Journal of Pediatric Rehabilitation Medicine: An Interdisciplinary Approach Throughout the Lifespan xx (20xx) x–xx
DOI:10.3233/PRM-220120
IOS Press
CORRECTED PROOF

Effectiveness of virtual reality training compared to balance-specific training and conventional training on balance and gross motor functions of children with cerebral palsy: A double blinded randomized controlled trial

Hussein Ziab[a,b], Soha Saleh[c], Saeed Talebian[b], Golamreza Olyaei[b], Rami Mazbouh[b,d], Ahmad Rifai Sarraj[a] and Mohamad Reza Hadian[b,e,*]

[a]*Department of Physiotherapy, Faculty of Public Health, Lebanese University, Beirut, Lebanon*
[b]*Department of Physiotherapy, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran*
[c]*Center for Mobility and Rehabilitation Engineering Research at the Kessler Foundation, West Orange, NJ, United States*
[d]*Health Rehabilitation, Integration and Research Center, Beirut, Lebanon*
[e]*Brain and Spinal Injuries Research Center (BASIR), Institute of Neuroscience, Tehran University of Medical Sciences, Tehran, Iran*

Received 22 November 2022
Accepted 1 April 2024

Abstract.
PURPOSE: The purpose of this study was to compare the clinical efficacy of a virtual reality rehabilitation-based training (VRT) with balance-specific training (BST) and conventional training (CT) on the balance and gross motor functions (GMF) of children with cerebral palsy (CwCP).
METHODS: This study was a double blinded, randomized controlled trial. Participants were recruited from different CP rehabilitation centers and clinics and were then randomly allocated using the block randomization method into three groups: (1) group 1 (VRT using a set of Xbox 360 games that triggered balance), (2) group 2 (BST applying a protocol of 13 exercises to enhance balance in different conditions), and (3) control group 3 (CT using traditional physiotherapy techniques). All groups received 18 sessions over six weeks, three sessions per week, each lasting 60 minutes. Participants were assessed at three timepoints (baseline, post-treatment, and follow-up) using the Pediatric Balance Scale (PBS), the Gross Motor Function Measure (GMFM D & E), the Five Times Sit-To-Stand Test, and upper and lower segments' center of mass (COM) displacement (U_{COM} and L_{COM}).
RESULTS: A total of 46 CwCP participated in this study. The repeated measures ANOVA revealed a statistically significant difference between groups in the dependent variables, except for the GMFM (D & E) and the PBS ($p < 0.05$ and partial $\eta^2 = 0.473$). The *post-hoc* test showed a statistically significant difference in favor of the VRT group compared to other

*Corresponding author: Professor Dr. Mohammad Reza Hadian, PT, Electroneurophysiologist, Ph.D., School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran. Tel.: +989101345368; E-mails: hadianrs@sina.tums.ac.ir; hadianrasan@gmail.com.

groups in terms of right U_{COM} ($p < 0.05$) with a large effect size of the time*group interaction (partial $\eta^2 = 0.87$). Moreover, there was a statistically significant effect of time (i.e., baseline to post-treatment and baseline to follow-up) with F (18, 23) = 59.954, $p < 0.05$, Wilks' lambda = 0.021, partial $\eta^2 = 0.979$.
CONCLUSION: The findings revealed that VRT was not superior to BST in the rehabilitation of balance and GMF in CwCP aged four to 12 years. However, when compared to CT, better results were reported. Furthermore, it appears that customized programs lead to greater improvements in balance than commercial programs. Future studies are needed to assess the physiological effects of the three types of rehabilitation interventions using more advanced measurement tools, such as functional magnetic resonance imaging, following VRT protocols.

Keywords: Cerebral palsy, balance, task-specific training, conventional rehabilitation, virtual reality

1. Introduction

Cerebral palsy (CP) is defined as a group of non-progressive disorders that affect the immature brain during the prenatal, neonatal, or postnatal period leading to disturbances in the development of movement and posture [1]. It is frequently associated with epilepsy, secondary musculoskeletal problems, and disturbances of sensation, perception, cognition, communication, and behavior. It can also lead to activity limitations [2].

It is worth noting that balance in bipedal standing, as detected by the reduction of the area (range) and the change in the speed of adjustment of the center of pressure (CoP) sway [3] is typically achieved during the first year of life, as described by the ontogenetic model [4]. In this model, children utilize different strategies to maintain balance, with a primary focus on choosing a stabilized anatomical reference segment and effectively utilizing and coordinating the degrees of freedom of body joints [4]. Consequently, accurate timing of these parameters reflects the maturation of the central nervous system (CNS) [5] and leads to good static and dynamic balance functions.

In contrast, there is still controversy regarding the age at which children exhibit more efficient (i.e., functional) balance. Rival et al. found that, at 10 years of age, children display higher maximal excursion and mean velocity of the CoP displacement in controlling static and dynamic balance than adults, especially when the eyes are closed, suggesting that they remain visually dependent [6]. However, Forssberg and Nashner stated that the maturation of adult-like balance-control strategies occurs around the age of 7-8 years [7].

Within this context, numerous studies have been established to explore the impact of balance deficits on the motor abilities and cognitive levels of children with CP (CwCP) [3, 4, 8–10]. In 2006 and 2013 respectively, Swaiman et al. and Richards et al. suggested that impaired postural control might lead to difficulties in walking or reaching for objects in CwCP [11]. Additionally, in 2013, Pavão et al. and Chen et al. emphasized that balance is crucial for being independent in activities of daily life tasks [12, 13].

Accordingly, substantial evidence suggests that balance training should be a primary focus for any rehabilitation program in order to enhance the performance of motor skills as well as other functional activities [14].

Virtual reality intervention (VRI) is defined as the use of interactive simulations to enable patients to practice exercises in virtual environments similar to real-world scenarios, which can facilitate multimodal sensorimotor procedures [15]. In essence, virtual reality provides the opportunity for users to interact, move, and manipulate virtual objects while experiencing a sense of virtual presence in the simulated world [16]. Recent meta-analysis studies have reported good evidence that VRI could improve standing balance and gait in CwCP, whether used alone or in combination with traditional physiotherapy protocols, regardless of the settings and parameters of the intervention protocol [17–21].

On the other hand, Kim et al. defined task-specific training (TST) as a neural rehabilitation approach [5], based on a systems model of motor control and contemporary motor learning theories [22], designed to systematically enhance specific motor tasks, including balance and activities of daily living [23] through goal-directed practice and repetition [22, 24]. Within this context, TST including specific, interesting, and motivating exercises to improve spatiotemporal orientation of balance and gross motor functions was studied in CwCP [25]. Kumar et al. reported that TST is more effective in improving the functional mobility and balance of children with spastic diplegia when compared to conventional training (CT) [26]; however, it demonstrated similar improvements in stride length, cadence, and gait velocity as well as in balance functions of CwCP when compared to the proprioceptive neuromuscular facilitation approach [22]. Similarly, in 2016, Han et al. stated that task-oriented training led to a significant improvement in walking and balance functions as detected by increased Gross Motor Function Measure (GFMF; D and E dimensions) scores [24].

Interestingly, the existing literature lacks studies examining the effects of virtual reality training (VRT) and TST approaches. The primary objective of this study was to examine the efficacy of a virtual reality rehabilitation-based protocol on balance and, subsequently, the gross motor functions of CwCP compared to a protocol of balance-specific training (BST) and CT. Furthermore, the study aimed to demonstrate that a well-designed active videogame rehabilitation protocol using an Xbox 360 device could improve balance in CwCP and could be recommended for home-based rehabilitation if properly monitored. The research also sought to assess the generalization of balance improvement in the daily life activities of CwCP after six weeks of training.

2. Design and methods

2.1. Study design

This was a double-blinded, randomized controlled study in which both participants and assessors were blinded. Informed written consent was signed by parents before participation.

2.2. Participants

The sample size calculation was powered using "G-Power" software, employing a *t*-test statistical model based on previously published data [14, 27, 28] (refer to Appendix 1 for details). The mean and standard deviation of the outcome measures utilized in the study, including the GMFM, Pediatric Balance Scale (PBS), and Five Times Sit-To-Stand Test (FTSTST), were used for this purpose. The assumed effect size (ES, $r \geq 1.05$) and a statistical power of 80% were considered during this calculation.

Upon conducting the power analysis, it was determined that the largest sample size would be 12 participants in each group. Therefore, to ensure adequate participant representation, a minimum of 12 patients were to be recruited for each group, adhering to the following criteria:

1. Diagnosis of CP: participants must have a confirmed diagnosis of spastic monoplegic, hemiplegic, or diplegic CP, as verified by a physician.
2. Age Range: the study included children aged four to 12 years.
3. Eligibility Criteria: Children were included if they were able to walk (Level I and II according to the Gross Motor Function Classification System – Expanded & Revised [GMFCS-ER]), had a mild level of spasticity (graded less than two according to the Modified Ashworth Scale) in the involved lower extremities, had not received any surgical intervention or botulinum toxin injections in the last six months, were able to understand therapist instructions and participate in the active videogame rehabilitation protocol, and were willing to voluntarily participate in the study. Conversely, children with severe sensory (visual or auditory) or cognitive impairments that hindered their participation in the rehabilitation program, those who had engaged in any active videogames (AVG) system based on parental reports (more than one hour per week for more than four weeks) within the last year, or those with medical conditions preventing engagement in the rehabilitation protocols were excluded from this study.
4. Consent: informed consent was obtained from the parents or legal guardians of all participants before their inclusion in the study.

Consequently, it was planned to recruit a minimum of 15 participants in each group, which included an additional 25% (+25%) to account for potential patient dropouts or missing data. The participants were selected from various CP rehabilitation centers and clinics to ensure a robust and reliable sample size for the study.

2.3. Method of allocation to study groups

After the baseline assessment, all eligible children were randomly allocated to either the VRT, BST, or CT group. Block randomization was stratified by sex and GMFCS levels (I and II). Within each stratum, equal-sized blocks were determined to minimize the risk of imbalances in the sample sizes. Sealed envelopes opened by a third party not involved in the study were used to achieve the allocation concealment. Following randomization, the participants underwent reassessment at two time points: immedi-

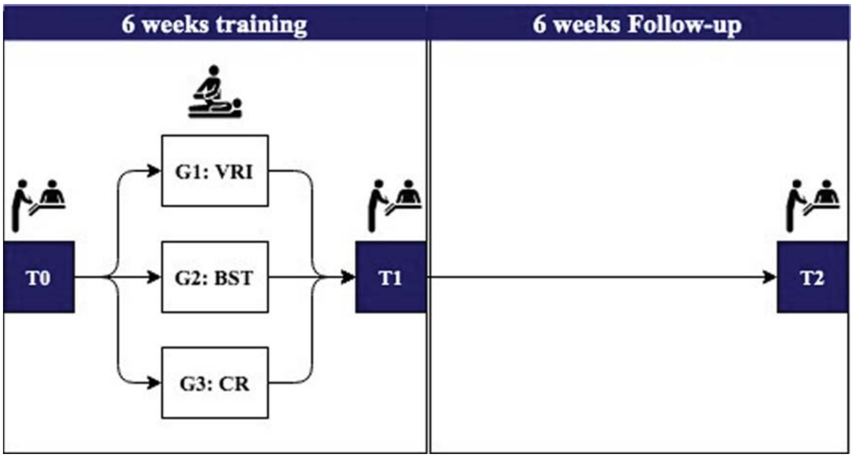

Fig. 1. Map of the study. T0: baseline assessment; G1: group 1; VRI: virtual reality intervention; G2: group 2; BST: balance-specific training; G3: group 3; CR: conventional rehabilitation; T1: post-training assessment; T2: follow-up assessment.

ately after completing the treatment cycle and again after a six-week follow-up (Fig. 1).

2.4. Outcome measures

Four outcome measures were carefully selected to provide a comprehensive evaluation of the balance function:

(1) *The GMFM* (dimensions D and E) is a standardized, valid, and reliable observational instrument [29, 30] for quantitatively evaluating changes in gross motor function over time in CwCP [31] and has been shown to be highly correlated with the PBS as clinical measures of static and dynamic CwCP balances [32].

(2) *The PBS* is a valid and reliable tool used to evaluate the functional balance of school-age children [12, 33]. It assesses 14 items related to balance: sitting to standing, standing to sitting, transfers, standing unsupported, sitting unsupported, standing with eyes closed, standing with feet together, standing with one foot in front, standing on one foot, turning 360 degrees, turning to look behind, retrieving an object from the floor, placing alternate foot on stool, and reaching forward with outstretched arm.

(3) *The FTSTST* is a reliable, objective functional test for measuring one component of transfer skill, quantifying functional lower extremity strength, and/or identifying movement strategies used by a patient during transitional movements [34, 35]. It measures the time required to perform the sit-to-stand function five times.

4) *The Digital Photography Tool (DP)* is a simple-to-use, safe, convenient, time-efficient and cost-effective method [36]. It can provide a high degree of reliability when conducting other clinical assessments, serving as a “snapshot in time” or an objective reference point for future re-assessment by the same examiner (test-retest reliability) or by a colleague (inter-rater reliability) [37]. In a previous study, the DP was validated as a measurement tool for assessing the balance function of CwCP [38].

In the current study, the DP was used as a secondary outcome measure to assess the location of the total center of mass (COM) of the upper and lower limbs (U_{COM} and L_{COM}) in reference to the shoulder and hip, respectively. The analysis of the changes in the COM location computed from the DP was then considered a predictor of the postural adjustment the child developed or acquired through training.

Accordingly, a Nikon COOLPIX L340 camera (Nikon Inc., Melville, NY) with a zoom lens ranging from 18 to 200 mm was used to capture digital photos of the eligible participants. The images were captured with a focal length of 4 mm and an aperture of F3.1. To ensure clarity for the purpose of locating measurement landmarks, a resolution of 2 megapixels was combined with a convergently low sensitivity to light (International Organization for Standardization [ISO]; 400).

Fig. 2. Standardized position of the patients. The patient is standing in his natural position, trying to keep his both feet parallel to each other. Non-reflective markers were attached on the eight selected anatomical landmarks.

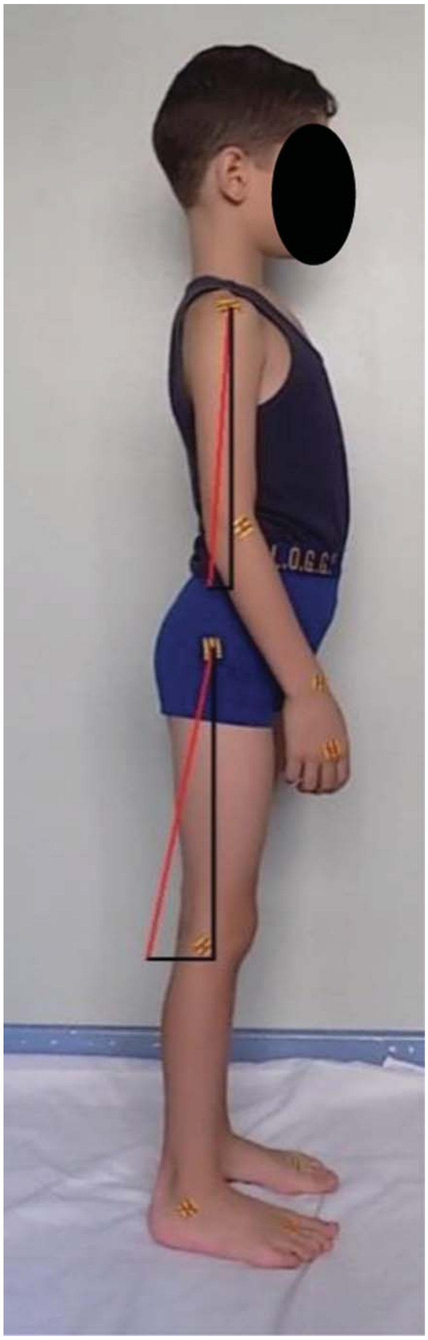

Fig. 3. Center of mass (COM) vectors. The vectors of upper and lower COM are drawn.

The assessors followed the same procedure described in a previous study [38] to record and compute the DP data. Figures 2 and 3 depict the vectors of the U_{COM} and L_{COM} on both sides.

In addition, demographic information including age, sex, height, weight, CP subtype, spasticity levels, and GMFCS level was also recorded. An independent therapist with five years of experience in assessing and treating CP evaluated the participants at baseline, post-intervention, and after a six-week follow-up period (Fig. 1). Adequate rest between tests was taken

Table 1
Games used in virtual reality-based training

Game Categories	Kinect Sports	Kinect Adventures	Your Shape: Fitness Evolved	Carnival
Specific games	Brunswick Pro Bowling Table tennis Boxing	20,000 Leaks Space Pop	Cardio boxing Wall breaker Zen (yoga)	Gold Rush Mountain Knockout Punch

into consideration by the therapist to avoid participant fatigue.

2.5. Intervention

In the current study, the focus was to develop and implement a simple and cost-effective virtual reality-based rehabilitation protocol tailored for CwCP. The primary aim was to create a user-friendly approach that remains adaptable to future technological advancements. Additionally, the study aimed to introduce a novel program of BST based on functional exercises, with the goal of activating various balance strategies and enhancing the overall balance abilities of participants.

Group 1: Virtual Reality Rehabilitation-Based Therapy (VRT)

In the virtual reality rehabilitation-based therapy session, an Xbox 360 with the Kinect device for motion capture was used in order to provide a full-body three-dimensional motion demonstration as a kind of visual feedback [39]. This enabled the user to control an avatar and to interact with the virtual environment mainly using gestures and body movements through a natural user interface without the need for a traditional game controller [40].

The Kinect intervention consisted of a six-week program with three individual 60-minute sessions per week. The games were chosen based on previous studies that showed their effectiveness in engaging body movements in all directions and facilitating balance adjustments similar to those required in daily life activities [39, 41–44]. The intervention included the following Kinect games: 1) Kinect Sports, 2) Kinect Adventures, 3) Your Shape: Fitness Evolved, and 4) Carnival (Table 1).

In the session, a trained physical therapist supervised and assisted the child's practice by providing physical support or feedback as needed to maintain balance and ensure the best practice. In addition, the progression in the difficulty of the games was determined by the physical therapist based on the balance performance of each participant to ensure that the program triggered improvement. Furthermore, a rest time was offered in case of fatigue, in addition to the rest period between games, which was set at two minutes for all children.

Participants in this group received a pre-training session to ensure their complete comprehension of the Xbox-Kinect system and the goal of the individual games. For children with a high risk of fall, small parallel bars were used.

Group 2: BST

This group of participants underwent a BST program consisting of 18 sessions over six weeks (three sessions/week, one hour each). This protocol was developed based on the key components of the PBS, a primary indicator of balance function. Thus, the exercises aimed to activate the muscle synergies responsible for maintaining balance in the standing position. Thirteen exercises were developed within three categories: (1) transfer, in which the child was asked to transfer from one position to another while keeping their balance, (2) holding balance, in which static balance was enhanced in various positions (sitting, standing, one leg stance), and (3) mobility in standing, in which the child performed movements while keeping their balance in standing (Table 2 and Appendix 2). Exercise settings, including holding time, repetitions, sets, and rest between exercises, were carefully established after in-depth discussion with pediatric physical therapists with more than five years of experience in this field.

The therapist adjusted the intervention based on each child's balance level, taking into account the level of difficulty and the progression policy outlined in the protocol (Appendix 3). They were aware of the number of repetitions and the rest period (20 seconds) between repeats, as well as the child's fatigue during the exercise. If the child was unable to complete the entire protocol during the session owing to fatigue, the therapist was instructed to increase the rest period so that the three categories of exercises could be completed in each session. Even if the rest period was extended, the session lasted only 60 minutes.

Group 3: control group

In the control group, participants received treatment from their therapists under the supervision and guidance of the principal investigator of this study. They underwent three sessions per week for

Table 2
Summary of Task-Specific exercises

Exercises		Repetitions	Holding (sec)	Rest (sec)
Transfer	Sitting to standing	5		20
	Standing to sitting	5		20
	Transferring from chair to another	5		30
Holding balance	Standing unsupported	5	30	20
	Sitting with back unsupported	5	30	20
	Standing with feet together	5	30	20
	Standing unsupported with one foot	5	30	20
	Standing on one leg	5	30	20
Mobility in standing	Turning 360 degrees	5		20
	Turning to look behind	5		20
	Retrieving object from floor	5		20
	Placing alternate foot on step stool	8*5		60
	Reaching forward	5	30	20

Fig. 4. A therapist conducting conventional balance training used in the control group.

six weeks, consisting of stretching, strengthening, neurodevelopmental treatment exercises, functional balance exercises, and aerobic exercises (such as treadmills, bicycle, etc.) [45] (Fig. 4).

2.6. Statistical analysis

Statistical analyses were conducted using IBM SPSS for Windows, version 23 (SPSS Inc., Chicago, Illinois, USA). The normal distribution of data was examined using the Kolmogorov-Smirnov test and Q-Q plot. Descriptive statistics were calculated for the demographic data using percentages and frequencies. Subsequently, the ANOVA test was used to compare baseline clinical measures between the groups.

To examine changes in dependent variables across time in all groups, repeated measures ANOVA (2 times $\times$ 3 groups) was conducted with the time*group interaction considered in a random model. Mauchly's test of sphericity was not assumed, and the degree of freedom for the averaged tests of significance was adjusted using the Greenhouse-Geisser correction. The Bonferroni pairwise comparison determined the changes in outcome measures at specific time intervals. Moreover, the independent *t*-test was used to detect the significant changes between times of evaluation (baseline, post treatment, and follow-up) with respect to group repartition.

The ES was calculated using partial eta squared (η^2) for the repeated measures ANOVA and the Cohen's d for the independent *t*-test. The magnitude of the ESs was classified as small (0.01), medium (0.06), and large (>0.14). A *p*-value of less than 0.05 was used to detect significance.

3. Results

3.1. Descriptive analysis

This study initially recruited 46 patients with various subtypes of CP. However, two participants from the VRT group and one from the BST group dropped out of the study due to an inability to continue their protocols ($n = 2$) or a refusal to undergo reassessment ($n = 1$). Therefore, the final analysis included 43 participants, consisting of 31 males and 12 females, who completed the follow-up assessment (refer to Fig. 5). The participants had a mean age of 7.9 ± 2.7 years, a mean height of 115.02 ± 20.17 cm, and a mean weight of 25.11 ± 8.9 kg. Among them, there were 15

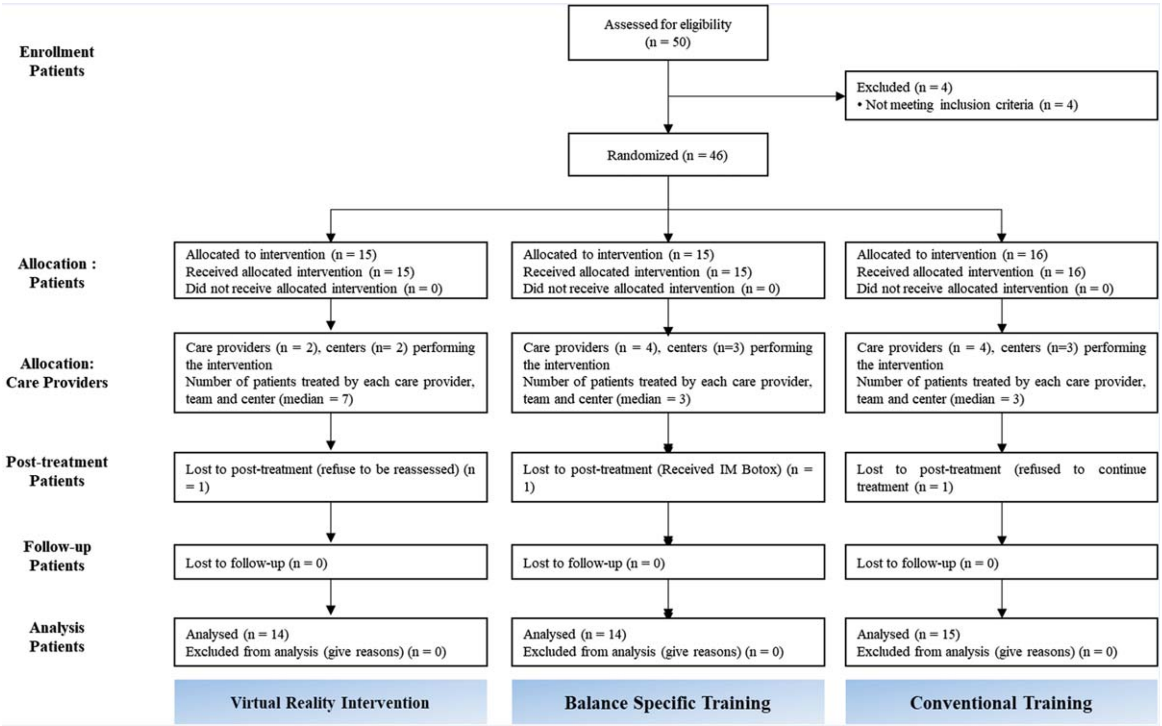

Fig. 5. Modified CONSORT flow diagram of randomized controlled trial.

Table 3
Demographic characteristics of participants

		Virtual reality training	Balance-specific training	Conventional training	Total
Sex	M	10	10	11	31
	F	4	4	4	12
	Total	14	14	15	43
Diagnosis	LSH	6	5	4	15
	RSH	3	3	2	8
	SD	4	5	8	17
	MP	1	1	1	3
Spasticity	1	11	9	13	33
	2	3	5	2	10
GMFCS	I	11	10	14	35
	II	3	4	1	8
Age	Mean (SD)	8.29 (±2.09)	7.94 (±2.85)	7.40 (±3.02)	7.86 (±2.67)
Height	Mean (SD)	118.36 (±13.57)	115.50 (±21.90)	111.47 (±24.01)	115.02 (±20.17)
Weight	Mean (SD)	24.50 (±8.60)	26.71 (±9.46)	24.20 (±9.02)	25.12 (±8.87)

M: male, F: female, LSH: left spastic hemiplegia, RSH: right spastic hemiplegia, SD: spastic diplegia, MP: monoplegia, GMFCS: Gross Motor Function Classification System, SD: standard deviation.

participants with left spastic hemiplegia (LSH), eight with right spastic hemiplegia (RSH), 17 with spastic diplegia (SD), and three with monoplegia (Table 3).

Compliance with treatment was consistent across the groups with 91% (mean of 16.35 sessions) in the VRT, 94% (mean of 16.93 sessions) in the BST, and 95% (mean of 17.2 sessions) in the CT group.

It is noteworthy that no children in any of the three groups had unusual extra rest time during the exercises. The exercises were performed in the same sequence for all children in the VRT and BST groups, with each session lasting 60 minutes.

3.2. Statistical analysis

The Kolmogorov-Smirnov test of all variables revealed that the data was normally distributed at baseline ($p > 0.05$) (Appendix 4). Visual interpreta-

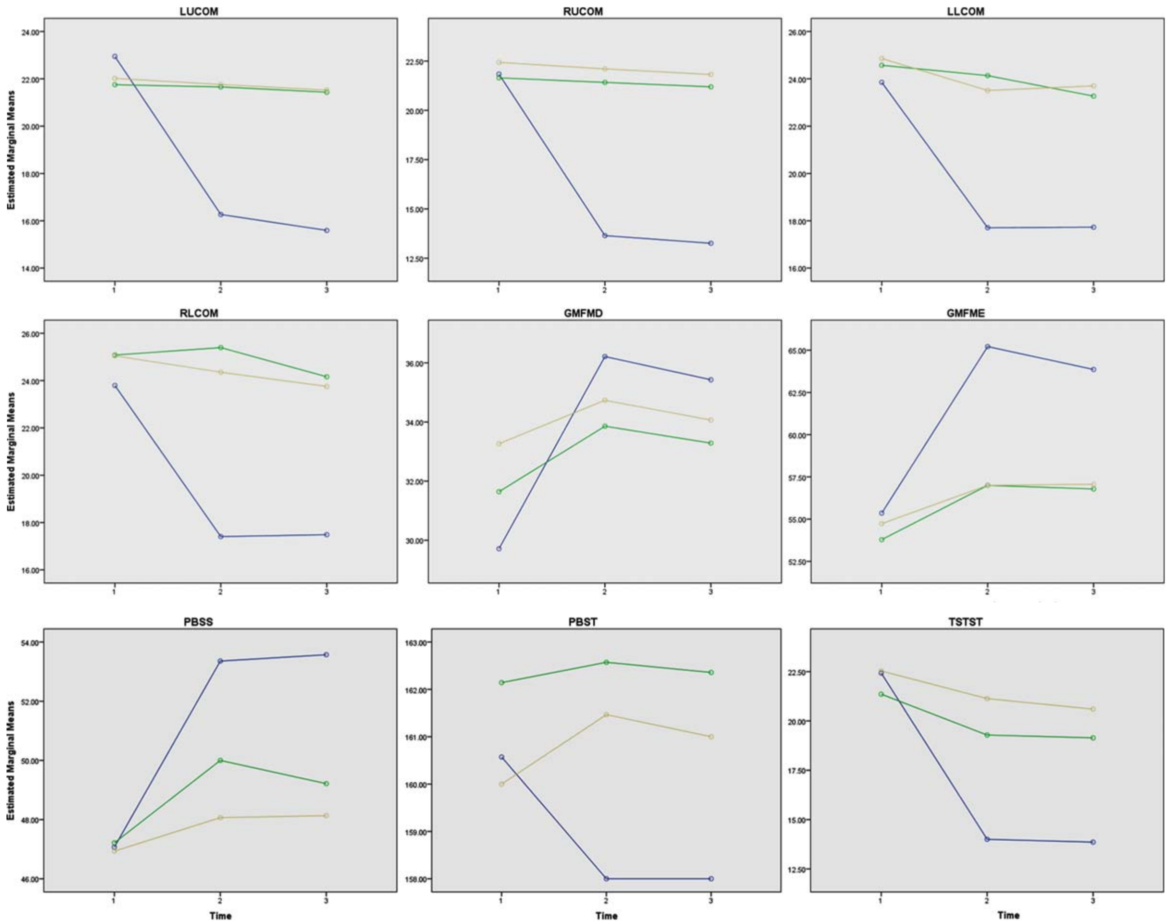

Fig. 6. Multivariate Analysis of between and within groups (with Blue: Virtual Reality Training, Green: Balance Specific Training, and Grey: Conventional Training). LUCOM: left upper center of mass, RUCOM: right upper center of mass, LLCOM: left lower center of mass, RLCOM: right lower center of mass, GMFM: Gross Motor Function Measure, PBS: Pediatric Balance Scale, 5TSTST: Five Times Sit-To-Stand Test.

tion of histogram, Q-Q plots, and boxplots satisfied the normal distribution. Moreover, no significant differences in demographic or clinical variables were found at baseline among the three groups ($p > 0.05$) (Appendix 5).

The repeated measures ANOVA yielded a large ES for the time*group interaction with F (36, 46) = 7.878, $p < 0.05$, Wilks' lambda = 0.019, and partial $\eta^2 = 0.87$, which revealed that VRT and BST had a greater positive impact on the participants' balance and GMFM compared to CT with regard to time of evaluation (Fig. 6). Interestingly, the main effect of group allocation (i.e., intervention protocol) analysis revealed a statistically significant positive difference between groups in the dependent variables (i.e., PBS, GMFM, FTSTST, and DP outcomes) with F (18, 64) = 3.188, $p < 0.05$, Wilks' lambda = 0.278, and partial $\eta^2 = 0.473$, except for GMFM D & E and time of PBS (Fig. 6 and Appendix 6). Moreover, regardless of group repartition, the effect of time (i.e., effect of intervention over time) analysis revealed that there were positive improvements at post-treatment assessments that were sustained to follow-up with F (18, 23) = 59.954, $p < 0.05$, Wilks' lambda = 0.021, and partial $\eta^2 = 0.979$ in all dependent variables except the time of PBS, which did not show significant positive or negative change among participants in all groups with F (2.09, 1.348) = 58.551, $p = 0.148$, and partial $\eta^2 = 0.05$ (Table 4).

On the other hand, the comparison between groups performed by using Tukey's honestly significant difference *post-hoc* test showed a statistically significant difference in the right U_{COM} in favor of the VRT group compared to other groups (i.e., BST and CT), while the left U_{COM}, right L_{COM}, PBS scores, and FTSTST showed its superiority to the CT group

Table 4
Pairwise comparison based on Time regardless of group repartition

Measure			MD	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Digital Photography	LUCOM	Baseline* Post-treatment	2.35*	0.000*	1.396	3.294
		Baseline* Follow-up	2.72*	0.000*	1.666	3.778
		Post-treatment* Follow-up	0.38	0.088	–0.040	0.794
	RUCOM	Baseline* Post-treatment	3.75*	0.000*	3.020	4.470
		Baseline* Follow-up	4.02*	0.000*	3.385	4.660
		Post-treatment* Follow-up	0.28*	0.045*	0.004	0.551
	LLCOM	Baseline* Post-treatment	2.65*	0.000*	1.963	3.327
		Baseline* Follow-up	2.86*	0.000*	2.040	3.685
		Post-treatment* Follow-up	0.217	1.000	–0.478	0.912
	RLCOM	Baseline* Post-treatment	2.36*	0.000*	1.690	3.028
		Baseline* Follow-up	2.79*	0.000*	1.884	3.694
		Post-treatment* Follow-up	0.43	0.379	–0.258	1.119
Clinical Measures	GMFM dimension D	Baseline* Post-treatment	–3.39*	0.000*	–4.033	–2.757
		Baseline* Follow-up	–2.81*	0.000*	–3.405	–2.214
		Post-treatment* Follow-up	0.59*	0.000*	0.248	0.923
	GMFM dimension E	Baseline* Post-treatment	–4.01*	0.000*	–4.997	–3.031
		Baseline* Follow-up	–4.13*	0.000*	–5.156	–3.108
		Post-treatment* Follow-up	–0.12	1.000	–0.955	0.720
	PBSS	Baseline* Post-treatment	–4.27*	0.000*	–5.069	–3.461
		Baseline* Follow-up	–4.22*	0.000*	–5.023	–3.409
		Post-treatment* Follow-up	0.049	1.000	–0.280	0.379
	PBST	Baseline* Post-treatment	–1.62	0.442	–4.353	1.118
		Baseline* Follow-up	–1.70	0.372	–4.405	1.005
		Post-treatment* Follow-up	–0.08	1.000	–1.376	1.211
	FTSTST	Baseline* Post-treatment	4.68*	0.000*	3.959	5.403
		Baseline* Follow-up	5.17*	0.000*	4.342	5.988
		Post-treatment* Follow-up	0.48*	0.026*	0.045	0.923

*. The mean difference is significant at the 0.05 level. LUCOM: left upper center of mass, RUCOM: right upper center of mass, LLCOM: left lower center of mass, RLCOM: right lower center of mass, GMFM: Gross Motor Function Measure, PBSS: Pediatric Balance Scale scores, PBST: Time of Pediatric Balance Scale, FTSTST: Five Times Sit-To-Stand Test, Sig.: significant, MD: mean difference.

($p < 0.05$). In contrast, the remaining outcome measures (i.e., left L_{COM}, GMFM D & E, and time of PBS) did not exhibit any preferences among the three groups ($p > 0.05$) (Table 5).

Furthermore, the independent sample *t*-test conducted in each group analysis revealed significant positive changes over time from baseline to post-treatment assessments in the majority of outcome measures within the VRT group except for right U_{COM} ($p = 0.045$), GMFM ($p = 0.000$), and FTSTST ($p = 0.026$). These improvements were maintained with no statistically significant positive or negative changes from post-treatment to follow-up assessments (Table 6).

4. Discussion

The primary objective of this study was to compare the effectiveness of three approaches (virtual reality rehabilitation-based training, BST, and CT) on the balance function of CwCP. The study hypothesized that a meticulously designed and cost-effective active videogame rehabilitation protocol utilizing an Xbox 360 device could significantly enhance the balance of CwCP and, if appropriately monitored, could be recommended for home-based rehabilitation.

The results of the current study revealed statistically significant differences between the VRT and CT groups in improving the balance function. Five outcome measures (LU_{COM}, RU_{COM}, RL_{COM}, PBS scores, and FTSTST) were more improved for the VRT group than the CT group. These findings were consistent with previous research [15, 46–50] showing that various VRI protocols led to an improvement in balance and gross motor functions in CwCP. For instance, Ren et al. suggested that VRT led to a greater improvement in the GMFM D & E and PBS scores when compared to the control group [47]. It is worth noting that Ren et al. focused on evaluating the effect of VRT on gross and fine motor skills in CwCP by using flexibility and mobility exercises rather than specific balance exercises. Similarly, Cho et al. found that children in the virtual reality tread-

Table 5
Post-hoc multiple comparison analysis (Tukey's honestly significant difference)

Measure		Combination	MD	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Digital Photography	LUCOM	VRT*BST	–3.35	0.055	–6.7516	0.0602
		VRT*CT	–3.49*	0.039	–6.8474	–0.1501
		BST*CT	–0.15	0.993	–3.5017	3.1956
	RUCOM	VRT*BST	–4.88*	0.004*	–8.3355	–1.4284
		VRT*CT	–5.83*	0.000*	–9.2348	–2.4438
		BST*CT	–0.96	0.773	–4.3529	2.4382
	LLCOM	VRT*BST	–4.23	0.064	–8.6644	0.2044
		VRT*CT	–4.26	0.057	–8.6200	0.0998
		BST*CT	–0.03	1.000	–4.3900	4.3298
	RLCOM	VRT*BST	–4.58	0.063	–9.3645	0.2049
		VRT*CT	–5.51*	0.018*	–10.2185	–0.8099
		BST*CT	–0.93	0.880	–5.6387	3.7699
Clinical Measures	GMFM dimension D	VRT*BST	1.02	0.580	–1.4638	3.5115
		VRT*CT	1.19	0.472	–1.2601	3.6315
		BST*CT	0.16	0.986	–2.2839	2.6077
	GMFM dimension E	VRT*BST	4.36	0.143	–1.1357	9.8500
		VRT*CT	4.68	0.101	–0.7228	10.0783
		BST*CT	0.32	0.989	–5.0799	5.7212
	PBSS	VRT*BST	2.48	0.075	–0.2004	5.1528
		VRT*CT	4.92*	0.000*	2.2922	7.5554
		BST*CT	2.45	0.073	–0.1840	5.0792
	PBST	VRT*BST	–2.83	0.297	–7.4028	1.7361
		VRT*CT	–1.59	0.665	–6.0911	2.8942
		BST*CT	1.23	0.783	–3.2577	5.7276
	FTSTST	VRT*BST	–2.17	0.218	–5.2690	0.9357
		VRT*CT	–4.24*	0.005*	–7.2899	–1.1895
		BST*CT	–2.07	0.235	–5.1232	0.9772

*. The mean difference is significant at the.05 level. LUCOM: left upper center of mass, RUCOM: right upper center of mass, LLCOM: left lower center of mass, RLCOM: right lower center of mass, GMFM: Gross Motor Function Measure, PBSS: Pediatric Balance Scale scores, PBST: Time of Pediatric Balance Scale, FTSTST: Five Times Sit-To-Stand Test, Sig.: significant, MD: mean difference, CI: confidence interval, VRT: virtual reality training, BST: balance-specific training, CT: conventional training.

mill training (VRTT) group exhibited higher GMFM and PBS scores than those in the treadmill training group, implying that VRTT is more effective in improving balance abilities in children with spastic CP. Likewise, Brien and Sveistrup reported that the functional balance and mobility of four adolescents with CP improved significantly after five consecutive days of VRT [15]. They attributed this improvement to the neuroplasticity of the CNS, which allows children to acquire and implement new complex tasks into their daily life activities as defined by the motor learning process. Correspondingly, Gatica-Rojas et al. stated significantly better improvement of standing balance in children with spastic hemiplegic CP when compared to a standardized physiotherapy protocol [50].

On the other hand, no previous studies in the literature directly compared the effects of virtual reality-based rehabilitation protocols and TST on the balance function of CwCP. However, one study of participants with developmental coordination disorder found that Wii-based training (WT) and TST were both effective on some aspects of balance and motor performance [51]. They did, however, suggest that TST was more effective than WT on balance skills, while WT had slightly stronger effects on manual dexterity than TST. Kaur et al. (2020) found that VRT was more effective than TST in improving the upper limb motor recovery of stroke survivors, while both treatments improved trunk performance equally [52]. Similarly, Molhemi et al. (2020) suggested that VRT and balance-specific exercises improved specific dimensions of balance in patients with multiple sclerosis; VRT improved cognitive motor function and reduced falls, whereas BST improved directional control [44].

In the current study, only one outcome measure (i.e., right U_{COM}) showed that VRT was superior to BST; however, both interventions resulted in significant improvements in balance and gross motor functions of CwCP. This lack of significant differences between VRT and BST could be attributed to the following: (1) Both approaches are basically designed on specific exercises that enhance the bal-

Table 6
Independent t-test of pre-post-treatment and follow-up in each group

	Variables	Groups	Baseline to Post-treatment		Baseline to Follow-up		Post-treatment to Follow-up	
			MD	Sig.	MD	Sig.	MD	Sig.
Digital Photography	LUCOM	VRT	6.68	0.00*	7.36	0.00*	0.67	0.14
		BST	0.09	0.69	0.32	0.19	0.22	0.17
		CT	0.26	0.25	0.49	0.17	0.24	0.29
	RUCOM	VRT	9.68	0.00*	10.07	0.00*	0.39	0.14
		BST	0.85	0.08	1.07	0.03*	0.22	0.22
		CT	0.70	0.00*	0.92	0.00*	0.22	0.14
	LLCOM	VRT	6.15	0.00*	6.13	0.00*	–0.02	0.87
		BST	0.44	0.35	1.30	0.09	0.87	0.27
		CT	1.35	0.03*	1.16	0.05*	–0.19	0.59
	RLCOM	VRT	5.75	0.00*	6.02	0.00*	0.27	0.36
		BST	0.97	0.1	0.92	0.20	–0.05	0.86
		CT	0.36	0.36	1.43	0.07	1.07	0.15
Clinical Measures	GMFM dimension D	VRT	–6.50	0.00*	–5.71	0.00*	0.79	0.01*
		BST	–2.29	0.00*	–1.71	0.00*	0.57	0.01*
		CT	–1.40	0.01*	–1.00	0.03*	0.40	0.14
	GMFM dimension E	VRT	–7.07	0.00*	–7.43	0.00*	–0.36	0.71
		BST	–2.57	0.00*	–2.50	0.00*	0.07	0.82
		CT	–2.40	0.00*	–2.47	0.00*	–0.07	0.81
	PBSS	VRT	–9.14	0.00*	–9.29	0.00*	–0.14	0.34
		BST	–2.79	0.00*	–2.43	0.00*	0.36	0.31
		CT	–0.87	0.00*	–0.93	0.00*	–0.07	0.67
	PBST	VRT	–1.71	0.36	–1.71	0.39	0.00	1.00
		BST	–2.07	0.21	–2.79	0.03*	–0.71	0.55
		CT	–1.07	0.63	–0.60	0.8	0.47	0.48
	FTSTST	VRT	9.21	0.00*	9.43	0.00*	0.21	0.62
		BST	3.43	0.00*	4.00	0.00*	0.57	0.06
		CT	1.40	0.00*	2.07	0.00*	0.67	0.00*

*. The mean difference is significant at the.05 level. LUCOM: left upper center of mass, RUCOM: right upper center of mass, LLCOM: left lower center of mass, RLCOM: right lower center of mass, GMFM: Gross Motor Function Measure, PBSS: Pediatric Balance Scale scores, PBST: Time of Pediatric Balance Scale, FTSTST: Five Times Sit-To-Stand Test, VRT: virtual reality training, BST: balance-specific training, CT: conventional training, MD: mean difference, Sig.: significance.

ance and gross motor functions of CwCP through repetition, practice, and increased complexity [53], (2) both trainings emphasize a global approach focusing on functions rather than an analytical approach focusing on impairments, and (3) both approaches may stimulate proprioceptive senses, leading to an improvement in sensory inputs that are essentials in motor learning processes, including the control of balance and gross motor functions, and can facilitate the transfer of motor skills from the training context to real-life situations.

Moreover, the authors attempted to develop a VRT protocol that specifically triggered trunk mobility in different plans and directions in standing, incorporating arm and leg movements similar to real-life practice, taking into account that increasing the homogeneity between reality and game settings may facilitate the transfer of spatial knowledge from a virtual reality context to real-life conditions, as stated by Behrouz and Maryam in 2021 [54]. Additionally, the virtual environment and the settings of the selected games imposed unexpected changes in directions, speeds, and contexts, requiring participants to practice the movements repeatedly with respect to the difficulty, adjusted by the therapist. As a result, repetition may stimulate the CNS to build on prior attempts and coordinate new muscle synergies to maintain balance or perform motor functions.

Furthermore, it was also revealed that 10 days of active videogame practice may lead to a significant increase in attention [55] as well as in the perception-action coupling process [54], facilitating performance in motor tasks. In the current study, it was believed that the Xbox 360 device offered two types of visual feedback to participants. First, achievement-related feedback through their game scores motivated children to enhance their performance. Second, posture-related feedback was conveyed through their avatar, encouraging them to adjust their posture and prevent falls or failure during gameplay, thereby facilitating the experience of challenging conditions.

As a result, the authors contend that active videogames can indirectly contribute to improvements in multidirectional postural adjustment, reduce the displacement of the COM and its transfer from a larger to a smaller base of support while in a standing position, and challenge equilibrium strategies, ultimately promoting better balance and gross motor functions in CwCP.

Furthermore, the BST, as a kind of task-oriented training, consisted of 13 exercises that enhanced the balance function of children in sitting and standing positions by activating different trunk muscle groups (flexion, extension, rotations, and lateral flexions) and reducing unnecessary compensations. It thus led to better improvement in balance in various directions. This aligns with previous studies emphasizing the effectiveness of task-oriented training in improving the gross motor functions and balance of CwCP [24, 26, 53, 56].

In contrast, some outcome measures (the left L_{COM}, GMFM D & E, and time of PBS) revealed no preferences for any of the three groups. These results are consistent with other research regarding the effect of VRT compared to other techniques [57–60]. For example, in 2012, Chen et al. reported no significant differences between the home-based cycling training (hVCT) group and the CT group in the balance subset of the Bruininks Oseretsky Test of Motor Proficiency after 12 weeks of intervention. However, they reported that the hVCT program enhanced knee muscle strength in CwCP [58]. Pin et al. (2019) suggested no significant differences between the virtual reality group receiving seated interactive computer play for four sessions per week, 20 minutes per session, for six weeks and the conventional physiotherapy program [59]. Similarly, Saxena et al. reported no significant difference in balance improvement (as measured by the velocity of sway of the CoP) between the intervention group receiving computer-based visual feedback and the CT groups.

On the other hand, the lack of significant differences between the three groups in the PBS time was attributed to the fact that time was not the most influential factor in distinguishing item scores. For instance, a child could receive a score of 3 for standing unsupported for 10 seconds with eyes closed under supervision or a score of 4 for maintaining the same position for the same duration without supervision. Consequently, the improvements in overall PBS scores of a participant might not necessarily reflect changes in the time aspect of this scale for the same participant.

Interestingly, the significant improvement detected by clinical outcome measures at post-treatment evaluations was objectively confirmed by significant changes in DP variables (U_{COM} and L_{COM}), specifically in the VRT group. Accordingly, taking into consideration the previous findings regarding the correlation between the PBS scores and the DP variables as assessors of balance parameters, the authors hypothesize that VRT is more effective in closely relocating U_{COM} and L_{COM} to the child's body, leading to better outcomes than other interventions. The results showed that the distances from the COM of the upper and lower limbs to the proximal joints were reduced remarkably in the VRT group. No significant differences were found in these variables in the BST and CT groups. While clinical tests effectively identify changes in balance function, more objective and quantitative measurements, such as DP, may better capture these improvements.

The retention effect of VRT, measured at follow-up, revealed that changes in all outcome measures were maintained for six weeks after treatment. This result aligns with the findings of Gatica-Rojas et al., who reported that improvement lasted two to four weeks post-treatment [50]. Similarly, Lazzari et al. claimed that the effect of VRT combined with active transcranial direct current stimulation (tDCS), five sessions per week for two weeks, lasted one month after treatment [61]. Jelsma et al. also reported that a three-week Nintendo Wii Fit training program improved the balance of children with spastic hemiplegia with results lasting up to two months post-treatment [62].

In summary, the study cannot definitively assert that VRT is superior to BST. However, it is possible that VRT may lead to better improvements compared to traditional rehabilitation methods. This statement aligns with Warnier et al., who suggested that VRT should complement rather than replace conventional treatment and be used as an adjunct to traditional and active exercise protocols [18].

Moreover, VRT has been described as a motivating and challenging approach [15, 47, 62]. Although motivation was not measured using a standardized outcome measure in the current study, compliance with the VRT was comparable to other studies. Participants in the virtual reality group reported a high level of enjoyment and satisfaction during the sessions and that the variety of games avoided boredom and repetition, which could occur in traditional sessions. Within this context and based on Wulf and Lewthwaite's OPTIMAL theory of motor learning (Optimizing

Performance through Intrinsic Motivation and Attention for Learning) [63], the participants' motivation, attention, and enjoyment during VRT sessions may optimize balance control by strengthening the coupling of goals to actions. The authors highlight the need for further studies to explore the relationship between increased motivation in virtual reality and subsequent improvements in motor skills, such as balance and gross motor functions, in CwCP.

4.1. Limitations

The efficacy of VRT and BST compared to CT in enhancing balance and gross motor skills in CwCP was examined for the first time in this study. While the findings are promising, some limitations have been recognized. Firstly, the unequal number of participants from both sexes ($N_{\text{males}} = 31$ vs. $N_{\text{females}} = 12$) was attributed to poor cooperation of parents. Thus, further studies with larger samples are still needed to confirm the findings and explore the effect of VRT and BST on balance function in children with various subtypes of CP. Furthermore, studies are required to investigate the usefulness of both approaches in a home-based context remotely controlled by the therapist as a type of continuous training for CwCP.

Secondly, it is important to note that the children recruited for this study had GMFCS levels I and II, with unequal representation in each group (GMFCS-I: $N_{VRT} = 11$, $N_{BST} = 10$, and $N_{CT} = 1$; GMFCS-II: $N_{VRT} = 3$, $N_{BST} = 4$, and $N_{CT} = 1$). Therefore, the findings cannot be generalized to children with more severe functional limitations (i.e., levels III, IV, and V). Future studies should investigate the effects of VRT and BST versus CT on children at various levels of the GMFCS.

Thirdly, the active videogames used in this study were commercially designed, and the rehabilitation protocol was adapted to suit the game's requirements and settings as well as the children's abilities. Future studies should consider customizing active videogames to specifically target the balance of CwCP. Moreover, it is highly recommended that games be chosen based on children's preferences and abilities, aiming to enhance their motivation and engagement in the therapy process.

Fourthly, motivation over the six weeks of training was not assessed using a standardized outcome measure in the current study. Therefore, future studies should assess motivation and other psychological factors to better understand their impact on engagement in individual therapy sessions and improvements in motor function. Examining the effect of group therapy sessions using active videogames on motor functions and motivation in CwCP could also be beneficial for further research.

5. Conclusion and recommendations

Balance is required for autonomy in performing motor functions in the daily life activities of CwCP. Researchers and practitioners are still debating the most effective intervention protocols for addressing balance as a major contributor to functional limitations [15]. In the current study, PBS and the GMFM (D & E) scores proved that VRT and BST led to similar significant improvements in balance and gross motor functions of CwCP, and that the effect of VRT was superior to that of CT. Interestingly, DP measures (U_{COM} and L_{COM}), as the main indicators of postural adjustments, supported this result in the VRT group only.

Despite the fact that the variety of games provided by VRT makes therapy sessions more diverse and motivates children to train, along with the possibility of having a cheap VRT device that is simple and easy to use, there is no certainty that using VRT is better than using BST or CT in improving all dimensions of balance and gross motor functions. Instead, combining VRT with other approaches is recommended.

This study has many clinical implications for therapists as it underscores the potential benefits of both VRT and BST by rigorously evaluating their impact on balance and gross motor functions of CwCP aged four to 12 years classified at GMFCS levels I and II through a randomized controlled trial. It provides more evidence supporting the effectiveness of VRT and underscores the importance of customized games. Additionally, it considers long-term outcomes and the role of motivation, offering valuable insights for clinicians and researchers. Ultimately, this research enhances understanding of how VRT optimizes balance and gross motor function improvement in CwCP by generating new muscular synergies to facilitate the motor learning process and enhance the repertoire of balance strategies.

Finally, future studies need to assess the cortical reorganization underlying the observed improvement by using more advanced measurement tools such as functional magnetic resonance imaging following VRT protocols.

Acknowledgments

The authors acknowledge all participants who participated in this study.

Conflict of interest

All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/disclosure-of-interest/ and declare no support from any organization for the submitted work; no financial relationships with any organizations that might have an interest in the submitted work in the previous three years; and no other relationships or activities that could appear to have influenced the submitted work.

Ethical considerations

This study was approved by the ethical committee of Tehran University of Medical Sciences (ID: IR.TUMS.VCR.REC.1399.537) and was registered in the Iranian Registry of Clinical Trials (Registration ID: IRCT20090301001722N25).

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Supplementary material

The Appendix is available in the electronic version of this article: https://dx.doi.org/10.3233/PRM-220120.

References

[1] Carol LR, Francine M. Cerebral palsy: definition, assessment and rehabilitation. Handb Clin Neurol. 2013;111:183-95. doi: 10.1016/B978-0-444-52891-9.00018-X

[2] Odding E, Roebroeck ME, Stam HJ. The epidemiology of cerebral palsy: incidence, impairments and risk factors. Disabil Rehabil. 2006;28(4):183-91. doi: 10.1080/09638280500158422

[3] Assaiante C, Amblard B. An ontogenetic model for the sensorimotor organization of balance control in humans. Human Movement Science. 1995;14(1):13-43. doi: 10.1016/0167-9457(94)00048-J

[4] Assaiante C, Mallau S, Viel S, Jover M, Schmitz C. Development of postural control in healthy children: a functional approach. Neural Plast. 2005;12(2-3):109-18; discussion 263-272. doi: 10.1155/NP.2005.109

[5] Kim Y, Lee B-H. Clinical Usefulness of Child-centered Task-oriented Training on Balance Ability in Cerebral Palsy. J Phys Ther Sci. 2013;25(8):947-51. doi: 10.1589/jpts.25.947

[6] Rival C, Ceyte H, Olivier I. Developmental changes of static standing balance in children. Neurosci Lett. 2005;376(2):133-6. doi: 10.1016/j.neulet.2004.11.042

[7] Forssberg H, Nashner LM. Ontogenetic development of postural control in man: adaptation to altered support and visual conditions during stance. J Neurosci. 1982;2(5):545-52. doi: 10.1523/JNEUROSCI.02-05-00545.1982

[8] Riach C, Starkes J. Velocity of centre of pressure excursions as an indicator of postural control systems in children. Gait Posture 1994;2(3):167-72. doi: 10.1016/0966-6362(94)90004-3

[9] Rojas VG, Rebolledo GM, Muñoz EG, Cortés NI, Gaete CB, Delgado CM. Differences in standing balance between patients with diplegic and hemiplegic cerebral palsy. Neural Regen Res. 2013;8(26):2478-83. doi: 10.3969/j.issn.1673-5374.2013.26.009

[10] Horak FB. Clinical assessment of balance disorders. Gait & Posture. 1997;6(1):76-84. doi: 10.1016/S0966-6362(97)00018-0

[11] Swaiman KF, Ashwal S, Ferriero DM. Pediatric Neurology: Principles & Practice. Philadelphia: Mosby Elsevier; 2006.

[12] Chen C, Shen I, Chen C, Wu C, Liu W, Chung C. Validity, responsiveness, minimal detectable change, and minimal clinically important change of Pediatric Balance Scale in children with cerebral palsy. Res Dev Disabil. 2013;34(3):916-22. doi: 10.1016/j.ridd.2012.11.006

[13] Pavão SL, dos Santos AN, Woollacott MH, Rocha NACF. Assessment of postural control in children with cerebral palsy: a review. Res Dev Disabil. 2013;34(5):1367-75. doi: 10.1016/j.ridd.2013.01.034

[14] El-Shamy SM, Abd El Kafy EM. Effect of balance training on postural balance control and risk of fall in children with diplegic cerebral palsy. Disabil Rehabil. 2014;36(14):1176-83. doi: 10.3109/09638288.2013.833312

[15] Brien M, Sveistrup H. An intensive virtual reality program improves functional balance and mobility of adolescents with cerebral palsy. Pediatr Phys Ther. 2011;23(3):258-66. doi: 0.1097/PEP.0b013e318227ca0f

[16] Weiss PLT, Tirosh E, Fehlings D. Role of virtual reality for cerebral palsy management. J Child Neurol. 2014;29(8):1119-24. doi: 10.1177/0883073814533007

[17] Chen Y, Fanchiang HD, Howard A. Effectiveness of Virtual Reality in Children With Cerebral Palsy: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Phys Ther. 2018;98(1):63-77. doi: 10.1093/ptj/pzx107

[18] Warnier N, Lambregts S, Port IVD. Effect of Virtual Reality Therapy on Balance and Walking in Children with Cerebral Palsy: A Systematic Review. Dev Neurorehabil. 2020;23(8):502-18. doi: 10.1080/17518423.2019.1683907

[19] Wu J, Loprinzi PD, Ren Z. The Rehabilitative Effects of Virtual Reality Games on Balance Performance among Children with Cerebral Palsy: A Meta-Analysis of Randomized Controlled Trials. Int J Environ Res Public Health. 2019;16(21):4161. doi: 10.3390/ijerph16214161

[20] Chesser BT, Blythe SA, Ridge LD, Tomaszewski RER, Kinne BL. Effectiveness of the Wii for pediatric rehabilitation in individuals with cerebral palsy: a systematic

review. Physical Therapy Reviews. 2020;25(2):106-17. doi: 10.1080/10833196.2020.1740402

[21] Ziab H, Mazbouh R, Saleh S, Talebian S, Sarraj AR, Hadian M-R. Efficacy of Virtual Reality-Based Rehabilitation Interventions to Improve Balance Function in Patients with Cerebral Palsy: A Systematic Review and Meta-analysis of RCTs. Arch Neurosci. 2022;9(2):e122865. doi: 10.5812/ans-122865

[22] Kumar C, Ostwal P. Comparison between Task - Oriented Training and Proprioceptive Neuromuscular Facilitation Exercises on Lower Extremity Function in Cerebral Palsy-A Randomized Clinical Trial. J Nov Physiother. 2016;6(3):291. doi: 10.4172/2165-7025.1000291

[23] Leroux A, Pinet H, Nadeau S. Task-oriented intervention in chronic stroke: changes in clinical and laboratory measures of balance and mobility. Am J Phys Med Rehabil. 2006;85(10):820-30. doi: 10.1097/01.phm.0000233179.64769.8c

[24] Han H-K, Chung Y. Effects of task-oriented training for Gross Motor Function Measure, balance and gait function in persons with cerebral palsy. Physical Therapy Rehabilitation Science. 2016;5(1):9-14. doi: 10.14474/ptrs.2016.5.1.9

[25] Blundell SW, Shepherd RB, Dean CM, Adams RD, Cahill BM. Functional strength training in cerebral palsy: a pilot study of a group circuit training class for children aged 4-8 years. Clin Rehabil. 2003;17(1):48-57. doi: 10.1191/0269215503cr584oa

[26] Kumar C, Kataria S. Effectiveness of Task Oriented Circuit Training on Functional Mobility and Balance in Cerebral Palsy. Indian Journal of Physiotherapy and Occupational Therapy. 2013;7(4):23-28.

[27] Collange Grecco LA, de Almeida Carvalho Duarte N, Mendonça ME, Galli M, Fregni F, Oliveira CS. Effects of anodal transcranial direct current stimulation combined with virtual reality for improving gait in children with spastic diparetic cerebral palsy: a pilot, randomized, controlled, double-blind, clinical trial. Clin Rehabil. 2015;29(12):1212-23. doi: 10.1177/0269215514566997

[28] Katz-Leurer M, Rotem H, Keren O, Meyer S. The effects of a "home-based" task-oriented exercise programme on motor and balance performance in children with spastic cerebral palsy and severe traumatic brain injury. Clin Rehabil. 2009;23(8):714-24. doi: 10.1177/0269215509335293

[29] Weis R. Gross Motor Function Measure (GMFM-66 and GMFM-88) User's Manual. European Journal of Paediatric Neurology. 2004;8(2):111-2. doi: 10.1016/j.ejpn.2003.11.003

[30] Bjornson K, Graubert C, McLaughlin J. Test-retest reliability of the gross motor function measure in children with cerebral palsy. Pediatr Phys Ther. 2000;12(4):200-2.

[31] Harvey A. The Gross Motor Function Measure (GMFM). J Physiother. 2017;63(3):187. doi: 10.1016/j.jphys.2017.05.007

[32] Ko M, Chung J-H, Jeon H. Correlation between Pediatric Balance Scale(PBS) and Gross Motor Function Measurement(GMFM) Scores in Children with Cerebral Palsy. J Korean Soc Phys Med. 2010;5(2):637-45.

[33] Franjoine MR, Gunther JS, Taylor MJ. Pediatric balance scale: a modified version of the berg balance scale for the school-age child with mild to moderate motor impairment. Pediatr Phys Ther. 2003;15(2):114-28. doi: 10.1097/01.PEP.0000068117.48023.18

[34] Wang T-H, Liao H-F, Peng Y-C. Reliability and validity of the five-repetition sit-to-stand test for children with cerebral palsy. Clin Rehabil. 2012;26(7):664-71. doi: 10.1177/0269215511426889

[35] Whitney S, Wrisley D, Marchetti G, Gee M, Redfern M, Furman J. Clinical Measurement of Sit-to-Stand Performance in People With Balance Disorders: Validity of Data for the Five-Times-Sit-to-Stand Test. Physical Therapy & Rehabilitation Journal. 2005;85(10):1034-45. doi: 10.1093/ptj/85.10.1034

[36] Ashnagar Z, Hadian MR, Olyaei G, et al. Corrigendum to "Reliability of digital photography for assessing lower extremity alignment in individuals with flatfeet and normal feet types" [J. Bodyw. Mov. Ther. 21 (2017) 704-710]. J Bodyw Mov Ther. 2019;23(1):5. doi: 10.1016/j.jbmt.2018.08.001

[37] Peeler J, Leiter J. Using digital photography to document rectus femoris flexibility: A reliability study of the modified Thomas test. Physiother Theory Pract. 2013;29(4):319-27. doi: 10.3109/09593985.2012.731140

[38] Ziab H, Talebian S, Saleh S, Olyaei GR, Mazbouh R, Hadian MR. Reliability and Convergent Validity of Digital Photography in Assessing Postural Orientation of Children with Cerebral Palsy: A Methodological Study. Arch Neurosci. 2022;9(4):e129929. doi: 10.5812/ans-129929

[39] Beaulieu-Boire L, Belzile-Lachapelle S, Blanchette A, et al. Balance Rehabilitation using Xbox Kinect among an Elderly Population: A Pilot Study. J Nov Physiother. 2015;5(2):261. doi: 10.4172/2165-7025.1000261

[40] Zoccolillo L, Morelli D, Cincotti F, et al. Video-game based therapy performed by children with cerebral palsy: a cross-over randomized controlled trial and a cross-sectional quantitative measure of physical activity. Eur J Phys Rehabil Med. 2015;51(6):669-76.

[41] Luna-Oliva L, Ortiz-Gutiérrez RM, Cano-de la Cuerda R, et al. Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: a preliminary study. NeuroRehabilitation. 2013;33(4):513–21. doi: 10.3233/NRE-131001

[42] Jung S-H, Song S-H, Kim S-D, Lee K, Lee G-C. Does virtual reality training using the Xbox Kinect have a positive effect on physical functioning in children with spastic cerebral palsy? A case series. J Pediatr Rehabil Med. 2018;11(2):95-101. doi: 10.3233/PRM-160415

[43] Park D-S, Lee D-G, Lee K, Lee G. Effects of Virtual Reality Training using Xbox Kinect on Motor Function in Stroke Survivors: A Preliminary Study. J Stroke Cerebrovasc Dis. 2017;26(10):2313-9. doi: 10.1016/j.jstrokecerebrovasdis.2017.05.019

[44] Molhemi F, Monjezi S, Mehravar M, et al. Effects of Virtual Reality vs Conventional Balance Training on Balance and Falls in People With Multiple Sclerosis: A Randomized Controlled Trial. Arch Phys Med Rehabil. 2021;102(2):290-9. doi: 10.1016/j.apmr.2020.09.395

[45] Murphy KP, McMahon MA, Houtrow AJ. Pediatric Rehabilitation: Principles and Practice. 6th ed. Springer Publishing Company; 2020.

[46] Pourazar M, Bagherzadeh F, Mirakhori F. Virtual reality training improves dynamic balance in children with cerebral palsy. Int J Dev Disabil. 2021;67(6):422-7. doi: 10.1080/20473869.2019.1679471

[47] Ren K, Gong X-M, Zhang R, Chen X-H. [Effects of virtual reality training on limb movement in children with spastic diplegia cerebral palsy]. Zhongguo Dang Dai Er Ke Za Zhi. 2016;18(10):975-9. doi: 10.7499/j.issn.1008-8830.2016.10.011

[48] Cho C, Hwang W, Hwang S, Chung Y. Treadmill Training with Virtual Reality Improves Gait, Balance, and Muscle Strength in Children with Cerebral Palsy. Tohoku J Exp Med. 2016;238(3):213-8. doi: 10.1620/tjem.238.213

[49] Harris K, Reid D. The influence of virtual reality play on children's motivation. Can J Occup Ther. 2005;72(1):21-9. doi: 10.1177/000841740507200107

[50] Gatica-Rojas V, Méndez-Rebolledo G, Guzman-Muñoz E, et al. Does Nintendo Wii Balance Board improve standing balance? A randomized controlled trial in children with cerebral palsy. Eur J Phys Rehabil Med. 2017;53(4):535-44. doi: 10.23736/S1973-9087.16.04447-6

[51] Cavalcante Neto JL, Steenbergen B, Wilson P, Zamunér AR, Tudella E. Is Wii-based motor training better than task-specific matched training for children with developmental coordination disorder? A randomized controlled trial. Disabil Rehabil. 2020;42(18):2611-20. doi: 10.1080/09638288.2019.1572794

[52] Kaur A, Balaji GK, Sahana A, Karthikbabu S. Impact of virtual reality game therapy and task-specific neurodevelopmental treatment on motor recovery in survivors of stroke. International Journal of Therapy and Rehabilitation. 2020;27(8):1-11. doi: 10.12968/ijtr.2019.0070

[53] Heneidy W, Eltalawy H, Kassem H, Zaky N. Impact of task-oriented training on balance in spastic hemiplegic cerebral palsied children. Physiotherapy Quarterly. 2020;28(2):52-6. doi: 10.5114/pq.2020.89808

[54] Behrouz G, Maryam L. Transfer of Motor Skills from Virtual Reality to Real Environment. Research and Investigations in Sports Medicine. 2021;7(4):643-8. doi: 10.31031/RISM.2020.07.000667

[55] Green CS, Bavelier D. Action video game modifies visual selective attention. Nature. 2003;423(6939):534-7. doi: 10.1038/nature01647

[56] Salem Y, Godwin EM. Effects of task-oriented training on mobility function in children with cerebral palsy. NeuroRehabilitation. 2009;24(4):307-13. doi: 10.3233/NRE-2009-0483

[57] Jha KK, Karunanithi GB, Sahana A, Karthikbabu S. Randomised trial of virtual reality gaming and physiotherapy on balance, gross motor performance and daily functions among children with bilateral spastic cerebral palsy. Somatosens Mot Res. 2021;38(2):117-26. doi: 10.1080/08990220.2021.1876016

[58] Chen C-L, Hong W-H, Cheng H-YK, Liaw M-Y, Chung C-Y, Chen C-Y. Muscle strength enhancement following home-based virtual cycling training in ambulatory children with cerebral palsy. Res Dev Disabil. 2012;33(4):1087-94. doi: 10.1016/j.ridd.2012.01.017

[59] Pin TW, Butler PB. The effect of interactive computer play on balance and functional abilities in children with moderate cerebral palsy: a pilot randomized study. Clin Rehabil. 2019;33(4):704-10. doi: 10.1177/0269215518821714

[60] Saxena S, Rao BK, Senthil KD. Short-term balance training with computer-based feedback in children with cerebral palsy: A feasibility and pilot randomized trial. Dev Neurorehabil. 2017;20(3):115-20. doi: 10.3109/17518423.2015.1116635

[61] Lazzari RD, Politti F, Belina SF, et al. Effect of Transcranial Direct Current Stimulation Combined With Virtual Reality Training on Balance in Children With Cerebral Palsy: A Randomized, Controlled, Double-Blind, Clinical Trial. J Mot Behav. 2017;49(3):329-36. doi: 10.1080/00222895.2016.1204266

[62] Jelsma J, Pronk M, Ferguson G, Jelsma-Smit D. The effect of the Nintendo Wii Fit on balance control and gross motor function of children with spastic hemiplegic cerebral palsy. Dev Neurorehabil. 2013;16(1):27-37. doi: 10.3109/17518423.2012.711781

[63] Wulf G, Lewthwaite R. Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. Psychon Bull Rev. 2016;23(5):1382-414. doi: 10.3758/s13423-015-0999-9