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Narrative Review

Virtual Reality for Balance After Stroke: A Narrative Review

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Abstract

Background: The present study was conducted to provide an up-to-date understanding of clinical applications in balance capability, as well as delivering a review of pieces of literature on Virtual Reality (VR) on balance control in stroke survivors.

Methods: Databases including PubMed, Cochrane Library, and Pedro were searched for published papers from 2010 to 2020 with the terms "Game-based rehabilitation", "balance training", "virtual reality", "stroke", "neurorehabilitation", and "virtual environment". We evaluated the effect of VR on balance improvement after a stroke.

Results: 33 articles describing results following the use of VR on balance in patients with stroke that met our inclusion criteria were found. Among these studies, two studies described the results in acute, eight in subacute, twenty-two in chronic stroke patients, and one study included both chronic and subacute stroke patients. The results indicated that balance can be improved with VR.

Conclusion: The results of this study strengthen the idea that VR training has the potential to become an effective adjacent to routine rehabilitation treatments for improving balance status post-stroke. However, conducting a randomized control trial that incorporates all three stroke phases with an appropriate study setting is necessary to achieve an integrated clinical protocol.

Keywords: Clinical Protocols, Humans, Neurological Rehabilitation, Stroke, Survivors, Virtual Reality

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Introduction

Stroke is the third most common cause of disability in the world (1). Stroke can lead to a wide range of sensory, motor, cognitive, and visual impairments (2). About 83% of stroke survivors suffer from balance impairment (3). Poor balance is a risk factor associated with falling (4) and limits the ability to perform daily activities (5). Fear of falling can lead to a sedentary lifestyle and increased impairment (6). Falling also directly or indirectly contributes to lingering treatment, more medical and nursing expenses, and economic losses (3). For enhancing the ability of stroke patients with balance impairment, many rehabilitation strategies have been used, including whole-body vibration (7), mirror therapy (8), traditional Chinese medicine (9), virtual reality (10,11), exercise (12), ankle-foot orthosis (13), and traditional Chinese exercise (14).

According to the 2011 Global Atlas on Cardiovascular Disease Prevention and Control (CDPC) (15) cited in (16), lack of exercise is a significant risk factor for stroke recurrence and prolonged recovery. The CDPC showed that adherence to rehabilitation steps in patients with stroke started to decline after six weeks of the stroke and reached a minimum of 21 weeks after the stroke (16). While traditional rehabilitation approaches may lead to a lack of interest in patients as daily repetitive tasks are often involved (17), Virtual Reality (VR) rehabilitation can allow a higher dose of the simulated practice of functional activities than traditional therapies (18). VR seeks to replicate real-world activities that can provide more involving tasks compared to conventional rehabilitation (10). Children and adults have identified virtual activities as exciting and enjoyable, prompting higher repetition (19).

VR has increased engagement with the treatment through its program (20). It has a prominent role in supporting post-stroke functional rehabilitation (21). It has also offered a low-cost, effective intervention (22). It may have the ability to provide an enriched environment where individuals with strokes can solve problems and master new abilities (23). VR provides an engaging environment in which a subject can repetitively practice (24). VR compared with traditional exercise, can have a positive impact on the physiological, psychological, and rehabilitative outcomes of individuals (25). The context of a virtual environment is interactive and perceived as close to the real world. VR consists of a variety of technologies to produce artificial sensory information (26), as well as facilitating active exploration, increasing interaction, and providing inspiration. By either integrating games in the form of activities or by other engaging means, VR helps patients engage in their therapy (27). VR can be helpful since it provides multiple scopes for neurological recoveries, such as goal-oriented tasks and repetition (28). The level of physical activity of the user can vary from relatively passive to highly active. However, it depends on the intervention (23). VR depends on software and computer hardware that mediates contact of the users with the virtual world (23). Users relearn the coordination and sense of balance as the simulated real-world scenarios give patients with balance disorder more informational input than the real world (29). In the efficacy of recruiting neural circuits and the outcome of desirable results at the functional level, the fidelity of VR can play an important role (29).

In recent years, VR has been used in stroke recovery (30). The study of the effects of VR training on balance and gait capacity showed the major advantages of VR training on gait velocity, Berg Balance Scale (BBS) scores, and Timed Up & Go Test (TUG) scores when the time dose of VR matched to traditional therapy (10). In 2016, De Rooij *et al* carried out a meta-analysis that demonstrated higher advantages of balanced VR therapies over conventional approaches (31). Lee *et al* suggested that substantial changes were made after VR training in favor of combining postural balance therapies and upper limb motor control in a seated position (32).

To allow clinicians to provide an up-to-date understanding of clinical applications in balance capability, we aimed to deliver a review of pieces of literature on the VR on balance control in stroke survivors.

Materials and Methods

Study criteria

The eligible studies were required to have the following criteria:

1) To be published in English

2) Investigating any form of immersive or

non-immersive VR training aimed at improving post-stroke balance control
3) Full-text articles available
4) Study comparing pre-intervention and post-intervention outcome measures.
Systematic reviews for the participants who had other diseases than strokes, *e.g*., Parkinson's disease, and multiple sclerosis, Editorial, and letter were excluded.

Search strategy

We searched several electronic databases including, PubMed, Cochrane Library, and PEDro, and published papers from 2010 to 2020. For further relevant studies, we manually reviewed references from the collections. To decide whether the studies met the predetermined inclusion requirements, we checked authors, titles, and abstracts. The following keywords were used: "Game-based rehabilitation", "balance training", "virtual reality", "stroke", "neurorehabilitation", and "virtual environment".

Results

Overview of the included papers

Tables 1, 2, and 3 summarize the findings from our review on VR in acute, subacute, and chronic stroke patients, respectively. We found 33 articles describing results following the use of VR on balance in patients with stroke that met our inclusion criteria. Among these studies, two studies described the result in acute, eight in subacute, twenty-two in chronic stroke patients and one study included both chronic and subacute stroke patients. The total number of participants in each study varied from 2 to 73.
Eighteen studies had a sample size of fewer than 30 participants (33-50) and two studies had over 50 participants (51,52). Of 33 studies, only two studies had follow-up assessments (22,53). Balance was assessed using various outcome measures in different studies. A range of outcome measures was used to measure balance (Tables 1, 2, and 3).

1) Effect of VR training on balance control in acute stroke patients

a) Main findings

Studying the effect of VR on balance in acute stroke patients showed improvement in balance in a randomized controlled and double-blinded pilot study (50). However, another study demonstrated that the addition of VR training to conventional training did not bring additional benefit to the patient's balance, although the balance was improved in all three balance-training modalities (VR, Tetrax, and standard treatment) (54).

b) Characteristics of the included studies

Two studies did not evaluate the long-term effect of VR on balance. Sample sizes were not adequate. One study had a sample size of fewer than 30 participants (50), and the other study had 30 participants (54). One study utilized The IREX virtual reality instrument (54), and the other study (50) used Wii-based VR as balance training for the experimental group. In one study, the control group performed conventional therapy, and in the other study, patients were assigned to a VR, Tetrax, or control group (conventional therapy) (54). Both studies included male and female participants.
A range of outcome measures was used to measure balance including, TUG (50), BBS (50, 54), CoP (50), FRT (50), MBI (50), and FI (54). Details can be found in table 1.

2) Effect of VR training on balance control in subacute stroke patients

a) Main findings

Two pilot studies showed the effectiveness of VR on balance performance in the subacute phase of stroke (32,49). Three RCTs confirmed its effectiveness (47,53,55). However, in one RCT, no superiority of VR training to conventional therapy was seen (52). The positive effect of the VR program on balance control was seen in other two trials (48,56).

b) Characteristics of the included studies

Study sample sizes were generally small. Three studies had a sample size of fewer than 30 participants (47-49) and one study had over 50 participants (52). All studies consisted of male and female participants. Only one study evaluated the long-term effects of VR training on balance control in subacute stroke patients (53), which assessed balance control three months after training. However, the dropout rate for follow-up was high. Three studies used Wii-based VR training as a treatment for the experimental group (47,53,55),

Table 1. Evidence of virtual reality (VR) on balance performance in acute stroke subjects

Reference and country	Participants	Intervention	Variable	The outcome measure of balance: Experimental Pre-session	Experimental Post-session	Control Pre-session	Control Post-session	Study Type	Relevant findings
B.S. Rajaratnam *et al* (2013)(50) Singapore	19 stroke patients. EG (n:10) and CG (n:9). Onset period (days): EG:14.7 (7.5), CG:15.2 (6.3) Age (yrs): EG:58.67 (8.62),CG: 65.33 (9.59) Gender:7M, 12F	CG:One-*hr* conventional rehabilitation. EG:40 *min* of convention rehabilitation and 20 *min* self-directed VR balanced rehabilitation	TUG (Pre/post differences)	−2.201		− 2.201		RCT	After 15 sessions of rehabilitation, there was a substantial difference in FRT scores between the EG and CG (P=0.017). In all other outcome measures after intervention between the EG and CG, there were no statistically significant differences. FRT was significantly correlated (P=0.028) with BBS.
			BBS (Pre/post differences)	−1.604		−1.604			
			CoP (Pre/post differences)	−0.552		−1.069			
			FRT (Pre/post differences)	−2.803		−1.363			
			MBI (Pre/post differences)	−2.207		−2.201			
Yoon Bum Song *et al* (2014)(54) South Korea	30 acute stroke patients VR (n:10), Tetrax (n:10), and CG (n:10). Onset period (days): VG:12.7±3.2, TG: 12.7±3.2, CG: 13.2±3.4 Age (yrs):VG: 65.6±13.5, TG: 60.6±18.2, CG: 61.2±13.8 Gender:16 M, 14 F	All patients received conventional balance training (5 times per week, at 25 *min* per session). The VR group received additional VR treatment, 3 times/week, at 25 *min* per session, for 3 weeks. The Tetrax group: additional Tetrax treatment, 3 times/week, at 25 *min*/ session, for 3 weeks.	BBS (mean±SD)	VG: 41.2±1.7 TG: 41.8±1.4	VG: 48.3±3.5 TG: 49.4±2.3	42.1±1.4	47.9±2.3	RCT	BBS and FI significantly improved after intervention in all three groups (p<0.05), but between the three groups, significant differences were not seen.
			FI (mean±SD)	VG: 82.9±7.2 TG: 84.0±8.9	VG: 53.0±6.6 TG: 52.0±7.6	81.8±8.1	55.8±6.7		

two studies used canoe VR (32,49), one study used X-box 360 Kinect (48), one study utilized motion-captured software (52), and VR-based eccentric training with Eccentron was used for one study (56). Among eight studies, six used conventional therapy as a treatment for the control group. Patients in one study were allocated to each of two eccentric training groups: one using a slow velocity and one using a fast velocity (56). In the other study, participants were randomly assigned to the Nintendo Wii group or Bobath neurodevelopmental treatment (NDT) group (55). A range of outcome measures was used to measure balance including, TUG (47,49,52), BBS (47,49,53), and FRT (47,49,52). Details of each study can be found in table 2.

Scale, TUG: Timed Up and Go test, PASS: Postural Assessment Scale, CE: Eyes Closed OE: Eyes Open, 10MWT: 10m Walking Test, SBI: Static Balance Index, mFRT: modified Functional Reach Test, FIM: Functional Independence Measure, FAC: Functional Ambulation Category, LoS: Limit of Stability, BI: Barthel Index, SV: sway velocity, RCT: Randomized Controlled Trial, CT: Clinical Trial.

Table 2. Evidence of virtual reality (VR) on balance performance in subacute stroke subjects

Reference and country	Participants	Intervention	Variable	The outcome measure of balance: Experimental Pre-session	Experimental Post-session	Control Pre-session	Control Post-session	Study Type	Relevant findings

Cont Table 2.

Myung-Mo Lee (2016)(49) South Korea	10 patients with stroke. EG (n:5) and CG (n:5). Onset period (mos): EG: 3.1±1.6, CG: 3.3±1.1 Age (yrs): EG: 65.2±5.0, CG: 66.2±3.4 Gender:5M, 5F	Both groups: conventional rehabilitation (30*min* 2/day, 5/week), EG had an additional 30 *min* canoe game-based VR training program 3/week for 1month	TIS(score) (mean±SD)	14.0±0.7	16.8±1.3	12.6±1.7	13.6±1.7	RCT	TIS score significantly improved in the EG but not in the CG. The FRT result showed significant improvement in both groups. When the two groups were compared, TIS and FRT scores changes were statistically more in the EG than in the CG. BBS score showed significant improvement in both groups. The TUG times significantly improved in the EG but not in the CG. When the two groups were compared, the changes in the BBS and TUG scores were statistically more in the EG than in the CG.
			FRT(*cm*) (mean±SD)	20.4±3.5	22.4±3.9	17.8±0.9	18.7±0.9		
			BBS(score) (mean±SD)	41.8±4.2	46.2±4.3	38.8±3.7	41.2±2.9		
			TUG(sec) (mean±SD)	16.6±4.3	15.1±4.0	18.1±2.7	18.2±1.5		
Trupti Kulkarni *et al* (2018)(48) India	28 patients with stroke. EG (n: 15)and CG (n:13). Onset period(mos): EG: 3.06±2.49, CG: 3±1.732Age: EG: 48.9±10.65, CG: 50.38±8.08 Gender: 23 M,5 F	EG: X BOX 360 Kinect for 6 weeks (30 *minutes* per day for 3 days a week). CT group performed mobility, balance, and trunk-specific exercises for the same period.	TIS (mean±SD)	10.71±3.7	19.6±1.6	12.84±2.7	17.92±2.06	CT	VR training using X box 360 is significantly more effective on the trunk and postural control in stroke patients compared to conventional physiotherapy.
			PASS (mean±SD)	16±5.60	30.8±3.91	16.46±3.59	22±2.48		
Ayça Utkan Karasu *et al* (2018) (47) Turkey	23 patients with stroke. EG (n:12) and CG (n:11). Onset period (days): EG:29, CG:31 Age (yrs): EG:62.3 (11.79), CG:64.1 (12.2) Gender: 10 M,13 F	Both groups: conventional balance rehabilitation. for 2–3 h/day,5/week. In addition to conventional therapy, EG received 20 *min* of balance exercise,5/week, for 1 month, with Wii Fit and Wii Balance Board	BBS	38.8 (6.9)	week 4:48.9 (6.4), week 8:48.7 (4.7)	39.1 (6.9)	week 4: 42.2 (6.4), week 8: 39.4 (5.7)	RCT	A significant improvement over time (time effect) was observed in all the measures except anteroposterior COP displacement with eyes closed, COP displacement during WSNS, and total COP displacement during weight shift. Group–time interaction was significant in the BBS, FRT, and postural sway parameters, excluding mediolateral COP displacement with eyes closed, and FIMI scores. Both groups displayed significant improvement, the EG showed more improvement than the CG.
			FRT (*cm*)	16.4 (5.5)	week 4: 25.2 (5.5), week 8: 23.6 (5.4)	18.8 (3.3)	week 4: 22.2 (5.1), week 8: 20 (3.14)		
			TUG (s)	32.5 (21.2)	week 4: 19.5 (9.8) Week 8: 20.5 (8.3)	27.4 (15.0)	week 4: 24 (13.5), week 8: 29.6 (10.5)		
			PASS	28.8 (4.3)	Week 4: 32.5 (2.5), week 8: 32 (2.4)	27.9 (5.2)	Week 4: 30.4 (4.1), week 8: 29.2 (3.5)		
			SBI	426.2 (285.3)	Week 4:369.3 (301.5), week 8: 337 (282.8)	412.4 (196.8)	Week 4: 314.2 (129.8), week 8: 399.7 (74.7)		

Cont Table 2.

Myung Mo Lee *et al* (2018)(32) South Korea	30 patients with stroke. EG (n:15) and CG (n:15). Onset period (mos): EG: 3.43±1.34, CG: 3.13±1.54 Age (yrs): EG: 61.80±6.80, CG: 61.33±8.44 Gender: 18 M,12 F	All subjects: conventional rehabilitation program. EG: the VR canoe paddling training for 30 *min* each day, 3 times per week, for 5 weeks.	mFRT Forward (*cm*)	21.50±4.28	26.65±4.36	20.04±4.34	24.14±4.53	RCT	mFRT for all directions significantly improved in both groups (p<0.05). CoP, PL, and SV significantly decreased in both the eyes open and eyes closed condition EG (p<0.05). In the CG, only the SV when the participant's eyes were open, was significantly decreased (p<0.05).
			mFRT Unaffected side(*cm*)	13.40±2.87	20.13±3.01	13.27±2.39	18.60±3.32		
			mFRT Affected side(*cm*)	8.09±2.36	13.73±3.15	8.04±2.80	12.16±3.49		
			EO-CoP PL(*cm*)	82.48±30.68	75.69±31.63	74.02±28.48	72.88±28.31		
			O-SV (*cm/s*)	2.78±1.05	2.42±0.94	2.58±0.96	2.50±0.96		
			EC-CoP PL(*cm*)	99.88±38.62	92.97±38.10	87.17±36.04	84.25±32.99		
			EC-SV (*cm/s*)	3.44±1.32	3.22±1.28	3.08±1.22	2.99±1.14		
			Activities-specific Balance Confidence (score)	91.4	Week 6: 81.8 Week 12: 89.4	85.5	Week 6: 93.5 Week 12: 93.3		
Seung Kyu Park *et al* (2016)(56) South Korea	30 stroke patients. Two groups of 15 participants. Onset period (mos):Group 1:5.4±1.4, Group 2: 5.3±1.2 Age:group 1:61.0±4.2, group 2: 60.9±4.2 Gender: 16 M,14 F	Group1:slow velocity and Group2:fast velocity. The VR-based eccentric training was performed by the patients for 30 *min* once a day, 5 days/week, for 8 weeks using an Eccentron system.	LOS(*cm2*) (mean±SD)	Group1: 90.5±9.2	168.8±9.1	Group2: 91.2±9.0	147.6±7.2	RCT	VR-based eccentric training using a slow velocity is effective for improving balance ability in stroke patients.
Giovanni Morone *et al* (2014) (53) Italy	50 stroke patients. EG (n:25) and CG (n:25). Onset period (days): EG: 61.00±36.47, CG: 41.65±36.89 Age (yrs): EG: 58.36±9.62, CG: 61.96±10.31 Gender: -	EG: Wii Fit (12 sessions of each 20 *min*, 3 times/week for1month). CG: usual balance training (20 *min* 3 times/week for1month). Both groups: treated with conventional physical therapy (40 *min* 2 times/day).	BI	-				RCT	Wii Fit was more effective compared to usual balance therapy in improving balance (BBS: 53 versus 48, p=0.004) and independence in activity of daily living (BI:98 versus 93, p=0.021).
			FAC	-					
			BBS	-					
			10MVT	-					

Cont Table 2.

John Cannell *et al* (2017)(52) Australia	73 patients with stroke. EG (n:35) and CG (n:38). Onset period (days): EG:26 (27), CG:19 (13) Age (yrs): EG:72.8 (10.4), CG:74.8 (11.9) Gender: 38 M,41 F	Both groups: functional retraining and individualized programs for up to an *hr*, on weekdays for 8–40 sessions. EG: motivating VR and novel gesture-controlled interactive motion capture software. Both groups:2 sessions/ day.	FRT (*cm*)	13.8 (2.6)	17.9 (1.4)	17.1 (1.8)	20.4 (1.3)	RCT	There were no differences between the rehabilitation units except in lateral reach (less affected side) (P=0.04)
			Lateral reach (more affected) (*cm*)	8.2 (1.9)	11.8 (1.6)	9.3 (1.3)	12.8 (1.1)		
			Lateral reach (less affected) (*cm*)	8.9 (2.0)	11.1 (1.8)	12.1 (1.4)	13.6 (1.2)		
			Sitting balance (number)	3.7 (0.2)	3.9 (0.2)	3.6 (0.1)	3.9 (0.1)		
			TUG (seconds) (n=50)	28.6 (6.1)	27.6 (6.1)	26.7 (3.9)	22.9 (5.3)		
			Step test more affected (number in 15 seconds)	4.0 (1.3)	5.8 (0.9)	5.3 (1.0)	7.2 (0.6)		
			Step test less affected (number in 15 seconds)	4.4 (1.3)	6.4 (1.1)	5.6 (1.0)	6.5 (0.8)		
Tülay Tarsuslu Şimşek *et al* (2015) (55) Turkey	42 stroke patients. Nintendo Wii group (n:20) and Bobath neurodevelopmental treatment (n:22). Onset period (days):EG: 50.6±15.04, CG: 59.9±30.99 Age(yrs): EG: 54.15±20.29, CG: 61.5±11.63 Gender: 29 M,13 F	Both groups: ten weeks (45–60 *min*/ day, 3 days/ week). Nintendo Wii group 5 games. Bobath group: therapy program that included upper extremity activities, strength, balance gait, and functional training.	FIM (mean±SD)	96.80±22.33	111.7±15.06	101.09± 21.69	107.09± 19.24	RCT	FIM motorsub-parameter which evaluates transfer and locomotion which significantly influences balance and mobility level significantly improved.

Note: M: Male, F: Female, EG: Experimental Group, CG: Control Group, TG: Tetrax Group, VG: Virtual Group, BBS: Berg Balance Scale, CoP: Center of Pressure, TUG: Timed Up and Go test, MBI: Modified Barthel Index, FI: Falling Index, FRT: Functional Reach Test, RCT: Randomized Controlled Trial.

3) Effects of VR training on balance control in chronic stroke patients

a) Main findings

Studies regarding the use of VR for improving balance control in chronic stroke survivors were in favor of its effectiveness when compared to conventional therapy (33-37,40,42,43,57-59). In one study, VR was compared with Proprioceptive Neuromuscular Facilitation (PNF)(60). In three studies, the effectiveness of VR treadmill training was assessed (38,45,61,62). VR-based telerehabilitation effectiveness of VR training was investigated in one study (22). One study used Speed-Interactive Pedaling Training using VR to see its effectiveness in improving balance performance (63). And finally, two studies were case-series, and there was no control group designed in the study (41,44). In one study (51), the patients were assigned to two groups based on the time since stroke (<6 months) or chronic (>6 months) to examine the effect of VR on balance. The findings of this study suggest that the VR provided to the patients was beneficial for both chronic and subacute groups. Details of each study are demonstrated in table 3.

b) Characteristics of the included studies

Table 3. Evidence of Virtual Reality (VR) on balance performance in chronic stroke subjects

Reference and country	Participants	Intervention	The outcome measure of balance					Study Type	Relevant findings
			Variable	Experimental		Control			
				Pre-session	Post-session	Pre-session	Post-session		
Shih-Hsiang Ciou *et al* (2015)(46) Taiwan	2patients with stroke. Onset period (mos): 6Mon,11Mon Age(yrs): 49,39 Gender: 2 M	Three 30-*min* sessions/ week for 3 weeks	Case 1 BBS	36point	43 point	-	-	CT	Only the patient who had a recent stroke benefited significantly.
			Case 2 BBS	42point	47 point	-	-		
			Case 1 MAS	6point	12 point	-	-		
			Case 2 MAS	16point	17 point				
			COP Case1	OE(−16.20 ,−1.97), CE (−13.80,3.35)	OE (2.55,−0.36), CE (13.48,−22.41)	-	-		
			COP Case2	OE (27.10,93.99), CE (12.23,76.06)	OE (22.89,56.71), CE (23.42,59.19)	-	-		
Gui Bin Song *et al* (2015)(64) South Korea	40 patients with stroke. Ergometer training group (n:20) and virtual reality group (n:20). Onset period (mos): EG: 14.75±6.06, CG: 14.30±3.40 Age(yrs): EG: 51.37±40.6, CG: 50.10±7.83 Gender: 22 M, 18 F	VRG: training with the Xbox Kinect for 30 *min*/session, 5/week, for 2 months, ETG: ergometer bicycle training 30 *min*/session, 5/week, for 2months.	Forward LOS (*mm*) (mean±SD)	2732.9±3137.1	3311.7±3786.5	5670.8±4291.1	4322.6±3565.5	RCT	Both groups showed significant improvement in the weight distribution ratio on the paralyzed side, anterior LOS, posterior LOS, and TUG, and 10-*m* walking times after the intervention (p<0.05). When the post-intervention improvements of the two groups were compared, the VRG demonstrated more significant improvements in weight distribution ratio on the paralyzed side, anterior LOS, posterior LOS, and TUG.
			Backward LOS(*mm*)	2072.7±2050.4	1895.9±2097.5	3971.7±2794.3	2889.7±2769.7		
			TUG(s) (mean±SD)	21.17±7.7	21.9±7.9	16.6±4.7	19.5±7.5		
Jinhwa Jung *et al* (2012)(45) South Korea	21 stroke patients. EG (n:11) and CG (n:10) Onset period(mon): EG: 12.6±3.3, CG: 15.4±4.7 Age(yrs): EG: 60.5±8.6, CG: 63.6±5.1 Gender: 13M, 8 F	EG:VR treadmill training 30 *min*/day, 5/week, for 3 weeks. CG: treadmill training on the same schedule.	TUG (sec) (means± SD)	21.9±3.5	19.2±4.5	23.8±4.9	23.0±5.2	RCT	Improvements in balance and balance self-efficacy in the virtual reality treadmill training group were significantly greater compared with the CG(p<0.05). Significant increases in balance and balance self-efficacy were seen in both groups after training (p<0.05).
			ABC scale(%) (means± SD)	43.3±5.7	52.8±6.5	47.0±5.0	51.3±5.6		
Nikita Girishbhai Shobhanal *et al* (2020)(58) India	30 subjects with stroke. Conventional Physical Therapy group(n:15) and EG (n:15) Onset period: Age:- Gender:-	EG: exposed to two software for XBOX 360 Kinect. CG performed ROM exercises, Balance training, and Gait training: 3days/week for one *hr*.	BBS (mean (SD)	43.73 (4.11)	50.13 (3.70)	44.06 (4.19)	48.6 (3.35)	RCT	The VR group showed significant improvement in BBS compared with the CG.

Cont Table 3.

Irene Cortés-Pérez *et al* (2020)(44) Spain	3 stroke patients. Onset period: P1:6, P2:9, P3:10 (mos) Age: P1:45, P2:50, P3: 53 Gender:M	Patient 1:25 sessions of immersive VR (3sessions/week of 45 *min* each) for 2 months. Patient 2: equivalent CT (3 sessions/ week of one *hr* each for 2 months). patient 3:no intervention.	BBS Tinetti SVV Romberg ABC FES-I TGUGT	28 11 5.75±1.25 427 24 47 29	34 19 4±1.2 398 32 40 23	Case 2: 15 Case 3: 8 Case 2: 7 Case 3: 6 Case 2: 5.2±2.7 Case 3: 3.7±2 Case 2: 192 Case 3:- Case 2:13 Case 3:4 Case 2:59 Case 3:61 Case 2:33 Case 3:-	Case 2:18 Case 3:7 Case 2:9 Case 3:6 Case 2: 4.8±1.8 Case 3: 3.4±1.67 Case 2: 226 Case 3:- Case 2:15 Case 3:4 Case 2:54 Case 3:60 Case 2:31 Case 3:-	Case Series	The two patients receiving any of the treatments showed an improvement in balance compared to the untreated patient. In comparison to CT, the higher effect of immersive VR in the improvement of balance and a reduction of fall risk was seen due to the active upright work during the VR intervention.
Kyeongjin Lee (2019)(63) South Korea	42 patients with stroke. EG (n:21) and CG (n:21). Onset period (mos): EG: 14.81±7.30, CG: 16.48±7.13 Age (yrs): EG: 61.67±8.42, CG: 64.24±10.83 Gender:27 M,15 F	EG: cycle training with SIPT for 40 *min*/day, 5days/week, in 6 weeks, in addition to conventional therapy. CG: cycle training without SIPT and conventional therapy.	EO-MLS (*mm/s*) EO-APS (*mm/s*) EO-VM (*mm/s* 2 EC-MLS (*mm/s*) EC-APS (*mm/s*) EC-VM (*mm/s* 2) mFRT-forward (*mm*) mFRT-non-ffected (*mm*) mFRT-affected (*mm*) TIS (score)	3.95±1.27 5.85±1.41 5.06±2.18 3.95±1.27 5.85±1.41 4.18±1.30 302.27±113.40 175.23±48.60 88.72±24.24 12.33±1.59	3.00±0.82 4.60±1.38 3.71±1.68 2.85±0.66 4.73±1.43 2.79±1.32 328.41±108.52 197.89±54.79 108.07±33.26 14.38±2.09	3.75±1.21 5.89±1.18 4.74±2.04 3.75±1.21 5.89±1.18 4.03±1.13 274.97±122.87 158.75±61.74 84.31±37.48 12.24±1.89	3.34±1.03 5.20±1.30 4.12±1.93 3.24±0.93 5.20±1.30 3.27±1.29 279.15±126.13 161.13±63.61 85.62±38.88 13.14±0.48	RCT	The changes in the static sitting balance ability, the speed of medial and lateral sway, and the speed of the anterior and posterior sway improved significantly after intervention in both groups regardless of vision (p<0.05). However, EG showed a more significant improvement compared to the CG (p<0.05) The mFRT for all directions increased significantly post-treatment in both groups (p<0.05). However, the EG improved significantly compared to the CG (p<0.05). In the intragroup analysis, TIS was significantly improved from 12.23 to 13.38 in the EG (p<0.05), and from 12.24 to 13.14 in the CG (p<0.05). However, the EG demonstrated a significant improvement compared to the CG (p<0.05).

Cont Table 3.

Nara Kim *et al* (2015)(38) South Korea	17 chronic stroke patients. EG (n:10) and CG (n:7). Onset period: - Age: - Gender: -	Both groups: conventional physical therapy for 1*hr*/day, 5/week, for 1month. EG: community-based VR scene exposure combined with treadmill training for 30 *min*/day, 3/week, for 4weeks. CG: conventional physical therapy, including muscle strengthening, balance training, and indoor and outdoor gait training on the same schedule.	PSPL(*cm*) (mean(SD))	68.37 (19.11)	63.02 (13.56)	59.52 (10.36)	62.01 (10.67)	RCT	Anteroposterior postural sway path length in EG significantly improved (p<0.05), whereas the CG demonstrated no significant improvement in anteroposterior postural sway path length. The mediolateral postural sway path length did not have a significant difference between the two groups. However, the EG showed a significantly improved total postural sway path length (p<0.05). The total postural sway path length had no significant difference in the CG. The postural sway speed improved significantly in the EG(p<0.05), but not in the CG. The EG demonstrated a great improvement in multiple balance measures (p<0.05) compared with the CG, which advocates that CVRTT training can improve the static balance ability in stroke patients.
			APSS(*cm/s*) (mean(SD))	2.28 (0.64)	2.10 (0.45)	1.99 (0.35)	2.07 (0.36)		
Yo-Soon Bang *et al* (2016)(62) South Korea	40 stroke patients. EG (n:20) and CG (20). Onset period (mos): EG:30.4±5.4, CG:31.6±7.4 Age (yrs): EG:62.2±7.2, CG:63.2±5.4 Gender: -	All subjects: 40 *min* exercise program 3/week for 8weeks. EG:Wii board balance system for 40 *min.* CG:low-speed treadmills for 40 *min.*	Left/right weight-bearing(%) (M±SD)	17.1±5.5	10.6±4.8	16.9±6.5	13.1±5.8	RCT	Significant differences in both groups after completing the program were seen.
			Anterior/ posterior weight-bearing (%) (M±SD)	15.4±6.7	10.3±4.7	15.7±4.6	12.9±5.1		
Imre Cikajilo *et al* (2020)(37) Slovenia	20 acute and subacute stroke patients. EG (n:10) and CG (n:10). Onset period (mos): EG:4, CG:7.4 Age (yrs): EG: 50.3±7.9, CG: 51.8±15.5 Gender: 15 M, 5 F	CG: 1week of conventional balance training and EG:1week of multiple-game exergaming.	FSST	13.21 (3.90)	10.24 (2.44)	12.75 (12.10)	14.50 (13.78)	RCT	EG showed significant improvement in FSST but not TUG. Practically, no statistically significant differences between the EG and CG were found in tests performed with eyes open (ROM EO, sROM EO, STOL(R)L EO, and CTSIB EO). Significant differences between the EG and CG were found only in sROM and STORL tests,both performed with closed eyes.
			TUG	9.56 (2.69)		15.18 (10.20)	12.17 (6.74)		
			CTSIB eyes open	38.83 (13.15)	43.52 (4.68)	43.50 (4.74)	45.00 (0.00)		
			CTSIB eyes closed	31.39 (19.14)	36.69 (17.52)	29.13 (18.16)	34.77 (16.81)		
			STOLL eyes open	18.21 (19.30)	23.74 (19.01)	18.82 (19.83)	20.33 (20.57)		
			STOLL eyes closed	1.61 (1.18)	4.62 (5.01)	2.20 (3.16)	2.35 (3.40)		
			STORL eyes open	21.53 (20.42)	23.87 (19.40)	13.31 (16.36)	19.33 (18.07)		
			STORL eyes closed	3.92 (7.09)	2.82 (2.02)	1.29 (2.27)	1.16 (1.29)		
			ROM eyes open	44.33 (2.12)	43.75 (3.95)	45.00 (0.00)	45.00 (0.00)		
			ROM eyes closed	6.79 (13.66)	41.49 (11.10)	26.46 (19.85)	40.29 (9.94)		
			sROM eyes open	34.56 (17.02)	42.11 (8.46)	31.90 (21.12)	34.03 (18.07)		
			sROM eyes closed	19.65 (19.16)	18.96 (19.10)	8.57 (13.36)	9.67 (13.42)		

Cont Table 3.

Pawel Kiper *et al* (2020)(51) Italy	59 stroke patients. Subacute group (n:31) and chronic group (n:28). Onset period (mos): subacute group: 2.08 (1.34), chronic group: 26.31 (33.37) Age:subacute group: 60.02 (17.58), chronic group: 60.59 (11.14) Gender: 46 M,13 F	VR Rehabilitation System treatment was used for 15sessions, 5days/week for 1*hr*/day for all participants. Also, all the patients received conventional rehabilitation.	FM LE (mean(SD)) FIM (mean(SD)) BBS (mean(SD)) FAC (mean(SD)) 10MWT (mean(SD))	Subacute 24.65 (5.72) 101.8 (18.67) 45.39 (8.62) 3.07 (1.30) 24.38 (28.84)	26.29 (5.69) 104.8(16.8) 49.22 (6.18) 3.45 (1.26) 17.41 (12.18)	Chronic 18.71 (8.04) 105.80 (19.6) 43.04 (10.68) 3.68 (1.36) 44.03 (69.66)	20.89 (7.63) 108.10 (18.68) 46.32 (9.11) 3.86 (1.21) 32.34 (31.14)	CT	The VR provided to the patients was beneficial for both chronic and subacute groups.
Changho Yom *et al* (2015)(36) South Korea	20 stroke patients. EG (n:10) and CG (n:10). Onset period (mos): EG:11.14, CG:11.63 Age (yrs): EG:64.60, CG:78.10 Gender:11 M, 9 F	EG:a virtual environment system ankle exercise, and CG: watched a video. Both groups: interventions for 30 *min*/day, 5/week for 6weeks.	TUG (sec) (mean±SD)	24.59±14.42	19.09±12.73	35.96±16.50	34.74±16.20	RCT	TUG significantly improved in EG (p<0.05) and there were no significant changes after the intervention of the CG.
Seok Won Lee *et al* (2013)(43) South Korea	22 chronic stroke patients. EG (n:12) and CG (n:10). Onset period:- Age (yrs): EG: 60.6±8.8, CG: 63.7±4.7 Gender: 6M,16 F	All the participants received a conventional rehabilitation program for 1*hr* 5days/week for 4weeks. The EG additionally practiced VFT 30 *min* of sessions, 5days/week, for 1 month.	Right/Left Sway (*mm/s*) (mean±SD)) Anterior/ Posterior Sway (*mm/s*)(*v*) Velocity Moment (*mm2/s*) (mean±SD) mFRT Anterior (*mm*) (mean±SD) mFRT Lateral (*mm*) (mean±SD)	3.00±1.23 (EO) 3.45±1.60 (EC) 2.86±1.15 (EO) 3.12±1.14 (EC) 2.69±1.70 (EO) 3.83±2.59 (EC) 313.5±118.5 181.0±55.7	2.38±1.01 2.99±1.83 2.15±0.91 2.70±1.05 1.88±1.22 2.13±1.49 341.1±126. 202.9±66.1	3.24±1.37 (EO) 3.59±2.38 (EC) 2.59±0.69 (EO) 2.98±1.29 (EC) 2.05±0.94 (EO) 4.14±4.01 (EC) 307.2±126.6 161.5±76.5	3.41±1.27 3.73±2.70 2.72±0.72 3.02±1.37 2.13±0.71 4.30±4.70 310.2±126.7 162.6±74.0	RCT	The speed of right and left sway and anterior and posterior sway lowered significantly in the EG, regardless of vision. The CG showed an increase in the speed of sway, but not significantly. Velocity moment lowered significantly in the EG (p<0.05) while there was no significant increase in the CG, regardless of vision. Anterior and lateral reach was significantly greater in the EG (p<0.05) and was not significant in the CG.
Ki Hun Cho *et al* (2012)(33) South Korea	22 Stroke patients. EG (n:11) and CG (n:11). Onset period (mos): EG: 12.54 (2.58), CG: 12.63 (2.54) Age (yrs): EG: 65.26 (8.35), CG: 63.13 (6.87) Gender: 14 M, 8 F	Both groups: standard rehabilitation program for 1hour/day, 5sessions/week for 6 weeks. EG:VRBT for 30 *min*/day, 3times/week for 6 weeks.	PSV-apeo (*mm/s*) PSV-apec (*mm/s*) PSV-mleo (*mm/s*) PSV-mlec (*mm/s*) BBS (score) TUG (sec)	7.37 (2.20) 9.97 (2.69) 11.40 (2.24) 16.78 (2.25) 39.09 (5.66) 21.74 (3.41)	6.20 (1.70) 9.18 (1.75) 11.22 (2.06) 15.50 (3.59) 43.09 (4.80) 20.40 (3.19)	6.01 (1.85) 9.67 (2.72) 9.92 (1.28) 14.41 (4.08) 41.09 (4.01) 19.60 (4.42)	5.64 (1.57) 9.14 (2.31) 9.82 (1.20) 14.12 (4.01) 43.90 (4.06) 19.08 (4.52)	RCT	Greater improvement in the EG on dynamic balance (BBS and TUG) was seen compared to the CG, but not static balance in both groups.
Nildo Manoel da Silva Ribeiro *et al* (2015)(59) Brazil	30 stroke patients. EG (n:15) and CG (n:15). Onset period (mos): EG: 42.1 (26.9), CG: 60.4 (44.1) Age (yrs): EG: 53.7 (6.1), CG: 52.8 (8.6) Gender: 11 M,19 F	Patients received 1-*hr* treatment sessions twice/week for 2months.	Fugl–Meyer (Balance)	12.9 (1.8) (intergroup comparisons)		11.9 (1.8) (intergroup comparisons)		RCT	A significant difference was observed between both groups pre and post-intervention in terms of the following Fugl–Meyer balance variable.

Cont Table 3.

Taesung In *et al* (2016)(42) South Korea	25 patients with stroke. EG(n:13) and CG (n:12). Onset period(mos): EG: 12.54±4.14, CG: 13.58±5.28 Age(yrs): EG: 57.31±10.53, CG: 54.42±11.44 Gender: 15 M, 10 F	Both groups received a conventional rehabilitation program for 30 *min*. The VRRT group also performed a VRRT program for 30 *min*, 5times a week for 1month. The CG performed a conventional rehabilitation program and a placebo VRRT program.	BBS(score) (mean ±SD)	45.46±4.12	49.08±2.72	44.75±3.02	46.08±2.97	RCT	BBS in both the EG and the CG showed significant improvements and significantly improved in the EG (p<0.05). FRT and TUG demonstrated significant improvement in the EG but not in the CG. All conditions with eyes open and the medial-lateral sway with eyes closed demonstrated significant improvement in postural sway in the VRRT group (p<0.05), but not in the CG. The anterior-posterior sway and medial-lateral sway distance with eyes open showed significant improvements in the EG compared to the CG.
			FRT(*mm*) (mean±SD)	194.16±58.89	200.83±58.83	197.10±71.07	196.13±70.90		
			TUG(sec)) (mean±SD)	21.82±5.70	18.01±3.70	20.39±4.11	19.30±3.72		
			EO-APS(*cm*)	38.68±4.76	31.59±2.30	37.93±3.16	37.58±3.81		
			EO-MLS(*cm*)	35.41±3.31	33.51±2.91	34.78±3.74	33.19±4.47		
			EO-TS(*cm*)	52.16±5.97	49.27±6.71	51.30±5.93	50.94±3.97		
			EC-APS(*cm*)	56.80±8.43	55.40±9.12	60.86±14.67	60.87±15.28		
			EC-MLS(*cm*)	50.18±5.69	47.31±5.83	52.65±13.56	53.50±10.65		
			EC-TS(*cm*)	84.36±8.16	82.93±7.11	85.40±19.34	84.60±20.84		
Aristela de Freitas Zanona *et al* (2019)(41) Brazil	10 stroke patients. Onset period:- Age: 67.08±5.54 Gender: 6 M, 4 F	30 sessions/ week, of 1*hr*, in which VR games were selected to favor bilateral and symmetrical movements.	BBS (mean±SD)	37.5±9.81	44.0±8.66	-	-	CT	Balance significantly improved with VR.
Hyung Young Lee *et al* (2015)(40) South Korea	24 stroke patients. VR-based training group(n:12) and task-oriented training group(n:12). Onset period:- Age(yrs): EG: 45.91±12.28, CG: 49.16±12.85 Gender: 16 M,8 F	The VR-based training group: Nintendo Wii Fit Plus for 30 *min*/day, 3times/week for 6 weeks. The task-oriented training group:additional task-oriented programs for 30 *min*/day, 3times/week for 6 weeks. Both groups: conventional physical therapy for an *hr*/day, 5 times/week for 6 weeks.	FRT(*cm*) (mean±SD)	15.84±6.32	24.75±7.44	16.40±5.91	21.39 ± 6.31	RCT	The pre-and post-test values measured In both groups, stable FRT increased significantly (p<<A.0.05). In the FRT, there was a distinction between virtual Training and task-oriented training groups (p<<A.0.0001).
In-Wook Lee *et al* (2015)(39) South Korea	20 stroke patients. EG(n:10) and CG(n:10). Onset period:- Age(yrs): EG: 57.2±9.2, CG: 52.7±11.7 Gender: 11 M,9 F	CG: proprioceptive neuromuscular facilitation exercise program. The VR exercise program allocated to the EG included simultaneous cognitive tasks in VR space. Both exercise programs for the EG and CG were performed forty-5 *min*/day, 3times/week, for 6 weeks.	BBS(score) (Mean±SD)	37.8±2.2	46.2±2.3	38.6±1.3	41.5±3.7	RCT	The EG demonstrated a significant difference after intervention in BBS and TUGT (p<0.05). The differences in BBS and TUGT of the EG looked significant compared to the CG(p<0.05).
			TUG(sec (Mean±SD)	21.2±2.9	13.6±0.9	22.1±2.1	18.3±1.4		

Cont Table 3.

Roberto Llore´ns *et al* (2015)(22) Spain	30chronic stroke patients. Two 15groups. Onset period(days): EG: 334.13±60.79, CG: 316.73±49.81 Age(yrs): EG: 55.47±9.63, CG: 55.60±7.29 Gender: 17 M,13 F	Twenty 45-*min* training sessions with the telerehabilitation system, 3times/week. CG: trained with the system in the clinic. EG: trained in their homes.	BBS	47.53±3.85	Week 8: 51.20±2.11 Week12: 51.53±2.07	48.80±5.01	Week 8: 51.07±5.09 Week 12: 51.27±5.12	RCT	The clinical effectiveness of the VR-based intervention is supported by an improvement of 3 to 4 points in the BBS scores between the two evaluations, demonstrating that intensive, repetitive, adaptive, and task-oriented training can promote clinical benefits even long afterthe injury. Important improvements were observed in the POMA-B from the initial to the final evaluation, although the modifications detected were not as noteworthy as in the BBS. Major effects may have been avoided by the sensitivity of the POMA-B in detecting changes in the condition of our sample. The improvement was enhanced by 4 CG participants and 3 EG participants.
			POMA-B	14.53±1.68	Week8: 15.40±0.82 Week12: 15.47±0.74	15.07±1.10	Week8: 15.33±0.72 Week12: 15.53±0.74		
			POMA-G	10.00±0.93	Week8: 10.93±0.79 Week12: 11.00±0.84	10.40±1.45	Week8: 10.80±1.37 Week12: 10.93±1.22		
Roberto Lloréns *et al* (2014)(57) Spain	20 stroke patients. EG (n: 10), CG (n:10) Onset period (days): EG: 407.5±232.4, CG: 587.6 ±222.1 Age: EG: 58.3 ±11.6, CG: 55.0±11.6 Gender: 9M, 11F	Both groups: conventional therapy for 20 one-*hr* sessions, 5 sessions/week. The EG group underwent 30 *min* VR interventions and 30 *min* conventional therapy.	BBS	47.2 ±6.7	51.0 ±4.6	44.4 ±7.0	46.2 ±5.7	RCT	The EG showed statistically significant improvements in the BBS and the 10-m Walking Test compared with the CG. Also, a considerable number of participants from the EG decreased their balance disability as measured by the Brunel Balance Assessment. Results suggest that the VR-based intervention can promote the acquisition of the motor strategies necessary for performing the fast and safe postural changes that are necessary to confront the changing environmental stimuli that threaten stability.
			10-m Walking Test (s)	13.4 ±6.4	11.5 ±5.3	17.0 ±10.9	17.0 ±10.1		
			Tinetti Performance-Oriented Mobility Assessment – Balance	14.0 ±3.0	15.2 ±0.8	13.8 ±1.7	13.2 ±1.9		
			Brunel Balance Assessment	Level≤9: 2(20%) Level	1 (10%)	2 (20%)	1 (10%)		
				=10: 0 (0 %)	0 (0 %)	1 (10%)	2 (20%)		
				Level =11: 2 (20%)	1 (10%)	3 (30%)	3 (30%)		
				Level =12: 6 (60%)	8 (80%)	4 (40%)	4 (40%)		
Vitor Antônio dos Santos Junior (2019) (60)	40 stroke patients. PNF (n:15), VR (n:11), and PNF/VR (n:14). Onset period(mos): PNF: 95.8±99.4, VR: 87.9±64.7, PNF/VR: 46.7±58.6 Age: PNF: 58.2±7.7, VR: 55.5±9.6, PNF/VR: 52.7±13.3 Gender: 23 M, 17 F	Twice-weekly 50-*min* sessions for 2 months. The PNF/VR group performed both PNF and VR exercises performed Nintendo Wii electronic games.	(Fugl-Meyer Scale) balance	PNF: 10.5±1.3 VR: 10.64±1.4	PNF: 11.3±1.4 VR: 11.5±2.0	PNF/VR: 11.14±1.5	PNF/VR: 11.1±1.7	RCT	Significant improvement in the balance in the PNF and PNF/VR groups was seen.

Cont Table 3.

Devinder Kaur Ajit Singh *et al* (2013)(34) Malaysia	28 stroke patients. EG (n:15) and CG (n:13). Onset period (mos): EG: 40.5±41.8, CG: 34.9±23.6 Age (yrs): EG: 65.4±9.8, CG: 67.0±8.4 Gender: 16 M, 12 F	EG: 30 *min* VR balance games in addition to 90 *min* of standard physiotherapy. CG: 2 *hrs* of routine standard physiotherapy. Both groups: 12 therapy sessions: 2-*hr* sessions twice/week for 6 weeks.	TUG (score) (mean (SD))	25.33 (14.38)	23.07 (12.22)	23.27 (12.15)	21.69 (12.29)	CT	Both groups showed a decrease in static balance performance. There were no significant improvements in either group regarding BI scores.
			Overall balance score (score) (mean (SD))	2.53 (1.02)	2.70 (0.72)	3.25 (1.12)	3.31 (1.39)		
Ki Hun Cho *et al* (2014)(61) South Korea	30chronic stroke patients. EG (n:15) and CG (n:15). Onset period (days): EG: 414.46 150.38, CG: 460.33 186.78 Age(yrs) :EG: 65.86 5.73, CG: 10/5 (66.7/33.3) Gender: 15 M,15 F	Both groups: standard rehabilitation program, the EG: TRWVR for 30 *min*/day, 3times/week, for 6weeks. CG: treadmill walking program for 30 *min*/day, 3times/week, for 6weeks.	AP-PSV, *mm/s*	7.46 2.67	6.93 2.08	7.44 2.91	6.94 2.60	RCT	Significant differences in the time factor for dynamic balance and gait (P<0.05) in the EG and CG were seen, except for static balance. Findings indicate that the real-world video recording has an effect on dynamic balance and gait in chronic stroke patients when added to treadmill walking.
			ML-PSV, *mm/s*	8.52 3.28	8.08 3.51	9.38 4.91	8.68 5.42		
			PSVM, *mm2*	20.29 11.00	19.82 11.05	20.82 10.50	20.68 13.49		
			BBS (score)	39.26 4.13	42.60 3.06	39.53 5.69	41.06 5.29		
			TUG (s)	22.43 3.25	20.01 2.78	21.45 4.78	20.29 4.82		
			Tinetti Performance-Oriented Mobility Assessment	14.0±3.0	15.2±0.8	13.8±1.7	13.2±1.9		

TNote: M: Male, F: Female, EG: Experimental Group, CG: Control Group, BBS: Berg Balance Scale, MAS: Motor Assessment Scale , CE: Eyes Closed OE: Eyes Open, CoP: Center of Pressure, TIS: Trunk Impairment Scale; FRT: Functional Reach Test, FMA: Fugl-Meyer Assessment, PASS: Postural Assessment Scale, LoS: Limit of Stability, TUG: Timed Up and Go test, MBI: Modified Barthel Index, 10MWT: 10m Walking Test, SBI: Static Balance Index, PSPL: Postural Sway Path Length, APSS: Average Postural Sway Speed, A-P: AnteroPosterior, M-L: MedioLateral, 6MWT: 6 *Min* Walk Test, ABC: Activities-Specific Balance Confidence, mFRT: modified Functional Reach Test, SV: Sway Velocity, SVV: Subjective Visual Vertical Test, FES: Falls Efficacy Scale, MLS: Medial-Lateral Speed, VM: Velocity Moment, APS: Anterior-Posterior Speed, FSST: Four Step Square Test, CTSIB: Clinical Test for Sensory Interaction in Balance, STOLL: Standing On the Left Leg, STORL: Standing On the Right Leg, ROM: Romberg's Test, sROM: sharpened Romberg's Test, FMLE: : Fugl-Meyer scale for Lower Extremity, FIM: Functional Independence Measure, PSV: Postural Sway Velocity, apec: antero-posterior with eye close, APS: Anterior-Posterior Speed, TS: Total Sway distance, FAC: Functional Ambulation Category, PSVM: Postural Sway Velocity Moment, APSS: Average Postural Sway Speed, POMA-B: Performance-Oriented Mobility Assessment Balance subscale, POMA-G: Performance-Oriented Mobility Assessment Gait subscale, RCT: Randomized Controlled Trial, CT: Clinical Trial.

The sample size of the studies was mostly small. 14 studies had a sample size of fewer than 30 participants (33-46) and one study had over 50 participants (51). All the studies included male and female participants except two studies (44,46) in which the participants were only male participants. And, the gender of the participants in the two studies was not mentioned (38, 62).

Among all the studies, only one study included a follow-up result (22), which assessed balance control three months after training. Of the 23 studies included, eight studies used Wii-based VR for balance training (33,34,38,40,41,59,60,62). One study utilized a telerehabilitation system (22), one study used multi-exergaming (37), one used VR ankle exercise (36), and another study utilized VR stepping exercise (57). Xbox Kinect was utilized in two studies(58,64). Immersive VR was used as a balance training system in one study (44), and speed-interactive pedaling training using a smartphone VR application was reported in another article (63). A newly-developed game was tested and reported in an article (46). Visual feedback training was a method utilized in one study (43), while another study used VR reflection therapy (VRRT) (42). Patients in one study were treated using the Virtual Reality Rehabilitation System (51). In one study, researchers assessed the effect of VR accompanied by cognitive tasks on balance ability in chronic stroke patients (39). Authors in one study evaluated the effect of treadmill training based real-world video recording (TRWVR) on balance control of chronic stroke patients (61). VR treadmill training was reported in another article (45).

The control group in most studies performed conventional therapy, while three studies did not use any control group for comparing the results (41,46, 51). Control groups in other studies were treadmill training (45,61,62), placebo VRRT (42), task-oriented training (40), proprioceptive neuromuscular PNF (39), ergometer training (64), conventional therapy, and cycle training (63). In one study, control group participants watched a documentary as their treatment (36). The control group in one study performed either conventional therapy or no intervention (44). The effect of VR on balance control was assessed in a home or clinic setting (control group) (22). In one of the articles, the subjects were allocated to three groups, PNF, VR, and PNF, plus VR (60). A range of outcome measures was used to measure balance including BBS (22,33,35,39,41, 42,44,46,51,58,61), TUG (33,36,37,39,42,45,61,64), and Tinetti (44,57,61). Details of each study can be found in table 3.

Methodological quality of the included articles

We used the PEDro scale (65) to assess the methodological quality of the included studies. The PEDro scale comprised 11 items, and the study's score was determined by whether or not the items were met. Each satisfied item (except the first item) is worth one point toward the total score, which ranged from 0 to 10. The total score was divided into three levels: (1) high quality (score 6–10), (2) fair quality (score 4–5), and (3) poor quality (score≤3)
(66). The PEDro scores for the included articles are reported in table 4.

The methodological quality rating of included studies on the PEDro scale varied between 2 and 8 points with a median of 5.39 points. Two reviewers independently assessed the quality of included articles with the PEDro scale. In case of disagreement in the quality assessment of the two reviewers, a consensus was reached by discussion.

Discussion

Thirty-three papers involving a total of 930 patients with stroke were reviewed concerning balance improvement post-stroke with VR training. All the papers in this study are classified based on stroke stage and discussed in detail in the acute, subacute, and chronic stages.

a) Effects of VR on balance performance in acute stroke subjects

The results indicate that balance can be improved with VR. However, the addition of VR training combined with conventional training does not provide additional benefits over CT alone. The lack of sufficient studies regarding VR effectiveness in the acute phase of stroke might be a possible explanation for this unfavorable result. Also, the sample sizes of participants included in the studies were not large enough to be generalizable for the rehabilitation of all the patients after stroke. Though the two studies related to the effectiveness of VR training in balance post-stroke were randomized control studies, only one used random allocation and assessor blindness to the participant's grouping. Moreover, these studies did not evaluate the long-term effects of VR balance training within rehabilitation. Based on the PEDro scale, quality of the two articles was fair. Ranges of outcome measures were used in the articles, but BBS was the common used outcome measure in the related papers.

b) Effects of VR on balance performance in subacute stroke subjects

The current data highlight the importance of VR training as an adjacent to standard therapy for improving balance status in the subacute phase of stroke. While the usefulness of VR therapy is clearly supported in all studies, one study (52) showed that training with VR does not have superiority over conventional therapy. The study tested a novel interactive motion-capture-based rehabilitation using commercially available software (Jintronix™), which improved balance outcome measures in the experimental group, but there was a lack of between-group differences in the study.

There are several possible explanations for this inconclusive result. Randomizing concealment was used only in three studies (47,52,55). Nevertheless, it is worth mentioning that all seven studies used blinded assessors in their research. Based on the PEDro scale quality of five articles was high, and two papers had fair quality. Besides, sample sizes were generally small, which lacks external validity. Therefore, these findings may not be applicable to the wider population.

Another possible explanation for this heterogeneity is that, except for one study (53), studies did not include follow-up assessments in their research settings. The most frequently used outcome measures were BBS,

Table 4. PEDro scores of the included studies

Study	Eligibility Criteria	Random Allocation	Concealed Allocation	Baseline Comparability	Subject Blinded	Clinician Blinded	Assessor Blinded	Data for at Least 1 Outcome From> 85% of subjects	No Missing Data or If Missing intention-to-Treat Analysis	Between-Groups Analysis	Point Estimates and Variability	Total Score (/10)
B. S. Rajaratnam *et al* (50)	Yes	1	0	0	0	0	1	1	1	1	0	5
Yoon Bum Song *et al* (54)	Yes	1	0	1	0	0	0	0	0	1	1	4
Myung-Mo Lee (49)	Yes	1	0	1	0	0	1	1	0	1	1	5
Trupti Kulkarni *et al* (48)	Yes	0	0	1	0	0	0	1	0	1	1	4
Ayça Utkan Karasu *et al* (47)	Yes	1	1	1	0	0	1	1	**0**	1	1	7
Myung Mo Lee *et al* (32)	Yes	1	0	1	0	0	1	1	0	1	1	6
Seung Kyu Park *et al* (56)	Yes	1	0	1	0	0	0	0	0	1	1	4
Giovanni Morone *et al* (53)	Yes	1	0	1	0	0	1	1	1	1	1	7
John Cannell *et al* (52)	Yes	1	1	1	0	0	1	1	1	1	1	8
Tülay Tarsuslu Şimşek *et al* (55)	Yes	1	1	1	0	0	1	1	1	1	1	8
Shih-Hsiang Ciou *et al* (46)	Yes	0	0	1	0	0	0	1	1	0	1	4
Gui Bin Song *et al* (64)	Yes	1	0	1	0	0	0	0	0	1	1	3
Jinhwa Jung *et al* (45)	Yes	1	0	1	0	0	1	1	0	1	1	6
Nikita Girishbhai Shobhanal *et al* (58)	Yes	1	0	1	0	0	0	0	0	1	1	4
Irene Cortés-Pérez *et al* (44)	Yes	1	0	1	0	0	1	1	1	1	1	7
Kyeongjin Lee (63)	Yes	1	0	1	0	0	1	1	1	1	1	7

Cont Table 4.

Nara Kim *et al* (38)	Yes	1	0	1	0	0	0	0	0	1	1	4
Yo-Soon Bang *et al* (62)	Yes	1	0	1	0	0	0	0	0	1	1	4
Imre Cikajilo *et al* (37)	Yes	1	0	1	0	0	0	1	1	1	1	6
Pawel Kiper *et al* (51)	Yes	0	0	1	0	0	0	1	1	1	1	5
Changho Yom *et al* (36)	Yes	1	0	1	0	0	1	1	0	1	1	6
Seok Won Lee *et al* (43)	Yes	1	0	1	0	0	0	1	0	1	1	5
Ki Hun Cho *et al* (33)	Yes	1	0	1	0	0	0	0	0	1	1	4
Nildo Manoel da Silva Ribeiro *et al* (59)	Yes	1	0	1	0	0	1	1	0	1	1	6
Taesung In *et al* (42)	Yes	1	0	1	0	0	1	1	0	1	1	6
Aristela de Freitas Zanona *et al* (41)	No	0	0	1	0	0	0	0	0	0	1	2
Hyung Young Lee *et al* (40)	Yes	1	0	1	0	0	0	1	0	1	1	5
In-Wook Lee *et al* (39)	Yes	1	0	1	0	0	0	0	0	1	1	4
Roberto Llore´ns *et al* (22)	Yes	1	0	1	0	0	1	1	1	1	1	7
Roberto Lloréns *et al* (57)	Yes	1	1	1	0	0	1	1	1	1	1	8
Vitor Antônio dos Santos Junior (60)	Yes	1	0	1	0	0	1	1	0	1	1	6
Devinder Kaur Ajit Singh *et al* (34)	Yes	0	0	1	0	0	1	1	0	1	0	4
Ki Hun Cho *et al* (61)	Yes	1	1	1	0	0	1	1	0	1	1	7

TUG, and FRT, among a range of different outcome measures.

c) Effects of VR on balance performance in chronic stroke subjects

Studies across chronic stroke patients indicated that VR training could be an effective method of enhancing balance. However, in three studies, patients did not show significant improvement compared to the control group, which received only conventional therapy (34,37,59). Our findings confirm that studies have conflicting results, which can be due to several reasons. Firstly, among all studies, only two articles used allocation concealment (57,61). Also, more than half of the studies were non-blind studies. Although many of the studies had a PEDro scale of 6≥, small sample sizes of participants avoid generalizable results. A variety of outcome measures were used, but the most popular outcome measure among reviewed articles was BBS and TUG.

We performed a review to summarize and report the findings of included articles related to the effect of VR training on balance recovery in stroke survivors. Our results show that most of the articles claim that applying VR training in addition to standard rehabilitation has an added advantage over routine rehabilitation alone in improving balance status following stroke. On the contrary, a number of studies confirmed the usefulness of VR treatment as equal to standard rehabilitation for improving balance ability following stroke.

Varying results obtained from the studies have some possible reasons. Apart from different study settings and divergent quality of included articles, the intensity of the VR intervention and the VR system used were extensively variable among included studies. Furthermore, the chronicity of the stroke might be one of the most significant factors in balance recovery.

Overall, the benefit of VR treatment as an additional intervention to the standard rehabilitation of balance training following stroke has been confirmed in acute, subacute, and chronic phases. Nonetheless, the superiority of VR training to conventional therapy for improving stroke patients' balance ability has moderate evidence. It should be noted that some of VR training characteristics *e.g.*, strong motivation, high repetition ability, adaptability, and variability based on each patient baseline, *etc*. might be accountable for having a more beneficial effect with VR training. One point to be considered is that our results from the included papers did not report any adverse events with using VR-based interventions.

There have been systematic reviews (11,21,67-69) conducted to evaluate the utility of VR technologies in retraining post-stroke individuals. These reviews tended to have broader scopes of investigation and included gait and/or upper limb retraining and/or cognitive rehabilitation. Furthermore, these reviews only included RCTs, removing studies with different designs. The positive results of VR-based intervention in this review article are consistent with data from previous systematic reviews (10,11,67-69) and scoping reviews (26). However, Chen *et al* (21) in their systematic review suggested moderate evidence to support VR training as an effective adjunct to standard rehabilitation for improving balance for patients with chronic stroke. They also concluded that in acute or subacute stroke patients, the effect of VR training on balance recovery is less clear.

Our study aimed to review studies using VR-related systems as an intervention to improve balance control post-stroke. Findings from our review highlight the importance of a well-designed randomized control trial with an appropriate sample size that includes all three phases of stroke patients to implement VR in the rehabilitation programs of balance recovery. Another important factor is considering the severity of the patient's condition.

Conclusion

To the best of our knowledge, this is the first review study regarding the impact of VR on balance recovery that includes and categorizes articles based on stroke phases. Overall, this study strengthens the idea that VR training has the potential to become an effective adjacent to routine rehabilitation treatments for improving balance status post-stroke. However, to achieve integrated clinical practice protocols conducting a comprehensive RCT that incorporates all three phases of the stroke, and an appropriate study setting is necessary to identify the standard VR-based rehabilitation intervention settings for balance deficit stroke patients.

Study limations and suggestions for future studies

One of the limitations of this study is that only 33 studies were included in this review, which might not be representative of all the available research in this field. Another limitation of the study is the small sample size of the included studies which might limit the generalizability of the results.

Besides, the studies included in this review were heterogeneous in terms of VR interventions, outcome measures, and stroke severity, which might affect the comparability of the studies. Furthermore, most of the studies did not include follow-up assessments, which might limit the understanding of the long-term effects of VR interventions on balance recovery post-stroke.

Future studies should conduct well-designed randomized controlled trials with larger sample sizes to provide more robust evidence regarding the effectiveness of VR interventions on balance recovery post-stroke. Future studies should also include long-term follow-up assessments to evaluate the sustainability of the effects of VR interventions on balance recovery. Moreover, future studies can strive to standardize the VR interventions used, as well as the outcome measures, to enhance the comparability of the studies. It is important to suggest for future studies to include stroke patients with different severities to evaluate the effectiveness of VR interventions on balance recovery in different stages of stroke.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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