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Systematic review

Evaluation instruments for physical therapy using virtual reality in stroke patients: a systematic review

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Abstract

Background Physiotherapeutic rehabilitation is essential to improve functional mobility, muscular strength, balance and quality of life of stroke patients, but conventional techniques using repeated physical activities can soon become monotonous. The use of virtual reality (VR) in rehabilitation offers a possible alternative to the traditional methods of promoting improvements in muscle strength and balance. However, there is not yet consensus about which instruments should be used to assess the effectiveness of VR in stroke rehabilitation.
Objective To conduct a systematic review to identify the types of evaluation tools used for different VR interventions to rehabilitate stroke patients, considering balance, strength, function, quality of life, cognition and motivation.
Data sources A comprehensive literature search using MEDLINE-PubMed, Web of Science, Scopus, Lilacs and IEEE Xplore was undertaken.
Study selection Studies on stroke patients who had undergone VR therapy and an assessment of its effectiveness using evaluative instruments.
Study appraisal and synthesis methods Data were extracted by a single reviewer using standardised forms, and were checked by a second reviewer. The extracted information included study design, number of participants, type of stroke, items that were evaluated (balance, muscle strength, functional evaluation), console used, number of rehabilitation sessions, results and conclusions.
Results In total, 1836 articles were identified; of these, 29 were included in this review after consideration of the inclusion and exclusion criteria. The selected articles rated one or more of the following factors: balance ($n = 12$), grip strength (with or without devices for direct measurement) ($n = 8$), functionality ($n = 12$) and quality of life ($n = 12$).
Limitations The full text of one article was not available, despite a request to the authors to send it *via* email.
Conclusion and implications of key findings The Berg Balance Scale, the Fugl–Meyer Assessment and the Stroke Impact Scale were the instruments used most frequently to assess balance, function and quality of life, respectively, in stroke patients who underwent rehabilitation using VR.

Systematic review registration PROSPERO number: 87546.

Keywords: Stroke; Rehabilitation; Video game; Virtual reality; Exergame

Introduction

Approximately 80% of people who survive a stroke suffer motor disabilities, such as hemiparesis (partial paralysis of one side of the body), and 15–30% become permanently

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incapacitated [1]. Stroke is the second leading cause of disability. The sequelae of stroke, such as coordination difficulties, apraxia, postural control deficit and balance disturbances, may result in loss of independence and restricted social activity, leading to depression and a reduction in quality of life [2].

Physiotherapeutic rehabilitation is effective and essential to improve functional mobility, muscular strength, balance and quality of life of patients following a stroke, but, frequently, conventional techniques use repeated physical activities which soon become monotonous, reducing patient adherence to the therapy [3]. As such, virtual reality (VR) technologies have been gaining importance in rehabilitation over the last 20 years. VR uses video games that allow users to interact in three dimensions in a computer-generated scenario which provides feedback and encourages them to complete the activity [4].

Some studies report that the use of VR in stroke rehabilitation results in significant improvements in motor function, muscle strength and balance in the lower limbs [5–7]. However, Laver *et al*. [8], in their Cochrane review, reported that there is insufficient evidence to draw conclusions about the effect of VR and interactive video gaming on grip strength, walking speed and overall motor function in patients with stroke, as these patients can have different functional topographies and different therapeutic needs that must be considered in evaluation and therapeutic interventions. Reflecting on these functional differences, if an evaluation instrument is not appropriate or is of low precision, this may result in a false-negative or false-positive result.

To help understand the effects of these techniques, it is important to know which tools are used to assess the effects of VR therapy in patients with stroke. Therefore, the aim of this systematic review was to identify the types of evaluation tools used in different VR interventions to rehabilitate patients with stroke, considering the different instruments used for measuring balance, strength, function (walking, range of motion), quality of life, cognition and motivation. Furthermore, this study aimed to determine if a standard exists regarding evaluation instruments in this field.

Methods

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, supplemented by guidance from the Cochrane Collaboration Handbook, Version 5.2. *A priori*, a protocol for this systematic review was designed and registered in the PROSPERO database (Registration No. 87546).

Elaboration of the research question was performed using the PICO monogram. This strategy was used to allow resolution of the research question and to optimise the retrieval of evidence from databases. In this study, the following question was posed: in post-stroke patients, which evaluative instruments are used to measure the efficacy of VR treatment as a therapeutic tool? Following the criteria, P, post-stroke patients; I, VR treatment; C, no comparison; and O, evaluative instruments are used to measure efficacy of VR treatment.

Search strategy

Five online databases were used to search for papers meeting the study criteria: National Library of Medicine (MEDLINE-PubMed), Web of Science, Scopus, Lilacs and IEEE Xplore Digital Library. Different combinations of the following keywords were used: 'virtual reality', 'videogame rehabilitation', 'Nintendo Wii stroke', 'videogame stroke', 'exergame stroke', 'Nintendo Wii rehabilitation', 'PlayStation' and 'Xbox'. The databases were searched for studies conducted in the period up to and including March 2016. The structured search strategy was designed to identify any published document that used evaluation tools to analyse the use of VR in patients with stroke.

Additional papers were included in this study after analysis of all references from the selected articles. The investigators were not contacted, and no attempt was made to identify unpublished data.

Study selection

All electronic search titles, selected abstracts and full-text articles were reviewed independently by a minimum of two reviewers (FA, FO, NG, PA, AS). Disagreements over inclusion/exclusion were solved through consensus. The following inclusion criteria were applied: studies on patients with stroke undergoing therapy using VR, the results of which had been analysed by any evaluation method. Studies were excluded according to the following exclusion criteria: studies on humans with another pathology, studies which did not use methods to evaluate the use of VR, review articles, meta-analyses, abstracts, conference proceedings, editorials/letters and case reports.

Data extraction

Data were extracted by one reviewer using standardised forms and were checked by a second reviewer. The extracted information included study design, number of participants, type of stroke, items that were evaluated (balance, muscle strength, functional evaluation), console used, number of rehabilitation sessions, results and conclusions.

Results

Selection of studies

The process followed for article selection is shown in Fig. 1. In total, 1836 articles were identified: 935 articles in PubMed, 529 in Scopus, 341 in Web of Science, and 31 in Lilacs. After deleting duplicate articles, the titles and

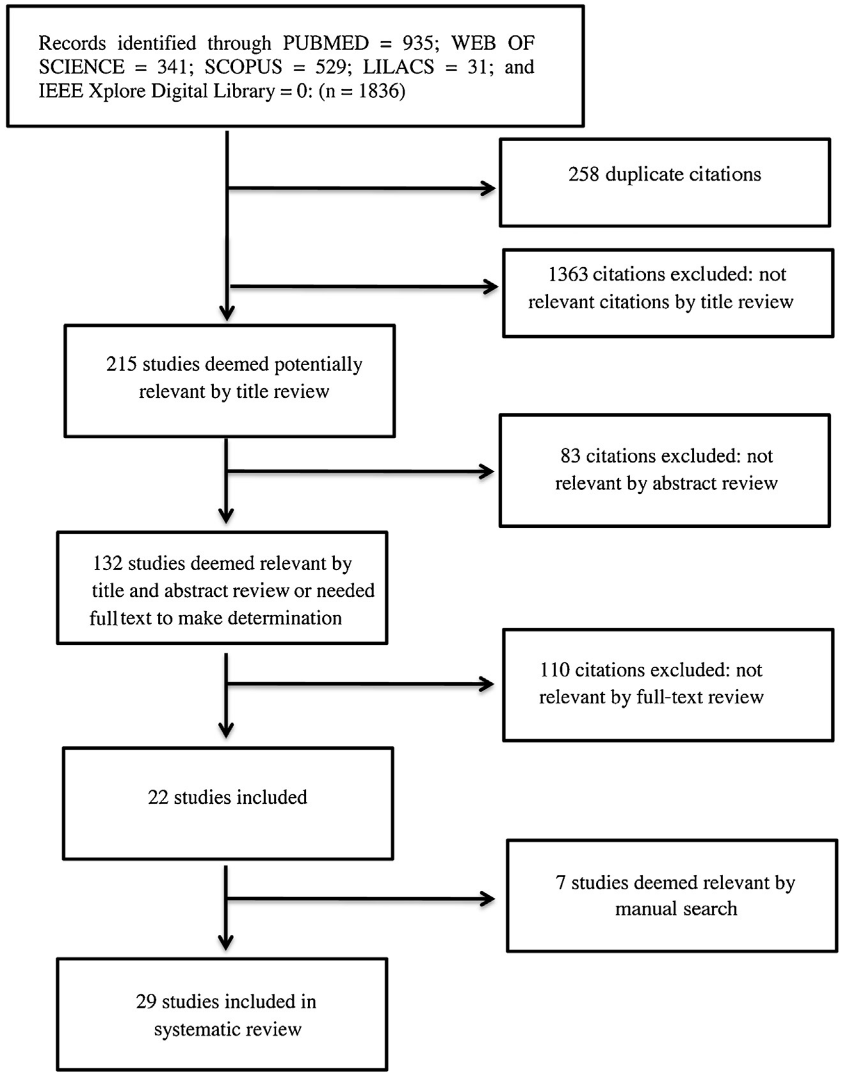

Fig. 1. Flow diagram for literature searching and screening.

abstracts of 1578 articles were read, and 132 articles were selected for full reading. After exclusion of the articles not shown in full, duplicates, letters, case studies, articles that were not in English, Spanish or Portuguese, and articles that were not about the study subject, 29 articles remained (Fig. 1). There was a high level of agreement on inclusion/exclusion between the two investigators who screened the retrieved articles. The full text of one article was not available, and no response was received after asking the authors to send it *via* email.

The studies included in this review were conducted in twelve countries: nine in Korea, six in the USA, two in the UK, two in Australia, two in Taiwan, two in Canada, one in Italy, one in Israel, one in Spain, one in Brazil, one in Turkey and one in Mexico.

Characteristics of included studies

The 29 studies included in this review were randomised studies (28 clinical trials and one cross-sectional study) (Table 1). Sample size ranged between eight and 235 volunteers (men and women). Only nine studies stated whether the patients had suffered an ischaemic or haemorrhagic stroke, and one study only included patients who had experienced a haemorrhagic stroke.

Sixteen instruments were used in the twelve studies that evaluated balance, and 75% of these studies reported the use of more than one instrument. The most common instrument used to measure balance was the Berg Balance Scale (50%). Table 2 shows that the Berg Balance Scale is a reliable and validated tool to evaluate balance in older people post stroke [9]. The Functional Reach Test was the second most commonly used tool to measure balance; this instrument is accurate, portable, inexpensive and reliable, with low inter-rater variability [10] (Table 2).

Eight studies assessed muscle strength of the upper limbs, and several instruments were used. These tools provided objective measures through devices that allow direct measurement of force (manual dynamometer, grip strength,

Table 1
Description of the main aspects of studies included in the systematic review.

Author, year, country	Study design	Population (*n*)	Type of stroke	Evaluation				Video game	Number of sessions	Results	Conclusions
				Balance	Muscle strength/location	Function, walking and ROM measurements	Quality of life/cognition/ motivation				
Yavuzer *et al*. 2008 [32], USA	Randomised controlled trial	CG ($n = 10$); VRG ($n = 10$) (>6 months after stroke)	Not specified	Not evaluated	Not evaluated	Bruunstrom stages, FIM	Not evaluated	PlayStation EyeToy	CG: 5 days/week for 2 to 5 hours/day for 4 weeks (20 sessions). VRG: further 30 minutes after 1 hour of treatment (20 sessions)	Improved self-care in VRG compared with CG, but no significant differences in Bruunstrom stages between groups	PlayStation EyeToy combined with a conventional rehabilitation programme improves function of the upper limb in stroke patients in the acute phase
Hung *et al*. 2014 [33], USA	Double-blind randomised controlled	CG ($n = 15$); VRG ($n = 13$) (>6 months after stroke)	Not specified	BBS, FES-I	Not evaluated	TUG	PACES	Nintendo Wii Fit	30 minutes of Wii Fit (VRG) or weight training (CG) twice per week for 12 weeks (24 sessions)	Both groups improved in TUG and FES-I. VRG showed improvement in static equilibrium with CG, but the effects did not last after 3 months of intervention	VRG had greater motivation than CG. Wii Fit can be used as a safe alternative for patients with or without moderate spasticity
Friedman *et al*. 2014 [22], USA	Randomised controlled trial	MusicGlove group ($n = 4$); IsoTrainer group ($n = 4$); tabletop exercises group (controlled, $n = 4$) (>6 months after stroke)	Ischaemic or haemorrhagic	Not evaluated	Hydraulic hand dynamometer	FMA, BBT, ARAT, WMFT	IMI	MusicGlove, IsoTrainer	Six sessions of treatment, within 1 hour, three times per week (18 sessions)	MusicGlove group had greater motivation and hand function compared with other groups	The ability to manipulate small objects and improved therapy is simple to access. MusicGlove can assist in achieving these goals
Prange *et al*. 2015 [34], USA	Double-blind clinical trial, randomised controlled multi-centre	CG ($n = 33$); VRG (arm support training, $n = 35$) (subacute stroke)	Ischaemic or haemorrhagic	Not evaluated	Not evaluated	FMA, SULCS	IMI	ArmeoBoom	Six weeks of training, three sessions of 30 minutes/week (18 sessions or 9 hours in total)	Both groups showed improvement in FMA and GROOVES, although motivation was higher in VRG	The experimental protocol was as effective as conventional therapy for improving function of the upper limb of patients with subacute stroke
Morone *et al*. 2014 [35], Italy	Randomised controlled trial (>3 months, subacute stroke)	CG ($n = 11$); VRG ($n = 19$)	Not specified	BBS	Not evaluated	BI, 10MWT, FAC	Not evaluated	Nintendo Wii Fit	20-minute sessions, three times per week for four weeks (12 sessions)	VRG had a significant improvement in BBS and IB when compared with CG	Wii Fit improved the functional response of the patients who used it in addition to conventional treatment
Sin and Lee 2013 [28], Republic of Korea	Randomised controlled trial	CG ($n = 17$); VRG ($n = 18$); both with chronic stroke (≥6 months)	Not specified	Not evaluated	Not evaluated	FMA, para MMSS, BBT, goniometer (ROM)	Not evaluated	Xbox Kinect 360	Both groups: sessions with 30'; three times per week for 6 weeks	Significant improvements in both groups: AROM of flexion, extension and abduction of shoulder; flexion of elbow; flexion and extension of wrist; scores for motor function and BBT scores for gross manual dexterity; follow-up for AROM of flexion, extension, and abduction of shoulder and flexion of elbow; punctuation for FMA and BBT	Additional VR training using Xbox Kinect 360, a home video game device not intended as a tool for rehabilitation, can improve the functioning of the upper extremity in post-stroke survivors

Table 1 (*Continued*)

Author, year, country	Study design	Population (n)	Type of stroke	Evaluation				Video game	Number of sessions	Results	Conclusions
				Balance	Muscle strength/location	Function, walking and ROM measurements	Quality of life/cognition/motivation				
Adie *et al*. 2014 [15], UK	Multi-centric, pragmatic, parallel group, with blinded, randomised controlled trial	CG (conventional, $n = 118$); VRG ($n = 117$ (≥6 months)	Ischaemic or haemorrhagic stroke	Not evaluated	MRC	ARAT, COPM, MRS, Motor Activity Log-14 (MAL 14)	SIS, EQ-5D 3L, Montreal Cognitive Assessment	Nintendo Wii Sports	Activity at home for 45 minutes (seated) for 6 weeks. Results evaluated 6 weeks and 6 months after the programme	There was no significant difference in the primary outcome of affected arm function at 6 weeks follow-up, and no significant difference in secondary outcomes, including occupational performance, quality of life or arm function at 6 months, between the two groups	Wii Sports was not superior to arm exercises in the study group. All participants showed significant improvement in arm function and health state at follow-up. Wii Sports was safe in the home setting in this study group
Ruparel *et al*. 2009 [29], USA	Randomised controlled trial	Fun driving group ($n = 5$); rote tracking group ($n = 5$)	Not specified	Not evaluated	MMT, GS	FMA (motor control scores), Ashworth Scale (for spasticity); Rancho Los Amigos Functional Test	Not evaluated	Experimental hardware (TheraDrive System Software UniTherapy)	24 sessions for 6 to 8 weeks	Fun group registered a greater increase in FMA and functional test scores compared rote group. Rote group registered a greater decrease in Ashworth scores compared with fun group. Baseline average MMT for rote group was lower than fun group	Changes in clinical parameters seem to correlate well with the motivation scores, which validates the choice of these clinical metrics as one part of the effort to establish the effectiveness of the TheraDrive system can be used as a CAMR device that may eventually be used in the home environment
Bower *et al*. 2014 [14], Australia	Single-blind, randomised, controlled	Balance group ($n = 14$); upper limb group ($n = 13$)	Ischaemic and haemorrhagic	Wii Balance Board Step Test, FRT, Short Falls Efficacy Scale	Not evaluated	STREAM, TUG, Upper Limb Motor Assessment Scale	Not evaluated	Nintendo Wii	45-minute sessions, three times per week for 2 to 4 weeks (6 to 12 sessions)	Both groups improved in Step Test and FRT, with no significant difference between them. The groups were similar on the basis of Upper Limb Motor Assessment Scale and STREAM scores. The balance group had significant improvement in balance	Exercise and additional training using Wii are safe and feasible for patients in stroke rehabilitation phase
Givon *et al*. 2016 [21], Israel	Single-blind, randomised controlled trial	VRG ($n = 23$); CG ($n = 24$) subacute, with a maximum of 6 months prior to interview	Not specified	FRT	Dynamometer (GS)	FIM, 10MWT, BADL, IADL, ARAT	Geriatric Depression Scale	Microsoft Xbox Kinect; Sony PlayStation 2 EyeToy; Sony PlayStation 3 Mova; Nintendo Wii Fit; Sistema SeeMe VR (alternate)	60 minutes twice per week for 3 months (24 sessions)	Significant improvements were demonstrated in both groups for gait speed and GS of the weaker and stronger hands. Daily steps and functional ability of the weaker hand did not increase in either group	Using VR in a small group setting is feasible, safe and satisfying. Video games improve indicators of physical activity of individuals with chronic stroke
Cameirão *et al*. 2011 [36], Spain.	Controlled study randomised pilot	CG ($n = 8$); RGS (VRG, $n = 8$) (3 weeks after acute stroke)	Not specified	Not evaluated	MRC, MI	BI, FMA, CAHAI	Not evaluated	RGS	20 minutes, three times per week	RGS (VRG) had a significant improvement in speed of the hemiparetic arm, accompanied by improved performance in FMA CAHAI, BI, MRC and MI	The tested system facilitates the rehabilitation of stroke patients

Cho *et al*. 2012 [37], South Korea	Clinical randomised study	CG ($n = 11$); VRG ($n = 11$)	Haemorrhagic and ischaemic	BBS, TUG, postural sway velocity	Not evaluated	Not evaluated	Not evaluated	Nintendo Wii Fit Balance Board	CG = 1 hour/day, five times per week for 6 weeks; CG = 30 minutes/day, three times per week for 6 weeks	Greater improvement in BBS and TUG in VRG compared with CG, but no improvement in static balance in either group	Significant improvement in dynamic balance in chronic stroke patients with VR. VR is feasible and suitable for chronic stroke patients with balance deficit in clinical settings
Choi *et al*. 2014 [4], Korea	Randomised controlled trial	CG ($n = 10$); VRG ($n = 10$) ($\geq$3 months after the first stroke, subacute)	Not specified	Not evaluated	MFT, Trapping Guide Test (GS)	FMAfor upper limb, BBT, K-MBI	K-MMSE	Nintendo Wii	30-minute sessions, five times per week for 4 weeks (20 sessions)	After 4 weeks, both groups showed significant improvement in FMA for upper limb, MFT, BBT, K-MBI and K-MMSE. However, GS only improved significantly in CG. There was no significant difference between groups before and after treatment.	Therapy with RV games was as effective as conventional treatment (CG) to recover the function of the upper end of stroke patients in the subacute phase treated at home
Saposnik *et al*. 2010 [38], Canada	Randomised controlled trial, single-blinded	CG (Terapia recreacional, $n = 8$; VRG ($n = 9$) (6 months after stroke)	Ischaemic or haemorragic	Not evaluated	Not evaluated	BI, BBT, WMFS, MRS	SIS	Nintendo Wii	Eight 60-minute sessions for 2 weeks	VRG (Wii) had a significant improvement in motor function [average 7 seconds (WMFS)] and trapping force. BBT improved in both groups, with no significant difference between them. There was no significant difference in SIS between groups	Nintendo Wii game technology is a safe, effective and potentially feasible way to facilitate rehabilitation therapy and promote motor recovery after stroke
Lee 2013 [39], Korea	Randomised controlled trial	CG ($n = 7$); VRG ($n = 7$) (>6 months after stroke)	Not specified	Not evaluated	MMT	FIM, MAS	Not evaluated	Xbox Kinect 360	Treatment for 6 weeks: VRG: 1 hour/day, 3 days/week. CG: 30 minutes/day, 3 days per week	Improvement in flexor and shoulder extensor strength, flexor and extensor elbow and improvement of FIM in both groups, with no significant difference between them. CG also showed significant difference in extensor elbow muscle strength	Positive effect on function and performance for daily activities
Lee *et al*. 2015 [18], Korea	Randomised controlled trial	CG ($n = 12$); VRG ($n = 12$) (>6 months after stroke)	Not specified	Wii Balance Board (Version2.0)	Not evaluated	Not evaluated	Not evaluated	Nintendo Wii Balance Board; Wii Fit Plus	CG: 1 hour/day, five times per week for 6 weeks (30 sessions). VRG: 30 minutes/day, three times per week for 6 weeks (18 sessions)	Values of the pre-test and post-test for stable path length and speed of the centre of gravity increased significantly in both groups. There was also significant improvement in FRT and balance quality with open and closed eyes in both groups	Both treatments improved patient function after stroke. However, the limitations of the study (small sample size, short duration and need to include resistance training, cardiovascular fitness and coordination) indicate the need to continue the study

Table 1 (*Continued*)

Author, year, country	Study design	Population (n)	Type of stroke	Evaluation				Video game	Number of sessions	Results	Conclusions
				Balance	Muscle strength/location	Function, walking and ROM measurements	Quality of life/cognition/motivation				
Mcclanachan *et al*. 2013 [40], Australia	Randomised cross-over blinded	CG (usual therapy, $n=8$); VRG (Wii Fit usual therapy, $n=6$)	Not specified	Balance Outcome Measure for Elder Rehabilitation	Not evaluated	CAQ, 6MWT, Borg Scale	Not evaluated	Nintendo Wii Fit	VRG: three times per week for 30 minutes for 8 weeks (24 sessions). CG: three times per week for 30 to 60 minutes for 8 weeks (24 sessions)	Compliance with gaming console exercise was high (99%). There was no significant difference in 6MWT (18 m), gait speed or balance compared with usual therapy after gaming console exercise	Gaming exercise appears feasible in people with acute brain injury. Four weeks of gaming console exercise in addition to usual therapy appears to result in similar improvements in endurance, gait and balance compared with usual therapy alone, and may enhance active engagement in therapy
Simsek and Cekok 2016 [41], Turkey	Controlled randomised	CG ($n=22$); VRG ($n=20$) (both with chronic stroke)	Ischaemic or haemorrhagic	Not evaluated	Not evaluated	FIM	NHP	Nintendo Wii Fit and Balance	45 to 60 minutes, three times per week for 10 weeks (30 sessions)	VRG had a significant difference in FIM and NHP following therapy. However, a significant difference was not found between the groups for FIM and NHP	These findings suggest that the Nintendo Wii training was as effective as Bobath (CG) for daily living functions and quality of life in subacute stroke patients
Chen *et al*. 2015 [3], Taiwan	Controlled clinical trial using sequential allocation into groups	CG ($n=8$); VRG with XaviXPort program ($n=8$); VRG with Nintendo Wii program ($n=8$) (3 to 24 months after the stroke)	Not specified	Not evaluated	Not evaluated	FMA, FIM, BBT, manual dexterity, ROM of upper extremity	Not evaluated	XaviX Port, Nintendo Wii	20 sessions of 30 minutes for 8 weeks	VRG XaviXPort had significant improvement in FMA, BBT, FIM and ROM of upper extremity. CG and VRG Nintendo Wii had improvement in FIM, FMA and ROM of upper extremity	Patients reacted positively to the use of video games in rehabilitation
Fritz *et al*. 2013 [42], USA	Randomised-matched, single blind, control group study	28 with chronic stroke (>6 months)	Not specified	DGI, BBS, TUG	Not evaluated	FMA, 6MWT, 3MWT	SIS	Nintendo Wii and Sony PlayStation 2	VRG ($n=15$) CG ($n=13$), 50–60 minutes/day, four times per week for 5 weeks (20 sessions)	No significant difference was found between the groups for any of the variables studied	VR can help balance and mobility of stroke patients, although the results did not shown significant differences between the groups
Orihuela-Espina *et al*. 2013 [43], Mexico	Randomised controlled trial	VRG ($n=8$) (>6 months, chronic stroke)	Haemorrhagic	Not evaluated	Not evaluated	FMA, MI	Not evaluated	Armeo System (Hocoma, Switzerland)	20 sessions of VR, 45 minutes each. Evaluations were performed during the 7th and 14th treatment sessions	There was significant improvement in behaviour, cerebellar recruitment, activation of brain activity, and improvement in FMA (especially upper extremity and coordination) and MI	VR-based therapies are still young, and the promising behavioural improvements demonstrated in clinical trials must now be paired with understanding of the underlying cortical and subcortical changes that form the biological basis for recovery
Jang *et al*. 2005 [44], Republic of Korea	Blind randomised controlled trial.	CG ($n=5$); VRG ($n=5$) with chronic stroke (≥6 months)	Ischaemic or haemorrhagic	Not evaluated	MFT	BBT, FMA	Not evaluated	IREX VR System	20 sessions, five times per week for 60 minutes just for VRG	VRG had a significant improvement in upper extremity function, BBT, FMA and MFT	VR induced cortical re-organisation while inhibiting aberrant cortical activation, perhaps to improve functional recovery of the affected limb

Shin *et al.* 2014 [30], South Korea	Observational study and randomised controlled trial	Observational study ($n = 6$ with chronic stroke); randomised controlled trial ($n = 16$ with acute stroke or subacute stroke)	Not specified	Not evaluated	Not evaluated	FMA, ARAT, MI	Not evaluated	RehabMaster	Ten sessions were held over 2 weeks. Occupational therapy group and VRG+ occupational therapy group	In the observational study, there was no significant difference in FMA, but MI increased during breaks. In the randomised controlled trial, FMA and MI were higher in VRG, although the difference was not significant ($P = 0.07$ and 0.16, respectively)	RehabMaster is a feasible and safe VR system for enhancing upper extremity function in patients with stroke
Shin *et al.* 2015 [45], South Korea	Prospective randomised single-blind study.	CG ($n = 16$); VRG ($n = 16$) (chronic stroke)	Not specified	Not evaluated	Not evaluated	FMA	SF-36, HAMD	RehabMaster	One hour of conventional therapy (CG) or 30 minutes of Wii + 30 minutes of conventional (VRG), 5 days per week for 4 weeks (20 sessions)	The emotional component improved significantly in VRG. The vitality component improved in VRG, but the difference was not significant. Both groups improved in HAMD and FMA, with no difference between groups	Game-based VR rehabilitation has specific effects on health-related quality of life, depression and upper extremity function among patients with chronic hemiparetic stroke
Kim *et al*. 2013 [6], Korea	Double-blind clinical study	CG ($n = 12$); VRG ($n = 12$) (patients with chronic hemiparetic stroke)	Not specified	BBS, BPM	Not evaluated	10 MWT, MMAS	Not evaluated	IREX VR System	CG: 40 minutes/day, four times per week. VRG: 30 additional minutes to conventional therapy, four times per week (16 sessions)	VRG improved significantly in BBS, BPM, dynamic balance angles, velocity of 10MWT and MMAS compared with CG	VR in conjunction with standard therapy improved balance and function in patients after stroke
Merians *et al.* 2009 [13], Taiwan	Single blind randomised controlled trial	CG ($n = 9$); VRG ($n = 11$) (>6 months after stroke)	Not specified	ABC	Not evaluated	10 MWT, walking speed, community walk test, WAQ	Not evaluated	Not specified	Nine sessions, three times per week for 20 minutes for 3 weeks	VRG had significant improvement in speed and walking time (WAQ)	VR-based training is feasible and beneficial for improving community ambulation in poor community ambulators with stroke

Table 1 (*Continued*)

Author, year, country	Study design	Population (n)	Type of stroke	Evaluation				Video game	Number of sessions	Results	Conclusions
				Balance	Muscle strength/location	Function, walking and ROM measurements	Quality of life/cognition/motivation				
McEwen *et al*. 2014 [46], Canada	Blind randomised controlled trial	CG (n = 24); VRG (n = 28) (>6 months after stroke)	Not specified	Chedoke–McMaster Stroke Assessment (Leg Domain)	Not evaluated	TUG, 2MWT	Not evaluated	IREX VR System	10 to 12 sessions of 20 minutes for 3 weeks	VRG had significant and positive change in TUG, 2MWT and Chedoke score	This VR exercise intervention for inpatient stroke rehabilitation improved mobility-related outcomes
Crosbie *et al.* 2012 [11], UK	Pilot randomised controlled trial	CG (n = 9); VRG (n = 9) (6 to 12 months)	Not specified	Not evaluated	Not evaluated	ARAT	ULMI	Not specified	Three sessions per week, 30 to 45 minutes/day (nine sessions)	Both groups demonstrated small or insignificant changes in ULMI and ARAT	VR comparable to conventional therapy would be feasible, with some suggested improvements in recruitment and outcome measures
Barcala *et al.* 2013 [47], Brazil	Randomised controlled clinical trial	CG (n = 10); VRG (n = 10) (6 to 12 months)	Not specified	BBS, baropodometry, stabilometry	Not evaluated	FIM, TUG	Not evaluated	Nintendo Wii Fit	Five weeks with two sessions/week: 60 minutes for CG and 30 minutes for VRG (10 sessions)	No significant differences were found between the groups, but all variables improved after interventions	VR improved body symmetry, balance and function of stroke patients. However, this improvement was similar to CG

2MWT, 2-minute walk test; 3MWT, 3-minute walk test; 6MWT, 6-minute walk test; 10MWT, 10-minute walk test; ABC, Activities-Specific Balance Confidence; ARAT, Action Research Arm Test; BADL, Independence in Basic Activities of Daily Living; BBS, Berg Balance Scale; BBT, Box and Block Test; BI, Barthel Index; BPM, Balance Performance Monitor; CAHAI, Chedoke Arm and Hand Activity Inventory; CAQ, Change Assessment Questionnaire; COPM, Canadian Occupational Performance Measure; DGI, Dynamic Gait Index; FAC, Functional Ambulatory Category; FES-I, Falls Efficacy Scale International; FIM, functional independence measure; FMA, Fugl–Meyer Assessment; FRT, Functional Reach Test; GS, grip strength; HAMD, Hamilton Depression Rating Scale; IADL, independence in instrumental activities of daily living; IMI, Intrinsic Motivation Inventory; IREX, Interactive Rehabilitation Exercise Software; K-MBI, Índice de Barthel Koreano; K-MMSE, Mini-Mental State Examination; MAS, Modified Ashworth Scale; MFT, Manual Function Test; MI, Motricity Index; MMAS, Modified Motor Assessment Scale; MMT, Manual Muscle Test; MRC, Medical Research Council Scale; MRS, Modified Rankin Scale; NHP, Nottingham Health Profile; PACES, Physical Activity Enjoyment Scale; RGS, rehabilitation gaming system; SF-36, Short Form Health Survey; SIS, Stroke Impact Scale; STREAM, Stroke Rehabilitation Assessment of Movement; SULCS, Stroke Upper Limb Capacity Scale; TUG, timed-up-and-go test; VR, virtual reality; VRG, virtual reality group; ULMI, Upper Limb Motricity Index; WAQ, Walking Ability Questionnaire; WMFS, Wolf Motor Function Superior; WMFT, Wolf Motor Function Test.

Table 2
Description of the most used instruments to evaluate balance and its psychometric properties.

Most used scales/instruments	Number of times quoted in percentages (%)	Description	Reliability	Validity	Responsiveness	Test–retest reliability
BBS	50%	Quantitatively assesses balance in older adults	Excellent intra-rater reliability (ICC = 0.92)	Correlations between BBS and BI were excellent (r = 0.80–0.94)	ES = 0.66 for initial 6-week post-stroke evaluation period, ES = 0.25 for 6–12 weeks post-stroke, and overall ES = 0.97	Excellent (ICC = 0.88)
TUG	17%	Screening tool used to test basic mobility skills of frail elderly patients (60–90 years old). Can be used for, but is not limited to, persons with stroke	Excellent inter-rater reliability: TUG (ICC = 0.98), TUG manual (ICC = 0.99), and TUG cognitive (ICC = 0.99)	Not available	Low responsiveness	Excellent (ICC = 0.99)
FRT	17%	Dynamic measure used to evaluate previous functional scope	Excellent intra-rater reliability	Concurrent – good, correlates with walking speed	Moderate	Excellent for adults aged 20–87 years
FES-I	17%	Questionnaire that assesses fear of falling	Excellent inter-rater reliability (r = 0.83)	Not available	Not available	Excellent (ICC = 0.92)
WBBS	17%	Balance with pressure sensors, an accessory from Nintendo. Used in the evaluation of balance	Excellent inter-rater reliability (r = 0.83)	Correlations between WBBS and SBM have a high degree of validity (r = 0.58 to 0.86)	Not available	Excellent (ICC = 0.97)

BBS, Berg Balance Scale; BI, Barthel Index; TUG, Timed Up and Go Test; FRT, Functional Reach Test; FES-I, Falls Efficacy Scale International; WBBS, Wii Balance Board System; ICC, intraclass correlation coefficient; ES, effect size.

handgrip test/palmar or the Manual Functional Test), as well as subjective instruments measuring estimated force using the Medical Research Council Scale, the Manual Muscle Test and the Motricity Index. In these studies, 50% used direct measurement devices and 50% used rating scales (subjective measures/indirect).

Table 3 shows the most commonly used functional evaluation tools in post-stroke evaluation and psychometric properties. The Fugl–Meyer Assessment is a specific scale designed for use in patients of all ages with post-stroke hemiplegia. Table 4 shows other instruments used for functional evaluation, locomotive evaluation and range of motion, such as the Action Research Arm Test, the Barthel Index, the 10-minute walk test and the Timed Up and Go Test.

Among the twelve studies that evaluated aspects related to quality of life, the most commonly used instrument was the Stroke Impact Scale. This was designed to evaluate multidimensional stroke outcomes, including strength, manual function, activities of daily living/instrumental activities of daily living, mobility, communication, emotion, memory and thinking, and participation. This instrument has excellent internal frequency and test–retest reliability in relation to other tools for patients with stroke (Table 5).

Other instruments used were the EuroQol five-dimensional three-level version, the Geriatric Depression Scale, the Hamilton Depression Rating Scale, the Mini-Mental State Examination, the Montreal Cognitive Assessment, the Motricity Index, the Nottingham Health Profile, the Physical Activity Enjoyment Scale and the Short Form Health Survey. Chang *et al*. [12] used the Upper Limb Motricity Index to measure quality of life through upper limb motor function (Table 5).

Discussion

According to Chang *et al*. [12], the video games used in therapeutic applications have advanced in recent years, particularly in terms of associating virtual stimuli with everyday situations. VR games, marketed and already used in leisure time, are more popular in therapeutic use, possibly because they are more familiar to both physical therapists and users. The image processing technology in the design of a system helps to motivate people with physical disabilities to increase the number of exercises performed, improving both the ability to move the affected limb as well as quality of life. Merians *et al*. [13] reported that it was possible to activate posterior parietal and premotor areas when patients with stroke observed movements of virtual hands and tried to imitate the action.

Post stroke, motor disorders such as imbalance and loss of muscle strength are among the main factors that influence independence and quality of life [14]. Tests that assess balance can be used not only as predictors of risk of falling, but also as instruments to rehabilitate the patient. In this review, approximately 45% [15] of the included studies evaluated balance or tests that indicate predisposition to falling. Among these, the most widely used tests were the Berg Balance Scale, the Timed up and Go Test and the Functional Reach Test. According to Miyamoto *et al*. [16], the Berg Balance Scale showed a strong correlation with the Timed Up and Go Test, balance boards and the Barthel Index (an instrument to assess functional capacity). In a study conducted by Silva *et al*. [17], the Berg Balance Scale was considered to be reliable and valid for use in clinical practice and scientific studies. Similarly, the Timed Up and Go Test analyses performance, and is practical, easy to apply and interpret, and can assess the individual's ability to move (mobility) in addition to their balance.

The balance platforms used in video games are a practical option for assessing patient balance. Among the studies cited here, only Bower *et al*. [14] and Lee *et al*. [18] used a game platform, the Wii Balance Board. However, neither of these studies performed correlation tests on the methodological and scientific accuracy of data provided by the platform (achieved equilibrium score) by comparing the results with previously established instruments or scales.

Several factors contribute to balance and postural control, including proper integration between the sensory, central nervous and skeletal muscle systems [19]. These are the systems that are commonly affected in patients with stroke. After the trauma, the affected side may be more affected than the other limb (e.g. upper limb more committed than lower limb). In all cases, an evaluation of strength must be considered. According to Kwakkel *et al*. [20], more than 60% of patients with stroke who have hemiparesis have a loss of dexterity and arm function, with the primary goal of rehabilitation programmes being to improve these functions.

Among the studies analysed, 48% used specific function tests for the arms, even when this area was not the main focus of their study. The Medical Research Council Manual Test, although practical and easy to use in daily practice, with good clinical correlation, may not be as sensitive and reproducible as the dynamometer [21]. Another reliable and valid method for the assessment of functional disorders of the upper limbs, used in two studies, is the Manual Functional Test [16].

The Fugl–Meyer Assessment was widely used, although not all authors specified why they used it; the presumption has been made that it was used to assess upper and lower limb function, balance, coordination and measure the recovery of the motor sensory condition of the patient [22]. The Wolf Motor Function Test also allows an assessment of function and time taken to perform a task and, unlike the Functional Independence Measure, the affected limb is better evaluated. This detail allows any functional gains from VR therapy in the affected upper limb to be measured more accurately.

In addition to assessment of the upper limbs, testing the force of the lower limbs, and assessing gait (quality, distance) and functionality are appropriate; these assessments are extremely important in a patient post stroke, especially if they present gait and balance deficits [23]. Performances in the 6-minute walk test, 2-minute walk test, 10-minute walk test and step tests may be limited by the functional capac-

Table 3
Description of the most used instruments to evaluate functionality and its psychometric properties.

Most used scales/instruments	Number of times quoted in percentages (%)	Description	Reliability	Validity	Responsiveness	Test–retest reliability
FMA	41%	Stroke-specific index, designed to assess motor functioning, balance, sensation and joint functioning in patients with post-stroke hemiplegia	Excellent intra-rater reliability (ICC = 0.98)	Spearman rank correlation between FMA scores was excellent (r = 0.95)	Not available	High correlation (r = 0.99)
FIM	17%	Developed to address the issues of sensitivity and comprehensiveness that were criticised as being problematic with BI (another measure of functional independence)	Excellent intra-rater reliability (ICC = 0.90 to 0.99)	Spearman correlation coefficients were excellent between BI and motor FIM (r = 0.95)	Motor FIM and total FIM demonstrated small effect sizes in patients with stroke (0.61)	Excellent (ICC = 0.93 for total FIM)
BBT	17%	Measures unilateral gross manual dexterity	Excellent inter-rater reliability for right and left hand (r = 1.00 and 0.99, respectively)	Not available	BBT, ARAT and NHP were all found to have moderate SRM (0.74, 0.64 and 0.79, respectively)	Excellent (ICC = 0.97 and 0.96 for right and left hand, respectively)

FMA, Fugl–Meyer Assessment; FIM, Functional Independence Measure; BBT, Box and Block Test; BI, Barthel Index; ARAT, Action Research Arm Test; NHP, Nottingham Health Profile; ICC, intraclass correlation coefficient.

Table 4
Description of the most used instruments to evaluate locomotion and its psychometric properties.

Most used scales/instruments	Number of times quoted in percentages (%)	Description	Reliability	Validity	Responsiveness	Test–retest reliability
ARAT	17%	Evaluative measure to assess specific changes in limb function among individuals who sustained cortical damage, resulting in hemiplegia	Not available	No studies have examined the predictive validity of ARAT	ARAT total score demonstrated a moderate effect size of 0.52, while Motor Assessment Scale total score demonstrated a small ES of 0.45	Excellent for total score (ICC = 0.99) as well as for the grasp, grip, pinch and gross movement subscales (ICC = 0.99, 0.98, 0.96 and 0.95, respectively)
BI	13%	Index that also indicates the need for assistance in care	Excellent inter- and intra-rater reliability (ICC = 0.96 and 0.99, respectively)	No studies have examined the content validity of BI in patients with stroke	MBI, total FIM and motor FIM all demonstrated large ES for patients with stroke (ES = 0.95, 0.82 and 0.91, respectively)	MBI and RMI were found to have the strongest test–retest reliability, with 75% and 85% agreement overall, respectively
10MWT	13%	Performance measure used to assess walking speed in metres per second over a short distance. It can be employed to determine functional mobility, gait and vestibular function	Excellent intra-rater reliability (ICC = 0.87 to 0.88); excellent inter-rater reliability (ICC = 0.998)	Excellent correlation between comfortable gait speed and TUG (ICC = −0.84), 6MWT (ICC = 0.89)	Small meaningful change = 0.05 m/second; substantial meaningful change = 0.10 m/second	Excellent (ICC = 0.99)
TUG	10%	Screening tool used to test basic mobility skills of frail elderly patients (60 to 90 years old). TUG can be used with, but is not limited to, patients with stroke	Excellent inter-rater reliability for TUG (ICC = 0.98), TUG manual (ICC = 0.99) and TUG cognitive (ICC = 0.99)	Not available	Low Responsiveness	Excellent (ICC = 0.99)
6MWD	6%	Submaximal exercise test that entails measurement of distance walked over a span of 6 minutes	Excellent inter-rater reliability (ICC = 0.78)	6MWD was moderately correlated with scores from the Duke Activity Status Index ($r = 0.502$, $P < 0.001$), and the physical function subscale of SF-36 ($r = 0.624$, $P < 0.001$)	Not available.	Excellent (ICC = 0.97)
WMFT	6%	Quantifies upper extremity motor ability through timed and functional tasks	Excellent intra-rater reliability (ICC = 0.97)	No studies have reported the content validity of WMFT	No studies have reported the responsiveness of WMFT	Excellent (ICC = 0.97)
MRS	6%	Used to categorise level of functional independence with reference to pre-stroke activities rather than on observed performance of a specific task	Excellent intra-rater reliability (kappa w = 0.95)	MRS had excellent correlation with the physical function subscale of SF-36 ($r = 0.84$) and BI ($r = 0.82$)	Not available	Excellent (kappa w = 0.95)
MAS	6%	Considers the primary clinical measure of muscle spasticity in patients with neurological conditions	Inter-rater reliability: adequate to excellent at the elbow (rho = 0.56 to 0.90) and poor to excellent at the knee (rho = 0.26 to 0.62). However, Spearman's rho is not recommended for use in reliability analyses	Not available	Not available	Excellent (kappa w = 0.95)

ARAT, Action Research Arm Test; BI, Barthel Index; TUG, Timed Up and Go Test; 6MWD, 6-minute walk test; 10MWT, 10-minute walk test; WMFT, Wolf Motor Function Test; MRS, Modified Rankin Scale; MAS, Modified Ashworth Scale; FIM, FIM, Functional Independence Measure; SF-36, Short Form Health Survey; ES, effect size.

Table 5
Description of the most used instruments to evaluate quality of life and its psychometric properties.

Most used scales/instruments	Number of times quoted in percentages (%)	Description	Reliability	Validity	Responsiveness	Test–retest reliability
SIS	25%	Stroke-specific, self-reported, health status measure	Excellent at all timepoints (a = 0.81 to 0.97)	ADL/IADL showed excellent correlation with FIM (r = 0.70, P < 0.01)	Most SIS domains showed small responsiveness (SRM = 0.22 to 0.33, Wilcoxon Z = 1.78 to 2.72)	Adequate to excellent (ICC = 0.7 to 0.92)
IMI	16%	Multidimensional measurement device intended to assess participants' subjective experience related to a target activity in laboratory experiments	Moderate intra-rater reliability (ICC = 0.78)	Not available	Not available	Not available
GDS	8%	Self-rating screening tool developed to detect depression in elderly individuals	No studies have reported on intra- and inter-rater reliability of GDS in patients with stroke	No studies have reported on content validity of GDS in patients with stroke	Not applicable as GDS is a screening tool	Excellent (ICC = 0.84, P < 0.001)
K-MMSE	8%	Originally developed as a brief screening tool to provide a quantitative evaluation of cognitive impairment and to record cognitive changes over time	Adequate intra-rater reliability (ICC = 0.63)	Baseline total MMSE scores were correlated with improvement in motor FIM at discharge (r = 0.31)	Not available	Using Pearson's correlations, ranged from adequate to excellent (r = 0.56 to 0.80)
MoCA	8%	Designed as a rapid screening instrument for detection of mild cognitive impairment. MoCA can be used for, but is not limited to, patients with stroke	Not available	Correlation between MoCA and MMSE was excellent (r = 0.87)	Not available	Excellent (r = 0.92)
SF-36	8%	Widely used, generic, patient-report measure created to assess health-related quality of life in the general population	Excellent, alpha = 0.75 for all dimensions of the scale with the exception of social functioning subscale (alpha = 0.73)	Not available	No studies on the responsiveness of SF-36 in patients with stroke were identified	The level of test–retest reliability reported in stroke populations indicates that SF-36 may not be adequate for serial assessments of individual patients, unless large differences are expected over time

SIS, Stroke Impact Scale; ADL/IADL, activities of daily living/instrumental activities of daily living; IMI, Intrinsic Motivation Inventory; GDS, Geriatric Depression Scale; K-MMSE, Mini-Mental State Examination; MoCA, Montreal Cognitive Assessment; SF-36, Short Form Health Survey; FIM, FIM, Functional Independence Measure.

ity and cardiorespiratory fitness of the subject [24]. Physical performance can also be measured using instruments that assess functional independence. In this review, the most cited in ascending order of quantity were the Fugl–Meyer Assessment, the Functional Independence Measure and the Box and Block Test.

Another instrument with potential is the Chedoke–McMaster Stroke Assessment, which measures physical impairment and disability in patients with stroke. As for the Functional Independence Measure, the Chedoke–McMaster Stroke Assessment allows assessment of the level of functional independence, but is more sensitive for the detection of changes and has excellent correlation ($r = 0.74$) [25]. In this review, only one study used the Chedoke–McMaster Stroke Assessment to evaluate the improvement of mobility in individuals post stroke, perhaps because this study had good internal consistency and because the use of this tool is time consuming.

An evaluation of the physical condition of an individual should always be made alongside an assessment of quality of life, as this variable contributes to a better understanding of the impact of the disease on the individual and the benefits of therapeutic care [26]. It has been shown that exercise increases brain metabolic activity and improves cognitive function, and that those who exercise report an increased sense of well-being compared with those who do not exercise [27]. The use of general questionnaires that assess quality of life, such as the Short Form Health Survey, although easy to apply, cannot provide a more specific assessment of the conditions that compromise a patient with stroke.

Studies have shown that virtual rehabilitation helps to increase the range of motion [28], with gains in muscle strength [22,29] and improved function of the area affected [30]. However, it is important to note that the most effective level of intensity of game use is still unknown; this may harm the expected results, as the patient can fatigue with the therapy because VR involves dynamic motion and involves the risk of falling and injury [31]. Failure to determine the ideal criteria in terms of duration and number of therapeutic sessions of VR to obtain the best therapeutic effects and minimise adverse reactions makes it impossible to compare the functional results obtained in the assessed studies.

Another important point to note is that this systematic review found a wide range of assessment tools being used for functional and performance testing. It is likely that some evaluation instruments were used due to the familiarity of the evaluator/researcher with the scale or test rather than the patient's profile and therapeutic objectives, because many questionnaires were used in this review despite the fact that questionnaires are not a very sensitive evaluation instrument; this shows that a standard for tool selection does not yet exist.

Conclusion

This study found that patients with stroke, treated or not with VR, had their functional responses evaluated by various instruments that had the same purpose, making it difficult to compare studies and to perform a meta-analysis to validate the importance of VR use in these patients. For this reason, it is problematic when studies use different instruments to evaluate patient performance.

Compiling the studies, the Berg Balance Scale was used most often to assess balance, although only 41% of the studies performed this evaluation. The Fugl–Meyer Assessment and the Stroke Impact Scale were used most often to assess function and quality of life, respectively.

It is important to emphasise that the evaluation tools varied between study centres, regardless of whether they were in Europe or North America. The use of instruments is more homogeneous in South Korea for assessment of both balance and function.

Finally, there is a need to establish an evaluation protocol that includes all the benefits of VR therapy, is capable of measuring gains, and has consistent results in the applied instruments and tests.

Key messages

- Virtual reality is a technology that has been investigated as an adjuvant treatment in the rehabilitation of patients with stroke.
- It is important to use appropriate evaluative instruments to verify the efficacy and safety of resources used in the rehabilitation of patients with stroke.

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References

[1] Yatar GI, Yildirim SA. Wii Fit balance training or progressive balance training in patients with chronic stroke: a randomized controlled trial. J Phys Ther Sci 2015;27:1145–51.

[2] Brito RG, Lins LCRF, Almeida CDA, Ramos Neto ES, Araújo DP, Franco CIF. Specific functional assessments for stroke. Rev Neurosci 2013;21:593–9.

[3] Chen MH, Huang LL, Lee CF, *et al.* A controlled pilot trial of two commercial video games for rehabilitation of arm function after stroke. Clin Rehab 2015;29:674–82.

[4] Choi JH, Han EY, Kim BR, *et al.* Effectiveness of commercial gaming based virtual reality movement therapy on functional recovery of upper extremity in subacute stoke patients. Ann Rehabil Med 2014;38:485–93.

[5] You SH, Jang SH, Kim YH, *et al.* Virtual reality-induced cortical reorganization and associated locomotor recovery in chronic stroke: an experimenter-blind randomized study. Stroke 2005;36:1166–71.

[6] Kim J, Son J, Ko N, Yoon B. Unsupervised virtual reality-based exercise program improves hip muscle strength and balance control in older adults: a pilot study. Arch Phys Med Rehabil 2013;94:937–43.

[7] Burdea CG. Virtual rehabilitation benefits and challenges. Methods Inf Med 2003;42:519–23.

[8] Laver KE, George S, Thomas S, Deutsch JE, Crotty M. Virtual reality for stroke rehabilitation. Cochrane Database Syst Rev 2015;12. CD008349.

[9] Mao HF, Hsueh IP, Tang PF, Sheu CF, Hsieh CL. Analysis and comparison of the psychometric properties of three balance measures for stroke patients. Stroke 2002;33:1022–7.

[10] Martins EF, de Menezes LT, de Sousa PH, de Araujo Barbosa PH, Costa AS. Reliability of the functional reach test and the influence of anthropometric characteristics on test results in subjects with hemiparesis. NeuroRehabilitation 2012;31:161–9.

[11] Crosbie JH, Lennon S, McGoldrick MC, McNeill MD, McDonough SM. Virtual reality in the rehabilitation of the arm after hemiplegic stroke: a randomized controlled pilot study. Clin Rehabil 2012;26:798–806.

[12] Chang YJ, Han WY, Tsai YC. A kinect-based upper limb rehabilitation system to assist people with cerebral palsy. Res Dev Disabil 2013;34:3654–759.

[13] Merians AS, Tunik E, Adamovich SV. Virtual reality to maximize function for hand and arm rehabilitation: exploration of neural mechanisms. Stud Health Technol Inform 2009;145:109–25.

[14] Bower KJ, Clark RA, McGinley JL, Martin CL, Miller KJ. Clinical feasibility of the Nintendo Wii™ for balance training post-stroke: a phase II randomized controlled trial in an inpatient setting. Clin Rehabil 2014;28:912–23.

[15] Adie K, Schofield C, Berrow M, *et al.* Does the use of Nintendo Wii Sports™ improve arm function and is it acceptable to patients after stroke? Publication of the protocol of the trial of Wii™ in stroke – TWIST. Int J Gen Med 2014;7:475–81.

[16] Miyamoto S, Kondo T, Suzukamo Y, Michimata A, Izumi S. Reliability and validity of the manual function test in patients with stroke. Am J Phys Med Rehabil 2009;88:247–55.

[17] Silva A, Almeida GJM, Cassilhas RC, Cohen M. Psicobiologia D De. Equilíbrio, Coordenação e Agilidade de Idosos Submetidos à Prática de Exercícios Físicos Resistidos. Rev Bras Med Esporte 2008;14: 88–93.

[18] Lee HY, Kim YL, Lee SM. Effects of virtual reality-based training and task-oriented training on balance performance in stroke patients. J Phys Ther Sci 2015;27:1883–8.

[19] Chandler JM. Equilíbrio e Quedas no Idoso: Questões sobre a Avaliação e o Tratamento. In: Guccione AA, editor. Fisioterapia Geriátrica. 2nd ed Rio de Janeiro: Guanabara Koogan; 2002. p. 265–77.

[20] Kwakkel G, Kollen BJ, Van der Grond J, Prevo AJ. Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. Stroke 2003;34:2181–6.

[21] Givon N, Zeilig G, Weingarden H, Rand D. Video-games used in a group setting is feasible and effective to improve indicators of physical activity in individuals with chronic stroke: a randomized controlled trial. Clin Rehabil 2016;30:383–92.

[22] Friedman N, Chan V, Reinkensmeyer AN, *et al.* Retraining and assessing hand movement after stroke using the MusicGlove: comparison with conventional hand therapy and isometric grip training. J Neuroeng Rehabil 2014;30:76.

[23] Anderson K, Behm DG. The impact of instability resistance training on balance and stability. Sports Med 2005;35:43–53.

[24] Pedrosa R, Holanda G. Correlação entre os testes da caminhada, marcha estacionária e TUG em hipertensas idosas. Rev Bras Fisioter 2009;13:252–6.

[25] Huijbregts MP, Gowland C, Gruber R. Measuring clinically important change with the activity inventory of the Chedoke-McMaster stroke assessment. Physiother Can 2000;52:295–304.

[26] Arruda MF, Bazaglia JA, Saravalli G, Cassettari LL, Souza HR. Strength and function gains in the elderly from isometric training with and without visual response. Rev Bras Med Esporte 2014;20: 309–14.

[27] Morgan DL, Allen DG. Early events in stretch-induced muscle damage. J Appl Physiol 1999;87:2007–15.

[28] Sin H, Lee G. Additional virtual reality training using Xbox kinect in stroke survivors with hemiplegia. Am J Phys Med Rehabil 2013;92:871–80.

[29] Ruparel R, Johnson MJ, Strachota E, McGuire J, Tchekanov G. Evaluation of the TheraDrive system for robot/computer assisted motivating rehabilitation after stroke. In: Conf Proc IEEE Eng Med Biol Soc 2009; 2009. p. 811–4.

[30] Shin JH, Ryu H, Jang SH. A task-specific interactive game-based virtual reality rehabilitation system for patients with stroke: a usability test and two clinical experiments. J Neuroeng Rehabil 2014;11:32.

[31] Cheok G, Tan D, Low A, Hewitt J. Is Nintendo Wii an effective intervention for individuals with stroke? A systematic review and meta-analysis. J Am Med Dir Assoc 2015;16:923–32.

[32] Yavuzer G, Senel A, Atay MB, Stam HJ. “Playstation eyetoy games” improve upper extremity-related motor functioning in subacute stroke: a randomized controlled clinical trial. Eur J Phys Rehabil Med 2008;44:237–44.

[33] Hung JW, Chou CX, Hsieh YW, *et al.* Randomized comparison trial of balance training by using exergaming and conventional weight-shift therapy in patients with chronic stroke. Arch Phys Med Rehabil 2014;95:1629–37.

[34] Prange GB, Kottink AI, Buurke JH, *et al.* The effect of arm support combined with rehabilitation games on upper-extremity function in subacute stroke: a randomized controlled trial. Neurorehabil Neural Repair 2015;29:174–82.

[35] Morone G, Tramontano M, Iosa M, *et al.* The efficacy of balance training with video game-based therapy in subacute stroke patients: a randomized controlled trial. BioMed Res Int 2014:1–6.

[36] Cameirão MS, Badia SB, Duarte E, Verschure PF. Virtual reality based rehabilitation speeds up functional recovery of the upper extremities after stroke: a randomized controlled pilot study in the acute phase of stroke using the rehabilitation gaming system. Restor Neurol Neurosci 2011;29:287–98.

[37] Cho KH, Lee KJ, Song CH. Virtual-reality balance training with a video-game system improves dynamic balance in chronic stroke patients. BioMed Res Int 2012:69–74.

[38] Saposnik G, Teasell R, Mamdani M, *et al.* Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation. A pilot randomized clinical trial and proof of principle. Stroke 2010;41: 1477–84.

[39] Lee G. Effects of training using video games on the muscle strength, muscle tone, and activities of daily living of chronic stroke patients. J Phys Ther Sci 2013;25:595–7.

[40] Mcclanachan NJ, Gesch J, Wuthapanich N, Fleming J, Kuys SS. Feasibility of gaming console exercise and its effect on endurance, gait and balance in people with an acquired brain injury. Brain Inj 2013;9052:1402–8.

[41] Şimşek TT, Çekok K. The effects of Nintendo WiiTM-based balance and upper extremity training on activities of daily living and quality of life in patients with sub-acute stroke: a randomized controlled study. Int J Neurosci 2016;126:1061–70.

[42] Fritz SL, Peters DM, Merlo AM, Donley J. Active video-gaming effects on balance and mobility in individuals with chronic stroke: a randomized controlled trial. Top Stroke Rehabil 2013;20:218–25.

[43] Orihuela-Espina F, Fernández del Castillo I, Palafox L, *et al.* Neural reorganization accompanying upper limb motor rehabilitation from stroke with virtual reality-based gesture therapy. Top Stroke Rehabil 2013;20:197–209.

[44] Jang SH, You SH, Hallett M, *et al.* Cortical reorganization and associated functional motor recovery after virtual reality in patients with chronic stroke: an experimenter-blind preliminary study. Arch Phys Med Rehabil 2005;86:2218–23.

[45] Shin JH, Bog Park S, Ho Jang S. Effects of game-based virtual reality on health-related quality of life in chronic stroke patients: a randomized, controlled study. Comput Biol Med 2015;63:92–8.
[46] McEwen D, Taillon-Hobson A, Bilodeau M, Sveistrup H, Finestone H. Virtual reality exercise improves mobility after stroke: an inpatient randomized controlled trial. Stroke 2014;45:1853–5.
[47] Barcala L, Grecco L, Colella F, Lucareli P, Salgado A, Oliveira C. Visual biofeedback balance training using Wii Fit after stroke: a randomized controlled trial. J Phys Ther Sci 2013;25:1027–32.