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The Effect of Virtual Reality Intervention Programs on the Functionality of Children and Adolescents with Cerebral Palsy. A Systematic Review

Nikolaos Chrysagis[1]*, Despoina Panagou[2], Kouzagioti Erasmia Maria[2], Efstathia M Vlachou[2], Vasiliki Sakellari[1], George A Koumantakis[1]

[1]*Laboratory of Advanced Physiotherapy (LAdPhys), Physiotherapy Department, University of West Attica (UNIWA)28 Ag. Spyridonos Street, Aigaleo, 122 43, Athens, Greece*

[2]*Physiotherapy Department, University of West Attica (UNIWA), 28 Ag. Spyridonos Street, Aigaleo, 122 43, Athens, Greece*

Corresponding Author: Nikolaos Chrysagis, E-mail: nchrisagis@uniwa.gr

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ABSTRACT

Background: Cerebral Palsy (CP) is a neurological disorder of movement and posture. Recent studies have shown that Virtual Reality (VR) is a useful and low-cost tool used in treating children and adolescents with cerebral palsy. Nevertheless, there is no substantial evidence supporting that VR therapy can help CP patients, not only as the primary treatment, but as a supplement. **Objectives:** The present systematic review aimed to investigate the effectiveness of VR intervention programs on the functional capacity of children and adolescents with CP, according to the International Classification of Functioning, Disability and Health (ICF). **Methods:** A systematic online search was conducted in PubMed, Scopus, and PEDro databases, as well as in the Google Scholar search engine, from inception till September 2022. The methodological quality of included studies was rated with the PEDro scale. **Results:** Twenty-two randomized-controlled trials were eligible for inclusion. The results indicated that there was a significant improvement after the implementation, of interventional VR programs, in balance and visual perception, while the results were controversial for muscle strength, coordination, gross motor function, gait, upper limb function, independence in activities of Daily Life Activities and participation. **Conclusion:** Significant balance and visual perception improvements may result from VR programs applied in children and adolescents with CP. Important factors that may influence the results are the functional level of the participants, the sample size, the context in which the therapeutic intervention is carried out (rehabilitation center, home), and the conventional treatments that the VR intervention programs are compared against.

Key words: "Cerebral palsy", "Children", "Adolescents", "Virtual reality", "Balance", "Fine motor function", "Gross motor function", "Participation"

INTRODUCTION

Cerebral Palsy (CP) is a group of neurological permanent disorders of movement and posture, caused by non-progressive interference in the developing brain (Yu et al., 2018). Also, CP is a socio-economic problem, since its associated conditions can impose a significant economic burden on the affected families, health care system, and general economy, as it requires long term supportive care services. Generally, the cost of cerebral palsy is estimated expenditure of $1.47 billion per year (Australian Cerebral Palsy Register Report, 2018). Cerebral Palsy has "varying severity and complexity" across the lifespan, so its management requires a multidisciplinary approach (Trabacca et al., 2016), focusing on "maximizing individual function, choice and independence", in line with the International Classification of Functioning, Disability and Health (National Guideline Alliance (UK), 2017). Modern CP rehabilitation is based on motor learning theory, guided by motor control and functional training through continuous repetition and feedback (Rostami et al., 2012).

On the other hand, Virtual Reality (VR) is defined as an immersive interactive 3D experience, that it responds to user's movements, occurring in real time (Harris & Reid, 2005). It's a new, very popular, assistive technology used in rehabilitation, with the main characteristic, that patients can immerse themselves in a non-physical world, through 3D displays at home. Therapeutic VR programs promote neuroplasticity and motor learning, as they are based on motor learning principles, such as multisensory feedback, alternating test sets, objective progression, and practice through repetitive bounded trials (Cano et al., 2018). In particular, the multisensory stimulation environment, motivates children and adolescents, as they are fun and entertaining in nature (Kachmar et al, 2021). Additionally, individuals with

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CP may not be able to participate in interactive activities, in a safe environment and this is done in real time, through VR (Chiu et al., 2014; Harris & Reid., 2005; Park et al.,2021, Rostami et al., 2012).

In recent years, several systematic reviews have been published, that evaluate the effectiveness of VR rehabilitation programs in CP. Ravi et al. (2016) included 31 studies with various research designs and reached conflicting conclusions. In particular, they reported that the intervention of VR programs could improve balance and mobility while it did not significantly affect the function of the upper limbs (Ravi et al., 2017). The systematic review and meta-analysis by Chen et al. (2018) included 19 randomized studies, reporting positive effects of VR on arm function, gait and balance in children and adolescents with CP (Chen et al., 2018). In addition, Rathinam et al. (2019) assessed the effectiveness of VR in children with CP but the results reported from 6 RCTs only for hand function were conflicting (Rathinam et al., 2019). Similarly, Fandim et al. (2020) included 23 randomized trials and observed short-term benefits in upper and lower limb function and balance, after using VR, as an adjunctive therapy (Fandmin et al., 2020). Similar conclusions were reached by Alrashidi et al. (2021), who supported that VR was ineffective in the arm function of children with CP.

All these studies point out that the use of different assessment tools, the heterogeneity of the results obtained, and the difference in the methodological quality of the studies precluded any generalization of the results and the production of valid conclusions. The present systematic review aimed to assess the effectiveness of VR intervention programs on the functional capacity of children and adolescents with CP based on the classification of their functions in the framework of the ICF. More specifically, the effects of VR training on physical structures and functions, activities, and participation of children and adolescents with CP, were evaluated according to the variables examined in the selected literature.

METHOD

Research Design

This systematic review has been conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al, 2021).

Eligibility Criteria

Initially, the eligibility criteria of the studies were according to the research question, which was formulated according to the principles of the PICO method. PICO is an acronym for the words: Problem/Population, Intervention, Comparison, Outcome, and is used to formulate the clinical question, in literature reviews and to specify keywords. These four words are the basic elements for searching the research question according to EBP (Evidence-Based Practice) (Mamédio-da Costa Santos et al 2007). Also, studies published in full text in English, randomized controlled trials (RCTs), were included, in which, the participants were diagnosed with cerebral palsy aged between 5-18 years old. Additionally, VR training had to be the main treatment of the experimental group, without surgery performed before or during the intervention. Alongside, VR training had to be used in both groups and the intervention group not to be compared with typically developed children.

Search Strategy and Screening

A systematic search of the PubMed, Scopus, and PEDro databases, as well as the Google Scholar search engine was conducted from inception to September 2022. The keywords used were: cerebral palsy, children, adolescents, virtual reality, video games, exergaming, walking, gait, balance, fine motor skills, gross motor skills, participation, activities, which arose from the analysis of the exploratory question, Also, the review was conducted using the controlled vocabulary of pre-defined terms [Medical Subject Headings (MeSH) terms] wherever possible. The entire articles were studied without a time limit. Two independent researchers studied and evaluated all studies initially selected from the electronic searches. Duplicates were removed manually. Then, several articles were rejected after reading their title or studying their abstracts. Finally, in case of doubt, the entire article was examined to decide whether to include it in the review, according to the inclusion and exclusion criteria already set.

Data Extraction

Data relating to the included population characteristics (age, CP type and classification), the VR intervention characteristics (type, frequency, duration), as well as the ICF-based outcomes each study utilized were extracted from included studies.

Data Synthesis and Analysis

Results were presented and analyzed according to an ICF-based categorization of the outcomes. Since clinical heterogeneity was present between-studies, a narrative synthesis was performed. Specifically, the combination of quantitative results between studies was performed according to the vote-counting method based on the direction of effect reported from each study, as described by McKenzie & Brennan (2022).

Assessment of Methodological Quality

The methodological quality of the studies was carried out with the PEDro scale, which has high enough validity and reliability (Maher et al., 2003). It consists of 11 criteria, 10 related to the internal and external validity of the results and are summarized for the overall score (Verhagen et al, 1998). Each criterion is scored 1 point, with a maximum score of 10 and a minimum of 0. From zero to three points, studies are rated as “low quality”, from four to six as “moderate”, and from seven to ten as “high” (Cahin & McAuley, 2020).

The International Classification of Functioning, Disability and Health (ICF) can be used during the evaluation, the formation of therapeutic goals and the selection of the intervention (Martinuzzi et al., 2010). The ICF consists of 2 parts: the 1st part includes the parameters-domains of functioning and disability, and the 2nd part includes the parameters-domains of the context factors (environmental and individual factors) (Rosenbaum & Stewart, 2004; Palisano et al., 2006; WHO, 2001).

RESULTS

Search Results

The electronic search of the databases amassed a total of 523 articles. From these, 91 duplicates were excluded. According to the procedure, from the remaining 432 articles, 383 were rejected, after the assessment based on the title or the summary. Specifically, 163 articles had no relevant content, 34 were not in English, while 186 were not RCT. The evaluation of the full text concerned 49 articles, of which, 27 were considered inappropriate for our review. Particularly, 5 articles included population outside the specified age range, 7 combined VR with specialized treatment, 3 included surgery population and 3 compared the sample to a typically growing population. One survey had not been published in all of its extent, while 6, included a VR program in both groups. Finally, the articles included in our systematic review were 22 (Figure 1).

Assessment of Methodological Quality

The evaluation of the methodological quality of the reviews was carried out with the PEDro scale, and all studies were rated separately by two different assessors. Specifically, 3 studies were of low quality (2-3 points), 10 moderate (4-6 points) and 9 high (7-9 points). The average PEDro score for the randomized studies, included in our systematic review was 4.5. The final score of the studies was formed after discussion by the assessors and are presented in Table 1.

Characteristics of the Participants

The present review incorporated 22 studies that included 728 patients in total. Of the patients initially recruited, 689 completed their participation in the study. All patients had been diagnosed with CP, aged 5-18 years. In each study the CP type varied among the patients. The functional capacity of those patients was classified according to the five levels of the GMFCS (Gross Motor Function Classification System) and MACS (Manual Ability Classification System). Furthermore, all studies included in their research protocol participants of both sexes (Table 2).

Duration of the VR Programs

The duration of the VR interventional programs ranged from 4 weeks to 5 months. In most papers, the frequency of the intervention was 2 or 3 times per week. As for the exercise duration, it varied from 20 to 145 minutes (Table 3).

Dependent Variables and Assessment Tools

Dependent variables, as well as the assessment tools that were used were categorized according to the domains of ICF. Specifically, categorization referred to: a) body structures and functions, b) activity and c) participation. The results are presented in Table 4.

Effectiveness of Virtual Reality Intervention Programs on Structure and Function

Initially, the effect of VR programs on CP patients' strength, was evaluated in 4 papers (Avcil et al., 2020;

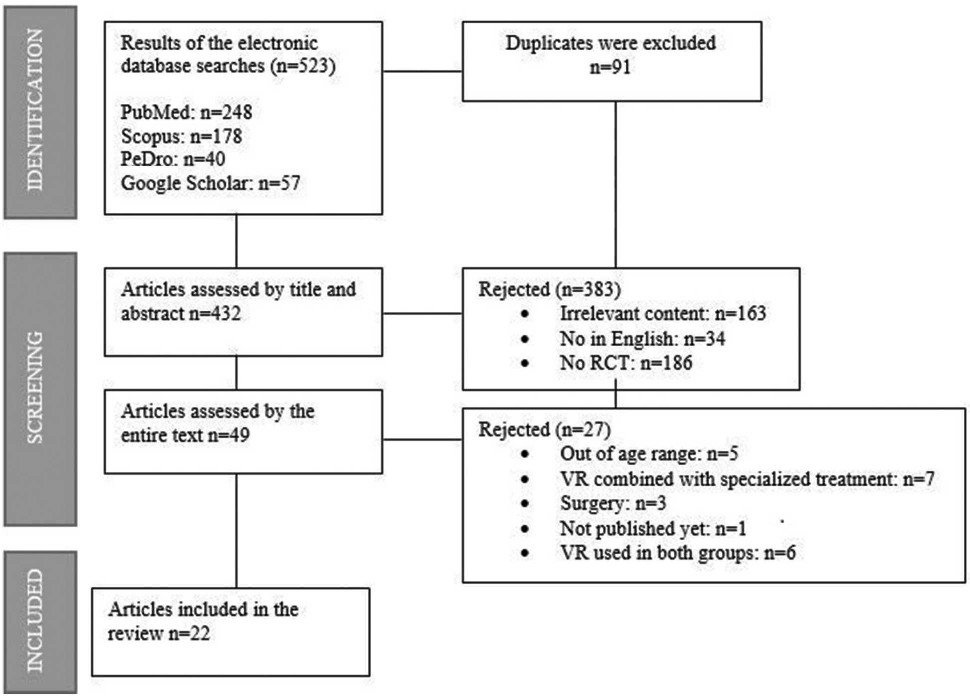

Figure 1. Search results

Table 1. PEDro score for the studies included

Study	Methodological Quality										Final Score
	1	2	3	4	5	6	7	8	9	10	
Al Saif & Alsenany, 2015	1	0	1	0	0	0	0	0	0	1	3/10
Arnoni et al., 2019	1	1	1	0	0	1	1	1	0	1	7/10
Atasavun Uysal & Baltaci, 2016	1	0	1	0	0	1	0	0	1	1	5/10
Avcil et al., 2020	1	0	1	0	0	0	0	0	1	1	4/10
Chen et al., 2012	1	0	1	0	0	0	1	0	1	1	5/10
Chiu et al., 2014	1	1	1	0	1	1	1	1	1	1	9/10
El-Shamy & El- Banna, 2018	1	1	1	0	0	1	1	0	1	1	7/10
Gatica- Rojas et al., 2017	1	0	1	0	0	0	1	0	1	1	5/10
James et al., 2015	1	1	1	0	0	0	1	1	1	1	7/10
Jannink et al., 2008	1	0	1	0	0	0	1	0	0	1	4/10
Jha et al., 2021	1	1	1	0	1	1	1	0	1	1	8/10
Jung et al., 2020	1	0	0	0	1	0	1	0	1	1	5/10
Okmen et al., 2022	1	0	1	0	0	0	1	0	1	1	5/10
Park et al., 2021	1	0	1	0	0	0	1	0	1	1	5/10
Pin & Butler 2019	1	0	1	0	0	1	1	1	1	1	7/10
Ramstrand & Lygnegård, 2012	1	0	0	0	0	0	0	0	1	0	2/10
Reid & Campbell, 2006	1	0	0	0	0	1	0	0	1	1	4/10
Rostami et al., 2012	1	0	1	0	0	1	1	1	1	1	7/10
Sahin et al., 2020	1	1	1	1	1	0	1	1	1	1	9/10
Tarakci et al., 2016	1	1	1	0	0	0	0	1	0	1	5/10
Wade & Porter, 2012	1	1	1	0	0	1	1	0	1	1	7/10
Wang et al., 2021	1	1	1	0	0	1	1	0	1	1	7/10

Chen et al., 2012; Chiu et al., 2014; El-Shamy & El-Banna, 2018). The study by Chen et al., (2012) found positive changes in the measurements, after the home-based Virtual Cycling Training (hVCT) intervention. Particularly, there was a statistically significant difference in the measurements of both angular velocities in the knee flexors (60 °/s: p=0.028; 120 °/s: p=0.003) and in the knee extensors (60 °/s: p=0.045; 120 °/s: p=0.003). Also, El-Shamy & El-Banna, (2018), found increase in the strength of all participants, in both hands, while the interventional group had better performance. In contrast, Chiu et al., (2014) noted no statistically significant difference, between groups of the upper limb muscles. However, participants in the intervention group had more strength compared to participants in the control group (p=0.10 in 6 weeks and p=0.19 at 12 weeks). Similarly, Avcil et al., (2020), reported no statistically significant changes between the groups (p>0, 05), although there was a change in both examined handles, with a statistically significant difference in each group (p<0.05).

Voluntary control and coordination

Voluntary control was evaluated only by Jung et al., (2020). Researchers, after the intervention, found significant improvements in all variables (ankle dorsiflexion (p=0.008), knee extension (p=0.008), left hip abduction (p=0.032)] except right hip abduction relative to the control group (p=0.151). Additionally, Al Saif & Alsenany, (2015) observed significant changes in the intervention group compared to the control group in eye-hand coordination. Specifically, on the BOTMP scale, the intervention group improved from 2.23 ± 0.47 to 3.78 ± 0.39, while the control group improved from 2.82 ± 0.51 to 3.12 ± 0.66. In contrast, Chiu et al., (2014) observed no change between groups. Specifically, no statistically significant difference emerged, either at 6 or 12 weeks, when the measurements were made in the elbow joint (6 weeks: p=0.30, 12 weeks: p=0.15) and in the finger joints (6 weeks: p=0.54, 12 weeks: p=0.92).

Visual perception

James et al., (2015), assessed visual perception and there was a statistically significant improvement in the intervention group, compared to the control group. The final TVPS-3 score had a difference of 6.79 (p=0.001), while its subscales, also showed a statistically significant difference [visual discrimination (p=0.017), spatial relations (p=0.01) and visual loss (p=0.03)].

Table 2. Characteristics of the participants

Study	Number of participants	Age	CP type	Classification
Al Saif & Alsenany, 2015	40 (control/intervention group: 20/20)	6-10	Diplegia	II (GMFCS)
Arnoni et al., 2019	15 (control/intervention group: 8/7)	5-14	Hemiplegia	I-II (GMFCS)
Atasavun Uysal & Baltaci, 2016	24 (control/intervention group: 12/12)	6-14	Hemiplegia	I-II (GMFCS) I-III (MACS)
Avcil et al., 2020	30 (control/intervention group: 15/15)	7-14	Diplegia/Hemiplegia	I-IV (GMFCS) I-IV (MACS)
Chen et al., 2012	28 (control/intervention group: 14/14)	6-12	Diplegia/Hemiplegia	I-II (GMFCS)
Chiu et al., 2014	62(control/intervention group: 30/32)	6-13	Hemiplegia	I-V (GMFCS) I-V (MACS)
El-Shamy & El- Banna, 2018	40 (control/intervention group: 20/20)	8-12	Hemiplegia	I-III (MACS)
Gatica- Rojas et al., 2017	32 (control/intervention group: 16/16)	7-14	Diplegia/Hemiplegia	I-II (GMFCS)
James et al., 2015	102 (control/intervention group: 51/51)	8-18	Hemiplegia	I-II (GMFCS) I-III (MACS)
Jannink et al., 2008	10 (control/intervention group: 5/5)	7-16	Tetraplegia/Diplegia/ hemiplegia	I, III, IV (GMFCS) II-IV (MACS)
Jha et al., 2021	38 (control/intervention group: 19/19)	6-12	Tetraplegia/Diplegia/	II-III (GMFCS) I-III (MACS)
Jung et al., 2020	10 (control/intervention group: 5/5)	11-17	Diplegia	I-II (GMFCS) I-II (MACS)
Okmen et al., 2022	46 (control/intervention group: 23/23)	5-15	Tetraplegia/Diplegia/ hemiplegia	I-III (ASHWORTH)
Park et al., 2021	20 (control/intervention group: 10/10)	6-18	Tetraplegia/Diplegia	III-IV (GMFCS)
Pin & Butler, 2019	18 (control/intervention group: 9/9)	6-14	Tetraplegia/Diplegia	III-IV (GMFCS)
Ramstrand & Lygnegård, 2012	18 (control/intervention group: 9/9)	8-17	Diplegia/Hemiplegia	I-II (GMFCS)
Reid & Campbell, 2006	31 (control/intervention group: 12/19)	8-10	No information	I-V (GMFCS)
Rostami et al., 2012	32 (control/intervention group: 8/24)	6-12	Hemiplegia	I-II (ASHWORTH)
Sahin et al., 2020	60 (control/intervention group: 30/30)	7-16	Hemiplegia	I-III (GMFCS) I-III (MACS)
Tarakci et al., 2016	38 (control/intervention group: 19/19)	5-18	Diplegia/Hemiplegia	I-III (GMFCS)
Wade & Porter, 2012	13 (control/intervention group: 7/6)	7-16	No information	IV-V (GMFCS)
Wang et al., 2021	20 (control/intervention group: 10/10)	5-12	Hemiplegia	I-III (MACS)

G.M.F.C.S.: Gross Motor Function Classification System, M.A.C.S.: Manual Ability Classification System

Effectiveness of virtual Reality Intervention Programs on Activity

Balance

The effect of VR programs on balance was studied in 11 papers (Al Saif & Alsenany, 2015; Arnoni et al., 2019; Atasavun Uysal & Baltaci, 2016; Jung et al., 2020; Gatica-Rojas et al., 2017; Jha et al., 2021; Pin & Butler, 2019; Park et al., 2021; Ramstrand & Lygnegård, 2012; Wade & Porter, 2012; Tarakci et al., 2016).

Specifically, Al Saif & Alsenany, (2015) and Gatica-Rojas et al., (2017) using the same VR program reported significant improvements, in the intervention group compared to the control group ($p<0.05$). Also, Atasavun Uysal & Baltaci, (2016) and Jung et al., (2020) found a statistically significant increase in balance of the intervention group, compared to the control group ($p<0.05$). Additionally, Tarakci et al., (2016) found that personalized rehabilitation games have a positive effect on the balance of children with CP, in combination with NDT (FFRT, FSRT: $p<0.001$, TGGT: $p<0.001$). Also, Park et al (2021) used three assessment tools for sitting balance.

Specifically, using Balancia program and mFRT, there was a statistically significant difference ($p<0.05$), while with K-TCMS there wasn't ($p=0.102$). Similarly, Wade & Porter (2012) evaluating sitting balance observed a statistically significant improvement in 2 of the 8, Chaily level evaluation items ($p<0.05$), as well as, in the final SACND score ($p<0.05$).

In contrast, Ramstrand & Lygnegård (2012) observed no significant changes in the intervention group ($p>0.05$). Also, Pin & Butler (2019) after their intervention, did not find any changes in the experimental group, as did Arnoni et al (2019), ($p=0.085$). Finally, Jha et al (2021) found improvement in both groups after their assessment with the PBS and Kids-Mini-BESTest scales. Statistical significance found only in the second scale ($p=0.001$), while in the first $p=0.06$.

Table 3. Duration and frequency of each intervention

Study	Intervention Duration (weeks)	Weekly Intervention Frequency
Al Saif & Alsenany, 2015	12	7
Arnoni et al., 2019	8	2
Atasavun Uysal & Baltaci, 2016	12	2
Avcil et al., 2020	8	3
Chen et al., 2012	12	3
Chiu et al., 2014	16	3
El-Shamy & El- Banna, 2018	12	3
Gatica- Rojas et al., 2017	6	3
James et al., 2015	20	6
Jannink et al., 2008	6	2
Jha et al., 2021	6	4
Jung et al., 2020	6	3
Okmen et al., 2022	4	3
Park et al., 2021	4	2
Pin & Butler, 2019	6	4
Ramstrand & Lygnegård, 2012	5	5
Reid & Campbell, 2006	8	1
Rostami et al., 2012	4	3
Sahin et al., 2020	8	2
Tarakci et al., 2016	12	2
Wade & Porter, 2012	12	No information
Wang et al., 2021	8	2

Gait

Gait was studied in 4 papers (Al Saif & Alsenany, 2015; Jung et al., 2020; Pin & Butler, 2019; Tarakci et al., 2016). Tarakci et al., (2016), found statistically significant improvements in the intervention group compared with the control group ($p<0.001$). Similarly, Al Saif et al., (2015) found positive effects on walking. Also, Jung et al., (2020) found an improvement in the intervention group compared to the control group, but it was not statistically significant ($p>0.05$). In contrast, Pin & Butler (2019) did not observe significant improvements after 6 weeks.

Gross mobility

In the present review 5 papers assessed gross mobility (Arnoni et al., 2019; Chen et al., 2012; Jha et al., 2021; Pin & Butler, 2019; Sahin et al., 2019). Pin & Butler, (2019) did not find a significant improvement in gross mobility (GMFM-66), although the participants in the intervention group, showed an increase from 52.39 to 55.00 and in the control group from 51.88 to 54.20. Similar results reported by Jha et al., (2021) and Chen et al., (2012). On the other hand, Arnoni et al., (2019) observed significant improvements in sections D (standing) ($p=0.021$) and E (Walking, Running and Jumping) ($p=0.008$) of the gross mobility rating scale (GMFM). Also, Sahin et al., (2019), reported significantly better gross motor performance in the group that followed the interventional VR program compared to the control group ($p=0.001$).

Arm function

Upper Limbs function concerns movements of the shoulder, elbow and fingers (fine motility) and were evaluated in 11 studies (Al Saif & Alsenany, 2015; Avcil et al., 2020; Chiu et al., 2014; El-Shamy & El-Banna, 2018; James et al., 2015; Jannink et al., 2008; Okmen et al., 2019; Rostami et al., 2012; Reid & Campbell, 2006; Sahin et al., 2019; Wang et al., 2021). All studies assessed fine motor skills in participants, either in terms of quality or quantity of Upper limp function. Al Saif & Alsenany, (2015), found a statistically significant improvement in arm function and targeted conception performance of the intervention compared to the control group. Also, Okmen et al., (2015) found statistically significant improvement in fine motor skills of the experimental group ($p<0.001$) compared to the control group ($p=0.317$). Additionally, El-Shamy & El-Banna, (2018), found an increase in hand function by 9 points in the intervention group, while in the control group, a 3 points' increase was recorded. A significant improvement was also reported by Rostami et al., (2012), Sahin et al., (2019) and Wang et al., (2021) in fine motor, speed and dexterity of the intervention group.

On the other hand, Avcil et al., (2020) reported similar results in arm function between the intervention group compared to the control group. Similarly, Chiu et al., (2014), found no improvement comparing the results of the two groups using the Nine-hole Peg Test (6 weeks: $p=0.91$; 12 weeks: $p=0.34$) or using the Jebsen –Taylor Test of Hand Function (6 weeks: $p=0.89$; 12 weeks: $p=0.46$). Wang et al., (2021) and Reid & Campbell, (2006) did not observe statistically significant changes in the fine motor skills of the experimental group compared to the control group. Additionally, James et al., (2015) reported that a web based therapy program was not superior compared to usual care (consultative sessions with medical and allied health professionals) regarding arm function, of children with unilateral cerebral palsy. Finally, Jannink et al., (2008) found little difference in only two, of the ten children (9% and 13%) who participated in the experimental group.

DLA independency

The studies by Jha et al., (2020), Sahin et al., (2019), Wang et al., (2021), and Tarakci et al., (2016) studied children and adolescents' independence in activities of daily living. Particularly, Tarakci et al., (2016) and Sahin et al., (2019) found a statistically significant improvement in the independence of the participants of the intervention group compared with those of the control group ($p<0.001$).

On the other hand, Wang et al., (2021) found a greater change in the group that did only Constraint-induced ther-

Table 4. Dependent variables and their measurement tool

	Dependent variable	Assessment Tool
Body Structures and Functions	Muscle Strength	Hand dynamometer
		Cybex isokinetic dynamometer
	Coordination/motor control	SCALE
		BOTMP5:6
	Visual perception	TVPS-3
Activity	Balance	Quiet Stance
		Kids-Mini-BESTest
		CoPsway
		SDAP
		SDML
		VAP
		VML
		PRT
		K-TCMS
		mFRT
		mSOT
		Rhythmic weight shift test
		Chailey level of box sitting ability
		SACND
		FFRT
		FSRT
		TGGT
		mABC-2
		PBS
	Gait	GAITRite electronic walkway
		1MWT
		2MWT
		10MWT
	Gross motor skills	GMFM
		BOTMP
	Arm Function	BOTMP, BOT-2, BOTMP-SF
		BFMF
		MMDT
		DHI
		QUEST
		NHPT
		JTTHF
		AHA
		MUUL
		PMAL (PMAL-R)
		ABILHAND-Kids

(*Contd...*)

Table 4. (*Continued*)

	Dependent variable	Assessment Tool
	DLA Independency	WeeFIM
		FMS
Participation	Participation	AMPS
		COMP
		PEDI
		ToP

BOTMP: Bruininks–Oseretsky Test of Motor Proficiency, TVPS: Test of Visual Perceptual Skills, CoPsway: Center-of-Pressure sway, SDAP: Standard Deviation anterior–posterior directions, SDML: Standard Deviation in the medial-lateral Directions, VAP: Velocity anterior–posterior directions, VML: Velocity in the medial-lateral directions, PRT: Pediatric Reach Test, K-TCMS: Korean version of the trunk control measurement scale, mFRT: modified Functional Reach Test, mSOT: modified sensory organization test, SACND: Sitting Assessment Test for Children with Neuromotor Dysfunction, FFRT: Functional Forward Reach Test, FSRT: Functional Sideways Reach Test, TGGT: Timed Get Up and Go Test, mABC-2: Movement Assessment Battery for Children-2, PBS: Pediatric Balance Scale, 1MWT: 1 Minute Walk Test, 2MWT: 2 Minute Walk Test, 10MWT: 10 Meter Walk Test, GMFM: Gross Motor Function Measure, BFMF: Bimanual Fine Motor Function, MMDT: Minnesota Manual Dexterity Test, DHI: Duruoz Hand Index, QUEST: Quality of Upper Extremity Test, NHPT: Nine-Hole Peg Test, JTTHF: Jebsen–Taylor Test of Hand Function, AHA: Assisting Hand Assessment, MUUL: Melbourne Assessment of Unilateral Upper Limb Function, PMAL-R: Revised Pediatric Motor Activity Log, COMP: Canadian Occupational Performance Measure, AMPS: Assessment of Motor and Process Skills, FMS: Functional Mobility Scale, PEDI: Pediatric Evaluation of Disability Inventory, ToP: Test of Playfulness, WeeFIM: Wee Functional Independence Measure

apy (from 67.78 to 105.56) than the group that combined Constraint-induced therapy with Wii (from 70 to 73.11). In addition, Jha et al., (2021) found no statistically significant difference between two groups, regarding their daily activities performance (p=0.201). Finally, Okmen et al., (2022) did not report any statistically significant changes, after the intervention of VR programs as a complementary treatment (p=0.676).

Participation

The effectiveness of VR intervention programs on participation, in children and adolescents with CP was examined in four studies (Atasavun Uysal & Baltaci, 2016; James et al., 2015; Reid & Campbell, 2006; Wang et al., 2021). Wang et al., (2021) found no significant changes in either the intervention or the control group regarding the motivation to play as measured by the Test of Playfulness. Specifically, the CIT and Wii group’s scores were 0.31 to 0.80 and the CIT-only group’s score was 0.25. to 1.22 from baseline to post test. Similarly, Atasavun Uysal & Baltaci, (2016) did not report any statistically significant differences between the two groups concerning Pediatric Evaluation of Disability Inventory: p=0.207 and Occupational Performance Measure (performance: p=0.352, satisfaction: p=0.172). Also, Reid & Campbell, (2006) applying COMP, found similar results.

However, James et al., (2015) used the COPM and Assessment of Motor and Process Skills and found statistically significant improvements in the intervention group compared to the control group (p<0.001). The results by ICF domain are presented in Tables 5, 6, and 7.

DISCUSSION

In the present systematic review several variables were evaluated, in order to investigate the effect of VR programs to children and adolescents with CP. The results showed that some variables had a positive impact, and others had no effect.

In particular, El-Shamy & El-Banna, (2018) and Chen et al., (2012) report a positive effect of VR programs on participants' muscle strength, upper limb and lower limb, respectively. In contrast, Avcil et al., (2020) and Chiu et al., (2014) found no statistically significant improvement between the two groups, but differences were observed in the intervention group. This may be due to the duration of the program, which was twice, as long as, in El-Shamy & El-Banna, (2018) study. The long-term effects of the treatment program were not examined in the Avcil et al., (2020) and El-Shamy & El-Banna, (2018) studies. Finally, the heterogeneity of the sample in terms of the type of CP and the functional level of the children are limitations acknowledged in those studies.

Interventional VR programs may contribute to the improvement of the voluntary motor control and coordination of children and adolescents with CP (Saif & Alsenany, 2015; Jung et al., 2020). Specifically, Al Saif & Alsenany, (2015), observed an improvement in upper limb and eye coordination. Additionally, Jung et al., (2020), report positive results in the voluntary motor control, of lower limb movements of children who participated in the group. In contrast, Chiu et al., (2014) found no significant differences in coordination, after completing the VR intervention program. The difference between the results may be due to the different context (home or clinic), in which the research was conducted. James et al (2015) report a significant improvement in visual perception, after completion of VR interventional programs. However, the weekly frequency and duration of the intervention program, was not adhered by all participants. Finally, the results cannot be generalized to all types of CP, as not all participants were diagnosed with hemiplegia.

Atasavun Uysal & Baltaci, (2016), Jung et al., (2020), Gatica-Rojas et al., (2017), Park et al., (2021) and Tarakci et al., (2016) found that the use of VR programs had a positive effect on the balance of children and adolescents with CP. Although Al Saif & Alsenany, (2015) and Wade & Porter, (2012) did not combine the VR program with another treatment, they found similar results. Additionally, the intervention program of Jung et al., (2020) was not designed with therapeutic intent. Also, in Gatica-Rojas et al., (2017) research all participants had a good cognitive level, so their conclusions cannot be considered in people with mental retardation.

In contrast, Arnoni et al., (2019), Jha et al., (2021), Ramstrand & Lygnegård, (2012) and Pin & Butler, (2019) did not observe a statistically significant improvement in balance, after completing the VR intervention. However, the interventions by Ramstrand & Lygnegård, (2012) and Pin &

Table 5. Details of studies testing the effectiveness of VR training on outcomes from the "Body Structures and Functions" domain of the ICF

Body Structures and Functions				
Study	**Number of Sessions/Minutes**	**Intervention**	**Result**	**PeDro Score**
Muscle Strength				
Chen et al.,20212	36//40	Eloton SimCycle Virtual Cycling System \	Statistically significant changes between the two groups (p<0.05)	5/10
El-Shamy & El-Banna 2018	36/60	Nintendo Wii & regular therapy	Statistically significant changes between the two groups (p<0.05)	7/10
Avcil et al., 2020	24/60	Nintendo Wii & L.M.C. games	No significant changes between the two groups (p>0.05)	4/10
Chiu et al., 2014	18/40	Wii sport resort & regular therapy	No significant changes between the two groups (p>0.05)	9/10
Voluntary control and Coordination				
Al Saif & Alsenany (2015)	84/20	Nintendo Wii	Statistically significant changes between the two groups (p<0.05)	3/10
Jung et al., 2020	18/40	Xbox Kinect & regular therapy	Statistically significant changes between the two groups (p<0.05)	5/10
Chiu et al., 2014	18/40	Wii sport resort & regular therapy	No significant changes between the two groups (p>0.05)	9/10
Visual Perception				
James et al., 2015	120/30	Mitii	Statistically significant changes between the two groups (p<0.05)	7/10

Table 6. Details of studies testing the effectiveness of VR training on outcomes from the “Activity” domain of the ICF

Activity				
Study	**Number of Sessions/Minutes**	**Intervention**	**Result**	**PeDro Score**
Balance				
Al Saif & Alsenany (2015)	84/20	Nintendo Wii	Statistically significant changes between the two groups	3/10
Atasavun Uysal & Baltaci 2016	24/30	Nintendo Wii & regular physical therapy	Statistically significant changes between the two groups (p<0.03)	5/10
Gatica-Rojas et al., 2017	18/60	Nintendo Wii & Balance Board	Statistically significant changes between the two groups (p<0.05)	5/10
Park et al., 2021	8/40	Wii Balance Board & Wii fit software	Statistically significant changes between the two groups at mFRT (p<0,05) no significant changes were observed between the two groups at K-TCMS (p=0.102)	5/10
Tarakci et al., 2016	24/60	Nintendo Wii & NDT	Statistically significant changes between the two groups (FRT: *P*<0,05 , TGGT: *P*<0,001)	5/10
Wade & Porter	Not mentioned	Platform that controls CoP movement	Statistically significant changes between the two groups (p<0,05)	3/10
Jung et al., 2020	18/40	Xbox Kinect & regular therapy	Statistically significant changes between the two groups (p<0,05)	5/10
Arnoni et al., 2019	16/45	Xbox Kinect & NDT	No significant changes were observed between the two groups (p=0.085)	7/10
Jha et al., 2021	24/60	Xbox Kinect &physical therapy	No significant changes were observed between the two groups at PBS: (0.06) statistically significant changes between the two groups at Kids-Mini-BESTest (p=0,001)	8/10
Pin & Butler 2019	24/20	TYMO & regular physical therapy	No significant changes were observed between the two groups	7/10
Ramstrand & Lygnegard 2012	25/30	Nintendo Wii &Wii balance board & Wii Fit software	No significant changes were observed between the two groups (p>0.05)	2/10
Gait				
Al Saif & Alsenany (2015)	84/20	therapeutic virtual treatment	Statistically significant changes between the two groups	3/10
Tarakci et al., 2016	24/60	Xbox Kinect & regular therapy	Statistically significant changes between the two groups (p<0,001)	5/10
Jung et al., 2020	18/40	Nintendo Wii	No significant changes were observed between the two groups (p>0.05)	5/10
Pin & Butler 2019	24/20	Nintendo Wii & NDT	No significant changes were observed between the two groups	7/10
Gross motility				
Arnoni et al., 2019	16/45	Xbox Kinect & NDT	Statistically significant changes between the two groups (p<0.05)	7/10
Sahin et al., 2019	16/45	VR & physical therapy	Statistically significant changes between the two groups (p=0.01)	9/10
Chen et al.,20212	36/40	Eloton SimCycle Virtual Cycling System	No significant changes were observed between the two groups (p=0,13)	5/10
Jha et al., 2021	24/60	Xbox Kinect & physical therapy	No significant changes were observed between the two groups (p=0,254)	8/10
Pin & Butler 2019	24/20	TYMO & regular physical therapy	No significant changes were observed between the two groups	7/10

(*Contd...*)

Table 6. (*Continued*)

Activity				
Study	**Number of Sessions/Minutes**	**Intervention**	**Result**	**PeDro Score**
Arm function				
Al Saif & Alsenany (2015)	84/20	Nintendo Wii	Statistically significant changes between the two groups	3/10
El-Shamy & El-Banna 2018	36/60	Nintendo Wii & regular therapy	Statistically significant changes between the two groups	7/10
Okmen et al., 2019	12/60	EyeToy-Play System & regular therapy	Statistically significant changes between the two groups (p<0,001)	5/10
Rostami et al., 2012	12/90	CIMT & VR	Statistically significant changes (P<0,05)	7/10
Avcil et al., 2020	24/60	Nintendo Wii & L.M.C. games	No significant changes were observed between the two groups (P>0,05)	4/10
Chiu et al., 2014	18/40	Wii sport resort & regular therapy	No significant changes were observed between the two groups (p=0,34/p=0,46)	9/10
Reid & Campbell 2006	8/90	VR	Improvement without statistically significant changes (p=0,43)	4/10
Jannik et al., 2008	12/30	EyeToy & regular physical therapy	No significant changes were observed between the two groups	4/10
James et al., 2015	120/30	Mitii	No significant changes were observed between the two groups (p>0,05)	7/10
Sahin et al., 2019	16/45	VR & physical therapy	No significant changes were observed between the two groups	9/10
Wang et al., 2021	16/45	CIT &Wii	No significant changes were observed between the two groups	7/10
DLA Independence				
Tarakci et al., 2016	24/60	Nintendo Wii & NDT	Statistically significant changes between the two groups (p<0,001)	5/10
Sahin et al., 2019	16/45	VR & physical therapy	Statistically significant changes (p=0,001)	9/10
Jha et al., 2021	24/60	Xbox Kinect & physical therapy	No significant changes were observed between the two groups (p=0,201)	8/10
Okmen et al., 2019	12/60	EyeToy-Play System & regular therapy	No significant changes were observed between the two groups (p=0,676)	5/10
Wang et al., 2021	16/45	CIT &Wii	No significant changes were observed between the two groups	7/10

Table 7. Details of studies testing the effectiveness of VR training on outcomes from the "Participation" domain of the ICF

Participation				
Study	**Number of Sessions/minutes**	**Intervention**	**Result**	**PeDro Score**
James et al., 2015	120/30	Mitii	Statistically significant changes between the two groups (p<0.001)	7/10
Atasavun Uysal & Baltaci 2016	24/30	Nintendo Wii & regular physical therapy	No significant changes were observed between the two groups (PEDI: P=0,207, COPM performance: P=0,352, COPM satisfaction: P=0,172)	5/10
Reid & Campbell 2006	8/90	VR	No significant changes were observed between the two groups	4/10
Wang et al., 2021	16/45	CIT &Wii	No significant changes were observed between the two groups	7/10

Butler, (2019) were not supervised and the duration of the research by Jha et al., (2021) was not long enough to draw firm conclusions. The level of mobility of the participants, the treatment time, as well as the small number of participants in the above studies may be important factors for differentiating the results (Arnoni et al., 2019; Jung et al., 2020; Pin & Butler, 2019; Park et al., 2021; Ramstrand & Lygnegård, 2012; Wade & Porter, 2012).

The results for the effect of VR on walking were conflicting, since positive indications were found in two of four studies. Al Saif & Alsenany, (2015) and Tarakci et al (2016) observed significant changes in children's gait. In contrast, Jung et al (2020) and Pin & Butler (2019) did not discern a statistically significant improvement in children's gait, after completing the VR intervention programs. The different results may be due to the small number of participants, the different level of mobility, which varied from I-IV on the GMFCS scale, and the location of the study. In particular, the study by Al Saif & Alsenany (2015), Jung et al (2020) and Tarakci et al (2016) was carried out in a supervised therapeutic setting while Pin & Butler (2019) was carried out in an unsupervised school.

Three out of five studies included in this systematic review reported a positive effect of VR programs on gross motor function of children and adolescents with CP. Specifically, Arnoni et al., (2019) and Sahin et al., (2019) argued that the application of VR programs in addition to classical therapy has positive effects on gross motor function. However, Sahin et al., (2019) used toys, which did not include movements used in daily activities and were not suitable for direct gross motor training. Chen et al., (2012) found similar results applying a VR program to ambulatory children and adolescents, who did not receive any other treatment at the same time. In contrast, Pin & Butler, (2019) and Jha et al., (2021) did not find a significant improvement in gross mobility in the experimental group, after a combined VR program. The different results may be due to the different mobility level of the participants (GMFCS: I-IV, MACS: I-III), differences in intervention duration (20 – 60 minutes), as well as the small number of participants (Arnoni et al., 2019; Chen et al., 2012; Pin & Butler, 2019).

The results for the effect of VR upper limb function were conflicting, since six out of eleven studies did not demonstrate improvement through VR interventions. Specifically, Al Saif & Alsenany, (2015), Okmen et al., (2015), El-Shamy & El-Banna, (2018) and Rostami et al., (2012) found significant improvements in the VR intervention groups compared with the corresponding control groups. Similarly, Sahin et al., (2019) found statistically significant changes in upper limb function in the group that received the VR intervention, even though the intervention group's games were not considered suitable for direct training. In contrast, in the intervention groups of Avcil et al., (2020), Chiu et al., (2014), Wang et al., (2021), James et al (2015), Jannink et al., (2008) and Reid & Campbell, (2006) an improvement of function capacity in the upper limbs was not observed after the VR intervention. The varied results may be due to the different types of VR intervention, used by the researchers in each study. In particular, with the use of the Nintendo Wii additionally to the usual treatment, of the children and adolescents participated, it appeared to improve the performance of the upper limb function capacity, but also, in its use in daily activities. Exceptions are 2 researches. The study by Chiu et al., (2014) evaluated fine motor skills, with the NHPT and JTTHF scales. Their intervention produced no change and respectively Wang et al., (2021) who used BOT-2, PMAL-R and ABILHAND-Kids scales. Some less famous toys, such as Mitii, Eye Toy, Mandala Gesture Xtreme, did not show improvements in the examined variable, perhaps, because they are not designed for therapeutic purposes (James et al 2008). Researches that had evaluated the effect of VR programs on upper limb, did not select a specific type of CP to include. Instead, they included children with any type of CP and different classification of upper limb functionality (MACS: I-V). In addition, the duration of the virtual reality intervention (20 to 90 minutes), as well as, the number of participants (10 to 102) are important factors, that may account for the differentiation of the results.

Of the 5 researches that evaluated DLA independence, a positive effect was reported in 2 of them. Specifically, in Sahin et al., (2019) and Tarakci et al., (2016) the independence of participants in the intervention group improved. However, in the study by Sahin et al., (2019) the games of the therapeutic program did not include movements that are used in daily activities, so they were not considered suitable for direct training. Additionally, Tarakci et al., (2016) reported that due to the different types of children's the results cannot be generalized. In contrast, Jha et al (2020), Okmen et al (2022) and Wang et al (2021) observed no significant changes between the 2 groups. The researchers report that the duration of the study was probably not long enough to support the effectiveness of the intervention, suggesting interventions lasting more than 6 weeks to achieve this goal. It is noted that children's functional capacity (GMFCS: I-III, MACS: I-III) and treatment time (from 45 minutes to 145 minutes) differed among the above studies.

Based on the analyzed studies, VR programs did not have a significant effect on the participation of children and adolescents with CP. Specifically, Atasavun Uysal & Baltaci, (2016), Reid & Campbell, (2006), Wang et al., (2021) did not observe any improvement in participation in daily activities, after the intervention programs. According to Atasavun Uysal & Baltaci, (2016) and Reid & Campbell, (2006), the results may be due to the small number of participants, the individual sessions and the lack of motivation, which did not contribute to the socialization of the participants. In contrast, in the study by James et al., (2015) a positive effect was observed, even though the maximum weekly dosage was not followed, by all in the intervention group. It should be noted that the duration of the intervention and the number of participants differed in the above research. In particular, in the studies of Atasavun Uysal & Baltaci, (2016) and James et al., (2015) each session lasted 30 minutes, while in Reid & Campbell, (2006) the session duration was 90 minutes and in Wang et al., (2021) 145 minutes.

The information from studies included and analyzed herein indicated the necessity to conduct more studies in VR-based rehabilitation to derive more concrete results on the effectiveness of such programs on the participation/body structures and the functionality/activity of children and adolescents with CP. Furthermore, research on the type of VR training (used as a single intervention or in combination with parallel interventions), the frequency and duration of sessions, so that it can be included in the therapeutic routine of children and adolescents with cerebral palsy. Amongst the limitations of this systematic review is the exclusion of studies that were not randomized, that only studies written in the English language were included, no information on the magnitude of effects was provided, nor did it account for differences in the relative sizes of the included studies, based on the type of data analysis followed.

CONCLUSIONS

The purpose of the present systematic review was to investigate the effectiveness of VR therapeutic programs on the functionality of children and adolescents with cerebral palsy, in the light of the ICF framework. Analysis of the relevant studies revealed a variety of results, regarding its effectiveness. Specifically, the effects of VR on visual perception and balance were positive, while the effects on muscle strength, coordination, gross mobility, gait, upper limb function, DLA independence and participation were conflicting. Additionally, the methodological quality of most studies included in this review, was low to moderate. Important factors that may differentiate the results are the functional level of the participants, the sample size, the context in which the therapeutic intervention is carried out (rehabilitation center, home), as well as the conventional treatment that is carried out alongside the VR intervention programs. Therefore, it is considered necessary to conduct more randomized studies with a larger number of participants, greater homogeneity of the sample and VR as a unique means of treatment, in order to, derive reliable results for its effect on the functionality of children and adolescents with cerebral palsy.

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