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REVIEW

Motor learning through virtual reality in cerebral palsy – a literature review

Thais Massetti,[I] Talita Dias da Silva,[II,III] Denise Cardoso Ribeiro,[I] Silvia Regina Pinheiro Malheiros,[IV] Alessandro Hervaldo Nicolai Ré,[I] Francis Meire Favero,[II] Carlos Bandeira de Mello Monteiro[I]

[I]Universidade de São Paulo, São Paulo, Brazil [II]Universidade Federal de São Paulo, São Paulo, Brazil [III]Harvard School of Public Health, Cambridge, Massachusetts, USA [IV]Faculdade de Medicina do ABC, Santo André, SP, Brazil

Cerebral palsy is a well-recognized neurodevelopmental condition beginning in early childhood and persisting throughout life. It is considered the most common non-progressive neurological disease of childhood. Subjects with cerebral palsy present complex motor skill disorders, the primary deficits being abnormal muscle tone that affects posture and movement, alterations of balance and of motor coordination, decrease in strength and loss of selective motor control, with secondary issues of contracture and bone deformity. This population may have difficulties in motor skill learning processes. Skill learning is learning as a result of repeated exposure and practice. Due to the increasing use of virtual reality in rehabilitation and the significance of motor development learning of subjects with cerebral palsy, we have recognized the need for studies in this area. The purpose of this study was to investigate the results of previous studies on motor learning using virtual reality with patients with cerebral palsy. Initially, 40 studies were found, but 30 articles were excluded, as they did not fulfil the inclusion criteria. The data extracted from the ten eligible studies is summarized. The studies showed benefits from the use of virtual reality in children with cerebral palsy in gross motor function and improvements in motor learning with skill transfer to real-life situations. Therefore, virtual reality seems to be a promising resource and a strategic option for care of these children. However, there are few studies about motor learning with virtual reality use. The long term benefits of virtual reality therapy are still unknown.

KEYWORDS: cerebral palsy; virtual reality and motor learning.

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E-mail: thaismassetti@terra.com.br

INTRODUCTION

Cerebral palsy (CP) is a well-recognized neurodevelopmental condition beginning in early childhood and persisting throughout life. It is considered the most common non-progressive neurological disease of childhood.[1] Motor disorders of individuals with CP are often accompanied by loss of functionality and dependence on others for many daily activities. Inactivity leads to a cycle of de-conditioning that results in the impairment of multiple physiological systems. The result is physical deterioration and subsequent further reduction in the performance of daily function.[2]

Papavasiliou[3] states that subjects with CP present complex motor skill disorders. The primary deficits include abnormal muscle tone that affects posture and movement, alteration of balance and motor coordination, decrease in strength and loss of selective motor control, with secondary issues of contracture and bone deformity. All of these particular disorders of CP hinder performance of motor abilities and consequently prevent the learning of daily skills.

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According to Savion-Lemieux et al[4], motor skill learning is the process by which motor skills come to be effortlessly performed through practice and as a result of repeated exposure and practice. Considering motor skill learning, little is known about the effects of developmental disorders, such as CP, on the ability to acquire new skills.

Motor learning is a phenomenon that refers to relatively permanent neuromotor changes leading to the acquired ability to perform motor skills. Such changes ensure that the objective is achieved. They are derived from experience and practice, resulting in the acquisition, retention and transfer of motor skills.[5] However, motor learning can be measured by improvements in performance, which can be seen to increase and correct errors of execution and to decrease the duration of the task.

The socio-cultural context in which the action is assumed to be performed influences the child's learning process and the child's opportunity to develop strategies for action. Action requires interpretation and creativity, but is not always explicit or even conscious. A child acts in different situations depending on his/her knowledge, experience, and understanding of the situation[3].

In this sense, a current possibility for evaluating motor learning is related to interactive computer systems, such as

virtual reality (VR). The use of video games with a VR device has been gaining ground in rehabilitation processes.

VR refers to a simulated interactive environment. According to Leon et al.[6] VR aims to create a visual, auditory and sometimes tactile and olfactory environment that appears real and enables the human user to become immersed in the interactive experience.

Some authors have reviewed studies on cerebral palsy and VR; Snider et al.[7] carried out a literature review observing the results of VR as a therapeutic modality for children with CP. The research was performed with no time limitation and systematized, using 11 articles for results. They noted a shortage of well-designed studies investigating the benefits of VR therapy in the rehabilitation of children with CP. A relevant point of this study was the difficulty in presenting scientific evidence, mainly because most studies are experimental and observational with small samples.

Michelle et al.[8] reviewed VR in pediatric neurorehabilitation, using evidence published in the last decade. Thirteen articles were located, among them findings on the use of VR in CP; they also observed that the located studies had small samples and that their levels of scientific significance were low. They suggested that future approaches be performed with more homogeneous groups and standardized methodology, probably through well-designed clinical tests.

On the other hand, Sveistrup et al.[9] located 12 articles on CP that observed the results of intervention programs that used virtual reality. In the results they observed the impact of VR; however they found that the studies ranged widely in terms of improvement scale, task duration and number of participants. Although still preliminary, these results suggest that the simple application of virtual reality has a significant impact on physical and psychosocial variables.

Due to the increasing use of VR in rehabilitation, the importance of motor learning in the development of those with CP and the need for current knowledge in this field, the objective of this work was to review the literature on themes relating to motor learning, VR and CP. The purpose of this study was to investigate the results shown in previous studies on motor learning with VR use in patients with cerebral palsy. We believe that the results will offer references for intervention and future scientific research.

METHOD

Figure 1 illustrates the search strategy used to locate and compare different works. It is based on PICO's and follows the method previously used by Snider et al.[7]

A bibliographic review was performed without time limitation. The research was carried out using PubMed. Considering keywords, we included articles that showed the three terms cerebral palsy, virtual reality and motor learning.

To increase the confidence in the selection of articles, all potentially relevant articles were reviewed independently by two researchers. In the end, a consensus established which articles fulfilled the inclusion criteria.[10]

There are many currently used scales that help with the evaluation of studies, the most common in the rehabilitation area being the PEDro[11] scale. This scale was developed by the Physiotherapy Evidence Database to be used in experimental studies and has a total score of 10 points, including evaluation criteria of internal validity and presentation of statical analysis used.[11]

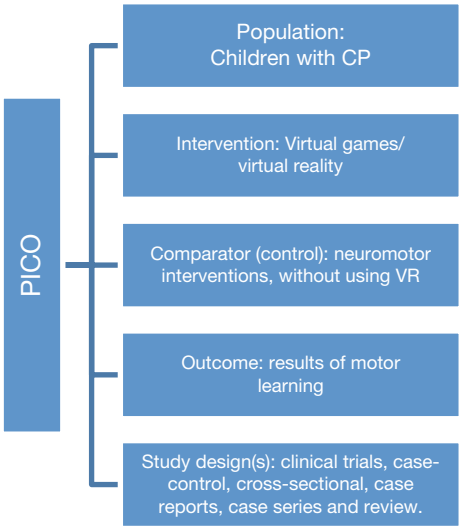

Figure 1 - Representation of the search strategy – PICOs.

In order to evaluate methodological quality, a study was considered to present a good level of evidence if it attained a score equal to or higher than 6 according to the PEDro evaluation scale. This criterion was based on the work by Snider at al,[7] which considers studies scoring 9–10 on the PEDro scale as methodologically 'Excellent', scoring 6–8, as 'Good', 4–5, as 'Fair' and below 4, as 'Poor'.

RESULTS

Initially, 40 studies were found, 30 articles were excluded as not fulfilling the inclusion criteria (Fig. 2). The data extracted from the ten eligible studies are summarized in Tables 1 and 2. The PEDro scale results are shown in Table 3.

DISCUSSION

Due to the importance of motor learning and the advance of technology in the use of virtual tasks in rehabilitation programs for people with CP, the main objective of this work was to carry out a review of this subject.

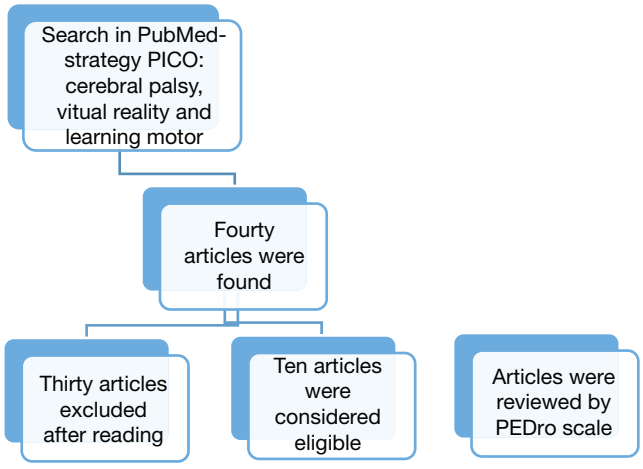

Figure 2 - Flow chart of search strategy and selection process.

Table 1 - Articles related to virtual reality and motor learning.

Type of article	
Experimental study	2
Pilot study	2
Case control	2
Review	2
Clinical trial	2

One of the characteristics observed in the ten selected studies was the number of people evaluated. Most had small sample sizes, which limited the extent to which results could be generalized and could impact the assessed outcomes. It is necessary to ensure that the sample represents the population. It is obviously important to use sample calculation to determine the number of necessary elements in order to obtain valid results, because an increase in the sample size will lead to increased accuracy in the population estimates. In the studies found, the number of participants was between 3 and 64 subjects. The research of de Mello Monteiro et al.[20] included 64 individuals, 32 with CP and 32 normally developing individuals; all were observed practicing two coincidence-timing tasks. In the more tangible button-press task, the individuals were required to 'intercept' a falling virtual object at the moment it reached the interception point by pressing a key. In the more abstract, less tangible task, they were instructed to 'intercept' the virtual object by making a hand movement in a virtual

Table 2 - Synthesis of manuscripts on virtual reality and motor learning.

C. Gordon et al. 2012[12]	Due to the lack of a comparative group, it is difficult to say whether the changes observed in gross motor function were due to the training programme, a learning effect or natural changes. However, these results indicate that there may be some potential for training with the Nintendo Wii to have an impact on gross motor function, and research studies should be conducted to explore this hypothesis.
Howcroft J. et al. 2012[13]	While all games may encourage motor learning to some extent, AVGs can be strategically selected to address specific therapeutic. Active video game (AVG) play for physical activity promotion and rehabilitation therapies in children with cerebral palsy (CP), through a quantitative exploration of energy expenditure, muscle activation, and quality of movement. AVG play via a low-cost, commercially available system can offer an enjoyable opportunity for light to moderate physical activity in children with CP.
Marie Brien, et al. 2011[14]	Results showed improvements in motor learning with skill transfer and integration into real-life situations. Functional balance and mobility in adolescents with cerebral palsy classified at GMFCS level I improve with intense, short duration VR intervention, and changes are maintained at 1-month post-training.
Leon M Straker et al. 2011[6]	Improvements in performance in VR are useful if they lead to improvements in real-world performance. This suggests VR games could improve real-world motor skills in children and could increase children's confidence, which would be additionally beneficial. VR electronic games may improve these children's skills by providing gross motor practice involving a high level of visual-spatial integration, but in a context which is private, and provides strong motivation through enjoyment of the game and the challenge of self-competition. However this will only occur if the nature of the movement required is suitable.
Michelle Wang, Denise Reid. 2011[8]	Using VR as an educational and therapeutic tool allows instructors and therapists to offer both flexibility and control when administering treatments, increasing the probability of skill transfer and ensuring safety during learning.
Golomb M. R. et al. 2010[15]	Improved function appears to be reflected in functional brain changes. Use of remotely monitored virtual reality video game tele-rehabilitation appears to produce improved hand function and forearm bone health (as measured by DXA and pQCT) in adolescents with chronic disability who practice regularly.
Shira Yalon-Chamovitz, Patrice L. (Tamar) Weiss. 2008[16]	The participants demonstrated clear preferences, initiation and learning. The VR-based activities were perceived by the participants to be enjoyable and successful. They performed consistently and maintained a high level of interest throughout the intervention period. VR appears to provide varied and motivating opportunities for leisure activities among young adults with intellectual and physical disabilities. Its ease of use and adaptability make it a feasible option for this population.
H. Sveistrup et al. 2004[9]	The impact of VR exercise participation ranged from improvements in clinical measures of functional balance and mobility, time on task, as well as participant and care provider perceptions of enjoyment, independence and confidence. Although still preliminary, the data suggest that simple applications of virtual reality have significant impacts on physical and psychosocial variables. Possibilities for and benefits of home and community-based access to virtual reality-based programs are explored.
Luanda André Collange Grecco et al. 2013[17]	The combination of transcranial stimulation and physical therapy resources will provide the training for a specific task with multiple rhythmic repetitions of the phases of the gait cycle, providing rich sensory stimuli with a modified excitability threshold of the primary motor cortex, to enhance local synaptic efficacy and potentiate motor learning. The combination physical therapy resources will provide the training of a specific task with multiple repetitions of the phases of the gait cycle, promoting rich sensory proprioceptive and visual) stimuli with a modified threshold of excitability of the primary motor cortex (enhanced local synaptic efficacy), thereby potentiating motor learning.
De Mello Monteiro CB et al. 2014	With the growing accessibility of computer-assisted technology, rehabilitation programs for individuals with cerebral palsy (CP) increasingly use virtual reality environments to enhance motor practice. The results showed that individuals with CP timed less accurate than typically developing individuals, especially for the more abstract task in the virtual environment. The individuals with CP did—as did their typically developing peers—improve coincidence timing with practice on both tasks. Importantly, however, these improvements were specific to the practice environment; there was no transfer of learning.

Table 3 - PEDro scale results.

Score	Number of articles
2	3
3	1
5	1
6	2
8	1
Not applicable	2

environment. Results showed that individuals with CP scored less accurately than normal controls. However, improvements in performance were specific to the practice environment; there was no transfer of learning.

Yalon-Chamovitz et al[16] evaluated the largest number of participants, 33 people with CP including 23 males and 10 females with a diagnosis of CP and moderate or mild mental disabilities. This study had subjects in the experimental group and in the control group, but the experimental group and the control group were composed of the same population, decreasing the comparison effect. The fact that the control group did not present a number equal to or larger than the intervention group also reduces the confidence of the results. On the other hand, Howcroft et al.[13] evaluated 17 people with CP, but did not use a control group. In spite of the fact that discrepancies at baseline between the control and intervention groups were not always considered, the use of a control group always provides interesting data.

The studies of Gordon et al.[12], Golomb et al.[15] and Brien et al.[14] included much smaller numbers of participants and no control groups. Brien et al.[14] note that studies with larger samples are necessary to increase validity and trust, and that groups with differences between CP subpopulations and with more homogeneous demographic groups (gender, age), would collectively lead to better results, because the study noted limitations in performing statistical analysis and possible difficulties in generalizing the observed outcomes.

Among the reviewed studies, some important convergence points can be found relating to gross motor function and the impact on CP. Straker et al.[6], Gordon et al.[12] and Brien et al.[14] claim that virtual reality can improve motor ability in this population.

Further investigation is necessary to examine the effectiveness of different training protocols for intense VR interventions in children in younger age groups, at different levels of motor function.[14] Moreover, additional research is needed to determine the intensity, frequency, and duration of the VR intervention required to best affect functional balance and mobility in children and adolescents with CP.[14]

Brien et al.[14] hypothesized that complex balance and coordination skills in walking performance, walking speed, endurance, stair climbing and descent would be improved in these children and that these improvements would be maintained at one week and one month following the end of training with VR. Results from their study support two major findings: (i) the data suggest that functional balance and mobility in adolescents with CP can improve with an intense, short duration VR intervention and (ii) improvements in outcome measures are maintained for at least one month following VR training.[14]

It is difficult to say whether the changes observed in gross motor function were due to the training program, to a learning effect or to natural changes.[12] However, these results indicate that there may be some potential for training with a VR environment (like Nintendo Wii) to have an impact on gross motor function, and research studies should be conducted to explore this hypothesis.[12]

The VR environment provides vibrotactile, visual (e.g. by way of the on-screen avatar), auditory, and cognitive (e.g., through game scores and performance) feedback to the user.[13] Grecco et al.[17] reported that feedback provided by the image generates positive reinforcement, thereby facilitating the practice and perfection of the exercises. Gordon et al.[12] and Straker et al.[6] reported that the training of these patients with VR devices may have a positive impact, because of the high level of visual and spacial integration.

Considering motor learning, Howcroft et al.[13] report that motor learning depends on factors such as improvement (in performance), consistency (uniformity in the results of a task) and stability. The learning of a motor task includes many principles of learning. Through practice, the individual has the opportunity to experience alternatives in finding solutions to a given motor problem. Practice is fundamental to the learner for the acquisition of motor skills. The objectives can result in stable and accurate performance and the ability to overcome difficulties imposed by environmental or physical factors pre-established by the pathology already present.

Generally, children learn cognitive and motor skills by training and through reasoning.[18] Training implies acquiring habits of mind and behaviour that have been shaped by others, enabling the child to acquire the skills required to fit in.[18]

Using VR as an educational and therapeutic tool allows instructors and therapists to offer both flexibility and control when administering treatments, increasing the probability of skill transfer and ensuring safety during learning.[8] Flexibility is essential when designing therapeutic programs because children with neurodevelopmental disorders are not only heterogeneous, but also require extra learning support.[8] The treatment programs for individuals with CP increasingly use virtual environments (VR) to improve motor functioning. Yet, although these programs are successful in terms of adherence, it remains unclear if increases in motor functioning in virtual environments transfer positively to motor functioning in natural environments.[20]

Three studies included in this review, Straker et al,[6] Golomb et al[15] and Grecco et al[17] claim that motor learning can be potentiated with VR, with transfer of motor abilities and real-life integration; they observed that VR can also be an important educational and therapeutic tool. Forms of physical therapy seek to promote motor learning through the administration of functional training and multiple sensory stimuli.[17]

Although it is clear that VR systems rely on hardware and software, their use in all rehabilitation situations requires clinicians to make decisions about the appropriateness of the intervention for the patient, implementation of treatment parameters and progression through different levels of the game or task.[19]

There is evidence to confirm that VR is a promising tool in the treatment of such children.[17] The potential uses of VR are vast, yet validation of findings is necessary as the current body of research is dominated by low quality evidence. Despite the benefits, this review shows that more research is required to confirm these findings, especially considering the training transfer from VR to a real environment.

CONCLUSION

The studies showed the benefits of the use of VR in children with CP in gross motor function and improvements in motor learning with skill transfer to real-life situations. Therefore, it seems to be a promising resource and a strategic option for care of these children.

However, there are few studies about motor learning with use of VR. The long-term benefits of VR therapy are still unknown. The published studies need to be better designed with more rigorous methodology. A high quality random clinical trial with a large sample is needed to determine that the use of VR for people with CP can be better than traditional rehabilitation interventions.

AUTHORS' CONTRIBUTIONS

All authors participated in the acquisition of data and revision of the manuscript. All authors determined the design, interpreted the data and drafted the manuscript. All authors read and gave final approval for the version submitted for publication.

DECLARATION OF INTEREST

The authors report no conflict of interest. All authors were responsible for the content and writing of this paper.

RESUMO

Indivíduos com paralisia cerebral apresentam distúrbios motores complexos, o principal sendo um déficit de tônus muscular, que afeta a postura e o movimento; observam-se alterações de equilíbrio e coordenação motora, diminuição de força e perda de controle motor seletivo com problemas secundários de contratura e deformidade óssea. Esta população pode ter dificuldades na aprendizagem de habilidades motoras. O aprendizado de habilidades resulta de exposição repetida e de prática. Devido ao aumento do uso de realidade virtual no processo de reabilitação e a importância do desenvolvimento motor na aprendizagem de indivíduos com paralisia cerebral, há necessidade de estudos nesta área. O objetivo do presente estudo foi investigar os resultados mostrados em estudos anteriores de aprendizagem motora com realidade virtual em pacientes com paralisia cerebral. Inicialmente, 40 estudos foram encontrados, mas 30 artigos foram excluídos por não preencherem os critérios de inclusão. Os dados extraídos dos dez estudos elegíveis são apresentados. Os estudos mostraram benefícios da utilização da Realidade Virtual em crianças com paralisia cerebral na função motora grossa e melhorias na aprendizagem motora com a possibilidade de transferir para situações da vida real. Portanto, a realidade virtual parece ser uma alternativa promissora e uma opção estratégica para o atendimento dessas crianças. No entanto, existem poucos estudos sobre aprendizagem motora com realidade virtual. Os benefícios a longo prazo do tratamento com realidade virtual ainda são desconhecidos.

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