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Original Article

Physiotherapy Section

Exploring Virtual Reality's Effects on Balance, Function, Daily Activities and Quality of Upper Limb Skills in Children with Hemiplegic Cerebral Palsy: A Systematic Review and Meta-analysis

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ABSTRACT

Introduction: Hemiplegic Cerebral Palsy (CP) significantly affects balance, functional abilities, daily activities, and overall quality of upper extremity skills. Virtual Reality (VR) can enhance the quality of life in children with CP by controlling training intensity and providing feedback to deliver customised treatment in a fun, safe, and engaging environment.

Aim: To examine the effectiveness of VR on balance, functional abilities, daily activities, and the quality of upper limb skills in children with hemiplegic CP.

Materials and Methods: A systematic search of Web of Science, Physiotherapy Evidence Database (PEDro), EBSCO, Medical Literature Analysis and Retrieval System Online (MEDLINE), Scopus, Excerpta Medica database (EMBASE) and ProQuest was conducted for articles published between March 2014 and September 2024. Randomised Controlled Trials (RCTs) were included if the sample comprised children with hemiplegic CP and reported outcomes related to balance, function, daily activities, and upper limb skills. Pre and postintervention mean differences, standard deviations, 95% Confidence Intervals (CI), and p-values were calculated, along with the difference between intervention and control groups after treatment. Random-effects models were used to interpret pooled effects based on improvements in balance, function, daily activities, and upper limb skill quality. Heterogeneity was assessed using the I^2 statistic.

Results: Fifteen randomised trials were included. Results revealed significant improvements in the VR groups compared to the control groups for balance (MD 4.84; 95% CI: 1.44-8.23; $p<0.05$), hand function (MD 2.05; 95% CI: 0.17-3.92; $p=0.03$), and upper extremity skill quality (MD 5.12; 95% CI: 3.50-6.74; $p<0.05$). However, no significant improvement was observed for Activities of Daily Living (ADL) (MD 0.86; 95% CI: -8.93 to 7.21; $p=0.83$).

Conclusion: VR-based rehabilitation may improve balance, functional abilities, and upper extremity skill quality more effectively than conventional rehabilitation in children with CP. However, VR did not show a significant effect on activities of daily living.

Keywords: Cerebral palsy, Motor function, Rehabilitation, Virtual reality-based games

INTRODUCTION

Cerebral Palsy (CP) is the most common cause of disability in children. It is a non-progressive motor disorder that evolves with age [1]. Motor dysfunction in CP often coexists with sensory, cognitive, communication, and behavioural challenges [2]. The incidence of CP has been increasing, frequently resulting in neurological impairments in children worldwide. Hemiplegic CP affects one side of the body and accounts for approximately 20%-30% of all CP cases [3], with a greater impact on the upper limb than the lower limb [4].

Children with hemiplegic CP typically exhibit poor sensory processing, reduced motor function, muscle weakness, and spasticity, particularly in the upper limb [5]. They also experience limitations in ADL and reduced quality of life [6,7].

Early and continuous rehabilitation is essential to prevent secondary complications associated with CP. Rehabilitation programs promote daily participation and improve functional abilities in children [8]. Advances in technology offer innovative rehabilitation strategies that may enhance social engagement and provide motivating therapeutic experiences [9,10].

VR is an artificial environment that enables interaction between the user and computer-generated sensory inputs-such as visuals and sounds-to observe the effects of their actions on the environment. VR has been widely used in healthcare settings for therapeutic purposes [11].

Various VR systems-including Xbox Kinect, Nintendo Wii, and video game based platforms-have been explored for improving motor function in children with CP [12].

VR offers several advantages in paediatric rehabilitation. It provides an engaging setting in which children can perform high-intensity exercises for longer durations and more frequently. It creates a realistic and safe environment for practicing task-specific activities while delivering immediate visual and auditory feedback. The difficulty level can be adjusted to match the child's capabilities, and task-oriented training enhances motor skill development through neuroplasticity. VR also boosts motivation and engagement through interactive game elements and animations. Moreover, it offers opportunities for social interaction during gameplay, encouraging support from parents, peers, and caregivers. VR-based programs can therefore improve functional abilities-such as range of motion, strength, reaching, grasping, and mobility-and positively influence personal factors like motivation and confidence [13,14].

Previous systematic reviews have reported positive effects of VR on children with CP. Rathinam C et al., examined improvements in hand functions [15]; Ren Z and Wu J studied VR's effects on motor skills [16]; and Warnier N et al., evaluated its impact on balance and gait in CP children [17].

However, none of the previous research has specifically examined the effect of VR on balance, functional abilities, ADL, and the quality of upper extremity skills in children with hemiplegic CP. Therefore, the present review aims to evaluate the effectiveness of VR on balance, functional abilities, daily activities, and the quality of upper limb skills in children with hemiplegic CP.

MATERIALS AND METHODS

The present review is registered in the International Prospective Register of Systematic Reviews (PROSPERO) database (CRD42024535464) and follows Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for conducting systematic reviews and meta-analyses.

Search Strategy

A comprehensive search was conducted across multiple databases including Web of Science, PEDro, EBSCO, MEDLINE, Scopus, EMBASE, and ProQuest. Studies published between March 2014 and September 2024 were considered for inclusion. The following keywords and their combinations were used:

("Hemiplegic Cerebral Palsy" OR "hemiplegic CP") AND ("virtual reality" OR VR OR "virtual games" OR videogame OR "augmented reality" OR "mixed reality" OR "Wii games" OR "Nintendo Wii" OR Wii OR "exergaming" OR Xbox OR "Xbox Kinect" OR "Wii controller").

Two authors collaboratively selected keywords and controlled vocabulary to ensure comprehensive coverage. All alternative keywords were included in each search trial, and search results were recorded separately for each database [Table/Fig-1].

Database	Keywords	Hits
Web of science	("Hemiplegic Cerebral palsy OR hemiplegic CP") AND ("virtual reality" OR VR OR "virtual games" videogame OR "augmented reality" OR "mixed reality" OR "Wii games" OR "Nintendo Wii" OR Wii OR "exergaming" OR (Xbox) OR (Xbox Kinect) OR (Wii controller).	87
PEDro	("Hemiplegic Cerebral palsy OR hemiplegic CP") AND ("virtual reality" OR VR OR "virtual games" videogame OR "augmented reality" OR "mixed reality" OR "Wii games" OR "Nintendo Wii" OR Wii OR "exergaming" OR (Xbox) OR (Xbox Kinect) OR (Wii controller).	43
EBSCO	("Hemiplegic Cerebral palsy OR hemiplegic CP") AND ("virtual reality" OR VR OR "virtual games" videogame OR "augmented reality" OR "mixed reality" OR "Wii games" OR "Nintendo Wii" OR Wii OR "exergaming" OR (Xbox) OR (Xbox Kinect) OR (Wii controller).	98
MEDLINE	("Hemiplegic Cerebral palsy OR hemiplegic CP") AND ("virtual reality" OR VR OR "virtual games" videogame OR "augmented reality" OR "mixed reality" OR "Wii games" OR "Nintendo Wii" OR Wii OR "exergaming" OR (Xbox) OR (Xbox Kinect) OR (Wii controller).	19
Scopus	("Hemiplegic Cerebral palsy OR hemiplegic CP") AND ("virtual reality" OR VR OR "virtual games" videogame OR "augmented reality" OR "mixed reality" OR "Wii games" OR "Nintendo Wii" OR Wii OR "exergaming" OR (Xbox) OR (Xbox Kinect) OR (Wii controller).	44
EMBASE	("Hemiplegic Cerebral palsy OR hemiplegic CP") AND ("virtual reality" OR VR OR "virtual games" videogame OR "augmented reality" OR "mixed reality" OR "Wii games" OR "Nintendo Wii" OR Wii OR "exergaming" OR (Xbox) OR (Xbox Kinect) OR (Wii controller).	63
ProQuest	("Hemiplegic Cerebral palsy OR hemiplegic CP") AND ("virtual reality" OR VR OR "virtual games" videogame OR "augmented reality" OR "mixed reality" OR "Wii games" OR "Nintendo Wii" OR Wii OR "exergaming" OR (Xbox) OR (Xbox Kinect) OR (Wii controller).	50

[Table/Fig-1]: Searching strategy for each database.

Rayyan Qatar Computing Research Institute (QCRI) software was used to support the screening process, improve reviewer collaboration, and ensure accurate eligibility assessment [18].

Inclusion criteria: The Population {(or Patient/Problem), Intervention, Comparison, and Outcome (PICOS)} framework was applied to determine the eligibility criteria:

1. Population: Children with hemiplegic CP, aged ≤18 years.
2. Intervention: Studies evaluating VR-based interventions.
3. Comparators: Studies with control groups receiving no intervention, conventional therapy, or alternative rehabilitation approaches.
4. Outcomes: Primary outcomes included improvements in balance, functional abilities, daily activities, and upper extremity skill quality.
5. Study Design: Randomised Controlled Trials (RCTs).

Exclusion criteria:

1. Non-English publications.
2. Non-randomised designs (observational studies, case reports, surveys, editorials).
3. Studies not focused on VR interventions for CP.

Data Extraction

Data were organised into a table including author name, publication year, study design, participant characteristics, Modified Ashworth Scale (MAS), Gross Motor Function Classification System (GMFCS), intervention details (VR model, method, and type), comparator intervention, outcome measures, and conclusions.

Microsoft Excel was used for data extraction. Two authors (AI and HH) performed the extraction, and a third author (AR) verified the data. Full-text articles meeting preliminary criteria were reviewed in detail. Additional studies were identified through manual reference list screening.

After removing duplicates, screening was performed using Rayyan QCRI software. Two authors (MS and AR) independently reviewed titles, abstracts, and full texts. A third author (AA) resolved any disagreements.

Quantitative Data Analysis

Statistical analysis was conducted using Review Manager software (version 5.4). Pre and postintervention mean differences, standard deviations, 95% confidence intervals, p-values, and between-group differences were calculated. Random-effects models were used to evaluate pooled outcomes for balance, functional abilities, daily activities, and upper limb skills. Heterogeneity was assessed using I^2 statistics [19].

Quality Assessment

Two authors (HH and AI) independently assessed study quality using the PEDro scale, with disagreements resolved by a third author (AR). The PEDro scale is a validated tool widely used for evaluating RCT quality [20], classifying studies into:

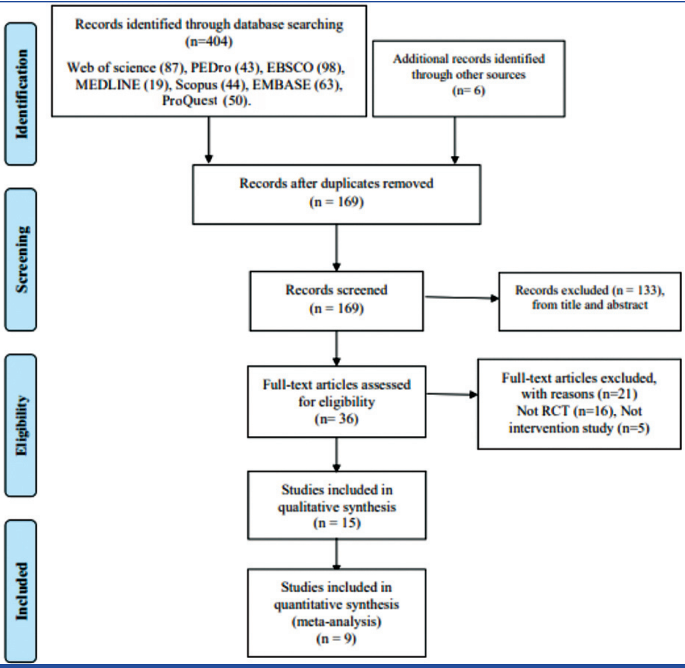
- Poor: <4
- Fair: 4-5
- Good: 6-8
- Excellent: 9-10

Additionally, the modified Sackett scale was used to determine the level of evidence for each study [21].

RESULTS

Study selection: According to the initially conducted search, our findings yielded 404 trials: Web of Science (87), PEDro (43), EBSCO (98), MEDLINE (19), Scopus (44), EMBASE (63), ProQuest (50), along with additional six studies identified through other sources (n= 6). After final screening 15 trials were included [Table/Fig-2].

Characteristics of included studies: These 15 trials involved 622 CP children, all aged ≤18-year-old, including the design, sample, MAS, GMFCS, intervention, comparative intervention, outcomes



[Table/Fig-2]: PRISMA flow diagram.

measurements, and the conclusion of each trial. Only thirteen trials from the included studies used the GMFCS as a baseline assessment for children, with GMFCS ranging between Level I-V [Table/Fig-3] [4,22-35].

The methods embraced in these studies were intentionally chosen to represent different types of VR applications, including different VR devices, such as Wii Fit training (Wii-Balance) [4,28,31], Nintendo® wii [25,26,30,32,34,35], Constraint-Induced Therapy (CIT) [23], Armeo Robotic Therapy [27], Kinect-based VR (games) used by şahin S et al., (2020) [24], multimodal web-based therapy (MitiiTM) utilised by James S et al., (2015) [29], and Oculus Quest 128GB immersive-type VR glasses used by Menekseoglu AK et al., (2023) [22]. The frequency of VR sessions ranged from 20 to 60 minutes, two to three days per week, for 4 to 12 weeks.

Quality assessment: Using the PEDro scale, a quality assessment was performed on the included studies. Three studies were of poor quality with an evidence level of 2b (limited) [30,33,35], six studies were rated fair [23-25,28,32,34] with an evidence level of 2a (limited), five studies were rated good [4,22,26,27,29] with a moderate level of evidence (1b), and one study was of excellent quality with a strong level of evidence (1a) [31], based on the Modified Sackett Scale [Table/Fig-4] [21].

Study	Design	Subject characteristics	MAS	GMFCS	Intervention	Comparative intervention	Outcome parameters	Conclusion
Korney SS et al., 2024 [4]	Double blinded randomised comparative study	36 children of both sexes with unilateral Cerebral Palsy (CP). Age 6-10 years	1-2	levels I and II	Videogame -VR 3 months, 3 days per week, 60 min per day	Mirror therapy 3 months, 3 days per week, 60 min per day	Balance, muscle strength and quality of life were assessed using the Biodex Balance System, Lafayette hand-held dynamometer -PedQoL , paediatric quality of life inventory CP Module	Children with unilateral CP can benefit from using VR as an effective and efficient tool to enhance their balance, muscle strength and QoL.
Menekseoglu AK et al., 2023 [22]	Prospective, randomised, controlled	38 hemiplegic CP (18 females, 20 males) Age 5-12 years	1-2	Levels I and II	Oculus Quest 128GB immersive-type VR glasses 60 mins 2 d/wk / for 6 weeks, (12 sessions in total)	General exercises for upper limbs	-AHA -ABILHAND-Kids, -Quest -KINDL - ROM	Upper limb function, quality of life, and active joint range of motion of the children with hemiplegic CP were increased with VR Group
Wang TN et al., 2021 [23]	Randomised pilot trial with a single-blinded	18 children with uni lat CP 5-12 years	≤2	-	8 weeks of CIT or 4 weeks of CIT, followed by 4 weeks of Wii augmented CIT	Typical CIT	-ABILHAND -PMAL-R -BOT-2 -WeeFIM -ToP -EQ	Both groups significantly improved motor outcomes and playfulness. The CIT group demonstrated greater improvement in self-care skills, whereas parental stress decreased only in the CIT-Wii group
Şahin S et al., 2020 [24]	Single-blind, randomised, controlled trial	60 children with uni lat CP Age 7-16	-	Level I-III	Kinect-based VR (games) 8 weeks /45 minutes twice a week,	Occupational therapy	- BOTMP-SF -WeeFIM	Kinect-based VR is crucial to improving motor functions and independence in daily activities of children with USCP
Gatica-Rojas V et al., 2017 [25]	Parallel-groups -randomised controlled trial	32 CP spastic hemiplegia Age 7-14 years	-	levels I and II	Nintendo Wii balance board (Wii-therapy) 3 sessions / week for 6 weeks	Standard physiotherapy	Standing balance	Wii-therapy was better than traditional ex in improving standing balance in patients with CP
El- Shamy SM and El-Banna MF 2020[26]	Prospective, single-blind randomised trial	40 hemiplegic CP children 8-12 years	Level I, II, and III	-	Wii gaming system (The Nintendo® Wii) + Usual care 40 min, 3 times/week/12 weeks	Usual care 3/ week/12 weeks	-MAS -Strength of power and pinch grip by dynamometry -Hand function by (PDMS-2),	Wii training combined with standard care improves spasticity, grip strength, and hand function in hemiplegic CP.
El-Shamy SM 2018 [27]	Randomised, controlled trial	30 hemiplegic CP Age 6-8 yrs	-	Level I, II, and III	Armeo Robotic Therapy- 45 min/ session, 3 times/wk, for 12 wks	Conventional exercise (eg: stretching, Strengthening), lasting 45 min/session, 3 times/wk, for 12 wks	MAS; QUEST.	Armeo robotic improves upper limb quality in children with hemiplegic CP more than traditional therapy.

Madboly MM et al., 2024 [28]	A randomised controlled comparative trial	75 children with hemiplegic CP, comprising 31 boys and 44 girls, age 7-11 years	-	levels I and II	VR training by videogame (WiiFit) Wii-Balance 3 months, 3 days per week, 60 min per day	Usual balance and gait training -Walking exercises with balance beam 3 months, 3 days per week, 60 min per day	Balance -(mCTSIB) - (COP) - (LOS) (6mWT)	VR and balance beam training have an effective influence on the improvement of walking performance among children with CP
James S et al., 2015 [29]	Randomised controlled trial	101 Unilateral CP 8-18 years	level I, II, or III	levels I or II	Web-based multimodal therapy 'Move it to improve it' (MitiiTM) 20 to 30 min, 6 days/ week/20 week	Standard care-20 week	(AMPS), (AHA), (JTTHF), (MUUL), COPM, TVPS-3	Mitii produced considerable increases in ADL motor and processing skills. And it has the potential to be a useful component of the therapeutic tool for CP children.
Kassee C et al., 2017 [30]	Pilot randomised trial	6 spastic hemiplegic CP Age 7-12	1 to 2	Level I, II, and III	A Nintendo Wii training at home- 40 min/day, 5 days a week/6 weeks	Resistance training at home-5 days a week / 6 weeks	Function by (MA2), ABILHAND-Kids, and grip strength	Wii training may be an effective home-based rehabilitation strategy
Chiu HC et al., 2014 [31]	Randomised, single-blind trial	62 hemiplegic CP 6-13 years	Level I-III and Level IV-V	Level I-III and Level IV-V	Home-based Wii Sports Resort™ training plus usual therapy 40 minutes 6 weeks	Received usual therapy- upper limb training	-Grip strength - Ninehole Peg Test and the Jebsen-Taylor Test of Hand Function - Functional Use Survey - Coordination	Wii™ training did not enhance coordination, strength, or hand function.
Atasavun Uysal S and Baltaci G, 2016[32]	Single-Blind Randomised Trial	24 spastic hemiplegic CP Age 6-14 years	level I, II, or III	level I or II	Nintendo Wii- NW twice a week, 45 min/12 weeks	Traditional therapy twice a week, 30 min/12 weeks	Activity performance by COPM Balance by PBS Activities of Daily Living by PEDI	NW contributed to the implementation of occupational performance, daily living activities, and functional balance.
Kim HW et al., 2019 [33]	Preliminary Pilot Study	10 CP children Age 6-14 years	-	Level III or IV	Horse Riding Simulator with Virtual Reality (HRSVR) 20 min / day, twice a week, for 4 weeks	Horse Riding Simulator (HRS)	Balance by Wii balance board Gait by gait analysis system.	Horse riding simulator training combined with three dimensional VR can be a new positive therapeutic approach for improving functional performance in children with CP
Tarakci D et al., 2016 [34]	RCT	30 CP child 5-18 years	>2	Level 1, 2 or 3	Wii-Fit balance-based video games - twice a week /12-week/ 30 minutes	Conventional balance training- twice a week /12-week/ 30 minutes	-Functional Reach Test -STS -TUG -Nintendo Wii Fit balance, age and game scores, - 10ST, - 10mWT -Wee FIM	A combination of Wii-fit balance-based video games and NDT treatment improves both static and performance-related balance parameters in children with mild CP
Ürgen MS et al., 2016 [35]	RCT	30 spastic hemiplegic CP 7-14 years	-	levels I and II	Nintendo Wii- twice a week/ 9 weeks	Control group	(GMFM), GMPM, (TUG), (PBS), (PEDI)	Nintendo®Wii-Fit training may affect on advanced motor skills and improve balance of children with spastic hemiplegic CP with physiotherapy

[Table/Fig-3]: Characteristics of the included studies [4,22-35].

VR: Virtual reality; Min: Minutes; MAS: Modified ashworth scale; GMFCS: Growth motor functional classification system; NDT: Neurodevelopmental therapy; VGBT: Video game-based therapy; 6mWT: 6 minutes walking test; mCTSIB: Modified clinical test of sensory integration of balance; COP: Center of pressure test; LOS: Limit of stability test; AHA: Assisting hand assessment; KINDL: Quality of life in children and adolescents with chronic diseases questionnaire; PSI-SF: Parenting stress index-short form; CIT: Constraint-induced therapy; BOT-2: Bruininks-oseretsky test of motor proficiency, second edition; BOTMP-SF: Bruininks-oseretsky test of motor proficiency short form; PMAL-R: Revised paediatric motor activity log; WeeFIM: Functional independence measures for children; ToP: Test of playfulness; EQ: Engagement questionnaire; QUEST: Quality of upper extremity skills test; MA2: Melbourne assessment; COPM: Canadian occupational performance measure; PBS: Paediatric balance scale; PEDI: Paediatric evaluation of disability inventory; GMPM: Gross motor performance measure; TUG: Timed up and go; STS: Sit-to-stand test; 10ST: 10 steps climbing test; 10mWT: 10 meter walk test; AMPS: Assessment of motor and process skills; JTTHF: Jebsen-taylor test of hand function; MUUL: Melbourne assessment of unilateral upper limb function; TVPS-3: Test of visual perceptual skill (non-motor) 3rd edition; PDMS-2: Peabody developmental motor scales, second edition; Wee FIM: Wee-functional independence measure; QoL: Quality of life; ROM: Range of motion; USCP: Unilateral spastic cerebral palsy

Study Outcomes

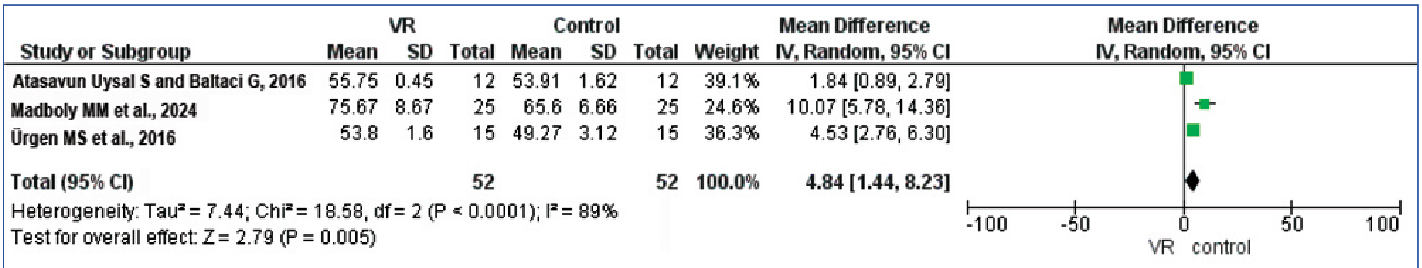
Balance: Seven studies evaluated the effect of VR training on balance in children with hemiplegic CP [4,27,30,34,36-38]. Various balance assessment tools were used, including the HUMAC balance and tilt system [28], the Biodex balance system [4], and Wii Balance Board in several studies [25,33,34]. Some studies also used the Paediatric Balance Scale (PBS). Overall, the results demonstrated a positive effect of VR training on balance [32,35].

A meta-analysis of three trials with similar design, population, and outcome measurements [30,34,37] {using PBS and the HUMan Assessment Computer (HUMAC) system} revealed that VR significantly improved balance ($p<0.05$), with a Mean Difference (MD) of 4.84 (95% CI: 1.44, 8.23) and a total effect size of Z=2.79. The I^2 value was 89%, indicating a high degree of heterogeneity [Table/Fig-5].

Upper limb function: The present review found a positive impact of VR on upper limb function in children with hemiplegic CP. Six studies evaluated upper limb and hand function using various assessment tools [22,23,26,29-31]. Menekseoglu AK et al., and James S et al., used the Assisting Hand Assessment (AHA) [22,29], while the ABILHAND-Kids scale was used in other studies [22,23,30]. El-Shamy SM and El-Banna MF (2020) assessed hand function using the Peabody Developmental Motor Scales, 2nd edition (PDMS-2) [26]. Chiu HC et al., used the Nine-Hole Peg Test and the Jebsen-Taylor Hand Function Test [31].

Authors (Years)	PEDro scale: Eligibility criteria	Random allocation	Concealed a location	Baseline comparability	Blind subjects	Blind therapists	Blind assessors	Adequate follow-up	Intention-to-treat analysis	Between group comparisons	Point estimates and variability	Total score
Korney SS et al., 2024 [4]	yes	yes	yes	yes	yes	yes	No	No	No	yes	No	6
Menekseoglu AK et al., 2023 [22]	yes	yes	No	yes	No	No	yes	yes	No	yes	yes	7
Wang TN et al., 2021 [23]	yes	yes	yes	yes	No	No	yes	No	No	yes	No	5
Aahin S et al., 2020 [24]	yes	yes	yes	yes	No	yes	No	No	No	yes	No	5
Gatica-Rojas V et al., 2017 [25]	yes	yes	No	yes	No	No	No	yes	No	yes	yes	5
El-Shamy SM and El-Banna MF, 2020 [26]	yes	yes	yes	yes	No	No	yes	yes	No	yes	yes	7
El-Shamy SM 2018 [27]	yes	yes	yes	yes	No	No	yes	yes	No	yes	yes	7
Madboly MM et al., 2024 [28]	yes	yes	yes	yes	No	No	No	No	No	yes	No	4
James S et al., 2015 [29]	yes	yes	yes	yes	No	No	No	yes	yes	yes	yes	7
Kassee C et al., 2017 [30]	yes	yes	No	yes	No	No	No	No	No	No	No	2
Chiu HC et al., 2014 [31]	yes	yes	yes	yes	No	yes	yes	yes	yes	yes	yes	9
Atasavun Uysal S and Baltaci G, 2016 [32]	yes	yes	No	yes	No	No	yes	No	No	yes	yes	5
Kim HW et al., 2019 [33]	yes	ye	No	yes	No	No	No	No	No	yes	No	3
Tarakci D et al., 2016 [34]	yes	yes	No	yes	No	No	No	No	No	yes	yes	4
Ürgen MS et al., 2016 [35]	yes	yes	No	yes	No	No	No	No	No	yes	No	3

[Table/Fig-4]: PEDro scores for the included trials [4,22-35].
PEDro score of < 4 indicated poor; 4-5 indicated fair; 6-8 indicated good, and a score of 9-10 indicated excellent quality



[Table/Fig-5]: Forest plot experimental vs control effect of VR in balance.

Meta-analysis showed no significant improvement in hand function when using AHA (MD 1.48, 95% CI: -2.95 to 5.9, p=0.5) with a total effect size of Z=0.65 and I^2=0%. However, analysis of studies using the ABILHAND-Kids scale demonstrated a significant positive impact (MD 2.17, 95% CI: 0.10, 2.24; p=0.04) with Z=2.06 and I^2=25%, indicating low heterogeneity.

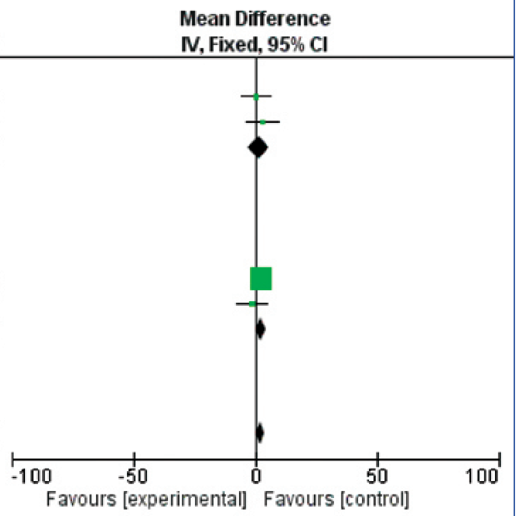
The overall meta-analysis showed a significant positive effect of VR on hand function in children with hemiplegic CP (MD 2.05, 95% CI: 0.17, 3.92; p=0.03) with a total effect size of Z=2.14 and I^2=0% [Table/Fig-6] [22,23,29].

Activities of Daily Living (ADL): ADL were assessed in five studies using different measurement tools. Two studies used the Paediatric Evaluation of Disability Inventory (PEDI) [32,35], while three studies used the WeeFIM to evaluate functional performance in daily activities [23,24,34]. Meta-analysis revealed no significant effect of VR on ADL in children with hemiplegic CP (MD 0.86, 95% CI: -8.93 to 7.21; P=0.83) with a total effect size of Z=0.21 and I^2=73%, indicating moderate heterogeneity. Subgroup analysis showed that neither PEDI (MD 5.73, 95% CI: -15.98 to 4.52; P=0.27) nor WeeFIM (MD 3.50, 95% CI: -6.23 to 13.23; P=0.48) demonstrated significant improvement [Table/Fig-7] [23,24,32,34,35].

Quality of upper limb skills: Three studies evaluated the overall quality of upper limb skills. Korney SS et al., used the Paediatric Quality of Life Inventory CP Module (PedsQoL) [4], whereas Menekseoglu AK et al., (2023) and El-Shamy SM (2018) used the Quality of Upper Extremity Skills Test (QUEST) [22,27]. These studies found that VR interventions improved the quality of upper limb skills more effectively than traditional treatment approaches.

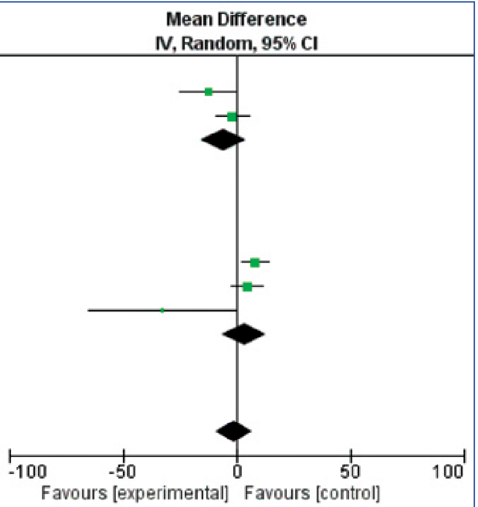
A meta-analysis of two studies using QUEST showed significant improvement in upper extremity skill quality (MD 4.30, 95% CI: 0.72, 7.89; p<0.02) with a total effect size of Z=2.35 and I^2=50%, indicating moderate heterogeneity [Table/Fig-8] [22,27].

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
7.1.1 function by AHA, Assisting Hand Assessment								
James S et al., 2015	68.24	14.32	51	67.84	15.41	51	10.5%	0.40 [-5.37, 6.17]
Menekseoglu AK et al., 2023	65.8	11.7	18	62.8	9.2	18	7.4%	3.00 [-3.88, 9.88]
Subtotal (95% CI)			**69**			**69**	**17.9%**	**1.48 [-2.95, 5.90]**
Heterogeneity: Chi² = 0.32, df = 1 (P = 0.57); I² = 0%								
Test for overall effect: Z = 0.65 (P = 0.51)								
7.1.2 function by ABILHAND-Kids								
Menekseoglu AK et al., 2023	34.3	3.9	18	31.7	2.7	18	73.0%	2.60 [0.41, 4.79]
Wang TN et al., 2021	28.4	8.8	9	29.67	3.57	9	9.1%	-1.27 [-7.47, 4.93]
Subtotal (95% CI)			**27**			**27**	**82.1%**	**2.17 [0.10, 4.24]**
Heterogeneity: Chi² = 1.33, df = 1 (P = 0.25); I² = 25%								
Test for overall effect: Z = 2.06 (P = 0.04)								
Total (95% CI)			**96**			**96**	**100.0%**	**2.05 [0.17, 3.92]**
Heterogeneity: Chi² = 1.73, df = 3 (P = 0.63); I² = 0%								
Test for overall effect: Z = 2.14 (P = 0.03)								
Test for subgroup differences: Chi² = 0.08, df = 1 (P = 0.78), I² = 0%								



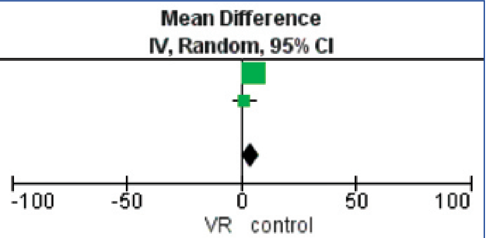
[Table/Fig-6]: Forest plot experimental vs. control effect of Virtual Reality (VR) in upper limb function [22,23,29].

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
8.1.1 Activities of Daily Living by Pediatric Evaluation of Disability Inventory (PEDI)								
Atasavun Uysal S and Baltaci G, 2016	180.5	19.9	12	192.9	10.43	12	17.7%	-12.40 [-25.11, 0.31]
Ürgen MS et al., 2016	180.07	12.36	15	181.7	8.18	16	24.9%	-1.63 [-9.06, 5.80]
Subtotal (95% CI)			**27**			**28**	**42.5%**	**-5.73 [-15.98, 4.52]**
Heterogeneity: Tau² = 29.78; Chi² = 2.06, df = 1 (P = 0.15); I² = 51%								
Test for overall effect: Z = 1.10 (P = 0.27)								
8.1.2 activity of daily living by WeeFIM ,Functional Independence Measures for Children								
Aahin S et al., 2020,	112.96	10.2	30	104.7	13.67	30	26.7%	8.26 [2.16, 14.36]
Tarakci D et al., 2016	100.26	8.75	15	95.5	10.47	15	25.6%	4.76 [-2.15, 11.67]
Wang TN et al., 2021	73.11	42.23	9	105.56	25.89	9	5.2%	-32.45 [-64.81, -0.09]
Subtotal (95% CI)			**54**			**54**	**57.5%**	**3.50 [-6.23, 13.23]**
Heterogeneity: Tau² = 42.48; Chi² = 6.07, df = 2 (P = 0.05); I² = 67%								
Test for overall effect: Z = 0.71 (P = 0.48)								
Total (95% CI)			**81**			**82**	**100.0%**	**-0.86 [-8.93, 7.21]**
Heterogeneity: Tau² = 53.78; Chi² = 14.78, df = 4 (P = 0.005); I² = 73%								
Test for overall effect: Z = 0.21 (P = 0.83)								
Test for subgroup differences: Chi² = 1.64, df = 1 (P = 0.20), I² = 39.0%								



[Table/Fig-7]: Forest plot experimental vs. control effect of Virtual Reality (VR) in the activity of daily living [23,24,32,34,35].

Study or Subgroup	VR Mean	VR SD	VR Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
El-Shamy SM, 2018	84.6	2.7	15	79.1	2	15	70.1%	5.50 [3.80, 7.20]
Menekseoglu AK et al., 2023	72.8	9.9	18	71.3	5.6	18	29.9%	1.50 [-3.75, 6.75]
Total (95% CI)			**33**			**33**	**100.0%**	**4.30 [0.72, 7.89]**
Heterogeneity: Tau² = 4.03; Chi² = 2.02, df = 1 (P = 0.16); I² = 50%								
Test for overall effect: Z = 2.35 (P = 0.02)								



[Table/Fig-8]: Forest plot experimental vs. control effect of Virtual Reality (VR) in quality of hand skills [22,27].

DISCUSSION

The present systematic review explored the influence of VR on balance, functional abilities, daily activities, and the quality of hand skills in children with hemiplegic CP. The results revealed that VR had a significant effect on all outcomes except ADL, supporting its potential use in the treatment of children with hemiplegic CP.

According to the PEDro scale, the review included 15 trials with a wide range of quality scores (two of poor quality, seven fair, five good, and one excellent). The meta-analysis demonstrated significant differences between VR and control groups in balance (MD 4.84, 95% CI: 1.44-8.23; p<0.05), hand function (MD 2.05, 95% CI: 0.17-3.92; P=0.03), and quality of upper extremity skills (MD 5.12, 95% CI: 3.50-6.74; p<0.05). However, the effect on ADL was not significant among children with hemiplegic CP (MD 0.86, 95% CI: -8.93 to 7.21; p=0.83).

Chang HJ et al., (2020) assessed the impact of VR-based rehabilitation combined with conventional therapy on upper extremity function and skill quality in children with CP. Their study reported significant improvements in QUEST and PEDI domains (p<0.05), suggesting that VR-based rehabilitation may enhance upper extremity functions and the quality of skills in this population [36].

Warnier N et al., in their review, demonstrated the positive effect of VR on balance in CP children. Twenty-six studies were evaluated for balance outcomes, and five were included in a meta-analysis, showing significant improvements favoring VR {SMD: 0.89 (95% CI: 0.14-1.63)}. These results emphasise VR as a promising intervention for the rehabilitation of children with CP [17].

Similarly, Liu W et al., (2022) concluded that VR interventions improved balance {SMD: 0.47 (95% CI: 0.28-0.66)} with no heterogeneity among the included studies, confirming the positive impact of VR treatment sessions for children with CP [37]. These findings align with the results of the present review, which also demonstrated a positive effect of VR on balance in hemiplegic CP (MD: 4.84, 95% CI: 1.44-8.23; p<0.05), although high heterogeneity was noted among the studies.

Tobaiqi MA et al., (2023) reported that VR-assisted exergaming may be more effective than traditional therapy in improving functional potential, daily activities, mobility, and cognitive function in children with CP, with no adverse effects noted in the included trials [38].

The present study similarly identified positive effects of VR on hand function in children with hemiplegic CP (MD: 2.05, 95% CI: 0.17-3.92; p=0.03) with no heterogeneity. However, VR did not significantly improve ADL (MD: 0.86, 95% CI: -8.93 to 7.21; p=0.83), showing moderate heterogeneity. The differences between the two reviews may be attributed to methodological variations. Tobaiqi MA et al., included both RCTs and cohort studies, assessed a broader range of outcomes such as GMFM, PEDI (mobility and cognition), COPM, and the Melbourne Assessment of Unilateral Upper Limb Function. In contrast, the current review included only RCTs and used AHA and ABILHAND-Kids for functional ability and WeeFIM for ADL assessments.

The present review also reported a significant effect of VR rehabilitation on the quality of upper extremity skills in children with hemiplegic CP (MD: 5.12, 95% CI: 3.50-6.74; p<0.05), with moderate heterogeneity among the included studies. To our knowledge, no prior systematic review has specifically examined the effectiveness of VR-based rehabilitation on the quality of upper extremity skills.

Similarly, a case study by Mirich R et al., assessed the quality of upper extremity skills using QUEST domains in a child with spastic hemiplegic CP undergoing VR therapy. The findings indicated that VR rehabilitation may effectively improve the quality of upper limb skills in children with CP [39].

The sensory-motor regions of the brain responsible for enhanced motor skills may undergo neuroplastic changes due to VR use. VR can substantially improve motor skills by promoting neuroplasticity and cortical reorganization [40]. In addition to physiotherapy, VR-based therapies make rehabilitation more enjoyable and motivating. These components facilitate active participation in task-oriented training for children with CP [41].

The direct motivational feedback provided by VR games-visual, auditory, and tactile-encourages sustained engagement. Over time, the rehabilitation experience becomes more enjoyable, and the difficulty level can be progressively increased. These dynamics, coupled with repetitive tasks and graded challenge, may contribute to greater responsiveness among children undergoing VR-assisted rehabilitation. Coupled with improved accessibility and cost-effectiveness, VR-assisted interventions offer a promising and advanced adjunct to conventional physiotherapy [40,42,43].

Limitation(s)

The present review had several limitations. First, only one study achieved a high-quality PEDro score, whereas three were of poor quality. High heterogeneity was observed among the included trials, particularly for balance outcomes. Additionally, due to limited available data, the meta-analysis was restricted. Despite these limitations, the current study is significant as it is the first review to evaluate the impact of different VR modalities on balance, function, daily activities, and upper extremity skill quality in children with hemiplegic CP.

CONCLUSION(S)

VR-based rehabilitation may be more effective than conventional approaches for improving balance, functional abilities, and the quality of upper extremity skills in children with hemiplegic CP. However, its effect on ADL was not significant. Future studies are recommended to identify the most effective VR modalities using high-quality research designs with larger sample sizes to compare different types of VR interventions.

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