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REVIEW ARTICLE

The Effects of Virtual Gaming on Lower Extremity Function in Children with Cerebral Palsy: A Narrative Review

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ABSTRACT

Background: Investigations into the use of virtual gaming, focussing on its effect on lower extremity function within therapy of children with cerebral palsy is conspicuous by its absence.

Purpose: The aim of this review is to provide an evidence-based account and associated discussion surrounding current research in the area.

Data sources: A literature search of 'PubMed', 'Google Scholar' and 'MetSearch' with relevant keywords, with article inclusion requiring publication between 2011 and 2021 was completed.

Content: Virtual reality influences multiple lower extremity functions when compared to conventional therapy or no therapy. However, information surrounding optimal prescription and participant characteristics is not evident.

Implications: Virtual gaming for use concurrently with other therapies is recommended, with the requirement for further high-quality research to advance the use of virtual gaming further and individual dose response.

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Introduction

Cerebral Palsy (CP) is a neurological disorder occurring in children due to trauma to one or more areas of the developing brain, prior to full cerebral development [1,2]. The condition of CP is recognised worldwide, and is estimated to be present in 2-3 per 1000 live births [3]. The impaired body structure and function has significant influence on the child's quality of life impacting on their independence, inclusion and participation level, where daily activities can be significantly limited. The condition may cause both physical and psychological issues [4]. Cerebral palsy is a congenital, life-long condition where continuous therapy and strength training is necessary to maintain, and/or increase functional mobility [5].

The integration of technology within rehabilitation is rapidly developing, with Virtual Reality (VR) and Active Gaming (AG) being incorporated into both clinical and everyday life of individuals with CP [6]. Virtual reality is defined as computer hardware and software allowing interactive stimulation permitting the user to engage and participate in an environment similar to real-world experiences and objects [5]. The platforms offer a greater level of sensory stimulation, motor learning and motivation for the engagement with therapy [6-8].

Previous reviews have been conducted into motor function, upper extremity function [3,6,9-13], all confirming support towards the effectiveness of the use of

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VR as an intervention. However, currently no reviews have been conducted into multiple variables which influence Lower Extremity (LE) function making the research area somewhat conspicuous by its absence. Therefore, the current review looks to address the effectiveness of VR therapy on LE function mobility, muscle strength, gait and Range of Motion (ROM) in children with CP. Due to the scope of the review discussions surrounding research methodological approaches is limited and therefore only superficial discussions are presented.

Research Methodology

The review aims to describe studies, which have used VR as a rehabilitation tool for children with CP. Consequently the research followed narrative review guidelines from two separate studies [14,15]. A PICO framework (participants, interventions, comparators, and outcomes) was used to provide clear scope of the research required for the review [16]. PICO framework: P = Children with spastic cerebral palsy; I = Virtual reality gaming; C = A comparison therapy or no therapy; O = LE function (e.g. GMFM, strength, gait, ambulation, ROM). The process of screening and analysing studies was completed out by a single researcher.

Identification and selection of studies

This review aims to capture a representative sample of existing literature. Electronic searches were conducted on the following databases: 'PUBMED', 'Google Scholar' and 'MetSearch'. The search strategy included terms with words to the effect of 'cerebral palsy', 'virtual reality', 'video games', 'virtual gaming', 'lower extremity', 'gait', '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). Full copies of relevant studies were obtained, and their reference list screened for further research relevant to the subject area.

Eligibility criteria

The inclusion criteria for the current review was: (a) papers written in English Language, and dated between 2011-2021, (b) the target population was between birth and 18 years old, with any classification of CP, (c) the results compared VR with conventional therapy or no therapy, (d) the study reported outcome measures surrounding the LE function and performance. The studies included often measured multiple outcome measures, only measures solely relating to the LE are included (excluding any postural or balance related measures).

Discussion

Cerebral palsy

Cerebral palsy most commonly occurs during the prenatal period with 80% of cases occurring during this time, mainly due to unknown causes; however, complications such as asphyxia have been confirmed to cause CP in some cases [1]. Cerebral Palsy can also occur during postnatal and neonatal periods [17], with common risk factors including a child weighing <2.5kg at birth, premature birth, brain haemorrhage, child abuse and bacterial meningitis [1]. The damage can lead to musculoskeletal and neuromuscular impairments, ultimately effecting daily living of children and adults with CP [2].

Individuals with CP are most commonly affected by motor impairment, which is commonly displayed through muscle weakness, muscle hypertonicity, tremors, scissor-gait and increased tendon reflexes [18]. However, the disease can often be accompanied by less apparent symptoms such as disturbances to sensation, perception, cognitive and behavioural performances [2,9].

The Gross Motor Function Classification System (GMFCS) is one of many standardised assessments used to assess the severity of CP. It consists of five levels representing differences in function relating to daily life [19]. The assessment is widely accepted throughout research with a strong inter-rather reliability (0.84) for children younger than six and 0.89 for children 6 years of age and older [20]. Other scales used in research include, Child Health Questionnaire, Paediatric Evaluation of Disability Inventory, Functional Independence Measure, and Ashworth scale [21-24]. With such grading in place it allows CP patients quality of life and development milestones to be monitored effectively [2].

A range of techniques has been used to minimise and lessen the severity of CP [25-27]; however, the interventions cannot eliminate CP completely and therefore, treatments must be on-going and ever-present throughout an individual's life. With a lack of access to available therapy in the UK, especially, as patients get older, multiple time consuming appointments and expensive equipment, alternative approaches are being used to make treatment more flexible, enjoyable and affordable [28,29].

Virtual reality

An increase in technology has permitted gaming platforms and devices to be integrated into CP rehabilitation. Virtual reality therapy and active gaming have increasingly become a popular method for home, school and in-clinic rehabilitation interventions [30]. The systems can be used to achieve rehabilitation goals by immersing individuals into 3D games, whilst adapting game type, complexity, and intensity to suit the individual therapy requirements of the individual, as well as children being able to carry-out real-life activities without the risk of real-life hazards [8,31,32].

There are two versions of VR systems for rehabilitation, with the first being commercial video game platforms and devices, this includes devices such as the Nintendo Wii, Sony

PlayStation and Xbox Consoles [30]. The second method is custom VR systems which are specifically developed for rehabilitation purposes, systems such as, Move to improve it (MiTII; Mitii Development A/S) [33], E-Link Evaluation and Exercise System and Eloton SimCycle Virtual Cycling System (Eloton, Inc., NV, USA). Both commercial and custom systems offer a more enjoyable experience for users and subsequently, increase motivation and buy-in for rehabilitation purposes [34-36].

Commercial and custom systems have been reported to have positive effects in numerous LE research studies with improvements being shown in mobility, daily living ability, gait and other limb components [29,37-42]. However, no significant findings are still evident throughout the research with a variety of methodologies and equipment proving unable to elicit responses when compared with other therapies or no therapy [43]. A previous review in the area concluded that interventions were able to elicit improvements to gross motor function and skill transfer to daily living tasks and for the brain to create new connections between neurons and motor learning requirements to be exploited to make relatively permanent motor changes [44-46]. Approaches such as task repetition, task difficulty and motivation all contribute to motor-learning development [47,48]. Papers within the review suggest that motor learning can be potentiated with VR and therefore, skills can transfer to motor abilities and real-life integration [49-51]. However, the review was comprised of papers which lacked a high- quality methodology and subsequently reduces the credibility of findings [52].

A more recent meta-analysis of randomised control trials with a fair to good Pedro quality determined that VR was a viable intervention for improving ambulation. Only 8 of the 19 papers included in the review measured ambulation variables, the papers showed a medium to large effect size of 0.755. However, with the detection of publication bias a Duval-Tweedie trim and fill technique was applied which reduced the effect size to 0.378, suggesting that the findings of the results are sensitive to change [53]. In addition, the authors did not provide information on which ambulation variables of gait velocity or gait endurance were enhanced, therefore speculation remains surrounding which attributes are enhanced. Further conclusions related to engineer-built systems showing a greater effect than commercial systems, it could be suggested that specifically built systems more optimally target the child's needs with adjustments of game difficulty and training goals being available [54]. In addition, commercial platforms aren't created for rehabilitation purposes and therefore have limited therapeutic value. However, these findings are not exclusive to LE variables.

Lower extremity functions

Children with CP are faced with a variety of symptoms which can alter their overall LE function and ultimately their quality of life. Previous investigations of VR effects on LE functions have focused on a child's ability to walk, stand and additional functional movements [12,55,56]. These movements although considered to be a child's later life goals, cover a vast amount of the body of research due to the importance of such aspects and the contribution it has to for life-long rehabilitation [55,56]. However, additional components are evident throughout research and will also be discussed within the review. The review will aim to discuss research surrounding ambulation and gait, gross motor function measures, functional mobility, muscle strength and Range of Motion (ROM) of the LE. Although ambulation is considered through both functional mobility and gross motor function, it will be considered separately to ensure thorough discussions surrounding the necessary gait variables. These include, gait velocity, gait endurance, gait cadence, stride length and step length. It should also be noted that although gait and gross motor function measures are directly related to functional mobility, they are discussed separately in the review.

Virtual reality and functional mobility

Functional mobility is required to perform daily activities, to enhance participation and functional independence [43,57]. A primary goal of many CP rehabilitation programmes is to reduce limitations related to lower extremity function which influences the ability to walk, ascend and descend stairs [58]. The most recognised and commonly used method throughout CP research is the Gross Motor Function Measure [59], which will be discussed further in the review. Other LE functional tests have been used by following at 12-week intervention using the WiiFit system (Nintendo, Kyoto, Japan). Children carried out the 10-stair climbing test, where they were tested on their ability to climb 10 steps as fast as possible [60], significant improvements were observed from the VR therapy group compared to the control group, although only a small effect size was evident (p = 0.001; ES= 0.19). Moreover, the Timed Up and Go (TUG) test was also measured and findings showed improvements for both groups, with the VR therapy group yielding a significantly faster performance (p = 0.001; effect size [ES] = 0.48). It is suggested that tailored games to test balance and weight-transfer of the LE allowed children to become more stable when completing functional movements [42].

Conversely, further investigations into the TUG measure have elicited no significant differences to conventional therapies. The studies also found other non-significant differences between groups in other measures [38,61], including a timed up and down stairs measure. However, there were observed trends towards experimental groups, suggesting that the programmes provided may not have been a sufficient intensity or length to elicit responses [61].

Qualitative measures have also been used to assess the influence of VR therapy on daily living activities, the functional independence measure for children test has an strong reliability (ICC = 0.91-0.98) and indicated significantly greater responses following a Wii Fit VBT intervention [42]. Conversely, following the use of the same gaming platform the 28-mobility measure and quantitative analysis of participants physical activity over a four-day period was unable to confirm significant differences to conventional training. Although, within the study performance capacity was shown to have greater improvements this was not replicated for activity performance or mobility limitations. Numerous barriers are associated with a child's participation in activity such as school, peers and therapy [62], therefore it is suggested that ecological influence would be evident throughout physical performance measures.

Virtual reality and gross motor function measures

Gross motor function measures are used to assess motor skills within children with cerebral palsy. The GMFM, along with other modified versions (GMFM-66, which consists of 66 items and GMFM-88, consisting of 88 items) covers the five components of lying and rolling, sitting, crawling and kneeling, standing and walking, running and jumping [63]. A meta-analysis found a medium effect size (hedges g = 0.44) of GMFM scores following VR therapy of six studies; it also revealed that a shorter programme session of 20-30 minutes length led to a greater influence on adaptation when compared to a longer session (40-45 minutes) with an effect size of 0.56 compared to 0.14 respectively [64]. However, the recommended programme prescription is limited to length of session and is limited to six study designs; therefore, speculation remains surrounding optimal prescription.

Additional VR therapy is reported to have no significant difference to conventional therapies following a 12-week intervention [6,65]. The studies only provided a whole score for the GMFM, so details regarding the influence on individual elements of standing and walking, and running and jumping which were considered in the meta-analysis, are not able available for comparison. It is important to note the research were able to elicit other lower extremity responses more specific to the VR intervention [6].

Further investigations confirmed both groups were able to elicit significant improvements for standing and walking, and running and jumping ($p < 0.05$) [38]. However, following group comparison only the latter showed a significant difference following VR therapy. The study also used a GMFM which used the same grading items but rated the quality of each movement rather than the ability to complete the movement [63]. The results showed both groups had an increase in standing variables but only the VR intervention group showed a significant increase in walking variables [38]. However, no other investigations have used the performance measure and reliability investigations suggest that highly skilled therapists are required to complete this form of analysis sufficiently [66]. Although the measure offers interesting insights surrounding the motor performance of CP children, further research is required.

Virtual reality and gait

Several methods throughout CP research have been used to assist reduce muscle over-activity and imbalance, ranging from surgery to walking aids [67]. The functional movement requires musculoskeletal integrity and neurological control between multiple joints and agonist and antagonist muscle groups simultaneously, therefore the challenges faced by children with CP can often lead to the inability to walk or gait disturbance [68,69]. A recently published meta-analysis used 16 studies to evaluate gait ability and the recommended training programme of VR therapy. All the gait sourced articles for the current review were used within the meta-analysis, the review rated the quality of methodologies using a Pedro scale [70], on average studies reported 'good' quality (5.7 mean 1.4 SD) [64]. Three gait parameters which were analysed throughout the review are confirmed to improve performance following VR intervention, this included gait velocity (hedges g = 0.76), cadence (g = 0.80), stride length (g = 0.76). Stride width was reported to have a small negative effect (g = -0.23).

These results are supported by an aforementioned review, with a 0.75 effect size being provided in ambulation function [4]. It is suggested that the results presented across the two meta-analyses could be due to different underlying mechanisms associated with VR therapy. The first is related to the therapy offering a multi-sensory (visual, audial and proprioceptive) feedback of movements, therefore allowing an enhanced retention of movement amplitudes and limb position and ultimately improving gross motor function [71-73]. Secondly, VR therapy allows participants to focus on control and movement timings of real-life activities, thus, with practice an enhanced efficiency of movement pattern and improved kinematic scores can be seen [41,74,75].

Virtual reality and lower extremity strength

Children with CP have been shown to have smaller muscles and reduced muscular strength than their healthier peers, which impedes their gross motor function and gait [33,76-80]. Mitchell investigated strength measures through maximal repetition tasks of multiple functional movements (sit-to- stand, lateral step up and half kneel) over a 30-second period [81,82].

Following a 20-week intervention the findings showed a 19.3 mean difference in the functional strength scores ($p < 0.001$). Measures into the sit-to-stand were also observed following a 12-week Wii-Fit intervention, both groups were able to show significant increases in repetitions ($p < 0.05$), but greater increases were observed for the VR group ($p < 0.001$, effect size = 0.70) [42]. The studies used different VR platforms and completely different methodological approaches but were both able to elicit function strength improvements of the LE. However, both studies noted that some parts of the protocols were unblended and therefore, could suggest potential for bias.

Further investigations compared VR treadmill training to conventional treadmill training for responses in knee extensor and flexor strength. The study reported that the VR training had been significantly more effective in improving muscular strength than treadmill training alone, with right knee flexion strength reporting no significant differences between experimental groups. It has been suggested that the VR system offers a greater reflection of daily life and therefore, the child becomes more task-orientated whilst participating [37]. Furthermore, the child will need to problem solve through repetitive movements, which facilitates an increase in motor learning, in addition, a structured level and rewards system throughout leads to a greater motivation to repeat tasks [8]. The study did have a limited sample size and therefore, can limit data saturation and accurate conclusions from the subject population.

Virtual reality and lower extremity range of movement

Both muscle shortening and decreased ROM is common within children with CP and is commonplace in patients with and without spasticity [8,83]. Contractures in the LE commonly seen through flexion at the hips and knees and plantarflexion of the ankles, subsequently affects alignments and causes imbalance around the limbs, ultimately effecting the functional ability to walk, stand and sit [84-86]. Research is conspicuous by its absence into the influence of VR therapy on LE ROM, with only three investigations assessing this function.

We measured changes to the ankle dorsiflexion angle at initial of foot contact during a gait analysis. Three participants carried out repeated active plantarflexion and dorsiflexion movements on each ankle for 20 minutes; they were not compared against a control group [87]. The results showed only one participant had significantly improved their ankle dorsiflexion, with the additional participants having little change. The study presents many limitations surrounding lack of control group and unblinding of the therapist, leaving speculation surrounding whether findings were due to the experimental procedure, influenced by external variables, or bias [88].

A study by Fowler used a Selective Control Assessment of the Lower Extremity (SCALE; ICC 0.88-0.91) tool to assess the multiple motor functions, including ankle dorsiflexion, knee extension and hip abduction [89]. The VR group and control group completed 40 minutes of conventional therapy, following this, the experimental group completed an additional 40 minutes of VR therapy. The results indicated that both groups significantly improved following the 6-week intervention, with the VR group demonstrating an increased between group difference ($p < 0.05$) across all variables except the right hip abductor. However, the measurement tool was shown to have a limiting influence on statistical changes due to a sealing effect. Therefore, it could be suggested that improvements observed for the VR group are due to the additional therapy completed [90].

Similarly, Curtis found significant improvements to passive and active ankle dorsiflexion with an extended knee ($p = 0.02$ and $p = 0.001$, respectively) following a 10-week training intervention [91]. Although, no significant changes were found for a flexed knee. Differences within the two knee positions is suggested due to the intervention being completed with an extended knee and thus, greater adaptations are caused to the gastrocnemius muscle and a greater response in ankle dorsiflexion with an extended knee. The ankle ROM was collected through the use of a modified goniometer, which shows high reliability (0.9) when used for children with CP [92]. The test was completed three times and the therapist was blinded to the individual results to eliminate measurement bias.

Further limitations were presented between the first two studies, a reduction in follow-up of participants and all studies lacked a sufficient sample size. It should also be understood that two of the studies used robotic and specialised equipment, which is not available to many clinics or patients and therefore limits the generalisation to more affordable and commercial platforms. It is clear through this section of the review that ROM improvements are observed, however, advanced methodologies with confirmed reliability are required to draw conclusions on whether improvements to ROM are solely the result of VR therapy.

Practical application

Virtual reality therapy research has shown it can progress LE functions; however, speculation remains surrounding the research and some of the experimental methodologies used. It is clear throughout the current review that VR therapy has no detrimental influence of function when used alongside other therapies [6,12,93-95]. Therefore, the use of commercial and specific platforms to improve lower extremity function is advised if available to the child. However, research is still requiring providing direction and guidance on optimal dose prescription; furthermore, clinicians should consider a patient's individual characteristics during the use of VR therapy [96].

Limitations

The narrative review structure used can be associated with author bias, with interpretation and conclusions from data extracted subjectively [97]. The review may also be influenced by selection bias, with a single reviewer selecting all studies discussed throughout the composition [98,99]. Further, the scope of the study limited the discussion surrounding the LE function topics, with important areas such as programme design and participant characteristics consider as beyond the scope of this review. Therefore, the findings of the review are limited and a more systematic review considered as an alternative for future reviews.

Conclusion

In conclusion, it is evident through the different functions that VR therapy can influence and facilitate LE performance in children with CP. The current review findings would advise VR therapy to be used in conjunction with other conventional therapies, until a more research is conducted into the sole use of VR therapy. Future research is required to review the influence of participant characteristics on results and the complex methodological approaches, which are utilised to elicit improvements in LE functions, with hope that conclusions can be drawn on optimal dose prescription for children with CP.

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