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Review Article

Effects of Virtual Reality and Active Gaming Integration on Performance and Lower Extremity and Trunk Function in Cerebral Palsy Patients: A Systematic Review

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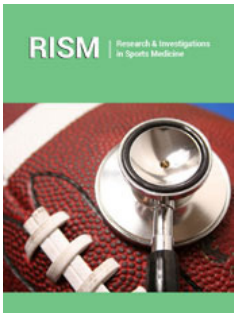

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Abbreviations: 1MWT: 1-Minute Walk Test; 10MWT: 10-Meter Walk Test; 2MWT: 2-Minute Walk; 6MWT: 6-Minute Walk Test; AG: Active gaming; aBMD: Areal Bone Mineral Density; CP: Cerebral Palsy, d: Days; FMS: Functional Mobility Scale, GMFM-66: Gross Motor Function Measure-66; iso: Isokinetic; min: Minutes; MiTii: Move to Improve It; RCT: Randomised Control Trials; STST: Sit to Stand Test; TGGT: Timed Get Up and Go Test; TUDST: Timed Up and Down Stairs Test; TYMO: Tyromotion GmbH; VR: Virtual reality, wks: Weeks

Introduction

The neurological condition of Cerebral Palsy (CP) occurs due to trauma to one or more areas of the developing brain in children before the completion of cerebral development [1,2]. Most commonly, the causes of 80% of recorded cases occur during the prenatal period of development because of unknown causes. However, complications during pregnancy or labour, such as asphyxia, have been linked to causes of CP in many documented cases [1]. Instances of CP may also occur during the post-natal and neo-natal periods [3], with common risk factors, which may include the birth of a child weighing <2.5kg, premature birth, brain hemorrhage, child abuse and bacterial meningitis [1]. These instances can cause both musculoskeletal and neuromuscular impairments. Such conditions will affect the daily living of children and in later life, adults with CP [2]. Motor impairments commonly affect individuals with CP and can be observed through muscle weakness, hypertonicity, tremors, scissor gait and increased tendon reflexes [4]. Conversely, the neurological condition can also exist with less apparent symptoms such as sensation, perception and cognitive and behavioural performance disturbances [2,5]. Several techniques have been adopted to lessen the severity and tackle CP [6-8]. However, these treatments cannot completely eradicate CP, so treatments throughout the individual's lifespan must be ongoing. With a shortage of access to therapy in the United Kingdom, especially with increased age [9], time-consuming appointments and increasing equipment expenses, more alternative approaches that are affordable, enjoyable and flexible treatments must be considered to conventional therapies [10].

Rehabilitation methods that integrate technology are a developing area, with Virtual Reality (VR) and Active Gaming (AG) incorporated into clinical therapy and the everyday life of CP patients [11]. VR and AG have recently increased in popularity when completing at-home, in-school and in-clinic rehabilitation interventions [12]. Using computer VR hardware and software allows interactive user stimulation for engaging with the environment, like real-world experiences and objects [13]. These systems can be used to develop and achieve rehabilitation goals by immersing individuals in three-dimensional games while manipulating game types, complexity and intensity for the desired physical, performance and rehabilitation outcomes [14,15]. Two adaptations of VR are currently used within CP rehabilitation. The first is commercial video game devices and platforms, including, but not limited to, systems like Nintendo Wii, Sony PlayStation and Microsoft Xbox consoles [12]. The second involves custom VR systems specifically developed for rehabilitation purposes, systems such as Move to Improve It (MiTII; Mitii Development A/S, Copenhagen, Denmark) [16], E-Link Evaluation and Exercise System (Biometrics Ltd) [17] and Eloton SimCycle Virtual Cycling System (Eloton, Inc., NV, USA) [18]. Both commercial and custom systems offer users a more enjoyable and specific experience and increase motivation and buy-in for rehabilitation [19].

Although some studies using varying methods and equipment to elicit a response, compared to other therapies or no other intervention, show no effect [20-25], both commercial video game devices and VR systems have been shown to elicit positive effects in numerous research studies, with improvements in daily living ability [10,20], gait [26-28], mobility [29,30] and limb bone mineral density [26]. These interventions elicit improvements in gross motor function and skill transfer to daily living tasks [28]. However, for the brain to make these motor changes permanent, motor learning needs to be exploited [29,30]. Contributions to motor-learning development are most evident when adopting task repetition, task difficulty and motivation [31,32]. Although the current review is comprised of studies lacking high-quality methodologies, reducing the credibility of some of the findings [33], these studies suggest that motor learning can be potentiated with VR, with these motor skills transferring to motor abilities and real-life integration [34-36]. Therefore, the current study aims to review the existing literature on the effects of VR and active gaming integration for improving performance and lower extremity and trunk function in cerebral palsy patients.

Methods

Methods

The systematic review followed the guidelines for systematic reviews by Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [37], following the Medical Research Methodology for healthcare systematic reviews [38]. A PICO framework (participants, interventions, comparators, and outcomes) was used to provide a clear scope of the research required for the review [38]. PICO framework: P=children with spastic cerebral palsy; I=Virtual gaming; C=a comparison therapy or no therapy; O=Lower extremity function (e.g. GMFM, strength, gait, ambulation). The principal researcher conducted an independent review of the results of the papers included, and the results gathered. A second researcher verified a portion of the search and analysis with 100% accuracy.

Identification and selection of studies

Electronic searches were conducted on the following databases in May 2021: 'PUBMED', 'Google Scholar' and 'MetSearch'. The search strategy included terms with the effect of 'cerebral palsy', 'virtual reality', 'video games', 'virtual gaming', 'lower extremity', and 'ambulation'. A truncation technique was used to help broaden searches; the method allows for various word endings to be applied by using an asterisk (*) in search bars (e.g. game* allows results for games and gaming). All publications were stored in the citation management centre, and duplicates were removed. Titles were screened, and articles of interest were further inspected for abstracts with keywords related to the literature search. Full copies of relevant studies were found, and their reference list was screened for further studies relating to the research topic.

Eligibility criteria

The inclusion criteria for the systematic review were: (a) randomised control trials or randomised cross-over trials that examined the effects of virtual reality, (b) the papers were required to be peer-reviewed and in the English language, dated between 2011-2021, (c) the target population was between birth and 18 years old, with any type and severity of CP, (d) the study compared VR with conventional therapy or no therapy, (e) the study examined outcome measures surrounding the lower extremity and trunk function, and performance. The research papers provided data describing the magnitude of the intervention effect and data allowing for effect size calculations (e.g., standard deviation). Studies were excluded if immediate responses were measured and the intervention was not implemented over a minimum of three weeks.

Data extraction

The articles that met the criteria were extracted for a full review of the strength and quality of the study design, study characteristics and outcome measures. The information extracted from the research included methodological design, sample size, participant description (age, sex, type of CP and CP severity), intervention protocol (duration, intensity, etc.), gaming method and the results of the outcome. Other miscellaneous variables, such as year of publication and name of authors, were included. All variables are displayed in Table 1. The included studies often measured multiple outcome measures. Only measures relating to the lower extremities are included (excluding postural or balance-related measures). The quality of the study design was evaluated through the criteria described by the Physiotherapy Evidence Database (PEDro scale). The scale has 11 items, with one referring to the external validity (inclusion criteria and source), which is not included in the final score.

The remaining 10 items assess internal validity through:

a. Random allocation
b. Concealment of allocation
c. Baseline comparability
d. Blinding of subjects
e. Blinding of therapists
f. Blinding of assessors
g. Adequacy of follow up (>85%)
h. Intention-to-treat analysis
i. Between-group analysis
j. Point estimates and variability [39].

Table 1: Characteristics of the Cerebral Palsy (CP) and Virtual Reality (VR) studies that met inclusion criteria.

RCT=Randomised Control Trials; min=minutes; d=days; wks=weeks; MiTii =Move to improve it; TYMO = Tyromotion GmbH (Graz, Australia); 1MWT =1-Minute Walk Test; GMFM-66=Gross Motor Function Measure-66; iso = isokinetic; aBMD=areal bone mineral density; 10MWT=10-Meter Walk Test; 2MWT= 2-Minute Walk Test; 6MWT=6-Minute Walk Test; FMS=Functional Mobility Scale; TGGT=Timed Get Up and Go Test; TUDST=Timed Up and Down Stairs Test ; STST=Sit to stand test.

Author and Year	Method	Sample Size (VR vs Control)	Age Range (Mean Age)	CP Type	VR Type	Intervention	Comparison Group	Setting	Outcome Measures	Quality Rating
AlSaif and Alsenany [44]	RCT	40 (20 VR, 20 C)	6 - 10 (8.0)	Spastic Diplegia	Nintendo Wii Fit	20min x 7dx12wk	None	Home	1MWT	05-Oct
Chen et al., [26]	RCT	27 (13 VR, 14 C)	6 - 12 (8.6)	Spastic Hemiplegia and diplegia	Eloton SimCycle	40minx3dx12wks	Conventional Rehab	Home	GMFM-66; Knee extension and Flexion iso. torque; aBMD of distal femur	07-Oct
Cho et al., [24]	RCT	18 (9 VR, 9 C)	4 - 16 (9.8)	Spastic CP	Nintendo Wii	30min x3d x 14wks	Treadmill training	Clinic	10MWT; 2MWT; Manual Muscle Test - Knee extension and flexion strength	07-Oct
Okmen et al., [45]	RCT	41 (21 VR, 20 C)	(5 - 15) 8.5	Mixed	Eye Toy-Play System	60minsx3d x4wks	Conventional Rehab	Clinic	GMFM; FMS	06-Oct
Pin and Butler, [46]	RCT	18 (9 VR, 9 C)	6 - 14 (9.2)	Spastic Dipelgia	TYMO	20minx4d x 6wks	Routine Physical Therapy	School	GMFM-66, 2MWT	07-Oct
Rgen et al., [25]	RCT	33 (16 VR, 17 C)	7 - 14 (11)	Spastic Hemiplegia	Nintendo Wii-Fit	45minsx2d x9wks	Routine Physical Therapy	-	GMFM; TGGT	06-Oct
Salem et al., [47]	RCT	40 (20 VR, 20 C)	3 - 5 (4.2)	Complex Neurological disorders	Nintendo Wii Sports and Wii Fit	30minx2d x14wks	Conventional Rehab	Clinic	TGGT; TUDST; 2MWT	08-Oct
Tarakci et al., [23]	RCT	38 (19 VR, 19 C)	5 - 18 (10.5)	Mixed	Nintendo Wii-Fit	50minx2d x12wks	Routine Physcial Therapy	Laboratory	TGGT; STST	05-Oct

A score of 9 to 10 represents an excellent methodological approach, 6 to 8 represents good, 4 to 5 represents fair and less than 4 represents poor [40]. The scale is widely used in systematic reviews, showing good reliability (Intraclass Correlation Coefficient [ICC] = 0.59-0.91) [40,41] with individual items ranging from fair to excellent (kappa = 0.50-0.88) [40,42]. However, the PEDro scale is not a gold-standard measure, with the study's validity being imperfect due to nonmethodological factors influencing the results [39].

Data analysis

After studies were screened, the required data was pooled into a Microsoft Excel workbook (Microsoft Excel, Microsoft Corporation, Redmond, WA). All variables were standardized into the same unit of measurement to allow for simple comparison. The mean and standard deviation of the difference between groups were inputted, allowing the mean percentage difference to be calculated for all results. Cohen's d effect size (d) calculation was determined for all results. Effect size allows for a greater description of the magnitude of differences between groups, with .2, .5 and .8 considered small, medium and large effect sizes, respectively [43].

Result

When comparing the results in both Tables 2 & 3 for movement competency, the intervention groups showed greater improvements in the 1-Minute Walk Test (1 MWT), 2-Minute Walk Test (2 MWT), Timed Get Up and Go Test (TGGT) and Timed Up and Down Stairs Test (TUDST) (9.66%, 35.18%, 10.29%, and 9.64%, respectively) when compared to the control groups (0.77%, 16.90%, 5.44%, and 3.36%, respectively). However, the control group showed greater improvements in GMFM-66 (3.92%). All groups elicited reductions in the Sit to Stand Test (STST), but the intervention group showed a higher percentage decrease than the control group (-42.41% vs -8.65%, respectively). Isokinetic measures of knee torque for the control group during extension and flexion were 3.87% and -14.74%, respectively, lower than the improvements in the intervention group, with an increase of 35.36% for extension and 57.78% when completing knee flexion. Knee flexion and extension strength results for the intervention groups displayed reductions in scores of -3.49% (flexion) and -9.31% (extension). In contrast, the control group improved by 20.29% when flexing at the knee and 20.71% during extension [44,45].

Table 2: Mean and ±SD test battery results for the control groups from all reviewed studies.

1 MWT=1-Minute Walk Test; 2MWT=2-Minute Walk Test; GMFM-66 =Gross Motor Function Measure-66; TGGT=Timed Get Up and Go Test; TUDST=Timed Up and Down Stairs Test; STST=Sit to Stand Test; Nm=Newton meter; kg=kilogram; s=seconds.

Test Name	Pre		Post		% Difference
	Mean	±SD	Mean	±SD	
1 MWT (m)	91.1	6.93	91.8	6.82	0.77%
2 MWT (m)	85.19	33.91	99.59	34.44	16.90%
GMFM-66	72.44	7.95	75.28	7.57	3.92%
Knee Extension Isokinetic Torque (Nm)	38.8	17.6	40.3	21.3	3.87%
Knee Flexion Isokinetic Torque (Nm)	15.6	12.8	13.3	7.1	-14.74%
Knee Flexion Strength (kg)	6.9	4.1	8.3	4.5	20.29%
Knee Extension Strength (kg)	15.2	5	18.5	5.5	21.71%
TGGT (s)	11.06	2.41	10.49	2.4	5.44%
TUDST (s)	27.7	1.6	26.8	2.7	3.36%
STST (s)	5.6	1.5	6.13	1.68	-8.65%

Table 3: Mean and ±SD test battery results for the intervention groups from all reviewed studies.

1 MWT=1-Minute Walk Test; 2 MWT=2-Minute Walk Test; GMFM-66=Gross Motor Function Measure-66; TGGT=Ti.

Test Name	Pre		Post		% Difference
	Mean	±SD	Mean	±SD	
1 MWT (m)	90.1	7.21	98.8	6.75	9.66%
2 MWT (m)	79.44	26.38	107.38	25.27	35.18%
GMFM-66	75.49	7.31	77.72	6.25	2.95%
Knee Extension Isokinetic Torque (Nm)	36.2	21.5	49	20.9	35.36%
Knee Flexion Isokinetic Torque (Nm)	13.5	8.1	21.3	9.9	57.78%
Knee Flexion Strength (kg)	8.6	3.7	8.3	4.5	-3.49%
Knee Extension Strength (kg)	20.4	9	18.5	5.5	-9.31%
TGGT (s)	9.91	2.07	8.89	1.89	10.29%
TUDST (s)	28.8	2	26.8	2	6.94%
STST (s)	6.13	1.55	8.73	2.08	-42.41%

Discussion

This systematic review examined studies that used the integration of VR and AG as an intervention technique for CP patients. Based on the studies reviewed, VR and AG can elicit improvements in several areas of CP rehabilitation, enhancing the movement quality and muscular strength of individuals with CP [46]. Although the studies showed that VR and AG interventions can elicit positive responses in populations with CP, Salem et al. [47] and Cho et al. [24] reported a decrease in knee movement strength (both flexion and extension) and STST in the intervention groups. STST decreased in both groups from pre- to post-testing, but the magnitude of the reduction was lower in the control group by 33.76% [47]. In the control condition, knee flexion and extension post-testing increased, suggesting that VR and AG may not be efficacious for CP patients if the outcome is to increase knee flexion and extension strength and STST [24]. The potential rationale for these findings is both multifactorial and non-conclusive, based on the range presented for the duration of the studies and the exercise mode used as the primary use of support (treadmill versus conventional rehabilitation). Cho et al. [24] was the only study where the control group performed treadmill training. In contrast, the control group performed conventional physical therapy in the other studies. Treadmill training for individuals with cerebral palsy has been shown to increase lower limb strength and power [48-50]. Although VR and AG benefit CP rehabilitation, other methods may elicit greater responses depending on the targeted outcome. VR and computer gaming are effective methods in CP rehabilitation due to their interactive nature and psychological impact, which may help with participant compliance and therapy mode adherence.

Computer games may have outcome goals that can intrinsically motivate the individual and increase self-motivation, leading to greater adherence [51]. Furthermore, if VR or computer game outcome goals are achievable, they can lead to an increased sense of mastery [52]. Both psychological benefits can help improve participation in the given activity, which may lead participants to achieve other physical performance parameters.

Conclusion

Although the findings for using VR and AG are encouraging and support their use in CP therapy, they may be best used in a multi-disciplinary approach by using more than one intervention or pairing their use with conventional CP rehabilitation. Future research should compare VR and computer gaming with other intervention methods and consider the outcomes of concurrently using VR and AG with different techniques. Pairing VR and AG with other CP therapies, such as whole-body vibration training [53], will further elucidate the scope of potential physical development using a multi-modal approach.

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