Dual effect of virtual reality on balance and cognitive functions in children with hemiparesis. A randomized controlled trial

Mohammed A. Kamel[1], Amira M. El-Tohamy[2], Hoda A. El-Talawy[2], Walaa A. Abd El-Nabie[2]

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Abstract

Background: Balance and cognition are vital components to a variety of daily activities that are major concern to physical therapists in the rehabilitation process. **Purpose:** This study aimed to evaluate the effect of virtual reality games on balance and cognitive skills in children with hemiparesis. **Subjects:** It was a randomized controlled trial. 40 spastic children with hemiparesis of both sexes were randomized into 2 groups. The inclusion criteria included children between the ages of 7 and 10 years with mild spasticity ranging from 1 to 1+ according to the Modified Ashwarth scale. They could stand independently according to the Gross Motor Function Classification System (GMFCS). Also, they were able to easily understand and comprehend instructions. Children were excluded if they had deformities, auditory or visual defects. They were divided into two equal groups; control group (A) and study group (B). **Methods**: The control group (A) received a selected physical therapy program based on Neurodevelopment approach. The study group (B) applied virtual reality in addition to receiving the same program as the control group. The applied virtual reality was in form of Wii games for balance training. For evaluating postural stability, the Biodex balance system was utilized and for evaluating cognitive skills, Rehacom system was utilized in both groups. **Results:** Regarding the results of biodex, findings revealed that there was a significant difference between both groups in overall stability index (OSI), antero/posterior stability index (APSI) and medio/lateral stability index (MLSI) ($p < 0.001$). Regarding the results of Rehacom system there was also a significant difference between both groups ($p > 0.001$). **Conclusions:** It can be concluded that the use of virtual reality combined with standard intervention may have a significant effect on balance and cognitive functions in the rehabilitation of hemiparetic children.

Key words: Biodex balance system, cognition, hemiparesis, postural stability, virtual reality.

[1]*Department Of Physical Therapy for Pediatrics, Faculty Of Physical Therapy, Misr University for Science and Technology, 6th of October, Egypt.*
[2]*Department Of Physical Therapy for Pediatrics, Faculty Of Physical Therapy, Cairo University, Giza, Egypt.*
Corresponding author: Mohammed A. Kamel, **email:** mohammed.13037@gmail.com

INTRODUCTION

Cerebral palsy (CP) is a non-progressive disorder of the immature brain affecting the motor system which involves posture and movement [1]**.** It represents a set of permanent disorders that are related to constant lesion in the developing brain and affect movement and posture [2].

Hemiparetic children have balance problems mainly to the affected side which affects motor function and quality of life [3].

Disturbed balance control is a major factor which affects gross and fine motor functions as the maintenance of stability is critical for all activities [4]. Postural balance means controlling the center of gravity (COG) in relation to the supporting area to avoid falling. Postural control is crucial for the motor capability control and is a basic need for the daily life activities [5].

Cognition refers to the process of gaining and modulating knowledge which leads to acquisition of different skills [6]**.** Cognition and motor function are closely related to each other. Improvement of one of them leads to improvement of other and enhances academic performance [7]**.**

Virtual reality (VR) means the use of an interactive and simulated environment. It seeks to create an auditory, visual, and occasionally olfactory and tactile environment [1]**.** It allows the human user to become fully involved in the interactive experience by creating a virtual world that looks to be genuine [8]**.** It can be used for improving balance problems and enhancement of motor skill rehabilitation related to a variety of functional deficits [9]**.**

Virtual reality games can improve intellectual, physical and motor skills in relation with educational and physical activity. As a result, physical therapy experts can employ interactive gaming consoles in the balanced training programs as a significant and effective tool to enhance their patients' balance as successfully as the traditional programs of training [10]**.**

Therefore, this study aim was to detect the VR games effect on balance and cognitive skills in children with hemiparesis. It was hypothesized that VR gaming wouldn't have a significant impact on cognitive or balance abilities in children with hemiparesis.

MATERIALS AND METHODS

Design

The study was a controlled and randomized trial. It was conducted between June 2021 and October 2021. The study's protocol details was thoroughly explained to each parent before they gave their informed permission at the start of the trial. The protocol of the study was approved by the Ethical Committee of the Faculty of Physical Therapy at Cairo University with approval number (P.T.REC/012/001710).

Sample size

The required sample size for this research was 20 subjects per group, according to the the calculation carried out using G*POWER statistical software (version 3.1.9.2) on the basis of the data obtained from the Overall Stability Index (OSI) from the pilot study carried out on 5 subjects in each group. Calculations were made using α=0.05, β=0.2, effect size = 0.91 and allocation ratio N2/N1 =1.

Participants

A sample of 40 children with spastic hemiparesis of both sexes was recruited from Outpatient clinic at Cairo University, Abo El- Rish hospital and National Institute for neurological and motor disorders. The inclusion criteria include children between the ages of 7 and 10 years. They have mild spasticity ranging from 1 to 1+ according to the Modified Ashwarth scale [11]. They could stand independently according to the Gross Motor Function Classification System (GMFCS) level I and II [12]. Also, they can understand and follow instructions. Children were excluded if they had deformities, auditory or visual defects and children who have perceptual or cognitive problems.

Randomization

A sealed envelope procedure by an independent individual was used to randomly distribute forty children into two equal groups (the control and study groups); the envelope included a note indicating which group the child would belong to. The children were unaware of the group they were assigned.

Outcome measures

Postural stability

In this study, Biodex balance system was utilized for postural stability evaluation. The system was formed of a mobile balance platform with several instability levels. The system was connected to computer software seen on the screen of the control panel. [13]. Each child took part in testing without shoes. Before each test condition, two test trials were necessary in order that the child became familiar with the device before collecting data. Before beginning the test, the child was instructed to take the correct position of the test (standing on both feet with holding his arms at his sides) and attempt to center himself on the foot platform. Testing started with stability level (8) (most stable) and ran through the levels till ended with level (5) (less stable) for 20 seconds. Children were instructed to concentrate on the visual feedback screen in front of them and try to keep the cursor, which stands for the platform's center, in the middle of circle screen throughout the test. A printed output report was obtained after each test including MLS, APSI and OSI information. According to different studies biodex balance system is valid and reliable in measurement of balance [14].

Cognitive skills

Rehacom system manufactured by (Schuhfrted, model No.454v, D- 14482 potsd am, Kar/- Liepknecht, Austria) is a computer - assisted cognitive functions assessment and training system. The system was formed of a basic program and number of training procedures. Rehacom system is an objective, valid and reliable in assessment of cognitive functions [15]. Each procedure had varied degrees of difficulty for the purpose of supporting the training of the following cognitive functions; Attention and concentration, Figural memory, Reaction behavior and Logical reasoning. The attention and Concentration Program was used in this study for evaluation. Different types of objects were represented in the form of pictures which may be either geometric-shaped objects in various sizes (rectangles, triangles and circles), concrete objects (animals, fruits, faces, etc.), or numbers and letters. The child was tested starting from level (1) and when passed this test successfully, he progressed forward to reach the next level of difficulties. In the procedure of attention and concentration; the training screen is divided into two parts; the first part containing one object separate picture, the other part represents the matrix containing a group of pictures according to the level of difficulty. The child must identify each separate displayed picture and select the one that resemble it in every detail from the matrix. These procedures continue until the child fails to achieve three correct choices at a certain level. So such level of attention and concentration was recorded as the maximum achieved level. Printout reports were obtained at the end of each test trial including, Level: current level of difficulty that the child had reached, maximum reaction time: longest reaction time and minimum reaction time: shortest reaction time.

Interventions

Both groups, control group (A) and study group (B) received a selected program of physical therapy based on Neurodevelopmental approach including core control and balanced exercise program for one hour per day (3 sessions per week) for 3 consecutive months.

Selected physical therapy program

This program aims to enhance postural stability through training of core muscles and antigravity muscles, facilitation of motor control through positioning, enhancement of postural reactions as righting, equilibrium and protective extensor thrust. Gymnastic Mats, balls, wedges, rolls and balance board are used at selected physiotherapy program to enhance balance.

In addition, Study group (B): received VR therapy in form of Wii games for balance training for 20 min (3sessions/week) for 3 successive months.

Nintendo Wii Fit plus system

It consists of hardware system (Console, Remote and Wii Fit balance board) and software system. The Wii Balance Board has four pressure sensors to assess the user's weight and balance centre using bluetooth technology to communicate with the Wii system. Additionally, the system offers the on-screen instructor to guide users through an exercise routine and show them the ideal form. The participants were asked to take steps on the Wii Fit balancing board and adhere to the guidelines of the games involved in this study. During this study, participants played some balance games under supervision as Soccer Heading and Tightrope Walk.

STATISTICAL ANALYSIS

The comparison of subject's characteristics between groups was performed using the unpaired *t*-test. Chi-squared was used to compare the distribution of sexes between groups. The Shapiro-Wilk test was used for all variables to determine whether the data had a normal distribution. The homogeneity between groups was examined using Levene's test for homogeneity of variances. The mean values of stability indices and cognitive tests were compared between groups using an unpaired *t*-test. The paired *t*-test was used to compare each group's pre- and post-treatment data. For all statistical tests, the level of significance was established at $p < 0.05$. The statistical package for social studies (SPSS) version 25 for windows (IBM SPSS, Chicago, IL, USA) was utilized for all statistical analysis.

RESULTS

Subject characteristics

The control and study groups' subject characteristics were shown in **Table 1**. Age, height, weight, and sex distribution did not significantly differ between the two groups ($p > 0.05$).

Table 1. Comparison of subject characteristics between control and study groups.

	Mean ± SD				
	Control group	**Study group**	**MD**	**t-value**	**p-value**
Age (years)	8.1 ± 1.02	8.45 ± 1.05	-0.35	-1.06	0.29
Weight (kg)	35.9 ± 6.06	36.55 ± 5.51	-0.65	-0.35	0.72
Height (cm)	131.85 ± 5.49	132.25 ± 6	-0.4	-0.22	0.82
Sex					
Girls	12 (60%)	14 (70%)		(χ^2 = 0.44)	0.51
Boys	8 (40%)	6 (30%)			

SD, standard deviation; MD, mean difference; χ2, Chi squared value; p value, probability value

Treatment impact on stability indices and cognitive skills

Within group comparison

The OSI, APSI, and MLSI in the control and study groups all significantly decreased after therapy compared to before treatment ($p < 0.001$).The decrease percent in OSI, APSI and MLSI in the control group was 31.77, 32.19 and 35.19 % respectively, while that in the study group was 52.2, 55.48 and 61.01% respectively. (Table 2).

In comparison to pre-treatment, the control and study groups' maximum and lowest reaction times significantly decreased and the difficulty level significantly increased ($p < 0.01$). The change percent in difficulty level, maximum and minimum reaction time in the control group was 9.16, 20.2 and 21.28% respectively, while that in the study group was 55.28, 74.83 and 63.07% respectively. **(Table 3).**

Between groups comparison

Pre-treatment, there was no discernible difference between the groups ($p > 0.05$). Post treatment, a comparison between the two groups showed that the study group's OSI, APSI, and MLSI were significantly lower than those of the control group ($p < 0.001$). Also, a significant decrease in maximum and minimum reaction time and a significant increase in difficulty level of the study group compared with that of the control group ($p > 0.001$) **(tables 2,3).**

Table 2. Mean OSI, APSI and MLSI pre and post treatment of the control and study groups.

	Control group	Study group			
	Mean ± SD	Mean ± SD	MD	t- value	p value
OSI					
Pre treatment	3.84 ± 0.77	3.41 ± 0.88	0.43	1.62	0.11
Post treatment	2.62 ± 0.49	1.63 ± 0.54	0.99	6.01	0.001
MD	1.22	1.78			
%of change	31.77	52.20			
t- value	10.13	11.87			
p value	***p = 0.001***	***p = 0.001***			
APSI					
Pre treatment	3.2 ± 0.56	3.01 ± 0.78	0.19	0.85	0.39
Post treatment	2.17 ± 0.47	1.34 ± 0.51	0.83	5.37	0.001
MD	1.03	1.67			
%of change	32.19	55.48			
t- value	9.42	10.95			
p value	***p = 0.001***	***p = 0.001***			
MLSI					
Pre treatment	2.87 ± 0.86	2.77 ± 0.88	0.1	0.34	0.73
Post treatment	1.86 ± 0.61	1.08 ± 0.35	0.78	4.93	0.001
MD	1.01	1.69			
% of change	35.19	61.01			
t- value	6.81	8.39			
p value	***p = 0.001***	***p = 0.001***			

SD, standard deviation; MD, mean difference; p-value, probability value

Table 3. Mean difficulty level, maximum and minimum reaction time pre and post treatment of the control and study groups.

	Control group	Study group			
	Mean ± SD	Mean ± SD	MD	t- value	p value
Difficulty level					
Pre treatment	6.55 ± 1.19	6.15 ± 1.04	0.4	1.13	0.26
Post treatment	7.15 ± 0.87	9.55 ± 0.51	-2.4	-10.59	0.001
MD	-0.6	-3.4			
%of change	9.16	55.28			
t- value	-4.48	-15.28			
p value	***p = 0.001***	***p = 0.001***			
Maximum reaction time (sec)					
Pre treatment	28.12 ± 7.78	29.36 ± 6.65	-1.24	-0.53	0.59
Post treatment	22.44 ± 3.05	7.39 ± 2.13	15.05	18.06	0.001
MD	5.68	21.97			
% of change	20.2	74.83			
t- value	4.22	16.94			
p value	***p = 0.001***	***p = 0.001***			
Minimum reaction time (sec)					
Pre treatment	10.81 ± 3.25	11.13 ± 3.66	-0.32	-0.29	0.76
Post treatment	8.51 ± 1.93	4.11 ± 1.33	4.4	8.37	0.001
MD	2.3	7.02			
% of change	21.28	63.07			
t- value	3.68	9.65			
p value	***p = 0.002***	***p = 0.001***			

SD, standard deviation; MD, mean difference; p-value, probability value

DISCUSSION

The aim of this study was to study the impact of virtual reality on balance and cognitive skills in children with hemiparesis. This study showed that there was a significant increase in stability and cognitive skills results in favor of group (B) which gives an indication of effectiveness of addition of VR therapy on balance and cognitive functions.

The VR sensory environment can be successfully manipulated in order to promote the desired motor outcome so that the active motor control process is facilitated. This concern was highlighted and supported by **Keshner et al.,** [16] who confirmed that the postural response was affected by all of the variable sensory signals provided by VR environment. Their findings clearly demonstrated that postural control kinematics were responsive to the multimodal VR inputs metrics.

Virtual reality offers a joyful and interactive environment which stimulates attention and concentration and decreases negative mood behavior and this point of view was established by a systematic review and meta-analysis of randomized controlled trials done by Gao et al., [7] which clarified that when a VR-based intervention was utilized together with conventional rehabilitation, better outcomes were observed for overall attention/execution, cognition and depressive mood in individuals with chronic stroke.

Virtual reality may be superior to traditional physical therapy program in management of CP if they compared to each other and this meets the same study results done by **Leal et al.,** [17] who want to evaluate the impact of computer innovation in the management of CP. They came to the conclusion that, when compared to a real characteristic environment interface, better motor performance of individuals with CP was observed through a virtual environment interface feature.This study gives superiority to VR therapy and strengthens our results.

Also, comparison between the effect of VR therapy combined with conventional therapy and conventional therapy only showed that VR therapy was a helpful therapeutic approach that can be utilised to improve motor function in CP rehabilitation. The effectiveness of treatment might be significantly impacted by incorporating this approach with traditional rehabilitation procedures [18].

In addition, a recent review done by **Tieri et al.,** [19] about VR contributions to cognitive and motor rehabilitation suggested that the most promising VR impacts were the capability to multitask in the virtual environment that can mimic the physical environment demands making it as a useful tool for ecological rehabilitation.

Additionally, the findings of this study agreed with a research study conducted by **Pavao et al.,** [20] who concluded that VR based therapy had positive effects on functional balance and motor performance when used in children with CP with mild functional impairment. They regarded VR as an innovative incorporated tool in CP rehabilitation.

A randomised controlled trial (RCT) of 16 post-operative cerebral palsy children that compared standard rehabilitation modalities versusVR based therapy combined with the conventional rehabilitation has reported that the use of VR based therapy had a significant effect on balance improvement. It also had a significant effect on participation, motivation and cooperation levels [21].

The obtained results remain in line with **Jelsma et al.,** [22] who reported a study on 14 spastic hemiparetic children aged from 7 to 14 years. The Nintendo Wii Fit system was used for 9 weeks. Balance was a primary outcome measure, and functional capacity was a secondary measure. Authors concluded that VR based therapy is effective and has significant effect in balance improvement. They added that VR should be used combined with conventional therapy not as alternative measure to obtain effective results.

Virtual reality may have underlying physiological effects on blood flow to brain which stimulates balance and cognition. This concern was supported by **Karim et al.,** [23] who have reported that virtual environment conducted by VR improves blood flow to cranial parts including the superior temporal gyrus, which controls balance. It causes also stimulation of primary motor cortex which is responsible for motor performance. By activation of those areas, cortical neuroplastic changes occur and enhance motor gain in daily living activities.

Virtual reality may have also a positive effect on balance and functional capacity in another age sector. This concern was supported by Brien and Sveistrup [24] who carried out a study on adolescent CP subjects between the ages of 13 and 18 years. They use VR to study its effect on two variables, the primary one is balance and the secondary one is functional capacity for walking. They concluded that participants who received VR had a significant refinement of balance as well as walking capacity.

On the other hand, Ramstrand and Lygengard [25] showed disagreement with the previous results. They evaluated balance by modified sensory organization test and they concluded that use of Nintendo Wii system had no significant effect on balance improvement in children with cerebral palsy.

LIMITATIONS

Despite the fact that the current study provides objective data and statistically significant findings, there are some restrictions. The main issue is the short duration of study. Longitudinal studies are also required to assess the long-term impact of VR on balance and cognitive abilities in children with hemiparesis.

RECOMMENDATIONS

More studies are needed to identify the efficacy of addition of VR therapy to the rehabilitation protocol in different cases of pediatric pathologies which affect balance or cognitive functions. More studies are needed to for other suggestions for future researches on usage of VR therapy as an alternative for conventional therapy and suggestions for more future studies on VR therapy and other technology therapies to make strong evidence. Also, more studies are required to evaluate the effectiveness of VR therapy on other functions rather than balance and cognition such as upper limb functions and pain management.

CONCLUSION

The study demonstrated that the VR based therapy when combined with conventional intervention had a significant effect on balance and cognitive functions improvement.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

Ethical approval

The protocol of the study was approved by the Ethical Committee of the Faculty of Physical Therapy at Cairo University.

Consent

The procedures of this study were explained to all parents, who signed consent form before the beginning of the study

ORCHID number for Mohammed A. Kamel: 0009-0007-0783-9502

ORCHID number for Walaa A. Abd El-Nabie: 0000-0002-9032-162X

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