Taylor & Francis
Taylor & Francis Group

Disability and Rehabilitation

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/idre20

The efficacy of virtual reality interventions compared with conventional physiotherapy in improving the upper limb motor function of children with cerebral palsy: a systematic review of randomised controlled trials

Mohammed Alrashidi, Curtis A. Wadey, Richard J. Tomlinson, Gavin Buckingham & Craig A. Williams

To cite this article: Mohammed Alrashidi, Curtis A. Wadey, Richard J. Tomlinson, Gavin Buckingham & Craig A. Williams (2022): The efficacy of virtual reality interventions compared with conventional physiotherapy in improving the upper limb motor function of children with cerebral palsy: a systematic review of randomised controlled trials, Disability and Rehabilitation, DOI: 10.1080/09638288.2022.2071484

To link to this article: https://doi.org/10.1080/09638288.2022.2071484

Published online: 16 May 2022.

DISABILITY AND REHABILITATION
https://doi.org/10.1080/09638288.2022.2071484

Taylor & Francis
Taylor & Francis Group

REVIEW ARTICLE

OPEN ACCESS Check for updates

The efficacy of virtual reality interventions compared with conventional physiotherapy in improving the upper limb motor function of children with cerebral palsy: a systematic review of randomised controlled trials

Mohammed Alrashidi[a,b,c], Curtis A. Wadey[a], Richard J. Tomlinson[d], Gavin Buckingham[b] and Craig A. Williams[a]

[a]Children's Health and Exercise Research Centre, Sport & Health Sciences, University of Exeter, Exeter, UK; [b]Sport and Health Sciences, University of Exeter, Exeter, UK; [c]Department of Physical Therapy, Faculty of Medical Rehabilitation Sciences, Taibah University, Madina, KSA; [d]Royal Devon and Exeter Hospital, Exeter, UK

ABSTRACT

Purpose: Cerebral palsy (CP) is the commonest motor disability affecting children. This study reviewed the evidence for virtual reality (VR) intervention compared with conventional physiotherapy in upper limb function of children with CP.

Methods: Searches were undertaken in MEDLINE, EMBASE, PEDro, CENTRAL, Web of Science, CINAHL, ERIC, ICTRP, EU-CTR, ClinicalTrials.gov and EThOS databases. Only randomised-controlled trials (RCTs) were included. Two reviewers independently screened the search results, assessed full-text articles, extracted data and appraised the methodological quality by using the Cochrane collaboration's risk of bias (RoB2) tool. Albatross plots were used to synthesise the data.

Results: Seven RCTs, examining motor function in a total of 202 children with CP, included. Four trials used the Quality of Upper Extremity Skills Test (QUEST) as an outcome measure, and three trials used grip strength. These outcome measures were utilised to develop two Albatross plots. Data from the plots showed contradictory findings of the included studies.

Conclusions: The effect of VR in the upper limb rehabilitation of children with CP remains unclear. All included studies used commercial non-immersive VR games. Future high-quality clinical research is needed to explore the extent to which non-immersive and immersive VR is feasible and effective with children and adolescents.

ARTICLE HISTORY
Received 23 November 2021
Revised 6 April 2022
Accepted 24 April 2022

KEYWORDS
Brain injury; paediatric physiotherapy; upper limb impairments; technology; video games

➤ IMPLICATIONS FOR REHABILITATION

- The current evidence supporting the use of VR as a rehabilitative tool is weak and uncertain.
- The current use of VR relies only on commercial non-immersive VR (off-shelf) games, which are not adjustable to meet the demands and goals of therapy programmes.
- Future research is needed to study the therapeutic feasibility of immersive VR with children and adolescents.

Introduction

Cerebral palsy (CP) is an umbrella term for a wide range of neurological disorders of the development of movement and posture that occur in the early life of infants and children and persist throughout their life [1]. The aetiology of CP is attributed to a non-progressive lesion to the developing brain, resulting in motor impairments [2]. Globally, the estimated prevalence of CP is approximately 2.1 per 1000 live births [3]. In the United Kingdom, the estimated CP prevalence is between 2.5 and 3.4 per 1000 live births [4]. Impairments to the upper limb, comprising the shoulder girdle, elbow joint and hand joints, are a common consequence of CP and include muscle tightness or weakness, uncontrolled and/or limited movements, and deficits in coordination [1]. These impairments negatively impact children's ability to perform their daily activities (e.g., eating, brushing, writing) and increase their dependence on others to complete these tasks [5]. Eventually, these impairments lead to a decline in quality of life [6], but can be attenuated through physiotherapy programmes.

Physiotherapy programmes play a pivotal role in the management of patients with CP. Upper limb impairments impact on functional daily activities and independence, and the rehabilitation programme is an important component of optimising upper limb function [7]. Programmes consist of stretching techniques, strengthening exercises, movement facilitation techniques and positioning [8,9]. With current advances in technology, the use of virtual reality (VR) as a therapeutic tool is becoming more popular in CP rehabilitation because it has brought several benefits to the rehabilitation outcomes of children with CP [10–12]. Evidence has indicated that VR may have the potential to enhance brain plasticity and reorganisation through active engagement, auditory and/

CONTACT Craig A. Williams c.a.williams@exeter.ac.uk Children's Health and Exercise Research Centre, Sport & Health Sciences, University of Exeter, Exeter, UK

or visual feedback, and repetition of tasks, which all help to increase motor performance [12]. Furthermore, VR can increase the compliance level of children with CP and augment the effectiveness of conventional physiotherapy exercises [13].

Research has shown that the combination of VR and a rehabilitation programme can be a beneficial new therapeutic approach for children with CP [14,15]. This combined approach works crucially to enable children to use their upper limb more functionally by teaching new functional motor skills, sustaining the effects of exercises, and generally improving independence [16]. Several systematic reviews examining the effect of VR training on children and adolescents with CP have been conducted. The first conducted in 2019 by Rathinam et al. [16] reviewed the effect of VR on hand function only and neglected to account for the impact of all upper limb joints. The second was conducted in 2021 by Demers et al. [17] and examined the ways in which motor learning principles are incorporated into VR interventions targeting the upper limb. The third conducted in 2021 by Fandim et al. [18] studied the effect of VR on the upper limb but failed to provide information on the outcome measure tools that used in the included studies. Therefore, each review had limitations and the clinical interpretation of the findings is questionable. Furthermore, conflicting results from these reviews indicate the need for a new review that synthesises the effect of VR interventions on the upper limb function with greater transparency regarding the selected outcome measures. Therefore, the aim of this review was to evaluate and consolidate the existing literature regarding the effect of VR training compared with conventional physiotherapy programmes on the upper limb motor function of children with CP. In addition, this review sought to answer the following research question: Does VR training improve the upper limb motor function of children with CP compared with a conventional physiotherapy programme in clinical settings?

Materials and methods

This systematic review was structured in accordance with the Preferred Reporting of Items in Systematic Reviews and Meta-Analysis (PRISMA) guidelines and recommendations [19] (see Appendix 1). The protocol of this systematic review was prospectively registered on the international database of prospectively registered systematic reviews in health and social care (PROSPERO – registration number: CRD42021226462).

Search strategy

A comprehensive systematic search was undertaken in the following databases: MEDLINE (*via* Ovid), EMBASE (*via* Ovid), the Physiotherapy Evidence Database (PEDro), the Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, CINAHL, ERIC, International Clinical Trials Registry Platform (ICTRP), EU Clinical Trials Register (CTR), ClinicalTrials.gov and British Library e-theses Online service (EThOS) and Google Scholar. The search keywords were pre-structured based on relevance to the question of this review. Appendix 2 presents an example of the search strategy that was conducted initially in the MEDLINE database and then adapted to the other databases to meet their requirements.

Inclusion criteria

Only RCTs published in English were included that compared VR games to conventional therapy (e.g., resistance exercises, reach-to-grasp facilitation techniques, proprioceptive training or task-oriented training) and focused on any upper limb function as the primary outcome and conducted in a clinical setting. The justification for focusing only on the clinical settings is related to physiotherapists' practice and supervision in clinics when ensuring that the children are correctly performing the VR tasks without any substitution movements. Moreover, it has been shown that maintaining children's motivation after multiple weeks of VR practice at home can be challenging [20,21], and ensuring a clinical setting allows results to be translated to physiotherapy practice. No restrictions were applied on the date of publication or the type of the upper limb outcome measure. In terms of participants, children and adolescents with CP between the ages of 4 and 17 years were included, and no restrictions were applied based on the subtypes of CP (e.g., hemiplegic, quadriplegic) or the sex of participants.

Exclusion criteria

Other study designs (e.g., cohort, case report, case series, pilot studies) were excluded as well as studies conducted in home settings and those not available in English. Studies comparing VR and video games to a placebo or other intervention, such as hydrotherapy, electrotherapy or manual therapy, were also excluded.

Study selection and data extraction

The results of the database searches were imported into the Covidence systematic review software manager [22]. Two reviewers (MA & CW) independently screened the titles and abstracts of the studies and excluded any duplicate or irrelevant studies. The reference lists of all retrieved studies were also screened to find any additional relevant studies. The reviewers then screened the full text of the remaining studies and further exclusions were performed based on the pre-specified inclusion/exclusion criteria. The remaining studies were eligible for inclusion in the review. Any disagreement between the two reviewers were resolved through discussion until an agreement was reached or it was arbitrated by a third author (GB).

The following data were then extracted from the eligible studies and reported in an Excel spreadsheet:

- Setting and location (country)
- Participants (CP diagnosis, total sample, number and percentage of females, pooled age in years)
- Sample sizes randomised/analysed in both intervention and control groups
- Inclusion/exclusion criteria
- Intervention (type, frequency, duration, dose, adverse events)
- Control (type, frequency, duration)
- Details of outcome tools used
- Results
- Drop-outs/missing data

Methodological assessment

The methodological quality of the studies was independently appraised by the two reviewers using the Cochrane collaboration's risk of bias (RoB2) tool [23]. This tool is designed to appraise the quality of RCTs and comprises five domains, each consisting of a series of signalling questions that are delivered by algorithms [24]. The domains provide a rating of bias in the randomisation process, deviations from the intended intervention, missing outcome data, measurement of the outcome and

selection of the reported result. Each domain is evaluated separately as follows: "low," "some concerns" or "high," and at the end of the assessment, an overall bias judgement is made for each study based on the five domain scores.

Data synthesis and analysis

Given the substantial heterogeneity of the included studies, a meta-analysis was not undertaken. Instead, the data were analysed using the synthesis without meta-analysis (SWiM) technique [25]. Albatross plots were created using Stata SE 17 software [26]. An albatross plot is a graphical tool that assists in summarising multiple studies when meta-analysis is not possible [27]. This statistical technique requires only the standardised mean difference (SMD), p value, and the number of participants for each outcome in a single study [27]. The SMD was calculated from the post intervention means, standard deviations, and sample sizes from the included trials. The plot then generates contours that represent an estimate of effect sizes and indicates if there is a positive, negative or null association between the studies.

The certainty of the body of evidence was assessed using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach. This approach helps to rate the extent to which a body of evidence for each outcome in a review is certain and categorises it as high, medium, low or very low in certainty [28]. The evaluation for each outcome involves risk of bias, inconsistency, indirectness and imprecision. Two reviewers independently conducted the assessment using the GRADEpro software tool (GRADE Pro 10) [29], and disagreements were solved by discussion until a consensus was achieved. After consensus, one GRADE evidence summary table for two outcome measures was developed using the GRADEpro tool. In addition, the rating for each domain was scientifically justified and noted in the footnote of the table.

Differences between registered protocol and full review

- No study reported the outcome of interest that is the Peabody developmental motor Scale-Second Edition (PDMS-2).
- We used RoB2 instead of PEDro tool to appraise the methodological quality of the included studies because of its increased reliability to the PEDro scale.

Results

Study selection

The systematic search in the databases identified 1439 studies. No further studies were obtained from reviewing the reference lists of these articles. After duplicates were removed, the titles and abstracts of 1189 articles were screened from which 66 studies were assessed in full text. Of these, seven studies met the inclusion criteria, were included in the review, and were critically evaluated. Figure 1 shows the PRISMA flow diagram of the selection process.

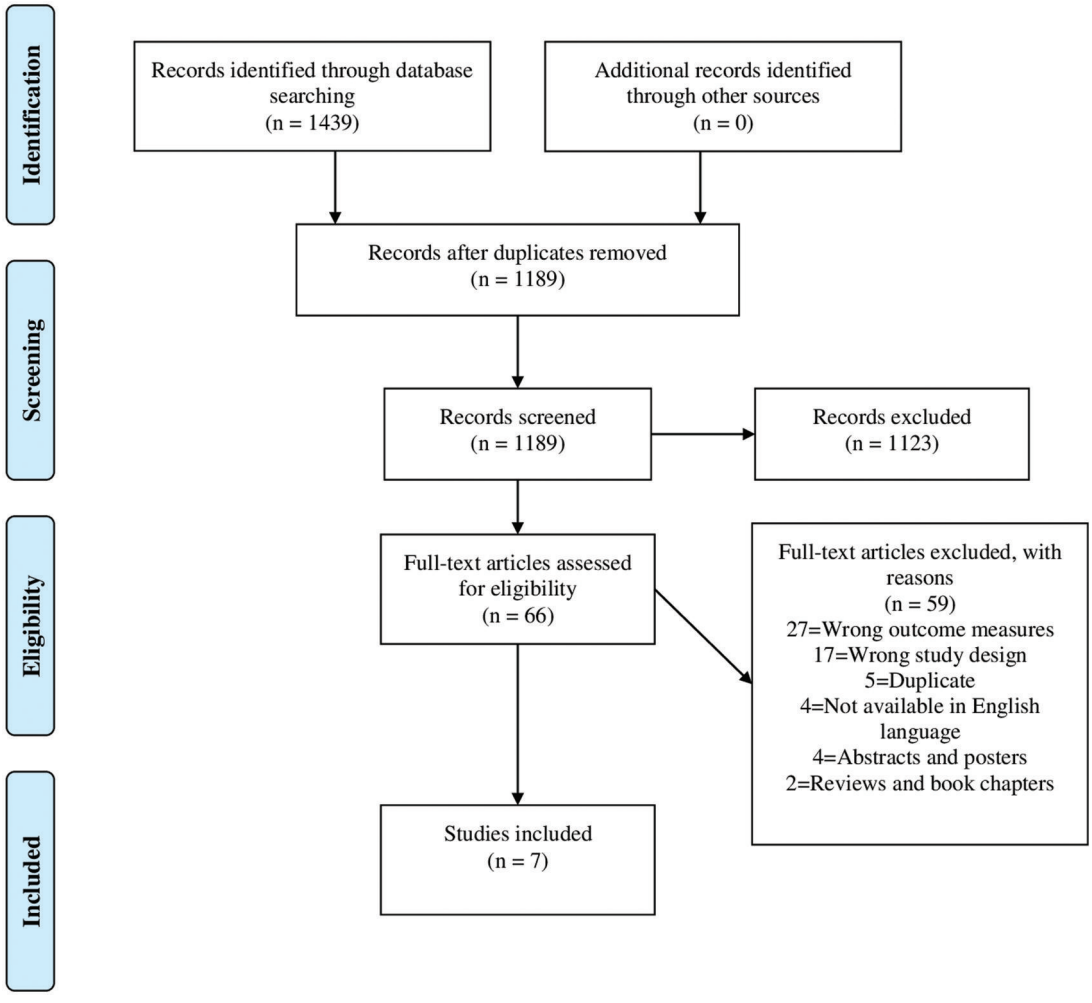

Figure 1. PRISMA flowchart for the selection process.

Characteristics of included studies

The characteristics of the included studies are presented in Table 1. Seven RCTs [15,30–35], with a total of 202 children with CP from 7 to 12 years of age (mean age = 9.5 years) were included. The sample sizes varied from 20 to 40 participants (mean = 30 participants). All studies were conducted in clinical settings and used VR and video games as an intervention compared to conventional rehabilitation exercises. Three studies were conducted in Turkey [30,31,34], two studies in Saudi Arabia [15,32], one study in India [33] and one study in Italy [35].

Methodological assessment

All included studies were critically appraised by two independent reviewers using RoB2 tool. The assessment for each outcome included the five domain ratings plus the overall judgement.

Table 1. Characteristics of the included studies.

Author (location)	Diagnosis total number (n female)	Intervention group age (years) (mean ± SD)	Control group age (years) (mean ± SD)	Outcome tools	Results
Acar et al. [30] (Turkey)	Unilateral CP 30 (16)	Nintendo® Wii plus NDT (45 min a session; 2 days a week for 6 weeks). (9.5 ± 3.1)	NDT only (45 min a session; 2 days a week for 6 weeks). (9.7 ± 2.8)	(a) QUEST, (b) JTHFT, (c) ABILHAND-Kids test, and d) Pediatric Functional Independence Measure (self-care)	Intervention and control groups had the same improvements on the above measures.
Avcil et al. [31] (Turkey)	Unilateral & bilateral CP 30 (13)	VGBT using Nintendo ® wii and LMC games (1 h per session; 3 days a week for 8 weeks). (10.9 ± 4.1)	NDT-based upper extremity therapy (1 h per session; 3 days a week for 8 weeks). (11.1 ± 3.2)	MMDT, CHAQ, DEI and grip and pinch strengths using a dynamometer.	The effects of both treatment programs on grip strengths and functional ability were similar beneficial.
El-Shamy [32] (Saudi Arabia)	Unilateral CP 30 (10)	Armeo robotic therapy (for upper limb – 45 min a session; 3 days a week for 12 weeks). (6.9 ± 0.8)	Conventional exercises (45 min a session; 3 days a week for 12 weeks). (6.8 ± 0.7)	MAS and QUEST	The study group showed significant improvement in the mean values of all the measured variables, compared to those in the control group ($p < 0.05$).
El-Shamy & El-Banna [15] (Saudi Arabia)	Unilateral CP 40 (14)	Wii training plus conventional exercises (40 min a session; 3 days a week for 12 weeks). (9.5 ± 1.2)	Conventional exercises (40 min a session; 3 days a week for 12 weeks). (9.8 ± 1.4)	MAS, hand-held dynamometry, and PDMS-2	The intervention group had: a decrease in the spasticity by 0.4 out of 4.0 (95% CI 0.1 to 0.8); power grip strength increased by 1.6 kg (95% CI 0.7–2.5) and pinch grip strength by 1.2 kg (95% CI 0.8–1.6); and Hand function (compared to the control group) increased by 6 out of 52 (95% CI 5–7).
Sajan et al. [33] (India)	Spastic diaplegic/triplegic/ quadriplegic CP 20 (9)	Wii games (boxing and tennis) for 45 min a session; 6 days a week for 3 weeks. Conventional exercises (Swiss ball exercises, visual-perceptual skills (e.g., ball throwing catching) and graded mobility training)	Conventional exercises (Swiss ball exercises, visual-perceptual skills (e.g., ball throwing and catching) and graded mobility training). No information regarding the conventional exercises' frequency and intensity.	Static posturography PBS; Box and Block Test; QUEST and TVPS	Significant improvement in upper limb functions was seen in the intervention group but not in the control group. For the other outcomes, there were no significant differences between the two groups.
Tarakci et al. [34] (Turkey)	Spastic and dyskinetic CP 30 (13)	LMC-based training (1 h a session; three sessions a week for 8 weeks). (10.9 ± 4.1)	Conventional exercises (1 h a session; three sessions a week for 8 weeks). (11.1 ± 3.2)	DHI, JTHFT, 9HPT, CHAQ, and a dynamometer.	After treatment, significant differences were found in CHAQ, DHI, JTHFT, 9HPT, and grip and pinch strength scores in almost all groups.
Zoccolillo et al. [35] (Italy)	Hemiparetic CP 22 (not stated)	VGT (1 h a session; 2 days a week for 8 weeks). (6.8 ± 1.9)	NDT (1 h a session; 2 days a week for 8 weeks). (6.8 ± 1.9)	QUEST and ABILHAND-Kids test	QUEST scores significantly improved in the VGT period ($p = 0.003$, from 76 ± 21 to 81 ± 20), but not in CT ($p = 0.056$). Both these improvements, of about 5 QUEST points after VGT and of about 2 Abilhand points achieved the respective minimal clinically important differences.

Abbreviations: CP: cerebral palsy; CT: conventional therapy; CI: confidence interval; SD: standard deviation; VGBT: video game-based therapy; LMC: leap motion controller; NDT: neurodevelopmental therapy; MMDT = Minnesota Manual Dexterity Test; CHAQ: Childhood Health Assessment Questionnaire; DHI: Duruoz Hand Index; 9HPT: nine-hole peg test; BOTMP-SF: Bruininks-Oseretsky Test of Motor Proficiency-Short Form; QUEST: Quality of Upper Extremity Skills Test; JTHFT: Jebsen Taylor Hand Function Test; PDMS-2: Peabody Developmental motor scale-2nd edition; MAS: Modified Ashworth Scale; PBS: The paediatric Berg's balance scale; TVPS: Test for Visual-Perceptual Skills.

Figure 2. Risk of bias assessment.

All included studies' outcomes demonstrated a high risk of bias (Figure 2).

Synthesis and analysis of results

Due to the diverse data in the included studies, two albatross plots were developed to synthesise two outcome measures; four trials [30,32,33,35] used the Quality of Upper Extremity Skills Test (QUEST) and three trials [15,31,34] used grip strength as an outcome measure. According to the pooled summary of the QUEST plot (Figure 3), only the study by El-Shamy [32] showed a highly significant improvement ($p < 0.001$) and a very large effect size for all subtests and the total score between intervention and control groups post the intervention. The other 3 trials did not find a difference between the intervention group and control group post intervention. However, Zoccolillo et al. [35] found a significant moderate effect size within the intervention group (pre-post change $p = 0.03$) for the total score (the study's authors did not measure the QUEST subtests). Acar et al. [30] found no significant differences between VR and control groups, though the grasp subtest was better in the control group. Interestingly, Sajan et al. [33] found a statistically significant improvement in the total score, grasp and dissociated movement subtests of QUEST in the VR group ($p = 0.027$) but not in the control group ($p = 0.109$). Regarding the pooled summary of the grip strength plot (Figure 4), El-Shamy and El-Banna [15] showed a very large effect size, whereas Avcil et al. [31] and Taracki et al. [34] showed a small effect size, and no statistical differences were found between groups.

Grading the evidence

According to the GRADE assessment, the certainty of the evidence that VR training is effective in improving upper limb motor function in children with CP were rated as very low (Table 2).

Discussion

The aim of the present study was to review the current evidence as to whether VR intervention is effective in the upper limb rehabilitation of children with CP compared with conventional physiotherapy. In summary, this systematic review found that the current evidence supporting the use of VR as a therapeutic tool in the upper limb rehabilitation of children with CP is weak. There is also a lack of high quality research studies comprising large sample sizes in VR and CP rehabilitation. Additionally, this review showed that the seven included studies reported conflicting results, and high risk of bias was identified across all these studies. Therefore, the effect of VR in the upper limb rehabilitation of CP children in clinical settings remains unclear and inconclusive. Our findings are similar to those reported by Fandim et al. [18] and Rathinam et al. [16], however, there are some important differences between our review and these reviews. The findings of Fandim and colleagues are difficult to interpret because they assessed the upper limb as an outcome without any clarification of the outcome measure tools used in the included studies. Rathinam and colleagues examined the effect of VR intervention on hand function only, while in our review, we examined the effect of VR intervention on all the upper limb functions, to have a broader scope of the role and effect of VR. Within rehabilitation practice, it can be difficult to neglect the salient involvement of elbow and shoulder joints in hand stability, movement, and function tasks.

The results of the study by El-Shamy [32] are consistent with those of Sajan et al. [33] who found that upper limb function improved significantly in the VR group but not in the control group (pre-post change). The VR training was very intensive in the studies by El-Shamy [32] and Sajan et al. [33] whose findings may be explained by the results of two meta-analyses [36,37], which found that the more intensive VR training is the more likely it is to obtain positive outcomes. Therefore, it could be argued that the positive results were due to the intensity of training, not the nature and/or quality of VR. Another possible explanation is that small-sample studies are more likely to result in larger effect

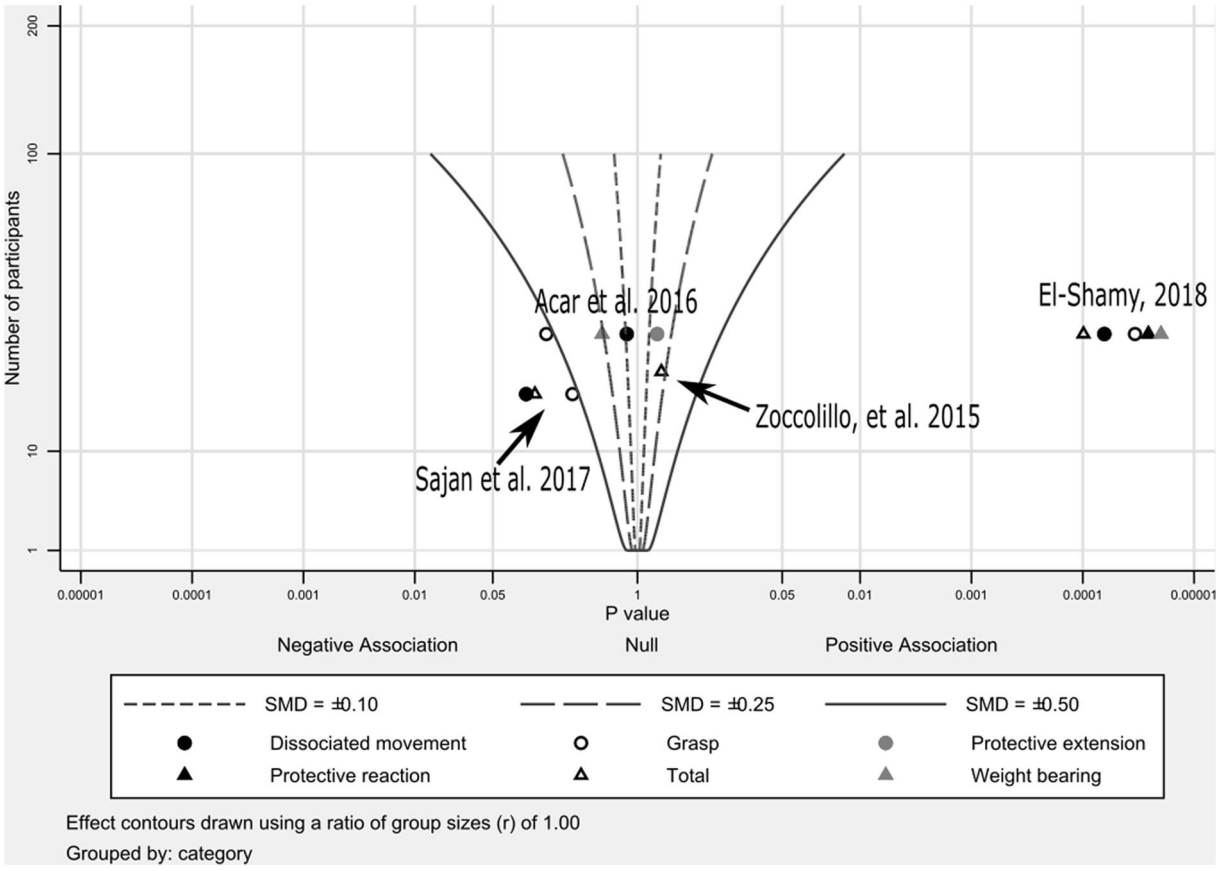

Figure 3. Albatross plot of QUEST.

Table 2. Certainty of the evidence (GRADE).

	Certainty assessment						No. of patients		Certainty	
No. of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other consideration	Intervention	Control	Overall score	Comments
QUEST (follow-up: mean 12 weeks; assessed with Questionnaire)										
4	Randomised trials	Very serious[a]	Very serious[b]	Not serious[c]	Very serious[c,d]	None	51	51	⨁◯◯◯ VERY LOW	The evidence is very uncertain about the effect of VR interventions on QUEST outcomes.
Grip strength (assessed with hand-held dynamometry)										
3	Randomised trials	Very serious[a]	Not serious[b]	Not serious[c]	Very serious[c,d]	None	50	50	⨁◯◯◯ VERY LOW	The evidence is very uncertain about the effect of VR interventions on grip strength outcomes.

Abbreviation: QUEST: quality of upper extremity skills test.
Explanations:
[a]Judged "High" using Cochrane Risk of Bias 2.
[b]Downgraded two levels. Methodological diversity between populations and interventions. Unable to pool in meta-analysis due to variability in reporting (i.e., some studies reported sub tests and/or total scores). Effect sizes between studies were very diverse.
[c]<400 participants in the analysis (Ryan, 2016).
[d]Imprecise estimate due to large variability in effect sizes between studies.

sizes compared to large-sample studies and the effect sizes in small studies are more highly variable than large studies [38]. This may introduce a potential risk of publication bias, as studies with negative results are less likely to be published [39]. Zoccolillo et al. [35] and Shin et al. [40] similarly found that a VR group has better hand improvement compared to control group. Although the results of Zoccolillo and colleagues showed positive outcomes with VR, the data might not be externally valid to support the benefits of VR in upper limb rehabilitation because the study relied on a very small sample size (eight in the VR group and 11 in the conventional group). Furthermore, the data from Zoccolillo et al. [35] should be interpreted with caution due to its high

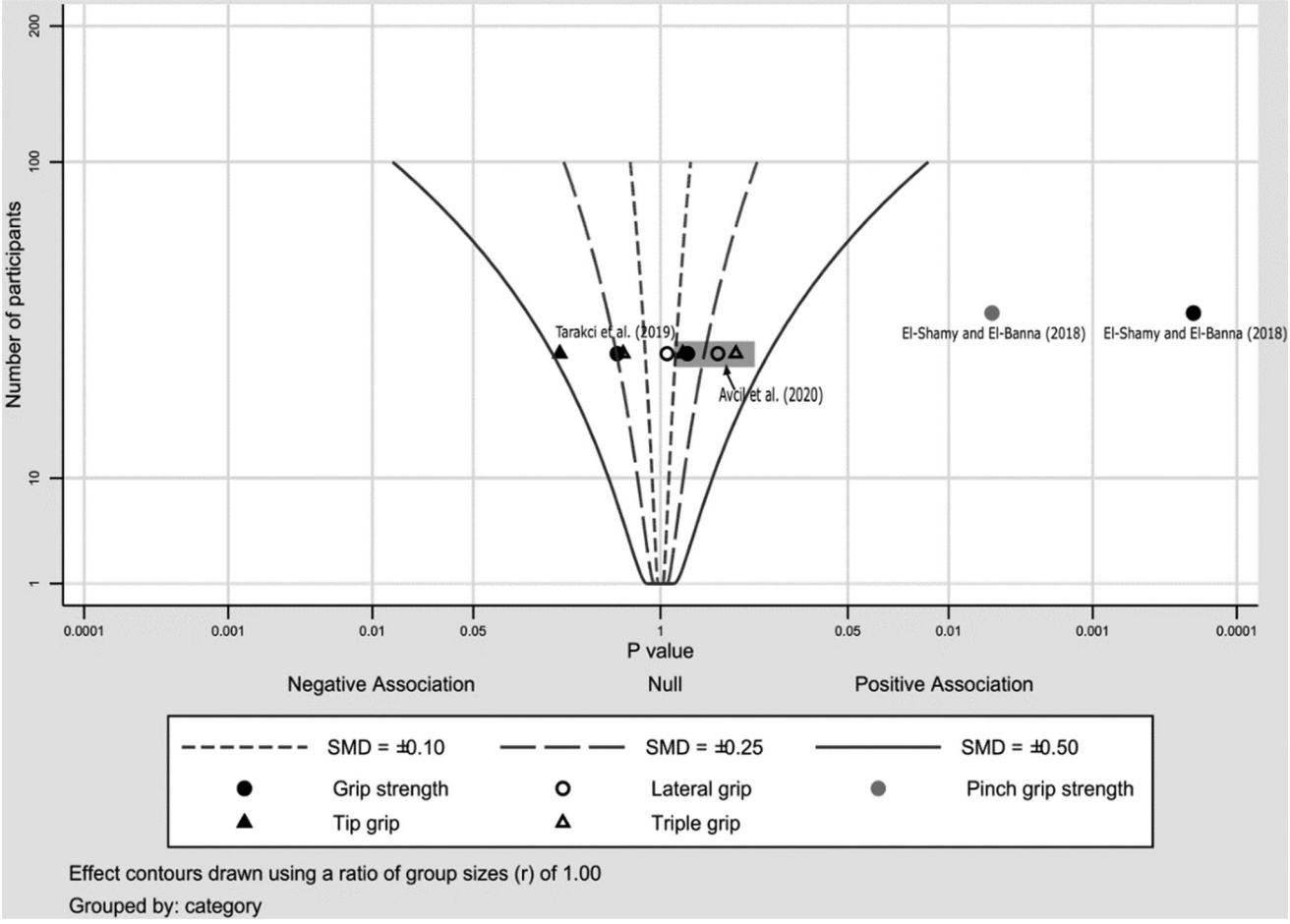

Figure 4. Albatross plot of Grip strength.

drop-out rate (41%; 9 out of 22), with four participants dropping out in the first phase and a further five dropping out in the wash-out phase. Contrary to the previous three trials, Acar et al. [30] did not find a significant difference between the VR and control groups, a finding that was similarly reported by Bedair et al. [41]. A possible explanation for the results of Acar et al. [30] may be attributed to insufficient exposure to VR training, as the children in the VR group received only 15 min of Wii training per session, while the control group received conventional exercises for 45 min per session.

The grip strength findings of El-Shamy and El-Banna [15] showed a very large effect size for the VR group, which may be related to the intensive VR training and/or may stem from the small sample size present in this study. It may also be that these participants in the VR group benefitted from the additional one hour of conventional physiotherapy, including passive stretching for upper limb flexors, strengthening of upper limb extensors, weight-bearing exercises for the upper limbs, and hand facilitation techniques for reach to grasp and hand manipulation skills, Moreover, the researchers reported that children's compliance during the 12 weeks was good, which is an indication of the potential of VR and video games to provide a motivational environment in CP rehabilitation. In the study by Avcil et al. [31], VR was found to cause a slight but significant improvement in the grip strength compared to the control group. This study supports evidence from previous research that found VR can improve the upper limb motor function of children with CP [42]. However, with a small sample size, caution should be exercised, and the findings might not be generalisable to the whole CP population. The findings from Tarakci et al. showed that the conventional programme was as effective as VR in all subtests of grip strength. These results reflect those of Chiu et al. [43] who also found that VR was as effective in improving the hand function and strength as conventional exercises.

As with all studies there are a number of limitations to consider. A potential limitation of this review is that we excluded non-RCTs, and this might have caused us to eliminate important data from other experimental studies. Also, we did not examine the safety of using VR intervention with children. In this review the findings were based on only two outcome measures (i.e., QUEST and grip strength), and this might have caused us to exclude evidence that used whole-body outcome measures that also include elements pertaining to the upper limb. From a clinical perspective, it is a questionable whether the grip strength is a comprehensive enough outcome measure. It can provide an insight about the hand strength, but not dexterity, endurance and/or function; and therefore, future studies need to carefully consider the selection of primary outcome measures and consider that the selected measures should be ecologically valid, to ensure more meaningful rehabilitation outcomes are reflected in daily activities. It is worth mentioning that there are limitations related to the current published literature; for example, the included studies were diversely reported and used heterogeneous protocols and small sample sizes. Future research with more robust, valid and consistent protocols and large-sample sizes is therefore suggested. Also, a high risk of bias was found in all included

studies. Therefore, future studies need to consider the randomisation sequence and ensure how this sequence is concealed from assessors. Additionally, future studies should be more transparent in reporting how the allocation concealment was met.

We noted that all included studies used commercial non-immersive VR, which is not designed for paediatric rehabilitation and thus may not have the necessary adjustments for the therapeutic demands and goals. However, evidence shows that non-immersive VR is a useful tool for maintaining the long-term effect of exercises and for use during home exercise rather than in the clinical environment [37]. Immersive VR (iVR), such as head-mounted displays, provides a three-dimensional environment in which the users can interact with virtual tasks [44]. The low cost and portability of this type of VR make it likely to become more popular and accessible. Moreover, this type of VR can help clinicians to individualise virtual tasks to meet each patient's goals, which could be justified by the flexibility of the computerised ecosystem compared to the closed commercial video games. Equally important, iVR can help assess patient prognosis by capturing movement kinematics *via* the included cameras and controllers [45]. Despite these promising traits, there is no evidence regarding the iVR with children and adolescents with CP, and this would thus be a fruitful area for further research. To develop a full and initial picture about the role of iVR in CP rehabilitation, future research is required to initially establish the viability of iVR with children and adolescents without CP to provide evidence that iVR is feasible to be used as a therapeutic tool with children with CP. Also, the prolonged exposure to iVR can provoke motion sickness symptoms, e.g., nausea, dizziness, disorientation [46], and this can be an important point to consider in future research to investigate the adverse effects of using iVR with children. The current evidence explained that integrating a new therapeutic intervention into clinical practice may pose some barriers and challenges [47]; therefore, future research is needed to explore the potential barriers and/or challenges to implementation of iVR in CP rehabilitation.

Conclusion

This study found that the evidence that VR utilisation improves two important outcomes measurements (i.e., QUEST and grip strength) of upper limbs is uncertain. Currently, better designed and more robust data is required before it is possible to conclude about the utilisation of VR in CP physiotherapy practice. This review also showed that the current use of VR in CP rehabilitation relies only on non-immersive VR. Therefore, future clinical practice and research is needed to explore the extent to which iVR is feasible and effective for children and adolescents with CP.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This review was funded by the external scholarship programme of the Ministry of Education in Saudi Arabia.

ORCID

Mohammed Alrashidi http://orcid.org/0000-0003-0439-592X
Curtis A. Wadey http://orcid.org/0000-0003-3275-7975
Gavin Buckingham http://orcid.org/0000-0002-6950-5504
Craig A. Williams http://orcid.org/0000-0002-1740-6248

References

[1] Richards CL, Malouin F. Cerebral palsy: definition, assessment and rehabilitation. Handb Clin Neurol. 2013;111:183–195.
[2] Gulati S, Sondhi V. Cerebral palsy: an overview. Indian J Pediatr. 2018;85(11):1006–1016.
[3] Oskoui M, Coutinho F, Dykeman J, et al. An update on the prevalence of cerebral palsy: a systematic review and meta-analysis. Dev Med Child Neurol. 2013;55(6):509–519.
[4] Carter B, Verity Bennett C, Bethel J, et al. Identifying cerebral palsy from routinely-collected data in England and Wales. Clin Epidemiol. 2019;11:457–468.
[5] Basu AP, Pearse J, Kelly S, et al. Early intervention to improve hand function in hemiplegic cerebral palsy. Front Neurol. 2014;5:281.
[6] Sakzewski L, Ziviani J, Boyd RN. Efficacy of upper limb therapies for unilateral cerebral palsy: a meta-analysis. Pediatrics. 2014;133(1):e175–e204.
[7] Baxter JA, Nixon MF. Upper limb problems in children with cerebral palsy. In: Paediatric orthopaedics. New York: Springer; 2017. p. 393–399.
[8] Hoare BJ, Wallen MA, Imms C, et al. Botulinum toxin A as an adjunct to treatment in the management of the upper limb in children with spastic cerebral palsy. Cochrane Database Syst Rev. 2004;(3):CD003469.
[9] Martin L, Baker R, Harvey A. A systematic review of common physiotherapy interventions in school-aged children with cerebral palsy. Phys Occup Ther Pediatr. 2010;30(4):294–312.
[10] Riener R, Dislaki E, Keller U, et al. Virtual reality aided training of combined arm and leg movements of children with CP. In: Medicine meets virtual reality 20. Amsterdam: IOS Press; 2013. p. 349–355.
[11] Sharan D, Ajeesh PS, Rameshkumar R, et al. Virtual reality based therapy for post operative rehabilitation of children with cerebral palsy. Work. 2012;41(Suppl 1):3612–3615.
[12] Snider L, Majnemer A, Darsaklis V. Virtual reality as a therapeutic modality for children with cerebral palsy. Dev Neurorehabil. 2010;13(2):120–128.
[13] Bryanton C, Bossé J, Brien M, et al. Feasibility, motivation, and selective motor control: virtual reality compared to conventional home exercise in children with cerebral palsy. Cyberpsychol Behav. 2006;9(2):123–128.
[14] Chang HJ, Ku KH, Park YS, et al. Effects of virtual Reality-Based rehabilitation on upper extremity function among children with cerebral palsy. Healthcare (Basel). 2020;8(4):391.
[15] El-Shamy SM, El-Banna MF. Effect of wii training on hand function in children with hemiplegic cerebral palsy. Physiother Theory Pract. 2020;36(1):38–44.
[16] Rathinam C, Mohan V, Peirson J, et al. Effectiveness of virtual reality in the treatment of hand function in children with cerebral palsy: a systematic review. J Hand Ther. 2019;32(4):426–434. e1.
[17] Demers M, Fung K, Subramanian SK, et al. Integration of motor learning principles into virtual reality interventions for individuals with cerebral palsy: systematic review. JMIR Serious Games. 2021;9(2):e23822.

[18] Fandim JV, Saragiotto BT, Porfírio GJM, et al. Effectiveness of virtual reality in children and young adults with cerebral palsy: a systematic review of randomized controlled trial. Braz J Phys Ther. 2021;25(4):369–386.
[19] Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med. 2009;151(4):264–269.
[20] Golomb MR, McDonald BC, Warden SJ, et al. In-home virtual reality videogame telerehabilitation in adolescents with hemiplegic cerebral palsy. Arch Phys Med Rehabil. 2010;91(1):1–8.e1.
[21] James S, Ziviani J, King G, et al. Understanding engagement in home-based interactive computer play: perspectives of children with unilateral cerebral palsy and their caregivers. Phys Occup Ther Pediatr. 2016;36(4):343–358.
[22] Covidence, Covidence: better systematic review management. 2020. Available from: https://www.covidence.org/reviewers/
[23] Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ. 2019;366:l4898.
[24] Higgins J, et al. Assessing risk of bias in a randomized trial. Cochrane Handb Syst Rev Interv. 2019;6:205–228.
[25] Campbell M, McKenzie JE, Sowden A, et al. Synthesis without Meta-analysis (SWiM) in systematic reviews: reporting guideline. BMJ. 2020;368:l6890.
[26] StataCorp LLC. Stata: software for statistics and data science. In: Stata longitudinal-data/panel-data reference manual release. 2019;16. Available from: https://www.stata.com/support/faqs/resources/citing-software-documentation-faqs/
[27] Harrison S, Jones HE, Martin RM, et al. The albatross plot: a novel graphical tool for presenting results of diversely reported studies in a systematic review. Res Synth Methods. 2017;8(3):281–289.
[28] Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008;336(7650):924–926.
[29] Basu A. How to appraise a body of evidence using GRADE system and GRADEPro: a step by step tutorial for the perplexed. Qeios. 2020. DOI:10.32388/2C2WG8
[30] Acar G, Altun GP, Yurdalan S, et al. Efficacy of neurodevelopmental treatment combined with the Nintendo(®) Wii in patients with cerebral palsy. J Phys Ther Sci. 2016;28(3):774–780.
[31] Avcil E, Tarakci D, Nilay Arman S, et al. Upper extremity rehabilitation using video games in cerebral palsy: a randomized clinical trial. Acta Neurol Belg. 2020;121(4):1053–1060.
[32] El-Shamy SM. Efficacy of Armeo® robotic therapy versus conventional therapy on upper limb function in children with hemiplegic cerebral palsy. Am J Phys Med Rehabil. 2018;97(3):164–169.
[33] Sajan JE, John JA, Grace P, et al. Wii-based interactive video games as a supplement to conventional therapy for rehabilitation of children with cerebral palsy: a pilot, randomized controlled trial. Dev Neurorehabil. 2017;20(6):361–367.
[34] Tarakci E, Arman N, Tarakci D, et al. Leap motion controller-based training for upper extremity rehabilitation in children and adolescents with physical disabilities: a randomized controlled trial. J Hand Ther. 2020;33(2):220–228.e1.
[35] Zoccolillo L, et al. Video-game based therapy performed by children with cerebral palsy: a cross-over randomized controlled trial and a cross-sectional quantitative measure of physical activity. Eur J Phys Rehabil Med. 2015;51(6):669–676.
[36] Arpino C, Vescio MF, De Luca A, et al. Efficacy of intensive versus nonintensive physiotherapy in children with cerebral palsy: a meta-analysis. Int J Rehabil Res. 2010;33(2):165–171.
[37] Chen Y, Fanchiang HD, Howard A. Effectiveness of virtual reality in children with cerebral palsy: a systematic review and meta-analysis of randomized controlled trials. Phys Ther. 2018;98(1):63–77.
[38] Faber J, Fonseca LM. How sample size influences research outcomes. Dental Press J Orthod. 2014;19(4):27–29.
[39] Mlinarić A, Horvat M, Smolčić VŠ. Dealing with the positive publication bias: why you should really publish your negative results. Biochem Med (Zagreb). 2017;27(3):030201–030452.
[40] Shin J-W, Song G-B, Hwangbo G. Effects of conventional neurological treatment and a virtual reality training program on eye-hand coordination in children with cerebral palsy. J Phys Ther Sci. 2015;27(7):2151–2154.
[41] Bedair R, Al-Talawy H, Shoukry K, et al. Impact of virtual reality games as an adjunct treatment tool on upper extremity function of spastic hemiplegic children. Int J PharmTech Res. 2016;9(6):1–8.
[42] Şahin S, Köse B, Aran OT, et al. The effects of virtual reality on motor functions and daily life activities in unilateral spastic cerebral palsy: a single-blind randomized controlled trial. Games Health J, 2020;9:45–52.
[43] Chiu H-C, Ada L, Lee H-M. Upper limb training using wii sports Resort for children with hemiplegic cerebral palsy: a randomized, single-blind trial. Clin Rehabil. 2014;28(10):1015–1024.
[44] Robert MT, Ballaz L, Lemay M. The effect of viewing a virtual environment through a head-mounted display on balance. Gait Posture. 2016;48:261–266.
[45] Voigt-Antons J-N, Kojic T, Ali D, et al. Influence of hand tracking as a way of interaction in virtual reality on user experience. In 2020 Twelfth International Conference on Quality of Multimedia Experience (QoMEX). IEEE; 2020. p. 1-4.
[46] Munafo J, Diedrick M, Stoffregen TA. The virtual reality head-mounted display oculus rift induces motion sickness and is sexist in its effects. Exp Brain Res. 2017;235(3):889–901.
[47] Levac DE, Miller PA. Integrating virtual reality video games into practice: clinicians' experiences. Physiother Theory Pract. 2013;29(7):504–512.

Appendix 1. PRISMA checklist

Section and Topic	Item #	Checklist item	Page where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	2
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	4 & 5
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	5
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	5 & 6
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	5 & 6
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g., for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	5 & 6
	10 b	List and define all other variables for which data were sought (e.g., participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	8
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	6
Effect measures	12	Specify for each outcome the effect measure(s) (e.g., risk ratio, mean difference) used in the synthesis or presentation of results.	
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g., tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	5
	13 b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	7
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	7
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g., subgroup analysis, meta-regression).	
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	7
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	7
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	7 & 8
	16 b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	8
Study characteristics	17	Cite each included study and present its characteristics.	8
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	8
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g., confidence/credible interval), ideally using structured tables or plots.	9
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	9
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g., confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	9
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	

(*continued*)

Appendix 1. Continued.

Section and Topic	Item #	Checklist item	Page where item is reported
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	9
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	9
	23b	Discuss any limitations of the evidence included in the review.	12
	23c	Discuss any limitations of the review processes used.	12
	23d	Discuss implications of the results for practice, policy, and future research.	9,10,11,12
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	4
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	4
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	13
Competing interests	26	Declare any competing interests of review authors.	13
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	

Appendix 2. Search strategy

Database: Ovid MEDLINE(R) ALL <1946 to March 15, 2022>

Search Strategy:

1. cerebral palsy.mp. (41658)
2. virtual reality.mp. (23481)
3. virtual gam*.mp. or virtual reality exposure therapy/(813)
4. video gam*.mp. (7245)
5. exergam*.mp. (842)
6. augmented reality.mp. or augmented reality/(3023)
7. mixed reality.mp. (507)
8. 2 or 3 or 4 or 5 or 6 or 7 (32810)
9. conventional physiotherapy.mp. (596)
10. functional training.mp. or functional training/(1711)
11. exercise therapy.mp. (5916)
12. upper limb therapy.mp. (125)
13. hand function*.mp. (11051)
14. 9 or 10 or 11 or 12 or 13 (19218)
15. 1 and 8 and 14 (39)