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Effect of virtual reality on muscle strength and motor proficiency in children with hemiparesis: A randomized controlled trial

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ABSTRACT:

Purpose: To investigate the effect of interactive training on muscle strength and motor proficiency in children with hemiparesis.

Methods: Thirty children of both sexes with hemiparesis included in this study, aged 8 to 10 years. They were randomized into control and study groups. Both groups received a specially designed physical rehabilitation program. Additionally, the study group participated in Wii Fit virtual reality-based program. Hip and knee extensors' strength were measured using a Lafayette hand-held dynamometer. Bilateral coordination, strength, running speed, and agility were evaluated using the Bruininks-Oseretsky Test of Motor Proficiency, (BOT-2) 2nd edition before and after the treatment program.

Results: Children in both groups showed significant improvements in their post-treatment results across all measured outcomes compared to their pre-treatment results. When comparing the post-treatment mean values between the groups, the study group exhibited significantly greater improvement than the control group (($P < 0.05$)).

Conclusion: Adding interactive training to the designed physical therapy program provide a significant effect on muscle strength and motor proficiency in children with hemiparesis.

Keywords: Cerebral palsy, Hemiparesis, Interactive training, Muscle strength, Coordination, Agility, Running speed
ClinicalTrials.gov Identifier: NCT06520644

INTRODUCTION

Cerebral palsy (CP) is a disability of childhood that can affect the motor function due to injury to the developing brain [1]. Cerebral Palsy is a term containing a different group of permanent disorders of movement and posture that can happen due to injury to the developing brain [2].

Cerebral palsy affects children's movement in various ways, including weak muscles, stiff muscles, limited joint mobility, and poor motor control. These issues hinder the normal development of gross motor skills. The main goal of CP therapy is to improve gross motor function enough for children to perform essential daily activities independently [3]. It can also cause a broad spectrum of lifelong challenges, which may include cognitive issues, seizures, problems with communication, sensory impairments, worsening bone and muscle deformities, and pain [4,5].

A common form of cerebral palsy in children is hemiplegia, a neurological condition that affects one side of the body. It can cause problems with precise movement control, muscle weakness, and muscle stiffness. While one side of the body is impacted, the opposite side seems to function normally. This resulting imbalance has been shown to interfere with many everyday activities, including walking [6].

Research has demonstrated that impaired gross motor skills significantly limit the ability of children with cerebral palsy (CP) to engage in physical activities [7]. It affects various aspects of motor function, including speed, agility, strength, coordination, balance, flexibility, and endurance. For children with CP, speed and agility are particularly crucial for movement. Speed is a refined ability that complements strength and endurance. Agility is a psychomotor skill enabling quick changes in movement direction while maintaining control and balance [8].

The BOT-2 is a standardized assessment tool that measures a child's motor skills through direct observation in a controlled environment. It's designed for individuals aged 4 to 21 and has been validated for assessing both gross and fine motor abilities. The test items reflect typical childhood motor activities, supporting its face validity, and its construct validity has been established [9]. For measuring isometric lower limb muscle strength, the Lafayette manual muscle testing system is frequently employed. Handheld dynamometers are also used for this

purpose, with test-retest reliability showing high consistency [10].

Virtual reality (VR) technology creates a sense of presence in a simulated environment using computer-generated 3D graphics and animations, allowing user interaction with virtual objects [11]. It's considered an advanced form of human-computer interaction, immersing users in a computer-generated world [12]. In cerebral palsy (CP) treatment, virtual rehabilitation is an emerging approach that engages patients in interactive games. Recently, the Nintendo Wii and Wii Fit have gained popularity as virtual rehabilitation tools, potentially enabling children with CP to engage in activities that might be challenging in the real world [13].

The Nintendo Wii Fit™ gaming console has shown promise as a novel exercise option for improving various physical attributes in healthy adults and the elderly, including strength, flexibility, fitness, and postural stability [14]. Essential components of effective motor learning are the child's active participation in therapy and goal-oriented movement. These components may be provided through the playing an interactive games which may lead to facilitation of normal patterns of movement in children with CP. Therefore, this study aimed to determine the effect of rehabilitation delivered as interactive games program on strength, agility and coordination in children with hemiparetic CP.

METHODS

Study design and randomization

This study is a randomized controlled trial (RCT) where the selected children were randomly divided into two groups of 15 children using sealed envelopes. The investigator prepared 30 sealed envelopes, each containing a card labeled either group A or B. The legal guardian of each child drew a sealed envelope to determine their allocation. Each child completed assessments at baseline (pre-treatment) and after 3 months of treatment (post-treatment). Evaluation was conducted by an assessor who was blinded to the participants' group assignments. Children in group A (control group, N=15, Female=8, Male=7) received a specially designed physical therapy program. Children in group B (study group, N=15, Female=10, Male=5) received the same program as group A, along with Wii-based interactive training Fig (1).

The sample size for the study was determined using the G*power program version 3.1.9

(G*power program version 3.1, Heinrich-Heine-University, Düsseldorf, Germany) for a one-tailed test and suggested that N=26 was the suitable sample size. However, 30 children were recruited for possible dropout.

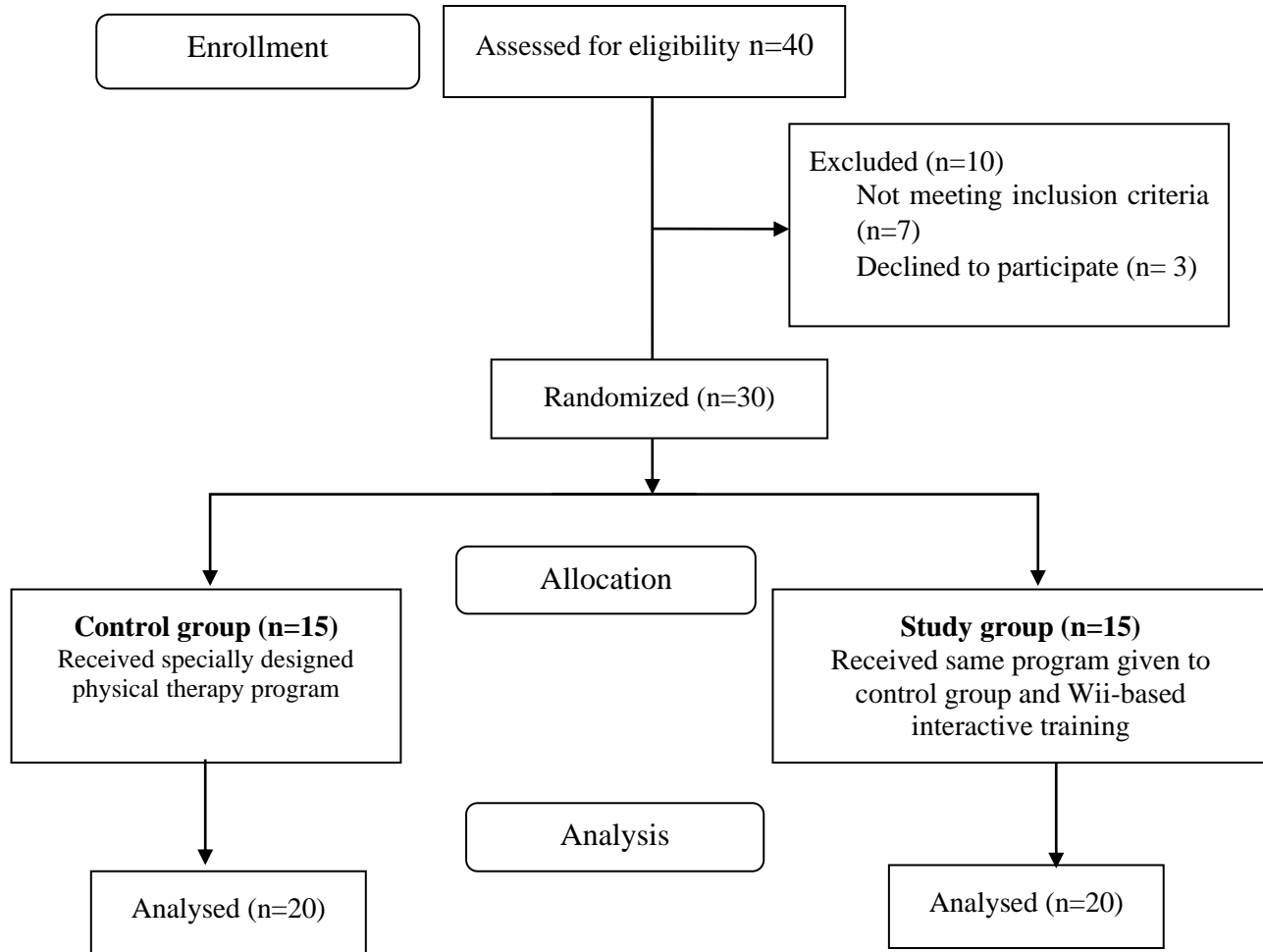


Figure (1): Flow chart of study design

Ethical Consideration

The Research Ethical Committee at Faculty of Physical therapy approved the study with reference number P.T. REC/012/003287. This study was registered prospectively on ClinicalTrials.gov with the number (NCT06520644). Participants’ legal guardians had their signature done on a written informed consent before participating in the study.

Participants

Thirty children with hemiparetic CP were enrolled in this study. They recruited from the Outpatient Clinic of Cairo University's Faculty of Physical Therapy, Cairo University. Participants were evenly divided into two groups of 15 children in each group, including both boys and girls aged 8 to 10 years. Inclusion criteria required mild spasticity (1 to 1+ on the Modified Ashworth Scale) [15], motor skill levels I or II on the Gross Motor Function Classification System (GMFCS) [16] and the ability to adhere to instructions during evaluation and treatment. Exclusion criteria included children that suffered from any cardiac conditions or respiratory disorders, received injections of botulinum toxin within the last 6 months, had history of lower limb or spine surgery, musculoskeletal issues or fixed deformities in the spine or lower extremities, experienced seizures, or had visual or hearing impairments.

Outcome measures

All children were assessed for hip and knee extensor strength using a Lafayette hand-held dynamometer. Motor proficiency including; bilateral coordination, strength, running speed, and agility were measured using the Bruininks-Oseretsky Test of Motor Proficiency, (BOT-2) 2nd edition before and after the treatment program.

Procedures of evaluation

Assessment of lower limb extensors' strength:

Lafayette manual muscle testing system is most common used device that measure isometric strength of the lower limb muscle. Handheld dynamometer is used to test strength of the lower limb. The test-retest interclass correlation coefficient ranged from 0.95 to 0.99 [10].

Assessment of knee extension strength was conducted from sitting position on a chair with knee and hip flexed (90) degree. The hand held dynamometer is applied anteriorly 5 cm proximal to the lateral malleoli. The dynamometer is inserted between the anterior surface of the leg and the strap, with the strap itself attached to the leg of the chair. The strap is also tightened to ensure (90) degree of knee flexion. In this way, the leg is well stabilized and the strap resists the isometric knee extension during the test [17].

Assessment of hip extension strength was performed from prone position with knee flexed 90° and hip in neutral position [18]. The dynamometer is applied on posterior surface of thigh distal just proximal to femoral condyle. The dynamometer is inserted between the posterior surface of the thigh and the strap. The strap is also tightened to ensure hip in neutral position. In this way, the thigh is well stabilized and the strap resists the isometric hip extension during the test.

Each child will give 2 submaximal contractions trial to warm-up the child and ensure that the task is understood and stabilization is well [19]. The child will perform 3 trails and the mean of 3 trails will used for the analysis. Each contraction will be held 5 seconds followed by a 60 seconds rest period.

Assessment of Motor Proficiency:

It was measured using BOT-2 which has supporting evidence to assess gross and fine motor proficiency of individuals aged 4 through 21[9]. The BOT-2 test consists of four composites and eight subtests including 53 items as follows: fine manual control (including fine motor integration and fine motor precision), manual coordination (covering upper limb coordination and manual dexterity), body coordination (encompassing balance and bilateral coordination), and strength and agility (including strength, agility, and running speed) [20].

Each child in both groups was assessed by the following subtests of BOT-2 including bilateral coordination subtest that consists of 7 tests (touching nose with finger -eye closed, jumping jacks, jumping in place with same side and opposite side synchronized, pivoting thumbs and index fingers, tapping feet and fingers - same and opposite synchronized).

Running speed and agility subtest which includes 5 tests (shuttle run, stepping sideways over a balance beam, one- legged stationary hop, one legged side hop and two legged side hop). Strength subtest that includes 5 tests (standing long jump, knee or full push-ups, sit-ups, well-sit and v-up).

Procedures of treatment

Children in both groups received specially designed physical therapy program consisting of 60-minute sessions, conducted 3 times a week for 3 consecutive months. The physical therapy program incorporated a range of exercises whose aim was improving balance, coordination, and strength. These encompassed balance training on boards and single-leg stands, weight shifting, and recovery from stooping. Counterpoising skills were developed through ball-kicking and throwing activities. Gait training involved walking on balance boards, navigating obstacles, and using stairs. Protective reactions were stimulated by gently pushing the child in different directions while standing. The program also focused on rising exercises, transitioning from lying or sitting to standing, and incorporated back, abdominal, and limb strengthening exercises, as well as jumping activities.

Children in the study group received this standard program of physical therapy with an additional component of 30 minutes Wii-based interactive training conducted 3 times per week over a three-month period.

The interactive training program conducted through using Nintendo Wii video game which consists of console, remote, nun chuck and balance board. The Wii gaming system is based on wireless controller. The balance board has multiple sensors which are located at the lower corners of the base that measure and calculate shifts in the center of pressure. When a player moves on the balance board, the sensor data is transmitted to a computer via Bluetooth, instead of being sent to the Nintendo Wii console [21]. The games used in this study include single limb extension, jumping, jogging, table tilt, step basic and hula hoop.

Single limb extension: Child stand on wii balance board and asked to follow the avatar movement in this exercise and balance on one leg and repeatedly pulling it back and forth. Each time the leg pulled back to the balance board, it was count as a single repetition.

Jumping: The child was instructed to stand on balance board and squat with knees bent and push his or her COG/COP forward by putting it in the blue area to gain speed. The child was instructed when he or she reached the end of the ramp, which was colored red, extends his or her knees, and then hold his or her balance. The aim was to get as far as you can, for a higher score.

Jogging: The child was asked to stand in front of the TV holding a Wii remote in his /her hand.

The child was instructed to go for a run while he or she watched TV. Let the Wii remote guide you. The therapist removed any obstacles in the room for child safety while he /she is running in his or her place in the room.

Table tilt: The child was asked to stand on balance board and when the game started, he/she lean their bodies left, right, forward, and backward trying to drop the ball into the holes.

Step basic: The child stood in front of the Wii board before the game began. The child was instructed to step on and off the Wii balance board in coordination with the on-screen steps. Successfully completing this multiple times unlocks the advanced step level. Red steps indicated stepping forward and backward, while blue steps signaled stepping left and right.

Hula hoop: The child was asked to stand on the Wii board and sway his or her hips front and side to side in circular motion. The child swivels his or her trunk trying to allow avatar to catch the circle around the avatar's trunk.

Statistical analysis

Data was screened, for normality assumption test and homogeneity of variance. Normality test of data using Shapiro-Wilk test, reflect that data was normally distributed ($P>0.05$) after removal outliers that detected by box and whiskers plots. Additionally, Levene's test for testing the homogeneity of variance revealed that there was no significant difference ($P>0.05$). The data is normally distributed, and parametric analysis is done.

The statistical analysis was conducted by using statistical SPSS Package program version 25 for Windows (SPSS, Inc., Chicago, IL). Quantitative data for demographic data (age, weight, height, BMI), knee extension, hip extension, BOT scale bilateral coordination, running and agility, and strength are expressed as mean and standard deviation. Qualitative data for gender and affected side data are expressed as frequency and percentage and compared statistically by Chi-square test between both groups. Paired t-test was used to compare between pre- and post-treatment mean values within each group for all measured variables and independent t-test was used for between group comparisons for all measured variables. All statistical analyses were significant and accepted at level of significance ($P < 0.05$).

RESULTS

Thirty children diagnosed with hemiparetic CP participated in this study. Comparing general characteristics of both groups including height, weight, BMI, age and distribution of gender revealed non-significant differences between groups ($p>0.05$) (Table 1).

Table 1. Comparative analysis of children's general characteristics between control and study groups

Items	Groups		P-value
	Control group (n=15)	Study group (n=15)	
Age (year)	8.47 \pm 0.83	8.93 \pm 0.96	0.167
Weight (kg)	23.30 \pm 3.60	23.06 \pm 3.55	0.153
Height (cm)	120.73 \pm 9.18	127.53 \pm 9.75	0.059
BMI (kg/m ²)	15.98 \pm 1.67	14.18 \pm 3.72	0.075
Gender (boys : girls)	7 (46.70%) : 8 (53.30%)	5 (33.30%) : 10 (66.70%)	0.456
Affected side right : left)	7 (46.7%) : 8 (53.3%)	11 (73.3%) : 4 (26.7%)	0.136

Quantitative data (age, weight, height, and BMI) are expressed as mean \pm standard deviation and compared by independent-t test.

Qualitative data (gender and affected side) are expressed as number (percentage) and compared by chi-square test.
P-value: probability value

As shown in Table 2, non-statistical significant differences were found between both groups when comparing their pre-treatment results concerning all measured variables ($p>0.05$). Statistical comparison within each group for knee extension and hip extension showed that there were significant improvement ($P<0.05$) at post-treatment compared to pre-treatment within the control group ($P=0.001$ and $P=0.016$ respectively) and study group ($P=0.0001$ and $P=0.0001$ respectively). There was significant improvement between both groups when comparing their post-treatment results of knee and hip extension in favor of study group ($P<0.05$).

Statistical comparison within each group for motor proficiency including bilateral coordination, running speed and agility, and strength showed that there were significant improvement at post-treatment compared to pre-treatment within the control group ($P= 0.035$, $P=0.002$ and $P=0.04$ respectively) and study group ($P=0.0001$, $P=0.0001$ and $P=0.0001$

respectively). There was significant improvement between both groups when comparing their post-treatment results of motor proficiency in favor of study group (P<0.05) (Table 2).

Table 2: Within and between groups comparison for strength and motor proficiency outcomes

Variables	Items	Groups (Mean ±SD)		Change	P-value ²
		Control group (n=15)	Study group (n=15)		
Knee extension	Pre-treatment	8.34 ±3.03	8.83 ±0.88	0.49	0.657
	Post-treatment	10.53 ±3.27	17.55 ±1.66	7.02	0.0001*
	Mean difference	2.19	8.72		
	Improvement %	26.26%	98.75%		
	P-value ¹	0.001*	0.0001*		
Hip extension	Pre-treatment	10.09 ±3.48	11.51 ±1.40	1.42	0.306
	Post-treatment	12.84 ±3.36	22.73 ±3.74	9.89	0.0001*
	Mean difference	2.75	11.22		
	Improvement %	27.25%	97.48%		
	P-value ¹	0.016*	0.0001*		
Bot scale bilat. coordination	Pre-treatment	9.67 ±1.97	9.00 ±2.32	0.67	0.758
	Post-treatment	11.13 ±4.25	17.67 ±3.57	6.54	0.002*
	Mean difference	1.46	8.67		
	Improvement %	15.10%	96.33%		
	P-value ¹	0.035*	0.0001*		
Running speed and agility	Pre-treatment	5.80 ±1.74	5.47 ±1.55	0.33	0.679
	Post-treatment	7.03 ±1.44	10.13 ±3.20	3.10	0.014*
	Mean difference	1.23	4.66		
	Improvement %	21.21%	85.19%		
	P-value	0.002*	0.0001*		
Strength	Pre-treatment	10.66 ±1.91	10.73 ±3.26	0.07	0.968
	Post-treatment	12.00 ±2.62	18.47 ±3.50	6.47	0.005*
	Mean difference	1.34	7.74		
	Improvement %	12.57%	72.13%		
	P-value ¹	0.041*	0.0001*		

Data are expressed as mean ± standard deviation (SD) P-value: probability value * Significant (P<0.05)
 P-value¹: probability value within each group compared by paired t-test;
 P-value²: probability value between both groups compared by independent t-test

DISCUSSION

The aim of this study was to examine how VR influences hip and knee extensors strength and motor proficiency including; bilateral coordination, strength, agility and running speed in children suffering from hemiparetic CP . Thirty children, aged 8 to 10 years, collaborated in the study and divided randomly into two groups of 15 children in each group. . The control group underwent specially designed physical therapy program, whereas the study group underwent the same program and Wii interactive training.

Data obtained from both groups pre and post treatment regarding hip and knee extensor strength, bilateral coordination, strength, running speed and agility were statistically analyzed. The findings revealed that the mean values for age, weight, height, BMI and all measured variables were not significantly variation between the two groups, owing to the sample homogeneity. The results of this study revealed significant improvements in all outcome measures in both groups with more improvement in the study group than control group.

The post-treatment improvement in all measured variables in the study group can be due to the effect of VR games in providing children with simplified feedback about the position of their bodies in space and allows them to interact with virtual components in real time, stimulating the learning of adaptive motor control strategies in response to stimuli. The motivation and the ability to customize the therapy provided by the contact with the virtual environment make VR an important rehabilitation tool, which offers sensorimotor experiences that are otherwise unfeasible in common therapies [22].

The present study revealed that children in both groups displayed improvement in all measured variables after intervention, which could be due to the positive effects of especially designed physical therapy program on balance, coordination, strength, and flexibility after participation in motor activities resulting from postural control improvement from different positions achieved through physical therapy program Children with CP can achieve functional independence through rehabilitation programs that apply neuro-developmental principles [23].

The post-treatment significant differences between control and study group can be attributed to the advantages of VR training as it has three key elements including repetition results in better learning of motor and functional skills. Sensory feedback as virtual environments

provide massive and intensive sensorimotor stimulation, which is necessary to induce brain reorganization. Motivation as subjects are motivated when the activities in their therapy programmes are presented in an enjoyable and attractive way [24].

The post-treatment significance differences between study and control groups come in agreement with Sahin et al. [25] who VR on both gross and fine motor functions and independence in daily living activities in children with unilateral spastic CP. They found a statistically significant improvement with VR intervention in gross motor functions, such as balance, running speed and agility, bilateral coordination, and strength.

The post-treatment improvement in running speed and agility score in the study group agrees with Jelsma et al. [26] who studied the impact of training using the Nintendo Wii Fit in children with spastic hemiplegic CP. They found statistically significant improvement in running speed and agility in these children following Interactive video gaming training children. These findings disagreed with Ziab et al. [27] who investigated the efficacy of virtual reality-based rehabilitation interventions to improve balance function in children with CP. They reported that there was no significant improvement in running speed and agility score following treatment.

The post treatment results showed statistically significant improvement of strength in the study group who received Nintendo Wii Fit games. This comes in agreement with AlSaif and Alsenany [28] who study the effect of interactive games on motor performance in children with spastic CP. They found improvements in balance, motor performance, muscle strength, and walking efficiency.

The post-treatment significant difference of hip and knee extensors strength between both groups is consistent with Fandim et al. [29] who evaluate the effectiveness of VR in CP patients and they reported that effectiveness of VR was greater than other treatments in improving lower limb strength. Also, Bilde et al. [30] found that muscle strength and visual perceptions of children with CP were significantly improved after a VR game intervention and Cho et al. [31] found that VR games increased the lower limb strength of children with CP, thereby raising the postural control of these children, enhancing their body symmetry.

The post-treatment significant differences between both groups may be due to the effect of VR in providing auditory and visual feedback, offering crucial insights to enhance their

postural stability [32]. Engaging with interactive training using Wii Fit has proven to boost energy expenditure and physical activity, making it a beloved exergame [33]. Prior research highlights that Wii Fit significantly improves lower-limb muscle activity, strength, and balance [34]. Also, it was reported that Wii balance board as an input tool, has a significant role in contemporary exercise programs for enhancing physical activity and muscle strength [35]. Ren and Wu [36] compare between children with CP who were undergoing traditional therapy and children who received VR games. They found that VR group can manage jumping remarkably more times with the leg on the hemiplegic side, especially in ski jumping and racing games than control group.

It is important to note that the VR games must be as specific as possible since the clinical improvements are dependent on delivered motor training. It was reported that different VR interactive games were used for patients with CP. Gatica-Rojas [37] reported that snowboards, penguin slides, and super hula hoop might recruit mediolateral and antero-posterior balance to induce valuable changes in motor performance. Also, Grecco [38] suggested that games encompassing a racetrack to simulate efficient walking at different velocities could significantly increase the motor performance scores. Virtual reality-based rehabilitation treatment is more effective in motivating children with CP. It provides the opportunity to safely play, learn, and acquire skills. Therefore, virtual reality is considered a promising method for motivating participation in rehabilitation programs [39].

Virtual Reality-based therapy improved gross motor function in children with mild CP, therefore adding VR-based therapy to therapeutic planning of children with mild CP may benefit the rehabilitation process by promoting motor gains [40]. Virtual Reality can effectively enhance the child's motor function by improving joint range of motion, increasing muscle strength, and raise the child's self-confidence and motivational level [41].

Conclusion

The study's findings verified that Wii interactive training is an effective approach to improve muscle strength and motor proficiency including bilateral coordination, strength, running speed

and agility in hemiparetic CP children.

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Disclosure statement

No financial interest or benefit was obtained by any of the authors from this research.

Conflict of interest

No conflict of interest

References:

1. Paul S, Nahar A, Bhagawati M, Kunwar AJ (2022). A review on recent advances of cerebral palsy. *Oxid Med Cell Longev*, 2622310. doi: 10.1155/2022/2622310
2. Jackman M, Sakzewski L, Morgan C, Boyd RN, Brennan SE, Langdon K, et al.,(2022).Interventions to improve physical function for children and young people with cerebral palsy: international clinical practice guideline. *Dev Med Child Neurol*, 64(5), 536-549. <https://doi.org/10.1111/dmcn.15055>.
3. Park EY, Kim WH (2017).Effect of neurodevelopmental treatment-based physical therapy on the change of muscle strength, spasticity, and gross motor function in children with spastic cerebral palsy. *J Phys Ther Sci*, 29(6), 966-969.<https://doi.org/10.1589/jpts.29.966>.
4. Ferguson GD, Aertssen WF, Rameckers EA, Jelsma J, Smits-Engelsman BC (2014). Physical fitness in children with developmental coordination disorder: measurement matters. *Res Dev Disabil*, 35(5), 1087-1097.<https://doi.org/10.1016/j.ridd.2014.01.031>
5. Arnaud C, Ehlinger V, Perraud A, Kinsner-Ovaskainen A, Klapouszczak D, Himmelmann K, et al. (2023). Public health indicators for cerebral palsy: A European collaborative study of the Surveillance of Cerebral Palsy in Europe network. *Paediatr and Perinata Epidemiol*,37(5), 404-412.<https://doi.org/10.1111/ppe.12950>

6. Di Nardo F, Strazza A, Mengarelli A, Cardarelli S, Tigrini A, Verdini F, et al. (2019) .EMG-based characterization of walking asymmetry in children with mild hemiplegic cerebral palsy. *Biosensors*, 9(3), 82.<https://doi.org/10.3390/bios9030082>.
7. Juras G, Brachman A, Michalska J, Kamieniarz A, Pawłowski M, Hadamus A, et al. (2019).Standards of virtual reality application in balance training programs in clinical practice: a systematic review. *Games for Health J*, 8(2), 101-111.doi.org/10.1089/g4h.2018.0034
8. Hanief YN, Sumarni S, Ellyas IS, Fadian UF (2020). Increasing Speed and Agility of Cerebral Palsy Football Indonesian Player with UMAC-CPF Exercise Model. *Int J Sports Med*, 8(6), 329-336.DOI: 10.13189/saj.2020.080604.
9. Bruininks R, Bruininks B (2005). Bruininks-Oseretsky test of motor proficiency (2nd ed.). Minneapolis, MN: NCS Pearson. <https://psycnet.apa.org/doi/10.1037/t14991-000>
10. Bohannon RW (2012). Hand-held dynamometry: A practicable alternative for obtaining objective measures of muscle strength. *Isokinet Exer Sci*, 20(4), 301-315.DOI: 10.3233/IES-2012-0476
11. Huang HM, Rauch U, Liaw SS (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Comp Edu*, 55(3), 1171-1182.[doi:10.1016/j.compedu.2010.05.014](https://doi.org/10.1016/j.compedu.2010.05.014).
12. Riva G, Mancuso V, Cavedoni S, Stramba-Badiale C (2020).Virtual reality in neurorehabilitation: a review of its effects on multiple cognitive domains. *Expert Rev Med Devices*,17(10), 1035-1061.<https://doi.org/10.1080/17434440.2020.1825939>
13. Kalantari M, Ghorbani N, Mokhtarpur P (2017). The effects of intensive Wii sport training on adolescents with spastic diplegic cerebral palsy: case study. *J Clin Physio Res*, 2(1), 48-50.Doi: 10.22037/jcpr.2017.08.
14. Siriphorn A, Chamonchant D (2015).Wii balance board exercise improves balance and lower limb muscle strength of overweight young adults. *J Phys Ther Sci*, 27(1), 41-46.DOI <https://doi.org/10.1589/jpts.27.41>
15. Bohannon RW, Smith MB (1987). Interrater reliability of a modified Ashworth scale of muscle spasticity. *Phys Ther*, 67(2),206:207.<https://doi.org/10.1093/ptj/67.2.206>.

16. Palisano RJ, Rosenbaum P, Bartlett D, Livingston MH (2008). Content validity of the expanded and revised Gross Motor Function Classification System. *Dev Med Child Neurol*, 50(10), 744-750.
17. Hébert LJ, Maltais DB, Lepage C, Saulnier J, Crête M (2015). Hand-held dynamometry isometric torque reference values for children and adolescents. *Pediatr Phys Ther*, 27(4), 414:423. doi: 10.1097/PEP.0000000000000179.
18. Crompton J, Galea MP, Phillips B (2007). Hand-held dynamometry for muscle strength measurement in children with cerebral palsy. *Dev Med Child Neurol*, 49(2), 106-111.
19. El Shemy SA, Amer FE, Madani HA (2019). Impact of Iron Deficiency Anemia on Functional Abilities and Muscle Strength in Children with Spastic Cerebral Palsy. *Pak J Biol Sci*, 22(5), 214-219. DOI: 10.3923/pjbs.2019.214.219
20. Wilson BN, Kaplan BJ, Crawford SG, Dewey D, Dadkhah A, Aksay E (2013). Bruininks-oseretsky test of motor proficiency, complete form report other information. *Sports Biomech*, 5(3), 2078-2273.
21. Lange B, Flynn S, Proffitt R, Chang CY, Skip Rizzo A (2010). Development of an interactive game-based rehabilitation tool for dynamic balance training. *Top stroke rehabil*, 17(5), 345-352. <https://doi.org/10.1310/tsr1705-345>.
22. Pavão SL, Arnoni JL, Oliveira AK, Rocha NA (2014). Impact of a virtual reality-based intervention on motor performance and balance of a child with cerebral palsy: a case study. *Revista Paulista de Pediatria*, 32(4), 389-394.
23. Mendoza-Sengco P, Lee Chicoine C, Vargus-Adams J (2023). Early cerebral palsy detection and intervention. *Pediatr Clin North Am*, 70(3):385-398. doi:10.1016/j.pcl.2023.01.014
24. Pereira EM, Rueda FM, Diego IA, De La Cuerda RC, De Mauro A, Page JM (2014). Use of virtual reality systems as proprioception method in cerebral palsy: clinical practice guideline. *Neurología*, 29(9), 550-559.
25. Sahin S, Kose B, Aran OT, Agce ZB, Kayihan H (2020). The Effects of Virtual Reality on Motor Functions and Daily Life Activities in Unilateral Spastic Cerebral Palsy: A Single-Blind Randomized Controlled Trial. *Games Health J*, 9(1):45-52. doi:

- 10.1089/g4h.2019.0020. Epub 2019 Jul 23. PMID: 31335174.
26. Jelsma J, Pronk M, Ferguson G, Jelsma-Smit D (2013).The effect of the Nintendo Wii Fit on balance control and gross motor function of children with spastic hemiplegic cerebral palsy. *Dev neurorehabil*,16(1),27-37.<https://doi.org/10.3109/17518423.2012.711781>.
 27. Ziab H, Mazbouh R, Saleh S, Talebian S, Sarraj AR , Hadian M R (2022). 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*, 9(2).DOI: <https://doi.org/10.5812/ans-122865>.
 28. AlSaif AA, Alsenany S (2015). Effects of interactive games on motor performance in children with spastic cerebral palsy. *J Phys Ther Sci*, 27(6), 2001-2003.
 29. Fandim JV, Saragiotto BT, Porfírio GJ, Santana RF (2021).Effectiveness of virtual reality in children and young adults with cerebral palsy: a systematic review of randomized controlled trial. *Braz J Phys Ther*, 25(4), 369-386.
 30. Bilde PE, Kliim-Due M, Rasmussen B, Petersen LZ, Petersen TH, Nielsen JB (2011).Individualized, home-based interactive training of cerebral palsy children delivered through the Internet. *BMC Neurol* Mar 9; 11:32. doi: 10.1186/1471-2377-11-32.
 31. Cho C, Hwang W, Hwang S, Chung Y (2016). Treadmill Training with Virtual Reality Improves Gait, Balance, and Muscle Strength in Children with Cerebral Palsy. *Tohoku J Exp Med*, 238, 213–218.DOI <https://doi.org/10.1620/tjem.238.213>
 32. Washington M, Owens RA, Moody J (2022). The effects of virtual gaming on lower extremity function in children with cerebral palsy: a narrative review *J Biomed Res Environ Sci*, 18; 3(7): 771-778. doi: 10.37871/jbres1512.
 33. Lau PW, Wang G and Wang JJ (2020). Effectiveness of active video game usage on body composition, physical activity level and motor proficiency in children with intellectual disability. *J Appl Res Intellect Disabil*, 33(6):1465-1477. doi: 10.1111/jar.12774..
 34. Montoro-Cárdenas D, Cortés-Pérez I, Ibanco-Losada MD, et al. (2022). Nintendo® Wii Therapy Improves Upper Extremity Motor Function in Children with Cerebral Palsy: a Systematic Review with Meta-Analysis. *Int J Environ Res Public Health*, 28;19(19):12343.

35. Liu C, Wang X, Chen R, Zhang J (2022). The Effects of Virtual Reality Training on Balance, Gross Motor Function, and Daily Living Ability in Children with Cerebral Palsy: a systematic Review and Meta-analysis. *JMIR Serious Games*. 10 (4):e38972. doi: 10.2196/38972.
36. Ren Z, Wu J (2019). The effect of virtual reality games on the gross motor skills of children with cerebral palsy: a meta-analysis of randomized controlled trials. *Int J Environ Res Public Health*, 16(20),3885. <https://doi.org/10.3390/ijerph16203885>.
37. Gatica-Rojas V, Mendez-Rebolledo G (2014) .Virtual reality interface devices in the reorganization of neural networks in the brain of patients with neurological diseases. *Neural Regen Res*, 9(8):888-96. doi: 10.4103/1673-5374.131612.
38. Grecco LA, Duarte ND, Mendonça ME, Cimolin V, Galli M, Fregni F et al.(2014). Transcranial direct current stimulation during treadmill training in children with cerebral palsy: a randomized controlled double-blind clinical trial. *Res Dev Disabil*, 35(11), 2840-2848. <https://doi.org/10.1016/j.ridd.2014.07.030>.
39. Harris K, Reid D (2005).The influence of virtual reality play on children’s motivation. *Can J Occup Therapy*, 72(1):21-9. doi: 10.1177/000841740507200107.
40. Arnoni JL, Pavao SL, dos Santos Silva FP ,Rocha NA(2019). Effects of virtual reality in body oscillation and motor performance of children with cerebral palsy: A preliminary randomized controlled clinical trial. *Complement Ther Clin Pract*, 35:189-194. <https://doi.org/10.1016/j.ctcp.2019.02.014>
41. Weiss PL, Kizony R, Feintuch U, Rand D, Katz N (2014). Virtual reality applications in neurorehabilitation. in: Selzer ME, Clarke S, Cohen LG, Kwakkel G, Miller RH (eds.), *Textbook of neural repair and neurorehabilitation*, Vol. 2 pp. 192-218. Cambridge University Press. <https://doi.org/10.1017/CBO9780511995590>