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Fully-Immersive Virtual Reality for Trunk Control and Balance in Children with Diplegic Cerebral Palsy

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ABSTRACT
Background: The motor impairment in cerebral palsy (CP) has an impact on posture and movement. Motor function and general well-being in children with spastic diplegic CP depend on trunk control. Fully-immersive virtual reality (VR) training may be a valuable additional therapy for habilitation of trunk control and balance in children with diplegic CP. **Purpose:** This study aimed to explore the effect of fully-immersive VR training on trunk control and balance in children with diplegic CP.

Patients and Methods: 30 children aged 6-8 years old with spastic diplegic CP were randomly assigned into 2 equal groups: Group (A) received traditional physical therapy exercises, and group (B) that received traditional program as the control group in addition to VR training, all participants received treatment for 12 weeks. Trunk control was evaluated using the Segmental Assessment of Trunk Control (SATCO) scale, while balance was examined using the Biodex balance system.

Results: The post-treatment mean value of SATCO scale of group (A) was 17.13 ± 0.74 and that of group (B) was 18.27 ± 0.7. There was a notable difference between the both groups (p=0.001). The mean value of the overall stability measure of balance did not differ significantly between both groups post-treatment (p = 0.841).

Conclusion: This study showed a positive effect of combined traditional physical therapy interventions with fully-immersive VR on trunk control in children with CP of spastic diplegic type. These findings highlight the importance of addressing combined techniques in the comprehensive management of children with CP.

Keywords: CP, Trunk control, Balance, Spastic diplegia, Virtual reality.

INTRODUCTION

Cerebral palsy (CP) is a condition of motor dysfunction that impacts posture and mobility. It is brought on by lesions or malformations in the developing brain that develop prior to, during, or within 2 years after birth [(1)]. Diplegic CP is a neurological condition that affects the lower limbs and is characterized by increased muscular tone. This condition often leads to significant motor impairments, including difficulties with trunk control, which is essential for maintaining balance, performing coordinated movements, and achieving motor milestones [(2)]. Impaired trunk control not only impacts motor abilities but also has a cascade effect on the entire quality of life (QoL) and balance of children with spastic diplegic CP. Trunk stability is integral to postural control, balance reactions, and the execution of daily activities. As these children navigate the challenges of impaired trunk control, their ability to participate in various aspects of life can be significantly compromised [(3, 4)].

Virtual reality (VR) gaming augments motor processing abilities via task-driven training and promotes problem-solving. With a higher concentration and engagement of goal-driven games, the VR gaming might influence the cognitive-motor planning of children with CP [(5)].

The neuroplasticity and motor learning linked to motivation, active engagement, and active repetition are enhanced by VR [(6)]. Playing VR games encourages practice of multisensory feedback and functional motions. Important elements for motor improvements include motivation, audio-visual feedback, and goal-directed movement practice. The VR method incorporates the fundamental ideas of motor learning theories, including patient motivation, feedback mechanisms, and the repetition of functional activities. VR has been shown to improve postural control, balance, gross motor function, and upper extremity functions. Additionally, children with CP can benefit from goal-directed motor practice, strengthening exercises, balance, gait and treadmill training [(5,7)]. The development of interventions for the functional recovery of the pediatric population with disability has accelerated in recent years due to technology advancements [(8)]. While the effect of trunk control on motor performance in children with CP is widely investigated, the link between trunk control and VR is less well recognized. Exploring this relationship is crucial for developing comprehensive intervention strategies that address both motor impairments and overall well-being [(9,10)].

This study aimed to investigate the effect of fully-immersive VR training on trunk control and balance in children with diplegic CP.

PATIENTS AND METHODS

Study design: A prospective randomized controlled trial that included 30 children diagnosed with spastic diplegic CP were recruited for the study from the Outpatient Clinic of the Faculty of Physical Therapy, Cairo University, Giza, Egypt.

Participants: G*POWER statistical software (version3.1.9.2; FranzFaul, Universität Kiel, Germany)

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was used to calculate the sample size. Based on GMFM data from a related study, it was determined that fifteen patients per group were needed for this investigation. α=0.05, β=0.2, effect size=0.8, and allocation ratio N2/N1=1 were used in the computations.

Inclusion criteria: 1. Diagnosis of spastic diplegic CP, in which there is increased muscle tone primarily affecting both legs. 2. Age range from 6 and 8 years old. 3. Spasticity grade 1 or 1+ according to the modified Ashworth scale, indicating mild to moderate spasticity. 4. Levels I or II according to Gross Motor Function Classification System (GMFCS), denoting moderate to severe limitations in gross motor function. This criterion ensured a level of functional impairment consistent with goals of the study [11].

Exclusion criteria: Children who had visual or hearing impairments, children with fixed lower limb abnormalities or those who had Botox injections in their lower limb muscles during the previous six months, children with a history of orthopedic surgeries involving the lower limbs [11].

Children were randomly assigned into 2 groups (control and study groups) of equal numbers using simple randomization with a closed-envelope technique. Each group consisted of 15 children as the following:

• Control group (Group A): Received a traditional physical therapy program for 12 weeks.

• Study group (Group B): Received the same program as the control group in addition to VR training for 12 weeks.

I-Assessment:

Each participating child underwent assessment by the same therapist, including:

1. ***Demographic data collection****:* age, sex, weight, height, spasticity level, and GMFCS level.
2. ***Trunk control assessment****:* The Segmental Assessment of Trunk Control (SATCO) scale is a valid and reliable measure that was used to evaluate trunk control in a sitting posture [12]. The child in sitting with their knees at 90 degrees and their feet supported. The therapist used straps to maintain the pelvis in a neutral position and physically held the child's trunk in an upright position. The arms and hands were totally free to move about and did not make contact with the assessors, the bench, or any other part of the body during the entire trunk and all other phases. The SATCO score was assigned a present or absent grade, and the following criteria were used to evaluate static, active, and reactive control: For five seconds, keep your head and trunk in a neutral, upright position. Active (anticipatory) control: Maintain a neutral vertical posture while bending the head 45 degrees and/or extending your arms to the left and right. Maintaining or rapidly returning to a neutral, upright posture when disturbed is known as reactive control. Each segment was measured separately and the score of the task was given, whether in static, active or reactive, which was 1 if the task was achieved or 0 if the task was not achieved. In the end, all the numbers and all the tasks in which the child achieved 1 were collected to give me in the end the total score of SATCO.
3. ***Balance assessment:*** Children's postural stability and dynamic balance were assessed using the Biodex balance system by tilting a platform [13]. Before administering the exam, the children were given an explanation of all test performance requirements. After modifying the railings to ensure the highest level of safety, children were instructed to stand in the center of the platform with both feet and gaze at a screen for feedback. In order to assess foot angles and steady the platform, children were advised to mimic the mid-screen feedback region by standing erect in the center of the platform. The test began once the angles were introduced to the device, and the youngster was instructed to keep the cursor in the center of the screen as the platform moved. Lastly, stability indices were produced in a report [14].

II- Treatment procedures:

Both the control and study groups received a typical physical therapy program based on neurodevelopmental technique. All participants received 3 sessions per week for 45-60 minute for 12 weeks. The study group received the traditional physical therapy program in addition to VR training (20 minute/session). The VR system that was used for training of the study group consisted of a VR headset, which is compatible with Oculus Quest™, and it is equipped with two handheld controllers, and a laptop to guide the activities during VR session. This study used two VR games (Viblio™ and GardenDo™) from VRapeutic's library of therapeutic modules which were developed using Unity™ (version 2019.4.40f1 LTS).

The GardenDo™ game: involves a plant watering activity. **The Viblio™ game:** is a book ordering activity.

The two games were chosen based on that they targeted functional tasks that are challenging enough, and addressing balance/trunk and postural control (15). A trained therapist introduced the game to the children to get them familiar with the required movements prior to the onset of VR training sessions. The complexity of the task and the nature of the environment were all customizable. GardenDo game: The child was instructed to fill a watering can from a tap by walking a few steps and lean forward to reach the watering tap, and then go water a number of plant pots in sequence which needs the child to maintain the water flow, being poured in each pot, until the plant blooms. Keeping the water flow necessitates keeping control the trunk position, and then go to the next pot. The Viblio game: The child was asked to arrange a specific number of books on the shelves in sequence. The child leans forward to reach the books placed on a table or on the ground, then puts it on the shelf in sequence.

Ethical considerations: Ethical approval for the study was obtained before starting the study from The Research Ethical Committee of the Faculty of Physical Therapy, Cairo University (P.T.REC/012/004447). Informed consent was obtained from the parents of each participating child before enrollment in the study. The Helsinki Declaration was followed throughout the study's duration.

Statistical analysis

The data were analyzed using SPSS software, version 20.0 for Windows. Subjects were compared using Mean ± SD, X^2-test and the unpaired t-test, the two groups' characteristics. Kolmogorov-Smirnov and Shapiro-Wilk tests were employed to determine if the data distribution was normal. Balance and trunk control were the assessed variables, and the effects of each group were compared within and between groups using MANOVA. A significance level of 0.05 or less was applied.

RESULTS

Participants' demographics: The mean values of demographic data were of no significant difference between groups A and B (p>0.05) (Table 1).

Table (1): Demographic data of participants of both groups

Demographic data	Group A (Control) (No=30)	Group B (Study) (No=30)	p-value
Age (years)	7.33±0.62	6.87±0.74	0.072
Weight (kg)	27.13±5.46	24.2±3	0.079
Height (cm)	127.53±3.9	125.2±3.23	0.082
Sex Males Females	N (%) 9 (60%) 6 (40%)	N (%) 8 (53%) 7 (47%)	0.713
Spasticity 1 1+	N (%) 8 (53%) 7 (47%)	N (%) 4 (26.7%) 11 (73.3%)	0.136
GMFCS level 1 2	N (%) 9 (60%) 6 (40%)	N (%) 4 (26.7%) 11 (73.3%)	0.065

GMFCS: Gross Motor Function Classification System.

Within-group comparisons: There was a significant decrease (p = 0.001) and improvement in the mean values of all measured outcomes for the control group (group A) post-treatment (Table 2).

Table (2): Pre and post-treatment comparisons of group (A)

Control group Group A	Pre-treatment	Post-treatment	% of improvement	p-value	Sig
AP stability index	2.37 ± 0.77	1.9 ± 0.6	20%	0.001	**S**
ML stability index	1.98 ± 0.63	1 ± 0.7	54%	0.001	**S**
Overall stability index	1.73 ± 0.6	1.23 ± 0.7	29%	0.001	**S**
SATCO scale score	15.33 ± 1.18	17.13 ± 0.74	11%	0.001	**S**

AP: anteroposterior, ML: mediolateral, SATCO: Segmental Assessment of Trunk Control, S: significant

There was a significant decrease (p = 0.001) and improvement in the mean values of all measured outcomes for the study group (group B) post-treatment (Table 3).

Table (3): Pre and post-treatment comparisons of group (B)

Study group Group B	Pre-treatment	Post-treatment	% of improvement	p-value	Sig
AP stability index	2.01 ± 1.1	1.33 ± 0.93	34%	0.001	**S**
ML stability index	1.62 ± 0.77	1.19 ± 0.59	27%	0.001	**S**
Overall stability index	2.2 ± 0.94	1.54 ± 0.52	30%	0.001	**S**
SATCO scale score	16.13 ± 0.99	18.27 ± 0.7	13%	0.001	**S**

AP: anteroposterior, ML: mediolateral, SATCO: Segmental Assessment of Trunk Control, S: significant.

Between groups' comparison: There was no significant difference in the mean values of all measured balance outcomes between both groups post-treatment, while significant difference (p=0.001) was found in the mean values of SATCO score between both groups post-treatment (Table 4).

Table (4): Post-treatment between groups' comparisons

Outcome	Post treatment	p-value	Sig
AP stability index Group (A) Group (B)	1.9 ± 0.6 1.75 ± 0.95	0.603	**NS**
ML stability index Group (A) Group (B)	1 ± 0.72 0.95 ± 0.53	0.841	**NS**
Overall stability index Group (A) Group (B)	1.23 ± 0.74 1.49 ± 0.75	0.335	**NS**
SATCO Group (A) Group (B)	17.13 ± 0.74 18.27 ± 0.7	0.001	**S**

NS: non-significant, S: significant

DISCUSSION

The impact of completely immersive VR training on trunk control and balance in children with diplegic CP was investigated in this study. According to this, children who received additional VR training appear to have improved trunk control and balance, which is consistent with earlier studies showing how beneficial fully immersive VR is for children with CP [16]. Adequate trunk stability provides a foundation for coordinated movements, balance reactions, and the performance of various functional tasks. When trunk control is compromised, children may experience difficulties with sitting, standing, walking, and performing activities of daily living, negatively impacting their QoL [17].

Our study's findings of improvement in trunk control and balance following traditional physical therapy program with VR training are consistent with other research showing the value of combining VR training with conventional interventions. **Pourazar *et al.*** [17] studied the effect of VR training on the dynamic balance of children with spastic hemiplegic CP utilizing video game training treatment, and the results revealed a significant difference between the study and control groups. They hypothesized that this form of training might assist children with CP improve their balance abilities. The virtual system is an attractive approach for treating children with CP.

According to **Kilcioglu *et al.*** [18] further research should investigate the effect of VR on balance and gross motor function in children with CP. **Liu *et al.*** [19] mentioned that the large number of children with CP has a significant influence on both individuals and society. New methods, such as VR, can be utilized to help children with CP improve their gross motor skills and balance.

Balance may have improved as a result of the virtual environment's stimulation of the learning process through repetitive movements, multisensory feedback, and active engagement. Postural control is challenged by the unexpected body motions in VR games. It is necessary for users to maintain a steady posture throughout training [20–21]. Balance scores may have increased as a result of the development and coordination of novel muscle synergies brought about by practice and feedback, which are crucial for motor gestures [22]. Both groups in our study showed improvement in trunk control and balance, but children in the study group showed more improvement in the scores regarding the trunk control than those in the control group.

Our results contribute to the growing body of evidence suggesting that additional interventions as fully-immersive VR may not only improve trunk control and balance but also motor function and general well-being of children with spastic diplegic CP [2]. By improving trunk stability, children may be better able to engage in various activities, experience greater independence, and have a better perception of their own health and well-being. However, it is crucial to acknowledge the potential influence of age and GMFCS level on this relationship.

Our sample included children between 6 and 8years old, a period of rapid motor development, potentially impacting their perceived QoL as they acquire more advanced motor skills [2]. Similarly, GMFCS level reflects the degree of motor impairment and functional limitations. While, our study included children at GMFCS levels I and II, the relative importance of fully-immersive VR on trunk control and balance might differ across GMFCS levels. For instance, children at GMFCS level III, with severe impairments, might experience a more pronounced impact of trunk control limitations on their daily activities and balance and overall well-being. Investigating the interplay between trunk control, GMFCS level, and QoL could provide valuable insights for tailoring interventions.

Furthermore, it is important to consider the contribution of psychosocial factors and family dynamics to the children with spastic diplegic CP trunk control and balance. Factors such as self-esteem, social support family functioning, and access to community resources can significantly influence a child's overall wellbeing and perception of their QoL and balance. Future research could explore the complex interplay between physical impairments, psychosocial factors, and family dynamics in shaping the QoL of children with CP. Understanding these interactions is essential for developing holistic intervention approaches that address not only the physical limitations but also the emotional and social needs of children and their families. This may involve incorporating psychological support, family counseling, and community-based programs to foster resilience, social integration, and overall well-being alongside targeted physical therapy interventions.

Our study focused on the impact of fully-immersive virtual reality on balance and trunk control. Future research may involve investigating how interventions designed to improve balance and quality of life for children with different types of CP. Longitudinal studies could assess changes in both trunk control and balance measures over time as children participate in targeted interventions [3,13]. This would provide valuable information on the effectiveness of specific interventions and their potential to enhance not only motor function but also the overall well-being and participation of children with CP in various aspects of life. Further research could explore whether the strength of the effect of fully-immersive VR on trunk control and balance across different age groups within the pediatric CP population.

CONCLUSION

Adding fully-immersive VR to traditional physical therapy interventions was found to improve trunk control in children with spastic diplegic CP. Balance improvement was not significantly different between groups after treatment. More research is still needed to confirm these findings and investigate the proper session design and the underlying mechanisms.

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