EFFECTIVENESS OF INTERACTIVE 3D VISUALIZATION TECHNIQUES IN CEREBRAL PALSY FOR IMPROVING THE GROSS MOTOR FUNCTIONS – A NARRATIVE REVIEW OF RANDOMIZED CONTROLLED TRIALS.

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Abstract

Background: Gaining improvement in gross motor function using traditional as well as developmental therapeutic techniques remaining challenging when it comes to expected corporation from children with Cerebral Palsy (mild to moderate cognitive impairment). Game based 3 D visualization techniques can create simulative environment and make the activity pleasurable. This review explores the effectiveness of game based 3 D visualization techniques in Cerebral Palsy children for improving the gross motor functions.

Methodology: 23 Randomized Controlled Trials were included in review using data bases such as PubMed, Cochrane Central Register of Controlled Trials, Web of Science, EMBASE, and Google scholar. Only Randomized Controlled Trails were included.

Results: 11 RCT's examined the effect of the 3 D visualization techniques in the gross motor functions among CP children. 9 RCT's were evaluated the effect of the 3 D visualization techniques in balance among the CP children and 3 RCT's were analysed the impact of AR and VR in gait among the CP children. The main outcome measures used in the studies were Gross Motor Function Measures (GMFM), Paediatric Balance Scale (PBS) and 6 Minute Walk Test (6-MWT).

Conclusion: This study appears encouraging when taking into account the game-based scenario like Virtual Reality and Augmented Reality to increase the engagement of kids with Cerebral Palsy. However, in future high-quality research is required to explore the extent to which the 3 D visualization techniques are effective in the CP.

Keywords: CP, 3 D Visualization techniques, Augmented Reality, Virtual Reality, Gross Motor Function, Balance, Gait.

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1. Introduction

Cerebral Palsy (C P) isone of the most frequently seen neurological condition in children.[1] According to Bax M et.al, 2005 the current definition of C P is "A group of permanent, but not unchanging, disorders of movement and/ or posture and of motor function which are due to a non-progressive interference, lesion or abnormality of the developing/immature brain".[2] C P populations shows different types of clinical manifestations according to the depth of the brain lesion. This includes abnormalities in the muscle tone, postural dysfunctions, variations

in the balance, and other composite impairments along with difficulties in doing gross motor activities. Gross motor function is one of the primary challenges in children with cerebral palsy. Gross motor function refers to the ability to control large muscles in the body, such as those in the upper extremities, lower extremities, and the trunk areas.[3] Inability to do the gross motor activities will hinder the child participation in the social activities. Appropriate recognition of the delay in the milestones plays an important role in the successive rehabilitation.

Several traditional as well as advanced Neuro Developmental Treatment (NDT) strategies has proven to be exceedingly helpful for CP children in improving gross motor function.[4,5]On the contrary some studies don't support conventional treatment protocols considering it is boring and monotonous for the children during the long rehabilitation process.[6] In CP with mild cognitive involvement, providing game-based scenario can promote interactive learning. Also, cognitive improvement can be targeted simultaneously to improve gross motor function. Interactive 3 D visualization techniques are considered as game-based scenario, where the child can immerse in virtually created world, where he can play and do activities. It is also known as simulated interactive learning. These simulative environments are safe, pleasurable, and make the child to play the activities in a relaxed way.[7] Studies are suggesting that when the cerebral palsy children do the activities in such environment, along with other functional activities there will be improvement in the cognitive function also. Fehlings D et.al, 2013 stated that Virtual reality (V R) a form of interactive 3 D visualization techniques, are significantly effective for improving the balance and coordination in CP children.[9] Concomitantly Cheng et.al 2014 expressed in his meta-analysis about the significant role of VR training in the cerebral palsy children for improving the upper extremity activities.[10]Hockings D R,2019 found a moderate effect on the children with CP on gross motor functions.[11]Augmented reality (AR) is another 3D visualization technique that can be used to improve gross motor function in children with cerebral palsy. A more contemporary techniques than VR, AR displays an inter disciplinary application frame work, with education and learning currently appearing to be the most active study area.[8] AR can be used to overlay digital information onto the real world. This can help the children with cerebral palsy to better understand their environment in better way and to improve their gross motor skills. Studies demonstrating a significant improvement in gross motor skills in cerebral palsy patients employing 3 D Visualisation techniques are few and far between as of now. Thus, the requirement for our study to look into how well Interactive 3 D Visualisation techniques work in cerebral palsy to enhance gross motor abilities.

Methods

Our search strategies were limited to studies consisting of keywords such as Cerebral Palsy, Interactive 3D visualization techniques, Virtual Reality, Augmented Reality, gross motor activities. Data collected consistently from different data bases such as- PubMed, Cochrane Central Register of Controlled Trials, Web of Science, EMBASE, and Google scholar. The published articles were eligible for inclusion (1) If they examined the effectiveness of VR in improving the gross motor function, (2) Studies which included the children age group of 4-20 years (3) All the type of CP were considered for the review (4) Published RCT's from 2012 January 1st to 2023 March 1st (5) Only English language article. The studies were excluded if there were case reports, case series reports, systematic review, meta-analysis, letter to editor and surveys,studies with missingresults data.

2. Results

Total 60 published articles were identified using different data bases. Out of which26 studies were rejected since they didn't attain the eligibility criteria. Thirty-Four studies were finally evaluated based on inclusion criteria among these, 11 studies were excluded. Total 23 full text articles were included in the study for the reviewing process (Fig 1.0). The details of characteristic of the 24 articles are given in the table 1.0, 1.1 and 1.2.

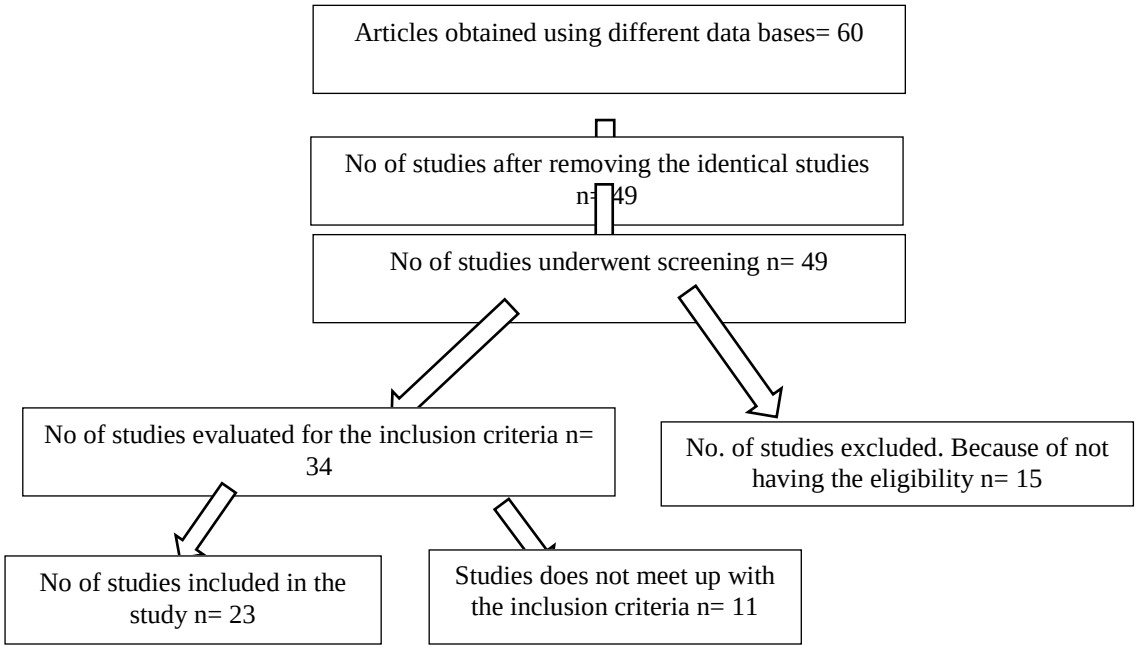

Fig:1.0 Flow diagram showing the studies selection process

Table 1.0: Interactive 3 D visualization techniquesfor improving the gross motor function in cerebral palsy

Sl. No	Author and Year	No. of participants, age and type of CP	Interactive 3 D visualization techniques protocol (Virtual Reality and Augmented Reality)	Outcome measures	Conclusion
1	Jung Y. G et.al, (2022).[12]	10 spastic C P, 5-18 years.	Virtual Reality training with horse driving imitation. Half an hour of treatment program for two times a week for a sum of 16 sittings.	GMFM, PBS, TUG	The study results concluded that Horse driving imitation using VR training can be used for improving the gross motor function in children with CP.
2	Guinet A L et.al (2022)[13]	25 spastic, hemiplegic, diplegic and quadriplegic CP. 12-18 Years.	Subjects underwent six sittings of AR training using Hoolen's Augmented Reality headset.	Mean speed, Time to reach target speed.	Providing the multi-sensory and variable kind of trainings are very efficient in enhancing the UE and LE motor activities.
3	Sahin S et.al (2019)[14]	60 Unilateral spastic CP, 7-16 Years.	Author randomly divided the patients into two groups and the Patients in the Virtual Reality group underwent 2 months of treatment program which	Bruininks- Oseretsky Test of motor proficiency- shortform Wee- FIM	The study reveals that VR rehabilitation is highly beneficial in improving the gross motor functions and

			includes 16 sittings with a time duration of 45 minutes. Games included are Air challenge, Boxing training, Wall brick, Jet run, Super Kick.		for reducing the dependency on caregivers for the daily activities.
4	Arnoni J L B et.al, (2019)[15]	15 spastic CP 5-14 years.	The participants in the study group underwent VR program two times a week for quarter to one hour for 8 successive weeks. The games included are 20,000 leaks, Space pop, River Rush and Reflex ridge.	GMFM	Research reveals that there are remarkable changes in the gross motor functions of cerebral palsy children.
5	Okmen B M et.al, (2019)[16]	41 CP (All types), 5-15 years.	The treatment group underwent Virtual reality training using the Sony play station 2 eye toy for 1 hour for three days in a week for the consecutive 4 weeks. The games are basketball, swimming and tennis.	Bimanual Fine motor function. Gross motor function measurement classification system Functional mobility scale	The author reveals that Virtual reality techniques are efficient in enhancing the gross motor function in CP patients. 464
6	Sajan E J et.al, (2016)[17]	20 Diplegic, Triplegic and Quadriplegic CP children, 5-20 years.	The children in the treatment group experienced Wii game for total of eighteen sittings of forty-five minute each. The games included are tennis and boxing. Games last for 20 minutes with 5-minute rest.	PBS Box and Block test Quality of UE skill test Test for visual perceptual skills.	The study disclosed that the VR training is having a significant positive impact on the gross motor function of children with CP.
7	Urgen M S (2016)[18]	37 spastic CP, 7-14 Years	The treatment group gone through VR session using the Nintendo Wii fit system 2 time in a week for 45 minutes and the total study duration was 9 weeks. Games included are: Jogging plus, Penguin slide, heading, Ski jump, Snow ball fight, tilt city, perfect 10, segway circuit play each game played for 10 minutes.	GMFM Gross motor performance measures Timed up and Go test PBS	The study shows increased gross motor function after the use of VR training.
8	Mitchell L E et.al, (2016)[19]	102 unilateral C P patients, 8-17 years	The subjects in the treatment group underwent half an hour of intervention on a daily basis up to six days per week, for 4.5 months. Games were focusing on arm and hand coordination and visuospatial improvement.	6 MWT Acti-graph GT3X- Tri axial accelerometer	The study concluded that the VR is effective for enhancing the gross motor function of children with CP.
9	Uysal SA (2016)[20]	24 Hemi paretic C P children (6-14 years)	The samples present in the Nintendo Wii group did the rehabilitation two days per week for three months, each sitting extends for an hour. Games includes Wii tennis, Wii basketball, Wii boxing. Each game for 10 Minutes.	Canadian occupational performance and measures PBS Pediatric evaluation of disability inventory	The study shows a positive response towards the VR Rehabilitation for boosting the daily functional activities

10	Chen C L (2012)[21]	28 spastic C P 6-12 years	Candidates present in the treatment group underwent treatment using the home-based virtual cycling training. The patient did the training for forty minutes a day, 3 counts week for 3 months. The candidates did simulate cycling activities.	Bruininks-Oseretsky test of motor proficiency.	Author concluded that VR training is beneficial in enhancing the motor coordination and power of muscles of the lower extremities in CP children.
11	Gordon S et.al (2012)[22]	7 dyskinetic CP 6-12 years	The children in the treatment group underwent two days treatment for 1 month and 2 weeks. Each sittings duration was 45 minutes. Wii sports including boxing, baseball and tennis.	GMFM	The researcher concluded the study by stating that VR is efficient training way for bringing positive impact on gross motor function in CP.

Table 1.1: Interactive 3 D visualization techniquesfor improving the balance in cerebral palsy

Sl. No	**Author and Year**	**No. of participants, age and type of CP**	**Interactive 3 D visualization techniques protocol (Virtual Reality and Augmented Reality)**	**Outcome measures**	**Conclusion**
1	Malick W H et.al, (2022).[23]	30 spastic hemiplegic CP 6-20 year.	The subjects received twenty-four sittings of AR training. For a total time, span of 8 week. Each sitting comprises with fifteen minutes training. The games include are Bubble pop, Scoop'd and Balance It.	PBS DASH questionnaire.	The author concluded that there is ameliorating effect in the arm and hands functions along with balance in the CP populations.
2	Jha K K et.al (2021)[24]	38 Bilateral C P, 6-12 Years.	The samples in the treatment group underwent half an hour of Virtual Reality training. Games included are Volley ball, Super Saver, Soccer, 20000 Leak, Space pok	PBS Kids- Mini BESTest GMFM-88 scale Wee FIM	The study shows significant improvement in the balancing ability after the receival of VR.
3	Jung S H et.al (2020)[25]	10, Spastic Diplegic CP. 11-17 years.	The participants in the treatment group underwent Soccer and Beach Volley Ball game using the X box Kinetic- 360 for forty minutes and each activities the child played for more than 15 minutes.	PBS GAIT- Ride	The author concluded that the VR training is effective in the LE muscle activities and for improving the balance.
4	Park S H et.al, (2020)[26]	20 spastic CP, 6-18 year.	The members present in the study group experienced forty minutes of VR training using Wii balance board and Wii fit software for 1 month. Each sitting extends for fifteen minutes.	Modified functional reach test Korean version of Trunk control measurement scale.	Study concluded that the VR treatment is effective in enhancing the balance in CP children.
5	Pin T W et.al, (2018)[27]	18 moderate C P 6-14 years	The participants in the treatment group underwent VR sessions for a duration of 1 month 2 weeks. Each treatment sessions consist	Pediatric reach test GMFM 2 MWT	The study concluded that VR training can be used as an alternative for the

			of 20-minute training. The training was provided using the TYMO device.		conventional treatment protocol for improving the balance and functional activities.
6	Gatica et.al, (2017)[28]	32 spastic hemiplegic and diplegic CP, 7-14 years.	The subjects in the Virtual reality group undergone training using the Wii fit plus Nintendo Wii balance board for half an hour, 3 times for a week over 1month 2 week. The games included are Snow board, Penguin slide and Super Hoola Hook	GMFCS GMFCS-ER	The results reveal that VR is very effective as compared to the standard treatment protocol for improving the balance.
7	Cho C (2016)[29]	18 spastic cp 4-16 years	The children take part in the Virtual Reality and Treadmill Training experienced VR for half an hour a day three times in a week for a total of two months.	MMT GMFM PBS 10 MWT 2 MWT	The outcome of the study shows a useful effect in balance, gait and motor control of lower extremity.
8	Jelsma J (2013)[30]	14 spastic hemiplegic C P children, 7-14 years	The participants involved in the Virtual Reality group underwent treatment on Wii fit balance board 4 times a week for 25 minutes. Games included are Snowboarding, Skiing, Penguin, soccer, bubble game and Hula hoop.	Running speed and agility scale, Bruininks- Oserestly test of motor performance.	In the end of the research the author concluded that the VR training is useful for improving the balance and thereby the motor activities.
9	Ranstrand N (2012)[31]	18 hemiplegic or diplegic CP. 8-17 years.	The candidates in the treatment group gone through Nintendo Wii games using Wii balance board and Wii fit software. The games include were soccer heading, Ski station, Ski jump, Table tilt, tight rope walk, balance rope. The treatment program was for half an hour a day for five days in a week.	Modified sensory organization test Reactive balance test Rhythmic weight shifting test	The study pointed towards the negative effect of VR training towards the balance function in CP children.

Table 1.2: Interactive 3 D visualization techniquesfor improving the gait in cerebral palsy

Sl. No	**Author and Year**	**No. of participants, age and type of CP**	**Interactive 3 D visualization techniques protocol (Virtual Reality and Augmented Reality)**	**Outcome measures**	**Conclusion**
1	Radwan A. et.al (2023).[32]	40 kids with both-sided spastic CP. 7-12 years old	Participants underwent Computerized balance training (using Nintendo Wii and Wii balance board) for half an hour, five sittings for seven days for two successive weeks.	Temporal and kinetic variables of the gait.	Author concluded that VR training is effective in the rehabilitation of the gait.
2	Gagliardi C et.al (2018)[33]	16 Bilateral C P, 7-16 years	The patients were randomly divided and the participants in the intervention group	GMFM 6MWT Functional	The study discloses that the usage of VR training significantly

			underwent the Virtual reality training for 1 month. The children underwent training daily 1 time with a duration of half an hour using the G- RAIL System.	assessment questionnaire	effective in ameliorating the gait variables. Along with this study shows a positive effect on the children's ability to do the activities of daily living independently.
3	Grecco L A C (2015)[34]	20 spastic dipareses CP 5-10 Years.	The treatment group gone through Virtual Reality treatment accompanying the trans direct cranial stimulation. They underwent 20-minute sittings for 14 days.	GMFM Pediatric evaluation disability inventory	The subjects treated with Virtual Reality reveals a significant improvement in the speed of the gait.

3. Discussion

The objective of our narrative review was to review the effectiveness of 3 D Visualization techniques in improving the gross motor function in children with CP. To accomplish this goal, we reviewed 23 randomized controlled trails. The reviewed articles used VR & AR in the area of CP rehabilitation. The potential mechanism behind the improvement in gross motor function can be muscle and neural plasticity.[39] The changes in the gross motor function as well as in the cognitive function can be described either in the view of neural plasticity which results from repetitive task specific practices provided by the virtually created environment (which is like actual world activities with all the kind of challenges and difficulties in the task) or in the view of the effortless support the parents, therapist or peer group imparts.[40] In addition to repetition, the positive and negative feedback mechanism and the motivation or encouragement which the child gained from playing the games also plays significant role in the outcome's success. Furthermore, the incremental effect of trial-and-error learning has been recognized as important reason for how VR acts on CP patients.[41]

Gross Motor Function

Characteristics of 11 studies that involved gross motor function are listed in table 1.0

Twelverandomized controlled trials supported the positive impact of AR and VR games on gross motor function of children with CP. Majority of the studies are focused on the effect on physical activity, intellectual, psychosocial and motor development. These studies compared the effect of VR and AR with traditional treatment. The average duration of the treatment to show the effective result was observed as 12 weeks with a frequency of 6 times per week treatment.

Balance function

Characteristics of 9 studies that involved balance function are listed in table 1.1.

Nine studies reported the effectiveness of AR and VR in improving the balance function. The improvement in balance was supported by improved stability, muscle strength of lower extremity, and concentration of the participating child. The treatment duration to comment on effectiveness varied from half an hour to 40 minutes. In contrast to these, Ranstrand N et.al pointed a decremental effect of balancing ability in the children with CP after using the VR training.

Gait function

Characteristics of 3 studies that involved gait function are listed in table 1.2.

Three studies evaluated the effect of VR and AR on functional and instrumental parameters of gait during incline walk on treadmill as well as on plane surface. However, the speed modulation limited the positive effect on gait.

Limitation of the study

a) The reviewed article varied largely in terms of type of CP
b) Subject participated in various studies were very less considering sample size as limiting criteria to comment on effectiveness.
c) The outcome measure to comment on GMF varied widely among the studies selected.

4. Conclusion

This review seems promising in considering game base scenario in the form of VRand AR to improve the participation of children with CP. The reviewed article supported the improvement in motivation and self confidence in various gross motor function however it is currently impossible to establish the individual benefits on various components of gross motor activities due to several documented limitation in the review.

Reference

1. Gagliardi C, Tavano A, Turconi AC, Pozzoli U, Borgatti R. Sequence learning in cerebral palsy. Pediatric neurology. 2011 Mar 1;44(3):207-13.
2. Bax M, Goldstein M, Rosenbaum P, Leviton A, Paneth N, Dan B, Jacobsson B, Damiano D. Executive Committee for the Definition of Cerebral Palsy. Proposed definition and classification of cerebral palsy, April 2005. Dev Med Child Neurol. 2005 Aug;47(8):571-6.
3. Rakhmadi A, Ariyanto R. Measurement motoric system of cerebral palsy disability using gross motor function measure (GMFM). Khazanah Informatika: Jurnal Ilmu Komputer dan Informatika. 2021 Apr 21;7(1).
4. Jensen JL, Marstrand PC, Nielsen JB. Motor skill training and strength training are associated with different plastic changes in the central nervous system. Journal of applied physiology. 2005 Oct;99(4):1558-68.
5. Ryan JM, Cassidy EE, Noorduyn SG, O'Connell NE. Exercise interventions for cerebral palsy. Cochrane Database of Systematic Reviews. 2017(6).
6. Acar G, Altun GP, Yurdalan S, Polat MG. Efficacy of neurodevelopmental treatment combined with the Nintendo® Wii in patients with cerebral palsy. Journal of physical therapy science. 2016;28(3):774-80.
7. Straker LM, Campbell AC, Jensen LM, Metcalf DR, Smith AJ, Abbott RA, Pollock CM, Piek JP. Rationale, design and methods for a randomised and controlled trial of the impact of virtual reality games on motor competence, physical activity, and mental health in children with developmental coordination disorder. BMC public health. 2011 Dec; 11:1-2.
8. Cipresso P, Giglioli IA, Raya MA, Riva G. The past, present, and future of virtual and augmented reality research: a network and cluster analysis of the literature. Frontiers in psychology. 2018:2086.
9. Fehlings D, Switzer L, Findlay B, Knights S. Interactive computer play as "motor therapy" for individuals with cerebral palsy. InSeminars in pediatric neurology 2013 Jun 1 (Vol. 20, No. 2, pp. 127-138). WB Saunders.
10. Chen YP, Lee SY, Howard AM. Effect of virtual reality on upper extremity function in children with cerebral palsy: a meta-analysis. Pediatric Physical Therapy. 2014 Oct 1;26(3):289-300.
11. Hocking DR, Farhat H, Gavrila R, Caeyenberghs K, Shields N. Do active video games improve motor function in people with developmental disabilities? A meta-analysis of randomized controlled trials. Archives of physical medicine and rehabilitation. 2019 Apr 1;100(4):769-81.
12. Jung YG, Chang HJ, Jo ES, Kim DH. The Effect of a Horse-Riding Simulator

with Virtual Reality on Gross Motor Function and Body Composition of Children with Cerebral Palsy: Preliminary Study. Sensors. 2022 Apr 10;22(8):2903.

13. Guinet AL, Bams M, Payan-Terral S, Khouri N, Otmane S, Bouyer G, Desailly E. Effect of an augmented reality active video game for gait training in children with cerebral palsy following single-event multilevel surgery: protocol for a randomised controlled trial. BMJ open. 2022 Oct 1;12(10):061580.
14. Şahin S, Köse B, Aran OT, Bahadır Ağce Z, Kayıhan H. The effects of virtual reality on motor functions and daily life activities in unilateral spastic cerebral palsy: a single-blind randomized controlled trial. Games for health journal. 2020 Feb 1;9(1):45-52.
15. Arnoni JL, Pavao SL, dos Santos Silva FP, Rocha NA. Effects of virtual reality in body oscillation and motor performance of children with cerebral palsy: A preliminary randomized controlled clinical trial. Complementary therapies in clinical practice. 2019 May 1; 35:189-94.
16. Ökmen BM, Aslan MD, Yüzer GF, Özgirgin N. Effect of virtual reality therapy on functional development in children with cerebral palsy: A single-blind, prospective, randomized-controlled study. Turkish journal of physical medicine and rehabilitation. 2019 Dec;65(4):371.
17. Sajan JE, John JA, Grace P, Sabu SS, Tharion G. Wii-based interactive video games as a supplement to conventional therapy for rehabilitation of children with cerebral palsy: a pilot, randomized controlled trial. Developmental neurorehabilitation. 2017 Aug 18;20(6):361-7.
18. Urgen MS, Akbayrak T, Günel MK, Çankaya Ö, Güçhan Z, Türkyılmaz ES. Investigation of the effects of the Nintendo® Wii-Fit training on balance and advanced motor performance in children with spastic hemiplegic cerebral palsy: A Randomized Controlled Trial. Int J Ther Rehabil Res. 2016;5(4):146-57.
19. Mitchell LE, Ziviani J, Boyd RN. A randomized controlled trial of web-based training to increase activity in children with cerebral palsy. Developmental Medicine & Child Neurology. 2016 Jul;58(7):767-73.
20. Atasavun Uysal S, Baltaci G. Effects of Nintendo Wii™ training on occupational performance, balance, and daily living activities in children with spastic hemiplegic cerebral palsy: A single-blind and randomized trial. Games for health journal. 2016 Oct 1;5(5):311-7.
21. Chen CL, Hong WH, Cheng HY, Liaw MY, Chung CY, Chen CY. Muscle strength enhancement following home-based virtual cycling training in ambulatory children with cerebral palsy. Research in developmental disabilities. 2012 Jul 1;33(4):1087-94.
22. Gordon C, Roopchand-Martin S, Gregg A. Potential of the Nintendo Wii™ as a rehabilitation tool for children with cerebral palsy in a developing country: a pilot study. Physiotherapy. 2012 Sep 1;98(3):238-42.
23. Malick WH, Butt R, Awan WA, Ashfaq M, Mahmood Q. Effects of Augmented Reality Interventions on the Function of Upper Extremity and Balance in Children with Spastic Hemiplegic Cerebral Palsy: A Randomized Clinical Trial. Frontiers in Neurology. 2022;13.
24. 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. Somatosensory & Motor Research. 2021 Apr 3;38(2):117-26.
25. Jung S, Song S, Lee D, Lee K, Lee G. Effects of Kinect video game training

on lower extremity motor function, balance, and gait in adolescents with spastic diplegia cerebral palsy: a pilot randomized controlled trial. Developmental neurorehabilitation. 2021 Apr 3;24(3):159-65.

26. Park SH, Son SM, Choi JY. Effect of posture control training using virtual reality program on sitting balance and trunk stability in children with cerebral palsy. NeuroRehabilitation. 2021 Jan 1;48(3):247-54.
27. Pin TW, Butler PB. The effect of interactive computer plays on balance and functional abilities in children with moderate cerebral palsy: a pilot randomized study. Clinical rehabilitation. 2019 Apr;33(4):704-10.
28. Gatica-Rojas V, Cartes-Velásquez R, Méndez-Rebolledo G, Guzman-Muñoz E, Lizama LE. Effects of a Nintendo Wii exercise program on spasticity and static standing balance in spastic cerebral palsy. Developmental neurorehabilitation. 2017 Aug 18;20(6):388-91.
29. Cho C, Hwang W, Hwang S, Chung Y. Treadmill training with virtual reality improves gait, balance, and muscle strength in children with cerebral palsy. The Tohoku journal of experimental medicine. 2016;238(3):213-8.
30. 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. Developmental neurorehabilitation. 2013 Feb 1;16(1):27-37.
31. Ramstrand N, Lygnegård F. Can balance in children with cerebral palsy improve through use of an activity promoting computer game? Technology and Health Care. 2012 Jan 1;20(6):531-40.
32. Radwan A, Eltalawy HA, Abdelziem FH, Macaluso R, O'Brien MK, Jayaraman A. Effect of Transcranial Direct Current Stimulation versus Virtual Reality on Gait for Children with Bilateral Spastic Cerebral Palsy: A Randomized Clinical Trial. Children. 2023 Jan 27;10(2):222.
33. Gagliardi C, Turconi AC, Biffi E, Maghini C, Marelli A, Cesareo A, Diella E, Panzeri D. Immersive virtual reality to improve walking abilities in cerebral palsy: a pilot study. Annals of Biomedical Engineering. 2018 Sep 15; 46:1376-84.
34. 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. Clinical rehabilitation. 2015 Dec;29(12):1212-23.
35. Cameirão MS, Oller ED, Verschure PF. Neurorehabilitation using the virtual reality-based Rehabilitation Gaming System: methodology, design, psychometrics, usability and validation. Journal of neuroengineering and rehabilitation. 2010 Dec;7(1):1-4.
36. Gao Z, Zhang T, Stodden D. Children's physical activity levels and psychological correlates in interactive dance versus aerobic dance. Journal of Sport and Health Science. 2013 Sep 1;2(3):146-51.
37. Pasco D, Roure C, Kermarrec G, Pope Z, Gao Z. The effects of a bike active video game on players' physical activity and motivation. Journal of sport and health science. 2017 Mar 1;6(1):25-32.
38. Weiss PL, Keshner EA, Levin MF, editors. Virtual reality for physical and motor rehabilitation. New York: Springer; 2014 Jul 24.
39. 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.

Physical therapy. 2018 Jan 1;98(1):63-77.

40. Wulf G, Lewthwaite R. Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. Psychonomic bulletin & review. 2016 Oct; 23:1382-414.
41. Teixeira PJ, Carraça EV, Markland D, Silva MN, Ryan RM. Exercise, physical activity, and self-determination theory: a systematic review. International journal of behavioural nutrition and physical activity. 2012 Dec;9(1):1-30.