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Effect of Virtual Reality on Balance Function in Children With Cerebral Palsy: A Systematic Review and Meta-analysis

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Virtual Reality (VR) therapy is popular in treating children with Cerebral Palsy (CP) as a new technology for rehabilitation. Nevertheless, no substantial evidence supporting VR therapy promotion has been developed to date. This study aimed to investigate the effects of VR therapy on balance in children with CP. We conducted a systematic search in PubMed and Web of Science (updated to December 30, 2021). The systematic review and meta-analysis included all randomized controlled trials that included children with CP. A total of 18 RCT studies were eligible for inclusion in the systematic review, and meta-analysis was performed on 16 of them. Results showed that the VR intervention was beneficial for balance (SMD 0.47 [95% CI, SD 0.28, 0.66]). We concluded that VR therapy interventions for children with CP have positive effects. However, cautious implementation is needed in clinical applications.

Keywords: virtual reality, cerebral palsy, balance, interactive games, systematic review

INTRODUCTION

Cerebral Palsy (CP) is a neurological disorder caused by non-progressive brain injury and developmental defects (1). The main manifestations are central motor deficits and postural disorders, which may also be accompanied by developmental delay, epilepsy, perceptual impairment, language disorders, and cognitive behavior abnormalities (2). According to the World Health Organization, the incidence of CP in developed countries is 0.2–0.3%, and the incidence of CP in China is about 0.248% (2–4). As reported, there are 6 million children with cerebral palsy in China, with an average annual increase of 50,000, which has become a severe problem in public health (5). CP is a significant cause of physical disability in children, and late damage to the central nervous system in children with CP can cause secondary injuries such as limb spasticity, muscular atrophy, skeletal deformities, muscle weakness, and developmental coordination disorders, which limit the child's mobility and thus affect the development of gross motor skills (6, 7). Studies have shown that failure to promptly identify and remedy impairments in the development of gross motor skills may lead to motor deficits (8). Current data show that 72–91% of children with CP have limitations in activities of daily living (ADLs) such as outdoor walking, stair climbing, and self-care activities (9). Restrictions in mobility and self-care are often associated with lower extremity impairment, making lower extremity function important for ADLs.

Motor skill training or rehabilitation is commonly associated with improvements in balance and walking ability of the lower limbs (10). In contrast, the quantity and quality of training are essential to promote plasticity and functional recovery of the child's brain (11). Therefore, developing a practical intensive training or rehabilitation program requires consideration of time and intensity (12, 13). Some studies have demonstrated that traditional center-based CP rehabilitation programs (e.g., hospitals, gyms, sports centers) positively affect children with CP with 30–45 min sessions per day, which seems to be necessary for neuroplasticity (14–17). Traditional center-based approaches in physical therapy, such as group therapy and therapist-assisted therapy, target children with certain types of CP in a face-to-face manner and can enhance communication between children with CP and their parents (18). However, center-based health care systems are often unable to provide weekly interventions for children with CP because of the time-consuming and expensive costs (19). Hence, it is necessary to find cost-effective physical therapies that can help children with CP long enough intensive training. Recently, family interactive training has been positive for the rehabilitation of children with cerebral palsy, improving balance (20). Consequently, home-based task-oriented exercise effectively complements center-based occupational therapy and physiotherapy to ensure more intensive and sustained exercise for children with CP (2, 21).

Virtual Reality (VR) therapy is a recently popular assistive technology in the rehabilitation of children with CP (22). Its characteristic is that people can immerse themselves in a non-physical world through 3D displays at home (23). An active video game is used and facilitates the systematic practice of functional movement and multisensory feedback (19). This immersive experience is in a safe and enjoyable environment, which may appeal to children, including those with CP (24). Some studies showed that VR-based rehabilitation facilitated perceptual training and task completion in a virtual environment similar to reality but with a higher predictability and activity control (19, 24, 25). Indeed, active video games promote functional activities with multisensory demands, active muscle stretching, and motor training that challenge postural stability, creating favorable conditions for children with CP (19, 26). Some studies showed that VR-based therapies provided visual perceptual stimuli generated by dynamic changes in the environment, which facilitated controlled exercise in children with CP (27–30). When children play games, the actions involved, such as laughing, gesticulating, and screaming, could enhance bioelectrical signals in the brain (31). Moreover, home-based VR therapy could enhance the somatic experience of these games. Factors such as the duration, intensity, and repetition of children's activities may improve their condition and facilitate the recovery of motor function in children with CP (32, 33). Compared to traditional center-based rehabilitation, home-based VR therapy has the advantages of small space (traditional centers require dedicated rehabilitation) and low cost (traditional center-based rehabilitation requires experienced therapists) (34, 35). Therefore, children with CP that are generally reluctant to receive traditional therapy tend to prefer VR therapy (19, 36), which will contribute to the motor skill development of children with CP. Home Virtual Reality GAME (VRG) therapy has become increasingly crucial for the rehabilitation of children with CP due to family economic reasons.

Review studies on VR therapy for children with CP showed that VRG therapy interventions could improve the development of gross motor skills, including strength, balance, coordination, and other physical qualities in children with CP (2, 37, 38). Meta-analysis of VRG on upper limb motor skills also found that VRG in a VR setting is a feasible instrument for improving motor skills in children with CP (38). Although previous review studies showed improvements in gross motor skills and upper limb skills in children with CP, the evidence for their assessment was limited by studies including randomized controlled trials (39, 40). Recent studies by Sajan et al., Pin et al., and Jha et al. did not support the hypothesis that VR therapy is more effective than physical therapy for balance in children with CP (41–43). To date, there is no strong evidence from studies showing the effectiveness of VR therapy on balance in children with CP. As such, this study aimed to explore the effects of VR therapy on balance in children with CP using a meta-analysis. Consequently, a conceptual model of the effects of VR therapy intervention for balance function is needed to analyze the strengths or weaknesses of typologies and methodologies (**Figure 1**). Additionally, the effects of the VRs intervention program (including single intervention time, intervention frequency, intervention period, and total intervention time) on the gross motor skills of children with CP were further determined. Thus, an essential theoretical basis for the effect of VR-based therapy on the balance ability of children with CP was established, which provides a vital decision basis for clinical rehabilitation staff.

METHOD

Search Strategy and Screening

A systematic review and meta-analysis were conducted and implemented following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA) (44). The online databases of PubMed and Web of Science were used to search for relevant studies up to December 30, 2021. The following search terms were used in the PubMed Mesh term and title abstract search terms. "video games" or "serious games" or "virtual reality" or "interactive games" or "VR" and "cerebral palsy." The same search terms as PubMed were used in the Web of Science Title/Abstract/Keyword search term. The search results were processed in Endnote Library X7, and duplicates were removed. Two independent reviewers assessed the full-text article (WL and YH). A third reviewer (JL) was adjudicated if no consensus was achieved. The reference lists of relevant full-text articles were manually searched to identify all relevant references.

Selection Criteria

The following criteria were met for inclusion in the study. (1) Participants were diagnosed with CP and their age was no more than 18 years. CP was defined as permanent impairments in motor and postural development that were often accompanied by insensitivity, cognition, communication, perception, and

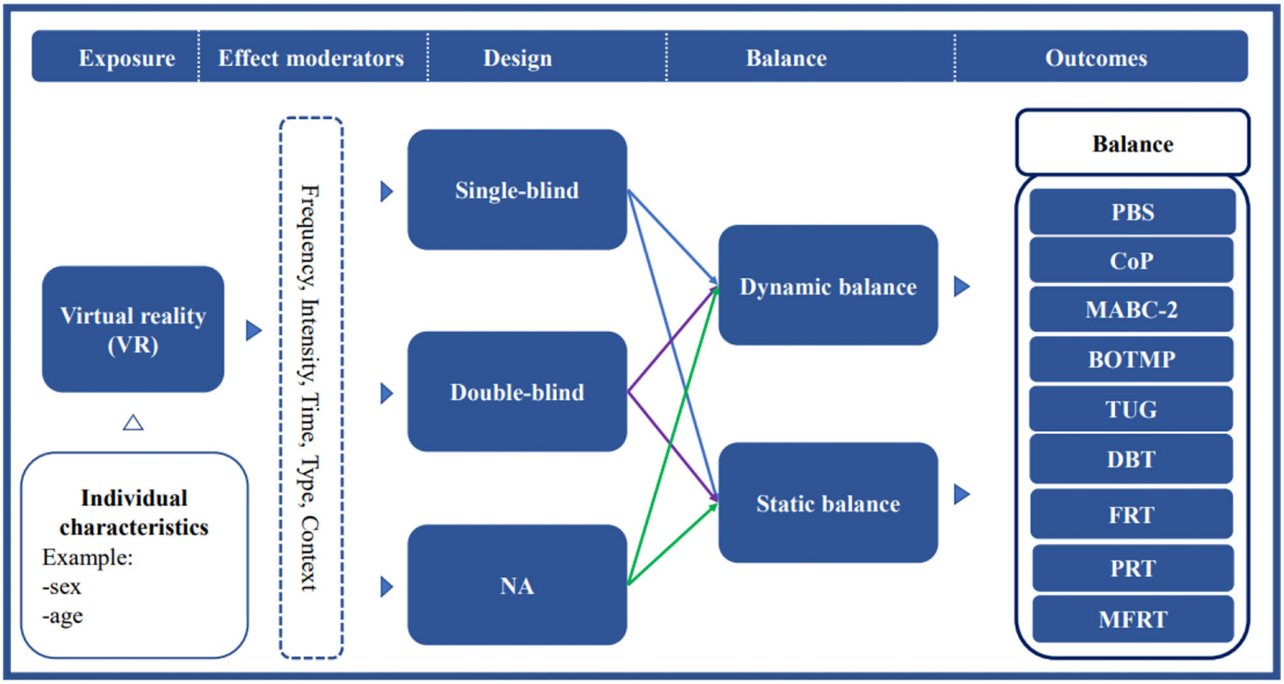

FIGURE 1 | A conceptual model of VR therapy intervention for balance function.

behavior problems. Participants had limitations in daily activities. (2) VR was used as a therapeutic intervention. VR was defined as a concept that uses real-time interaction with the patient and feeds back their motor patterns or performance knowledge acquired through visual, auditory, proprioceptive, vestibular, or olfactory stimuli. Visual stimuli could be displayed on a monitor, flat-screen, projection screen, or head-mounted device. VR could potentially produce environments with realistic-looking objects, or it could be a game environment. (3) Randomized controlled intervention studies with pre- and post-experimental performance were assessed using a balanced outcome measure. (4) Effects on balance were measured by motor performance scales or test instruments used pre-and post-VR.

The exclusion criteria were: (1) case reports, (2) non-peer-reviewed publications, (3) conference abstracts, (4) non-English language publications, (5) VR as an intervention supplement, (6) studies that included patients with comorbidities, and (7) studies that included other interventions that affected VR balance performance.

Data Collection

Data and information were collected in the included studies, including age, gender, number of participants, inclusion and exclusion criteria. The following outcomes were recorded for the VR experimental group: type of VR intervention, blinding of the RCT design, and balanced outcome measures. Two authors independently extracted this information from the included articles (38).

Qualitative Analysis

The Physiotherapy Evidence Database (PEDro) scale was used to assess the methodological quality of randomized controlled trials (RCTs) to assess the risk of bias (45, 46). The PEDro scale included 11 items, one associated with eligibility criteria (item 1, not scored), eight reflecting internal validity (items 2–9), two representing statistical comparisons between groups (item 10), and a measure of variability (item 11). Results of two independent reviewers' assessments were compared, and consistent decisions were made to ensure the accuracy and completeness of data extraction. A third reviewer resolved any persistent discrepancies and discussed further as necessary.

Data Analysis

Outcome measures on balance were extracted from the included studies and reported. Extracted data from the article included data related to mean change from baseline and Standard Deviation (SD) and sample size for the VR and control groups. The authors were contacted first if exact values cannot be extracted from the article. If contacting the authors was unsuccessful, alternatively, calculations based on the data provided in the article would be considered. When SD of change scores was not available in the study, the formula described in the Cochrane Handbook was used. For this formula, correlation coefficients were extracted from the available literature of the clinical trials used. All outcomes were included if a study used different outcome measures to determine balance. In these studies, the total number of participants was divided by the number of tests used (according

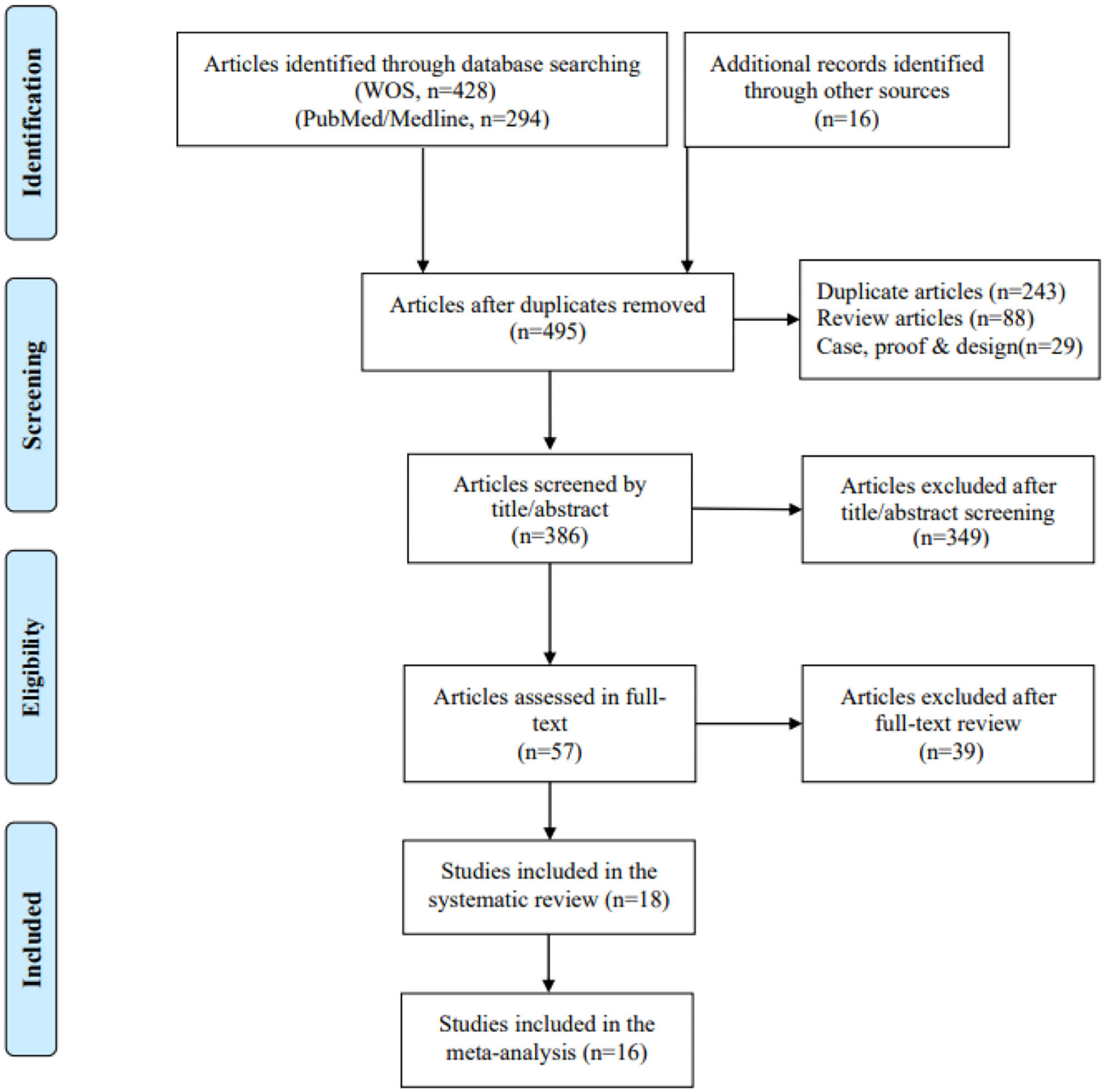

FIGURE 2 | PRISMA flowchart of included and excluded studies.

to the Cochrane Handbook) to calculate heterogeneity. Random-effects models were used even when heterogeneity was low because of the different clinical trials used in the included articles: heterogeneity only claimed that the results included in the analysis were not statistically heterogeneous and did not consider differences in the use of different clinical trials (38). Standardized mean differences (SMD) were used as effect measures because sometimes outcomes measured using different instruments were used to determine the same outcome (38). Effect sizes were determined using the rules of Cohen 1988 in this study (47). Review Manager 5.3 was used to perform a meta-analysis.

RESULTS

Identification of Studies

A total of 493 articles were retrieved after searching PubMed and WOS databases to remove duplicate data, of which 57 full-text articles were checked for eligibility (**Figure 2**). The 18 RCT studies were considered eligible for inclusion in the systematic review, of which 16 studies were obtained with valid data for meta-analysis.

Description of Included Studies

A total of 474 patients were included in the 18 studies (**Table 1**). The age range of participants was 4–18 years. The participants in one study included only Gross Motor Function Classification System (GMFCS) Level I (48), four studies included GMFCS Levels I-II (19, 49–51), eight studies included GMFCS Levels I-III (52–57), one study included GMFCS Levels I-IV (41), and four studies included GMFCS Levels III (58) or III-IV (42, 62, 63). All studies measured balance using at least one instrument, and five studies used two or more instruments to assess patients' balance (9, 53–56). Eight studies used the PBS assessment tool (41, 43, 51–53, 55, 57, 59), five studies used the CoP Kinematics system (balance force plate) (19, 41, 48, 50, 53), three studies used the TUG (54–56), two studies used the BOTMP (9, 49), and one study used the MABC-2 (58), FRT (56), MFRT (60), PRT (42) and DBT (54).

PEDro Scale Outcomes

Sixteen studies included in the meta-analysis identified PEDro scores to assess methodological quality. Of these studies, fourteen scored $\geq$6 on the PEDro scale, which denotes good quality. The other two studies scored 5 (53) and 3 (58), respectively. The raw scores are shown in **Table 2**.

Virtual Reality Intervention Setup

The applied VR interventions could be categorized into two groups (**Figure 3**). One group of 11 studies used the intervention with a game component (19, 41, 42, 50, 52, 54, 56–60), and the other seven used real-time feedback or interactive exercise in the virtual world (9, 43, 48, 49, 51, 53, 55). The interventions in all these studies were as follows: the total amount of treatment (160–1,680 min), duration of treatment (20–60 min), and intervention period (2–12 weeks). Furthermore, the treatment location varied across studies: for example, some used VR sessions supervised by researchers or therapists, while in other studies, participants practiced at home, and no studies combined both for home exercise.

Outcome Measure of Balance

Of the 18 studies that used balance as an outcome measure, five reported static balance (**Table 1**). Ledebt et al. (48), Arnoni et al. (19), Gatica-Rojas et al. (50), and Hsieh et al. (53) used static balance on a force platform; After using VR, four studies found a significant improvement between the intervention and control groups, whereas Sajan et al. did not find a significant improvement between groups (41).

For dynamic balance, there were various tests used in 15 articles. Cho et al. (52), Decavele et al. (59), Jung et al. (51), Hsieh et al. (53), and Uysal et al. (57) used PBS in RCTs and found significant improvement in balance compared to the control group in the intervention group, while Jha et al. (43), Sajn et al. (41) found no significant improvement. Tarakci et al. used two performance scales (FRT & TUG) to test dynamic balance and found a significant difference in improvement between the control and VR intervention groups (56). Park et al. further confirmed the effect of the intervention using the MFRT (60). Hsieh et al. (53), Kachmar et al. (54), and Lazzari et al. (55) also used TUG to confirm further significant improvement. AlSaif et al. also confirmed a significant effect of the Nintendo Wii intervention using the MABC-2 test (58). However, Pin et al. did not find a significant difference in improvement between the control and intervention groups using PRT (42). Chen et al. did not find a significant difference in improvement between the control and intervention groups using BOTMP (49), but Sahin et al. experimentally indicated that the Kinect-based VR intervention was significant (9). Of the included 18 studies, fourteen showed significant effectiveness of applied VR interventions. Moreover, five articles used both methods for outcome measurement (9, 53–56). Of these, two measured dynamic and static balance outcomes (41, 53), and three were focused on dynamic balance (54–56). Sajan et al.'s study showed no significant difference between the experimental and control groups for either dynamic balance or static balance (41).

Meta-Analysis

The meta-analysis of balance included 16 of 18 RCTs studies, and non-inclusion of two studies was due to unavailability of data. The outcome measures were BOTMP, MABC-2, PBS, TUG, FRT (MFRT), PRT, DBT, and CoP. There were 235 participants in the VR group and 235 participants in the control group. The combined statistics was not heterogeneous ($x^2 = 16.77$, $df = 34$, $p = 0.99$, $I^2 = 0\%$). The SMD value was 0.47 [95% CI, SD 0.28, 0.66] supporting the VR intervention (**Figure 4**). The effect size of meta-analysis was moderate using Cohen's 1988 Cochrane Handbook rules (47).

DISCUSSION

This systematic review and meta-analysis showed a significant improvement in balance for children with CP after VR therapy. As a result of this intervention effect, we believe the VR therapy is a well-designed intervention that can be used as a complementary therapy during the rehabilitation of children with CP. The findings of this RCT review study are consistent with previous studies on VR therapy for children with CP (38, 46, 61).

The study included high-quality literature, and there was no heterogeneity in the results measuring balance ability. These findings were not consistent with the high heterogeneity in balance ability in the previous study (38). Warnier et al. concluded that test diversity contributed to the high heterogeneity in the combined effect (38). In contrast, the present study included literature that used more measurement instruments. It may include the nine most recent publications from 2019-2021 in this study (9, 19, 42, 43, 51, 53, 54, 59, 60). VR treatment studies have become increasingly popular in recent years, with many recent publications (62–65). However, the quality of included RCT studies is generally high. It is supported by PEDro methodological quality assessment. This study included studies with a score of 6 and above in 87.5%, compared to only 57.1% in the Warnier et al.'s studies (38).

TABLE 1 | The characteristics of the inclusion studies.

References	Age (years)	Numbers total/male	Duration	Total (min)	RCT Design	VR Intervention	Balance	GMFCS	Location	Outcome measure
AlSaif and Alsenany (58)	Range 6–10	40/NA	20 min/d*7 d/wk*12 wk	1,680	NA	Nintendo Wii fit game	DB	III	Home	Balance: MABC-2
Arnoni et al. (19)	Mean: 10 ± 3	9/5	45 min/d*2 d/wk*8 wk	720	single-blind	Xbox 360 Kinect sensor	SB	I–II	SL	Balance: CoP
Chen et al. (49)	Range 6–12	28/19	40 min/d*3 d/wk*12 wk	1,440	NA	Virtual cycling system with interactive workouts	DB	I–II	Home	Balance: BOTMP
Cho et al. (52)	VR:10.2 ± 3.4 CG:9.4 ± 3.8	18/NA	30 min/d*3 d/wk*8 wk	720	single-blind	Nintendo Wii jogging program	DB	I–III	SL	Balance: PBS
Decavele et al. (59)	Range 6–15	32/NA	45 min/d*2 d/wk*12 wk	1,080	single-blind	MS Kinect for Windows and Nintendo Wii balance board	DB	III–IV	SL	Balance: PBS
Gatica-Rojas et al. (50)	Range 7–14 Mean:10.4	32/19	25 min/d*3 d/wk*6 wk	450	no blinding	Wii Fit Plus with the Nintendo Wii Balance Board	SB	I–II	SL	Balance: CoP
Hsieh (53)	Mean:7.33 ± 1.31	40/29	45 min/d*3 d/wk*12 wk	1,620	NA	Customized PC gaming	SB/DB	I–III	SL	Balance: CoP/PBS
Jha et al. (43)	Range 6–12	38/NA	60 min/d*4 d/wk*6 wk	1,440	observer-blinded	Kinect-based virtual reality gaming	DB	I–III	SL	Balance: PBS
Jung et al. (51)	EG:12.80 ± 1.60 CG:12.00 ± 2.53	10/5	45 min/d*3 d/wk*6 wk	810	single-blind	Kinect Video Game Training	DB	I–II	SL	Balance: PBS
Kachmar et al. (54)	Range 5–18 EG:11.5 ± 3.1 CG:10.8 ± 3.3	25/15	20 min/d*4 d/wk* 2 wk	160	NA	Daily training with personalized balance games	DB	I–III	SL	Balance: TUG/DBT
Lazzari et al. (55)	Mean:7.5 ± 2	20/14	20 min/d*5 d/wk*2 wk	200	double-blind	VR training	DB	I–III	SL	Balance: TUG/PBS
Ledebt et al. (48)	Mean:7.37	10/NA	30 min/d*3 d/wk*6 wk	540	NA	Force plate with real-time feedback with red dot on screen	SB	I	SL	Balance: CoP
Park et al. (60)	Range 6–18 EG:14.3 ± 4.2 CG:14.1 ± 4.3	20/7	40 min/d*2 d/wk*4 wk	320	NA	VR Wii Fit game	DB	III–IV	SL	Balance: MFRT
Pin and Butler (42)	EG:8.92 ± 2.25 CG:9.59 ± 1.87	18/11	20 min/d*4 d/wk*6 wk	480	single-blind	Interactive computer play	DB	III–IV	SL	Balance: PRT
Sahin (9)	Range 7–16 EG:10.5 ± 3.62 CG:10.06 ± 3.24	60/37	45 min/d*2 d/wk*8 wk	720	single-blind	VR intervention	DB	I–III	SL	Balance: BOTMP
Sajan et al. (41)	EG:10.6 ± 3.78 CG:12.4 ± 4.93	20/11	45 min/d*6 d/wk*3 wk	810	single-blind	Wii Games	SB/DB	I–IV	SL	Balance: CoP/PBS
Tarakci et al. (56)	EG:10.46 ± 2.69 CG:10.53 ± 2.79	30/19	20 min/d*2 d/wk*12 wk	480	single-blind	Nintendo Wii-Fit(R) video games	DB	I–III	SL	Balance: FRT/TUG
Uysal and Baltaci (57)	Range 6–14	24/10	30 min/d*2 d/wk*12 wk	720	single-blind	Nintendo Wii (TM) Training	DB	I–III	SL	Balance: PBS

PBS, Pediatric Balance Scale; FRT, Functional Reach Test; MFRT, Modified Functional Reach Test; TUG, Timed Up and Go Test; BOTMP, Bruininks-Oseretsky Test of Motor Proficiency; CoP, CoP Kinematics; MABC-2, Movement Assessment Battery for Children-2; DBT, Dynamic Balance Test; PRT, Pediatric Reach Test; SL, supervised location.
SB, static balance; DB, dynamic balance.

TABLE 2 | Assessment of quality of study design using PEDro.

References	1	2	3	4	5	6	7	8	9	10	11	Total
AlSaif and Alsenany (58)	yes	1	0	1	0	0	0	0	0	0	1	3
Chen et al. (49)	yes	1	0	1	0	0	0	1	1	1	1	6
Cho et al. (52)	yes	1	0	1	0	0	1	1	1	1	1	7
Decavele et al. (59)	yes	1	1	0	0	0	0	1	1	1	1	6
Gatica-Rojas et al. (50)	yes	1	1	1	0	0	0	1	1	1	1	7
Hsieh (53)	yes	1	0	0	0	0	0	1	1	1	1	5
Jha et al. (43)	yes	1	1	1	1	0	0	1	1	1	1	8
Jung et al. (51)	yes	1	1	0	1	1	0	1	1	1	1	8
Kachmar et al. (54)	yes	1	1	1	1	0	0	1	1	1	1	8
Lazzari et al. (55)	yes	1	1	1	1	1	1	1	1	1	1	10
Park et al. (60)	yes	1	0	1	0	0	0	1	1	1	1	6
Pin and Butler (42)	yes	1	1	1	0	0	1	1	1	0	1	7
Sahin (9)	yes	1	1	1	1	1	0	1	1	1	1	9
Sajan et al. (41)	yes	1	1	1	0	0	1	1	1	1	1	8
Tarakci et al. (56)	yes	1	1	1	0	0	0	1	1	1	1	7
Uysal and Baltaci (57)	yes	1	1	1	1	0	0	1	1	1	1	8

FIGURE 3 | Virtual scenario settings [**(A)** Game training; **(B)** Interactive exercise].

Nevertheless, there are many methodological limitations to the study in this article, and the results should be interpreted with caution in practical applications. For example, there are many doubts regarding exercise duration and the exercise effect (66). The total time of exercise is theoretically proportional to the exercise effect, and prolonged exercise is expected to yield good exercise benefits (67). However, in the studies by Chen et al. (49) and Jha et al. (43), the total exercise duration of VR amounted to 1,440 min, but it did not produce the expected intervention effect. In contrast, the studies of Kachmar et al. (54), Lazzari et al. (55), and Park et al. (60) showed positive effects within the exercise duration of only 160–320 min. Therefore, the relationship between VR exercise duration and exercise benefits needs to be further explored.

In addition, the principles regarding the use of dynamic and static balance in the balance test are opposite. In this study, the difference data from the static balance test results are reversed and used in the meta-analysis. Also, the absence of differential data from the original study text included in the study and the differential data obtained from indirect calculations may lead to bias in the results (68). The unavailability of data from two studies that were not included in the study may also affect the meta-analysis results (19, 48). Nevertheless, four of the included studies had findings that did not support the view that VR treatment was more effective than the other traditional treatments (41–43, 49). Despite the popularity of VR therapy as a newly popular adjunctive technology, we should use it with caution in clinical practice in the absence of a clearly defined consensus (69).

Based on the above limitations, future studies should focus on experimental design, increasing the number of participants, standardizing measurement criteria, clarifying interventions for VR, and strict randomized controlled trial

Test	Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
7	AlSaif 2015	5.8	5.32	20	0.2	5.22	20	8.1%	1.04 [0.38, 1.71]
5	Chen 2012	0.8	8.73	13	-2.1	5.56	15	6.4%	0.39 [-0.36, 1.14]
1	Cho 2016	3.3	13.26	9	2.1	15.8	9	4.2%	0.08 [-0.85, 1.00]
1	Decavele 2020	1.3	1.89	14	-0.4	1.29	13	5.5%	1.01 [0.20, 1.82]
6	Gatica-Rojas 2017	1.56	2.11	8	-0.76	1.1	8	2.9%	1.30 [0.19, 2.41]
6	Gatica-Rojas 2017	0.15	0.13	8	0.09	0.13	8	3.6%	0.44 [-0.56, 1.43]
1	Hsieh 2020	1.5	2.41	5	0.6	2.85	5	2.3%	0.31 [-0.94, 1.56]
1	Hsieh 2020	5.9	5.4	5	2.1	6.84	5	2.2%	0.56 [-0.72, 1.84]
1	Hsieh 2020	2.9	3.2	5	0.9	4.39	5	2.2%	0.47 [-0.80, 1.74]
6	Hsieh 2020	3	3.01	5	1.2	2.93	5	2.2%	0.55 [-0.73, 1.82]
6	Hsieh 2020	71	43.24	5	28.4	41.7	5	2.0%	0.91 [-0.43, 2.25]
6	Hsieh 2020	63.5	50.71	5	29.9	51.07	5	2.2%	0.60 [-0.69, 1.88]
1	Jha 2021	5.1	6.05	19	3.5	5.82	19	8.8%	0.26 [-0.38, 0.90]
1	Jung 2021	16.8	5.62	5	2.4	10.14	5	1.5%	1.59 [0.06, 3.11]
8	Kachmar 2021	0.88	1.03	7	-0.03	1.59	6	2.8%	0.64 [-0.49, 1.77]
4	Kachmar 2021	1	10	6	0	2	6	2.8%	0.13 [-1.01, 1.26]
1	Lazzari 2017	3.6	14.1	5	0.9	11.25	5	2.3%	0.19 [-1.05, 1.44]
4	Lazzari 2017	3.2	15.07	5	0.5	20.3	5	2.3%	0.14 [-1.11, 1.38]
6	Park 2021	1.57	1.35	2	0.37	0.62	2	0.2%	0.65 [-3.53, 4.83]
6	Park 2021	47.19	40.58	2	15.2	25.59	2	0.3%	0.54 [-3.09, 4.16]
3	Park 2021	5.03	3.65	2	1.2	3.22	2	0.2%	0.64 [-3.46, 4.73]
3	Park 2021	6.9	3.37	2	1.15	1.56	2	0.1%	1.25 [-6.09, 8.60]
3	Park 2021	7.12	3.96	2	2.94	2.31	2	0.2%	0.74 [-3.87, 5.34]
9	Pin 2019	5.39	5.48	3	4.94	6.96	3	1.4%	0.06 [-1.54, 1.66]
9	Pin 2019	4.28	7.18	3	3.78	5.38	3	1.4%	0.06 [-1.54, 1.66]
9	Pin 2019	0.06	4.09	3	0.39	6.01	3	1.4%	-0.05 [-1.65, 1.55]
5	Sahin 2020	1.03	1.18	30	1.03	2.32	30	14.1%	0.00 [-0.51, 0.51]
6	Sajan 2017	54.6	141.93	3	9.73	77.35	3	1.4%	0.31 [-1.31, 1.94]
6	Sajan 2017	44.36	141.92	3	-16.6	73.59	3	1.3%	0.43 [-1.22, 2.09]
1	Sajan 2017	4.56	3.17	3	3	2.98	3	1.3%	0.41 [-1.24, 2.05]
4	Tarakci 2016	2.34	3.49	4	1.1	4.53	4	1.8%	0.27 [-1.13, 1.66]
2	Tarakci 2016	3.6	5.35	4	0.94	5.33	4	1.8%	0.43 [-0.98, 1.85]
2	Tarakci 2016	4.27	6.41	4	1.2	8.41	4	1.8%	0.36 [-1.05, 1.76]
2	Tarakci 2016	3.2	6.43	4	0.67	4.1	4	1.8%	0.41 [-1.01, 1.82]
1	Uysal 2016	1.67	1.28	12	0.25	1.76	12	5.0%	0.89 [0.04, 1.74]
	Total (95% CI)			235			235	100.0%	0.47 [0.28, 0.66]

Heterogeneity: $Chi^2 = 16.77$, $df = 34$ ($P = 0.99$); $I^2 = 0\%$

Test for overall effect: $Z = 4.82$ ($P < 0.00001$)

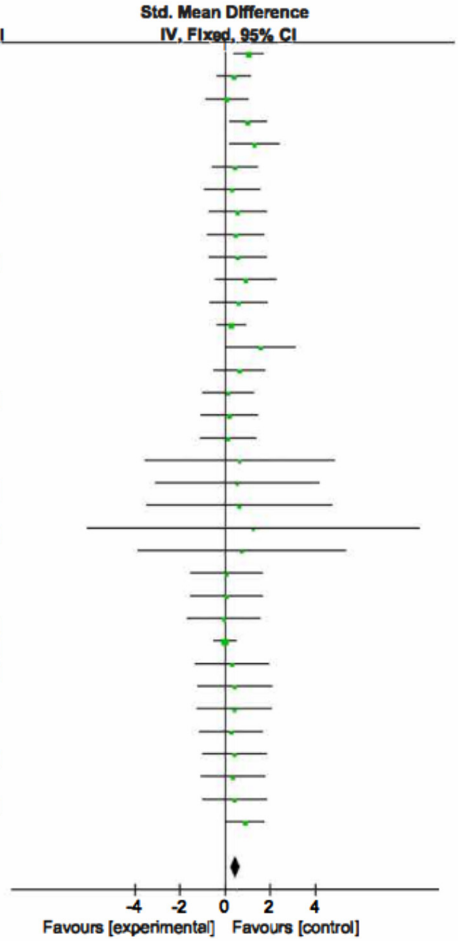

FIGURE 4 | The results of Meta-analysis balance. In the "Test" column, 1 = PBS (Pediatric Balance Scale); 2 = FRT (Functional Reach Test); 3 = MFRT (Modified Functional Reach Test); 4 = TUG (Timed Up and Go Test); 5 = BOTMP (Bruininks-Oseretsky Test of Motor Proficiency); 6 = CoP Kinematics; 7 = MABC-2 (Movement Assessment Battery for Children-2); 8 = DBT (Dynamic Balance Test); 9 = PRT (Pediatric Reach Test).

processes to provide more valid evidence for VR treatment. Furthermore, several studies on the role of VR in the management of children with CP (70), the use of robotics in the neuromotor rehabilitation of children with CP (71), and the use of hybrid assisted limb (HAL) for robot-assisted gait training of cerebral palsy patients (72) all contributed to the future direction of VR motor rehabilitation for children with CP.

CONCLUSION

Preliminary evidence indicates that VR therapy has a positive effect on improving balance function in children with CP. At least 20 min per session, twice a week for six weeks or more of regular VR therapy is more effective for improving balance function in children with CP. The application of robotics in motor function will be the new direction of VR therapy for children with CP in the future (73).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

WL, YH, and JL: data collection. WL and YH: data analysis, conception, and design. WL, YH, JL, and JC: research design, writing the manuscript and revision. All authors contributed to the article and approved the submitted version.

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