce risk of adverse effects in warm-up and cool down phases. 10 songs were selected for the first 2 weeks of dance games, 12 songs for their 3rd and 4th weeks, and 2 more for the last two weeks based on their choice (24 songs in general for each child) (Hackney and Earhart 2009, Fabre *et al*. 2002). The maximum practice and rest time for each slow- and fast-paced song was 4 and 5 minutes, respectively. After finishing a song, participants were asked to start the next song as soon as their heart rate reached under 85 beats/min (measured by the Panasonic EW3109W), they. Participants continued their practice for 1 hour and twenty five minutes to one hour and forty minutes (Subramaniam and Bhatt 2015). In order to reduce the risks of falling in children with cerebral palsy, they received external assistance by the researcher. Group assignment was double-blinded. Children in the control group did not participate in the VR interventions and were encouraged to do typical physical activity under parental supervision at home. A research assistant recorded their compliance with home-based program for the same 6-week period and reported a good collaboration in performing common physical activity program. All participants in experimental/control group continued their video game based training/common therapy program during the intervention and were not lost in the follow up evaluation. At the end of intervention, dynamic balance scores were assessed again in both groups.

2.3. Data analysis

Descriptive and inferential statistics were used to analyze the data. Normal distribution of all variables was checked using the Shapiro-Wilk test. Statistical analysis of MANOVA and ANCOVA were performed at the significant level of $p < 0.05$. Statistical analysis was conducted using SPSS 16.

Results

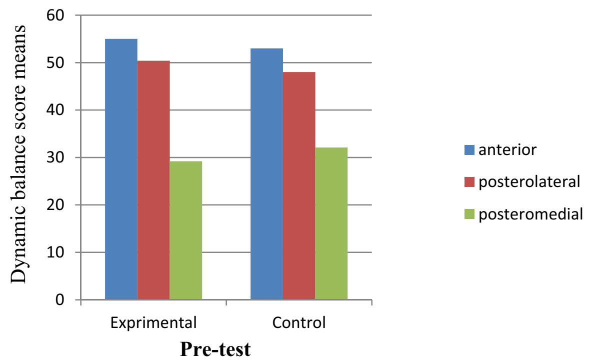
Anthropometric characteristics of the groups are presented in Table 1.There were no significant differences in demographic variables between the two groups of children with spastic hemiplegic cerebral palsy (SHCP). Based on the results of Shapiro-Wilk test, data distribution in pre-test phase was normal.

Dynamic balance means (anterior, posterolateral, and posteromedial) in the pre-test and post-test phases are presented in Figure 2.

Normal distribution of the data was shown by Shapiro Wilkes test. Also, results of the Leven test indicated the homogeneity of variances in the anterior ($F = 2.68$, $p = 0/118$), posterolateral ($F = 0.42$, $p = 0/522$), and posteromedial ($F = 0.99$, $p = 0.331$) directions. Equality of covariance matrices among dependent variables in the post-test stage

Table 1 Anthropometric characteristics of the groups.

Goups	N	Age (M + SD)	Weight (M + SD)	Height (M + SD)	handedness	MACS levels	GMFCS levels
Experimental	10	9.2 + 1.4	33.4 + 7.4	138.1 + 10.6	right (n = 10) left (n = 0)	level I (n = 7) level II (n = 3)	level I (n = 5) level II(n = 2) level III (n = 3)
Control	10	9.6 + 1.5	34.8 + 7.7	145.5 + 7.92	right (n = 10) left (n = 0)	level I (n = 9) level II (n = 1)	level I (n = 6) level II(n = 3) level III (n = 1)



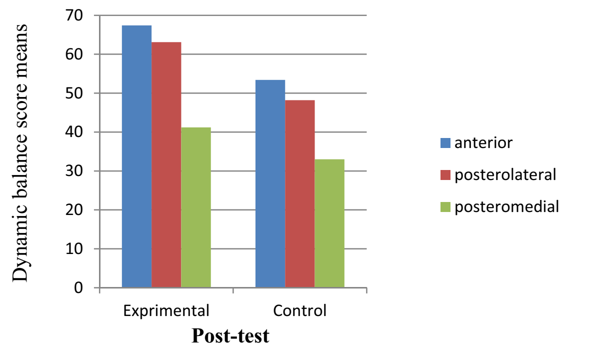


Figure 2 This Figure shows dynamic balance means (anterior, posterolateral, and posteromedial) of both experimental and control groups in the pre-test and post-test phases.

was also shown using the results of the M box test (F (6, 2.34) = 1.08, p = 0.371).

As shown in Table 2, there was a statistically significant difference between groups at least in one of the dynamic balance variables (anterior, posterolateral, and posteromedial) after controlling for pretest, $F(3, 13) = 41.81$, $p < .005$, Wilks' $\Lambda = .09$, partial $\eta^2 = .90$.

As shown in Table 3, results of the one-way covariance test by controlling the pretest showed a significant difference between the dynamic balance variables in the anterior (F = 52.80, p = 0.001), Posterolateral (F = 117.86, p = 0.001), and posteromedial (F = 23.84, p = 0.001) directions in children with cerebral palsy. Therefore, it can be concluded that video game based training have improved the dynamic balance indices in all directions in the experimental group of children with cerebral palsy compared to the control group.

Discussion

In the present study, we investigated the effect of motor practice using Virtual reality training on the balance of children with cerebral palsy. Results of the present study showed a significant improvement in dynamic balance of these children after VR interventions. These findings were consistent with the results by some research (Brien and Sveistrup 2011, Cho *et al.* 2012, Michalski *et al.* 2012, Sveistrup *et al.* 2004, You *et al.* 2005). In order to study the effects of virtual reality technology on balance function, researchers used various types of video games to stimulate the balance, power, and coordination of patients. They showed significant improvement in balance performance (Cho *et al.* 2012, Michalski *et al.* 2012). The results by Brien and Sveistrup (2011) demonstrated improvements in motor learning by integrating into real-life situations. In their study, functional balance and mobility in adolescents with cerebral palsy were improved through a short-term VR intervention and changes were maintained 1 month after the intervention (Brien and Sveistrup 2011).

Traditional rehabilitation might cause lack of enjoyment, independence, and motivation for participants; this problem would solve when playing in the video game based training (Brumels *et al.* 2008, Lange *et al.* 2011, Sveistrup *et al.* 2004). For example, Brumels *et al.* (2008) reported a high level of enjoyment in virtual reality games compared to traditional interventions (Brumels *et al.* 2008). Sveistrup *et al.* (2004) also found that the impact of participation in VR intervention included a range of improvements in functional balance and mobility, as well as the perception of pleasure, independence, and self-esteem (Sveistrup *et al.* 2004). Also, according to Lange *et al.* (2011) motivation is an important factor in the advancement of treatments using virtual reality technology. In our study, children with hemiplegic cerebral palsy could participate in an attractive virtual environment. These interventions helped children with cerebral palsy attend in the video game based training with any degree of ability, confidence, and control on the virtual environment. Therefore, planning these activities based on their level of ability might have reduced sense of fear and disappointment.

Improving balance skills, consistent with previous studies, can indicate the occurrence of learning mechanisms with features such as providing various and repetitive sensory feedback in the virtual environment (You *et al.* 2005). Practice and feedback have been reported as the most important components for motor gains (Mitchell *et al.* 2012). Pavão *et al.* (2014) have

Table 2 MANCOA test results.

effect		value	F	Hypothesis df	Error df	Sig	Patial Eta Squared
group	Pillai's Trace	.90	41.81	3	13	.001	.90
	Wilks' Lambda	.09	41.81	3	13	.001	.90
	Hotelling's Trace	9.65	41.81	3	13	.001	.90
	Roy's Largest Root	9.65	41.81	3	13	.001	.90

Table 3 Results of one-way covariance test.

Dependent Variable	Source	Type III Sum of Squares	df	Mean Square	F	Sig	Partial Eta Squared	Observed Power
anterior	group	77.159	1	77.159	52.808	.001	.779	1.00
	Error	21.917	15	1.461				
	Corrected Total	2100.800	19					
posterolateral	group	117.607	1	117.607	117.868	.001	.887	1.00
	Error	14.967	15	.998				
	Corrected Total	2126.550	19					
posteromedial	group	36.801	1	36.801	23.843	.001	.614	.99
	Error	23.152	15	1.543				
	Corrected Total	1503.800	19					

shown improvements in the fine motor skills of a child with cerebral palsy following the virtual reality-based intervention (Pavão *et al*. 2014). In the present study, continuous repetition of motor gestures, various source of feedback throughout the VR games, and verbal commands by therapist in video game based training might have been responsible for the construction and coordination of new muscle synergies and better balance scores in the experimental group.

Video game based training can trigger neural reorganization by activation of sensory-motor cortex. You *et al*. (2005) reported changes in the Central Nervous System (CNS) following virtual reality interventions. In this case study (with a hemiplegic cerebral palsy child), evidence of increased activity in sensory-motor cortex and decreased activity in other areas were found after video game based training. These changes in the sensory-motor cortex were associated with significant improvement in the functional tests of damaged organs (You *et al*. 2005). Thus, VR interventions in our study might produce cortical neuroplasticity changes by increasing the activation of specific brain areas responsible for movement control reflected in better balance scores in experimental group of children with cerebral palsy.

However, our findings were inconsistent with the results of two research (Carrougher *et al*. 2009, Pluchino *et al*. 2012). Based on the results of our study, balance might have improved due to cortical reorganization following video game based training in children with cerebral palsy; however, cortical reorganization of people with burn injuries, in the study by Carrougher *et al* (2009), might be meaningless. Also, findings of the present study showed the effectiveness of video game based training by using dance games in the dynamic balance of children with cerebral palsy; however, Pluchino *et al*. (2012) did not found a significant effect of video games on the balance of healthy people. Participants in the study by Pluchino *et al* (2012) were elderly people who might not have enough motivation to attend in the video games. In the present study, children with cerebral palsy (7-12 years old) had very different motivational conditions due to the age, motor limitation, and their difficulty in the video game based training compared to real situation. The main limitation of the present study was a 4-week period for the intervention. Thus, a follow-up test seems necessary to see whether improvements remain over time or not.

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