Review Article

JER

https://doi.org/10.12965/jer.2346114.057

Journal of Exercise Rehabilitation 2023;19(2):95-104

Virtual reality-based gait rehabilitation intervention for stroke individuals: a scoping review

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Virtual reality (VR)-based rehabilitation is rapidly gaining interest and has been shown to be an intervention to facilitate motor learning in balance and gait rehabilitation. A review of the current literature is needed to provide an overview of the current state of knowledge of VR-based gait physiotherapy for stroke patients. A systematic literature search was performed in PubMed and Scopus. Search terms included: "virtual reality," "stroke," "gait," and "physical therapy." Articles published in a peer-reviewed journal between 2017 and 2021 were considered. The intervention was mainly related to the use of VR as a therapeutic modality, and the outcome was gait performance. The initial search identified 329 articles. After an eligibility review, 13 articles that met the inclusion criteria were included in the study. Most of participants were in a chronic stage and were between 14 and 85 years old. The VR-based gait training ranged from nonimmersive to immersive, was mostly performed on a treadmill, and was usually combined with conventional physiotherapy. The duration of the program varied from 10 to 60 min, and there were about 9 to 30 sessions. VR-based gait rehabilitation has a positive effect on gait ability. The existing literature suggests that VR-based rehabilitation combined with conventional physiotherapy could improve gait ability of people with stroke, especially in the chronic stage. However, the duration of VR-based programs should be customized to suit individuals to avoid stimulation sickness. Further research is needed to investigate the long-term effects of this approach.

Keywords: Virtual reality, Stroke, Physical therapy, Rehabilitation

INTRODUCTION

Walking impairment affects >80% of stroke survivors (Duncan et al., 2005). Due to the disruption of neural networks in the motor cortex, their communication with the brainstem and its descending pathways, and the intraspinal locomotor network, abnormal gait patterns are a common disability after stroke. This damage leads to weakening of the muscles, changes in tone, and atypical synergistic movement patterns that are commonly seen in stroke patients (Li et al., 2018). Difficulty in walking may increase due to secondary impairments of the cardiovascular and musculoskeletal systems caused by physical inactivity. After a stroke, the gait pattern of affected individuals often consists of both new compensatory movement patterns specific to their injury and movement abnormalities (Balaban and Tok, 2014). Approximately 25% of stroke survivors have residual gait deficits in walking that require full physical support by the time they are discharged from the hospital, despite attempts at rehabilitation (Hendricks et al., 2002). As a result, gait impairment makes it difficult to perform activities of daily living and improve functional mobility (Li et al., 2018). To date, there are various gait rehabilitation interventions, including treadmill training with or without body weight support, robotic-assisted therapy, circuit training, self-rehabilitation programs, and virtual reality (VR) (Selves et al., 2020).

VR is a relatively new tool in the field of physical rehabilitation (Dockx et al., 2016; Tieri et al., 2018) and can be defined as "an artificial, computer-generated simulation or creation of a real-life environment or situation allowing the user to navigate through and interact with" (Baus and Bouchard, 2014). VR provides a safe, supervised environment for engaging, customizable rehabilitation

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Received: February 22, 2023 / Accepted: March 15, 2023

pISSN 2288-176X
eISSN 2288-1778

activities that support motor skill acquisition (Aida et al., 2018). The potential of VR-based interventions to provide meaningful and realistic experiences, thereby accommodating rehabilitative principles, may explain the remarkable improvement in rehabilitation outcomes of patients who have participated in VR-based interventions (Levin, 2011). When tasks are meaningful, specific, and repetitive and the level of difficulty increases over time, learning improves (Kleim and Jones, 2008; Levin, 2011). While maintaining stimulus control and consistency, the number of stimuli and the difficulty of tasks can be changed at VR to meet patients' needs and abilities (Maier et al., 2019a; Rizzo and Koenig, 2017). The systems of VR can send real-time strategic and goal-directed feedback, which is important for motor learning and accelerates self-correction (Ferreira et al., 2020; Pedreira et al., 2017). Therefore, the aim of this review was to assess the current state of information on the effects of VR on the gait performance of people after stroke from the current literature.

MATERIALS AND METHODS

This scoping review was conducted with the aim of identifying existing research findings and trends in the use of VR-based interventions to improve gait performance in stroke patients. The study protocol followed an article entitled "Guidance for conducting systematic scoping reviews" (Peters et al., 2015).

Search strategy

A systematic literature search was performed in PubMed and Scopus that included the following search terms: "virtual reality," "stroke," "gait," and "physical therapy." Articles published in English in a peer-reviewed journal between 2017–2021 were considered. The intervention was mainly on using VR as a therapeutic modality and the outcome was gait performance. Studies that were not published in English, were available only as abstracts, did not include individuals after stroke, or included a mixed etiology sample with no separate description of outcomes related to the stroke sample were excluded.

Study selection

After database searches were completed, citations and abstracts were compiled and entered into Covidence, where duplicate citations were removed. In the first phase, two reviewers independently reviewed the titles and abstracts. Conflicts were discussed until agreement was reached between the reviewers. The two reviewers obtained full-text articles and screened them independently. Articles that met the inclusion criteria were included in the review. The details of the study selection process are shown in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) flow diagram (Fig. 1).

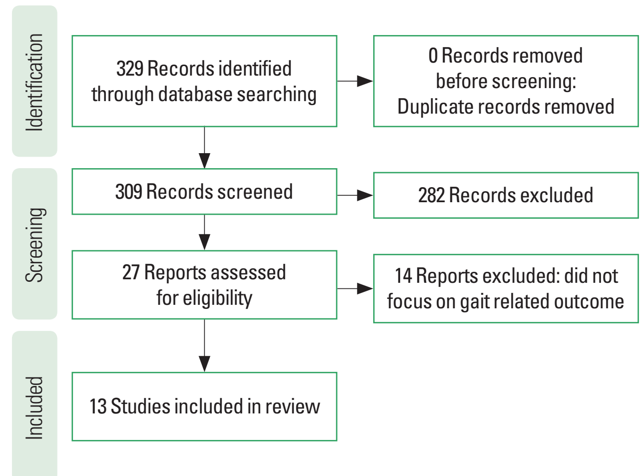

Fig. 1. The overall review process adapted from the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) diagram.

RESULTS

After the initial search, 329 records were identified. After removing 20 duplicates, 309 discrete titles and abstracts were screened for eligibility and 282 were excluded. The remaining 27 articles were selected for full-text reading, and 13 met our inclusion criteria.

Study context

Regarding the geographical context, the articles included in this review were mainly conducted in Europe, including two studies from Italy (Kiper et al., 2020; Luque-Moreno et al., 2021), two studies from Germany (Bergmann et al., 2018; Winter et al., 2021), one study from the Netherlands (de Rooij et al., 2021), and one study from Turkey (Kayabinar et al., 2021). Moreover, one study was conducted in a multi-setting in Spain and Switzerland (Held et al., 2018). The other geographic area included three studies from the Republic of Korea (Lee, 2019; Park and Chung, 2018; Park et al., 2021), one study from Israel (Fishbein et al., 2019), one study from Brazil (da Silva Júnior et al., 2021), and one study from Canada (Richards et al., 2018).

Participant characteristics

There were some differences in the characteristics of the participants in the included studies. Three studies recruited participants

https://doi.org/10.12965/jer.2346114.057

in the subacute phase (less than 6 months after stroke onset), six in the chronic phase, three recruited both subacute and chronic stroke participants, and one did not report chronicity. Most studies included participants aged 18 to 85 years. All included studies excluded participants with cognitive and/or visual impairment. Therefore, the typical sample in most studies consisted of middle-aged and older chronic stroke survivors without cognitive or visual deficits.

VR systems

This study included both custom-made and commercial VR systems used as interventions. Custom-made systems were typically laboratory-specific and often coupled other devices with the VR interface, such as robotic devices, treadmills, stationary bicycles, etc. For the commercial system, one study used a VR rehabilitation system (VRRS), a commercial medical device for rehabilitation. The other VR systems were the Sony PlayStation and Wii Fit. These devices are intended for the general public but are increasingly used in rehabilitation.

VR-based physiotherapy intervention

Among the 13 articles included in this review, the VR-based physiotherapy interventions could be classified into four categories: robot-assisted gait training, treadmill walking, stationary walking, and other interventions (Table 1).

Robot-assisted gait training

Three studies combined VR with robot-assisted gait training (RAGT). For example, Bergmann et al. (2018) used VR, to present a scenario in which participants had to walk a course displayed on the screen and solve various tasks by controlling the speed of the avatar by adjusting their motor activity while wearing the Lokomat robotic gait orthosis (Hocoma AG, Volketswil, Switzerland). The intervention lasted 12 sessions (4 weeks, 3 sessions per week). In a study by Kayabinar et al. (2021), VR was combined with RAGT 2 days per week for 6 weeks, for a total of 12 sessions. RAGT was performed with RoboGait (Middle East Technical University, Teknokent, Bama Teknoloji, Ankara, Turkey) and the two-dimensional game of RoboGait VR was played on the screen. The patients were tasked to walk in a forest environment with many trees without bumping into the trees and try to collect the coins appearing on the screen, using the scenario of collecting points in the system. Patients determined their direction during the game by transferring their weight to their extremities on the device. In another study by Park and Chung (2018), the Lokomat Pro (Hocoma AG, Zurich, Switzerland) was used for gait training. The VR function used a VR program called augmented feedback, a software embedded in the walking robot. In this VR program, the degree of mutual force between the patient and robot is represented by the movement of the avatar on the screen through the response of the sensors.

Treadmill walking

Four articles used treadmills for gait training. de Rooij et al. (2021) investigated the effect of gait training in VR by training participants on the gait real-time analysis interactive lab (GRAIL; Motekforce Link, Amsterdam, The Netherlands), which contains various rehabilitative applications in VR environments with specific rehabilitation goals (tasks). The difficulty levels were adjusted according to the individual abilities of the participants. The intervention took place for 6 weeks (12 30-min sessions). In a study by Fishbein et al. (2019), each training session began with an 8-min warm-up that included mobilization and flexibility exercises and a 2-min walk around the gym. Participants began walking slowly on a treadmill for 3 min. In subsequent phases, participants walked at the same speed while exercising using the three VR games. The total time walked on each trial was 20 min. Next, in a study by Richards et al. (2018), VR-based locomotion training was conducted using a walking simulator coupled with virtual environments back-projected onto a large screen. The participant, wearing a seatbelt and stereo goggles, walked on a motorized treadmill mounted on a six-degree-of-freedom motion platform, using a sliding handrail (to simulate the use of a cane), and progressed through virtual environment scenarios. Three levels of difficulty were set for the street crossing, gait, and park walk scenarios, in which the participant traveled 40 m. The participant then walked on the treadmill. For each program, participants attended nine training sessions over a 3-week period. Finally, in the study by Winter et al. (2021), a VR scenario called "Homecoming" was implemented using the Unreal Engine. The VR scenario is presented from a first-person perspective and aims to increase training motivation through an engaging storyline and gamification elements. As you walk on the treadmill, the world continuously becomes more fertile and colorful until it is completely rebuilt. For completing certain distances, users are awarded virtual stars as achievements in the virtual environment, accompanied by positive comments from the virtual companion. In the immersive VR condition, the virtual shoes were displayed at the position of the real feet. All participants took part in three conditions: No VR, semi-immersive VR, and immersive VR.

Table 1. Summary of the included articles according to the type of intervention

Study	Intervention type, and comparator (if any); duration of the intervention	Study populations	Aims of the study	Methodology	Outcome measures	Important results
The robot-assisted gait training						
Bergmann et al., 2018 Germany	Virtual reality (VR)-augmented of robot-assisted gait training and of robot-assisted gait training without VR Duration: 12 sessions (4 weeks, 3 sessions per week)	20 Subacute stroke patients (64±9 years)	To evaluate the acceptability of robot-assisted gait training (RAGT) with and without VR	Single-blind randomized controlled pilot trial with two parallel arms.	• Acceptability of the interventions • Intrinsic Motivation Inventory • Individual mean walking time	VR-augmented RAGT resulted in high acceptability and motivation, and in a reduced drop-out rate and an extended training time compared to standard RAGT.
Park and Chung, 2018 Korea	VR robot-assisted gait training (VRGT), auditory stimulation robot-assisted gait training and general gait training Duration: 45 min, 3 times a week for 6 weeks, and all subjects had undergone general PT for 30 min, 5 times a week for 6 weeks	40 Chronic stroke patients VRGT: 55.58±10.42 Auditory stimulation robot-assistant gait training group: 56.66±4.39 Control training: 57.50±9.90	To investigate the effects of robot-assisted gait training using VR and auditory stimulation on balance and gait abilities in stroke patients	Randomized controlled trial	• Medical research council • Berg balance scale (BBS) • Timed Up and Go (TUG) test • 10-m walk test (10MWT) • Fugl-Myer assessment • Modified Barthel Index	Improvements were observed in balance and gait abilities after VRGT compared with general physical therapy and were found to be effective in enhancing the functional activity of persons with stroke.
Kayabinar et al., 2021 Turkey	VR-augmented robot-assisted gait Training plus neurodevelopmental therapy and robot-assisted gait Training plus neurodevelopmental therapy Duration: 6 weeks, 2 days a week, for a total of 12 sessions	Thirty chronic stroke patients 57.93±5.91 years	To primarily investigate the effects of VR-augmented RAGT on dual-task performance and secondarily, functional measurements in chronic stroke patients	A randomized, single-blind trial.	• Dual-task performance measure ment • Functional gait assessment • BBS • Fall efficacy scale international • Functional independence measure (FIM)	VR-augmented RAGT improved dual-task gait speeds and dual-task performance of chronic stroke patients; however, there were no differences between the two groups after the treatment. Although functional improvements were determined with VR combined RAGT approach, it was not superior to RAGT only treatment.
Treadmill walking						
Richards et al., 2018 Canada	A treadmill walking program involves first a control protocol, then VR training. Duration: 9 training sessions over 3 weeks	A 62-year-old man entered the study 32 months after the onset of a right hemispheric stroke of thromboembolic origin.	To show that VR technology could be coupled with a self-paced treadmill to further improve walking competency in individuals with chronic stroke	Case report	• 5-m walk test • 6-min walk test (6MWT) • BBS • Activities-specific balance confi dence scale • Assessment of life habits scale and personal appraisal	Despite the limited potential for functional recovery from chronic stroke, an individual can achieve improvements in mobility and self-efficacy after participating in VR-coupled treadmill training, compared with treadmill training with the same intensity and surface perturbations but without VR immersion.
Fishbein et al., 2019 Israel	Dual-task treadmill walking while using a VR tool. And single-task treadmill-walking exercise routine. Duration: 8 treatment sessions carried out twice per week for 4 weeks	Twenty-two individuals chronic poststroke (66 and 64.36 years)	To investigate the feasibility of using a VR-based dual task of an upper extremity while treadmill walking, to improve gait and functional balance performance of chronic poststroke survivors	Randomized controlled trial with assessors' blinded regarding group allocation.	• The over-ground 10MWT (10 mW m/sec) • The number of steps completed by the participants during the 10-m walk • TUG test • Functional reach test • Lateral reach test • Activity-specific balance • Confidence • BBS	Dual-task training led to greater improvements in comparison to single-task walking, and thus it is suggested to combine different training sessions that require performing multiple tasks at the same time.

(*continued*)

https://doi.org/10.12965/jer.2346114.057

Table 1. Summary of the included articles according to the type of intervention (continued)

Study	Intervention type, and comparator (if any); duration of the intervention	Study populations	Aims of the study	Methodology	Outcome measures	Important results
De Rooij et al., 2021 Netherlands	VR gait training (VRT) group received training on the gait real-time analysis interactive lab, and participants assigned to the non-VRT group received treadmill training and functional gait exercises without VR. Duration: 2 30-min sessions per week for 6 weeks (12 sessions)	52 Subacute stroke patients (55–70 year)	To examine the effect of VRT compared to non-VR gait training (non-VRT) on participation in community-living people after stroke	Assessor-blinded, randomized controlled trial with 2 parallel groups,	• The restrictions subscale of the Utrecht scale for evaluation of rehabilitation-participation (US-ER-P) • The frequency and satisfaction subscales of the USER-P. • Subjective physical functioning (stroke impact scale-16) • Fatigue (fatigue severity scale) • Anxiety and depression (hospital anxiety and depression scale) • Falls efficacy (falls efficacy scale international) • Quality of life (stroke specific quality of life scale) • Functional mobility (TUG test) • Walking ability (6MWT) • Dynamic balance (mini balance evaluation systems test)	VRT is feasible and was positively experienced by people after stroke. However, VRT was not more effective than non-VRT for improving walking ability and participation after stroke.
Winter et al., 2021 Germany	Treadmill training without VR, semi-immersive VR (monitor), immersive VR Duration: 7.5 min in each condition	N = 36 students (26 females; mean, 22 years; standard deviation [SD], 3.7 years; range, 19–39 years). N = 14 patients with neurological disorders (n = 10 multiple sclerosis, n = 4 stroke) participated in the second study (mean, 52.6 years; SD, 7.5)	To evaluate an immersive VR application for supervised gait rehabilitation of patients with MS or stroke, to test its feasibility and acceptance and to compare its effects to those of a semi-immersive application and to conventional treadmill training	Within-subjects study design	• Heart rate • Borg scale • Raw task load index • National aeronautics and space administration task load index • Intrinsic motivation inventory • IPQ group presence ques-tionnaire • Simulator sickness questionnaire • System usability scale • Equipment and display question naire	The feasibility of combining treadmill training with immersive VR. Due to its high usability and low side effects, it might be particularly suited for patients to improve training motivation and training outcome e. g. the walking speed compared with treadmill training using no or only semi-immersive VR.
Stationary walking						
Held et al., 2018 Switzerland Spain	Autonomous rehabilitation based on virtual rehabilitation Duration: the average training duration per training day was 28 ± 15 min (Switzerland, 24 ± 11 min; Spain, 30 ± 7 min)	Fifteen participants with first-ever stroke, with a mild to moderate residual deficit of the lower extremities	To study the safety, usability and patient acceptance of an autonomous telerehabilitation system for balance and gait (the REWIRE platform) in the patients' home	Cohort study	• Technology acceptance mode questionnaire • The cumulative duration of weekly training	Autonomous telerehabilitation for balance and gait training with the REWIRE-system is safe, feasible and can help to intensive rehabilitative therapy at home.
Da Silva Júnior et al., 2021 Brazil	Stationary walking in a real and nonimmersive virtual environment (Wii Fit Plus-running mode) Duration: 3 minutes in random order	10 Poststroke patients (56.3 ± 1.05 years) 10 Healthy individuals (59.87 ± 9.96 years)	Compare the kinematics and performance of the affected lower limb of poststroke patients and healthy individuals during stationary walking activity between the real and virtual nonimmersive environments	Cross-sectional study	• Number of steps • Mean maximum flexion and ex tension of each joint (hip, knee, and ankle)	Compared to the real environment, poststroke patients took more steps, with a faster cadence, and a lower knees range of motion on the affected side in a nonimmersive virtual environment.

(*continued*)

Table 1. Summary of the included articles according to the type of intervention (continued)

Study	Intervention type, and comparator (if any); duration of the intervention	Study populations	Aims of the study	Methodology	Outcome measures	Important results
Other type of intervention						
Lee, 2019 Korea	Speed-interactive pedaling training (SIPT) The SIPT group pedaled while staring at the screen in front of the stationary bike, and the control group trained without the screen. The conventional rehabilitation program was conducted in the same way for both groups. Duration: SIPT for 40 min a day, 5 days a week, in a six-week period, plus 1 hr. conventional Rehabilitation	42 Subjects with chronic hemiplegia for 6 months or more due to stroke. Age SIPT group 61.67±8.42 years, control group 64.24±10.83 years	To investigate the effects of SIPT using a smartphone VR application to improve lower limb motor function, trunk sitting balance, and gait in stroke patients	Single-blinded, randomized study.	• Fugl–Meyer assessment, • Postural sway • Modified functional reach test • Trunk impairment scale • Spatiotemporal parameters	Based on this result, we propose that SIPT, which improves function, balance, and gait, could be used as an effective training method to improve patients' functional activities in the clinical setting.
Kiper et al., 2020 Italy	The patients were treated using the VR rehabilitation system. The VR rehabilitation system was equipped with editor software, allowing the tailoring of any type of motor tasks within the workspace of the motion tracking system. Duration: 15 sessions, 5 days/wk, 1 hr/day	59 Stroke inpatients (mean age, 60.3 years; SD, 14.8 years); subacute (n=31) and chronic (n=28)	To analyze the effect of VR therapy combined with conventional physiotherapy on balance, gait and motor functional disturbances, and to determine whether there is an influence on motor recovery in the subacute (<6 months) or chronic (>6 months) phases after stroke	Quasi experimental research	• Fugl–Meyer lower extremity • FIM • BBS • Functional ambulation category • Modified Ashworth scale • 10MWT • Kinematic parameters during spe-cific motor tasks in sitting and standing position (speed; time; jerk; spatial error; length)	Patients improved lower limb function in both subacute and chronic stroke phase. VR therapy could be a useful tool for specific rehabilitation of the lower limb, which may lead to improved rehabilitation outcomes.
Park et al., 2021 Korea	Full-immersion VR video game Duration: 30 min per session, 3 sessions per week, for 6 weeks	27-year-old woman with stroke	Investigated the feasibility of training using a full-immersion VR video game for improving motor function, balance, and gait in a young stroke survivor	Case report	• Motor assessment scale • BBS • TUG test • Tinetti balance • Assessment • 10MWT • Tinetti gait assessment • Dynamic gait index	Training using a full-immersion VR video game may be a safe and effective method to improve motor function, balance, and gait in a young stroke survivor.
Luque-Moreno et al., 2021 Italy	Combined therapy of 1 hr VR and 1 hr of conventional physiotherapy (CP) and the second group (CP; n=10) received 2 hr of CP Duration: 5 days/wk, for weeks	20 Patients	To evaluate the feasibility and clinical effect of a treatment based on a specific VR system, administered in conditions of hospital routine in combination with CP, on the functionality of the lower extremity in cerebrovascular accident patients	A controlled clinical trial on a new approach	• Functional ambulation category • FIM • Fugl–Meyer assessment • BBS • Trunk control test	The results indicate that the intervention with VR is a feasible treatment in the poststroke functional re-education of the LE, with the potential to be an optimal complement of CP.

IPQ, Igroup Presence Questionnaire; IE, lower extremity.

https://doi.org/10.12965/jer.2346114.057

Stationary walking

Two studies used stationary walking with VR to improve gait performance. According to a study by Da Silva Júnior et al. (2021), stationary walking was performed with a walker in front and a chair behind the patient to ensure safety. A Nintendo Wii device connected to a 52-inch screen TV was used to allow participants to interact with the virtual environment and create a nonimmersive virtual environment. The Wii Fit Plus game (running mode) was used in the virtual environment. In this game, the avatar runs through a park-like landscape and meets other runners, passing them along the way. In order for the avatar to run, the participants should perform a stationary walking with the control attached to their torso. The participants performed stationary walking in a real and nonimmersive virtual environment (Wii Fit Plus –Running mode) for 3 min in randomized order. In a study by Held et al. (2018), it was reported that the patient exercised in front of the TV screen, and the movement was tracked by the Kinect camera and used to animate the avatar. In some exergames, a force plate is used to track the pressure point projected on the virtual floor of the game to provide feedback to the patient. In an exergame, the patient sees himself. Autonomic rehabilitation based on virtual rehabilitation was conducted at participants' homes for 12 weeks.

Other types of interventions

Four articles could not be classified into the above themes including video game, VRRS, and pedal training. In a case report by Park et al. (2021), a full-immersive VR video game using Sony PlayStation VR (Sony Interactive Entertainment Inc., Tokyo, Japan) was used. The first game was Fruit Ninja, where the background was stationary. The second game was Everybody's Golf, a game in which the player uses a controller to play golf in a realistic VR environment with the feeling of being on a real golf course. Each game was played for 15 min, and there was an approximately 5-min break while the game was changed and the device was set up. Training with a full- immersive VR video game lasted 30 min per session, 3 sessions per week, for 6 weeks, for a total of 18 sessions. Two clinical trials used the VRRS (Khymeia Group Ltd., Noventa Padovana, Italy) as an intervention. In the study by Kiper et al. (2020), participants sat or stood in front of a large computer screen. The electromagnetic sensor was positioned at different locations on the participant's leg and represented the end effector of the task depending on the exercise goal (e.g., it was placed at the foot, ankle, knee, or hip depending on the virtual task to be performed). The VRRS allows the use of two sensors. Thus, one sensor was used as an end effector, and the second sensor detected insufficient position compensation. The VR treatment lasted 15 sessions, 5 days/wk, 1 hr/day. In another study by Luque-Moreno et al. (2021), therapy by VRRS included the performance of different types of motor tasks in which the patient had real objects as references (stairs, high objects, signs on the floor, etc.). In this process, he interacted with a virtual scenario in which the movements of lower extremities were monitored using the motion capturing system to guide the kinematic trajectories of movement in different tasks. The intervention consisted of 15 sessions of conventional physiotherapy (1 hr per day, 5 days per week). Lee (2019) used a stationary bicycle for pedaling training. The bicycle training was performed manually so that the patient could set his own speed. The patient started at a comfortable speed that he normally used for exercise. Then, the pace was set by the patient. The training lasted 40 min in total, including 5 min of warm-up stretching, 5 min of slow pedaling, 25 min of main exercise, and 5 min of cool-down. During the main exercise, each video for the Speed-Interactive Pedaling Training group consisted of 10 min, and participants were provided with two 10-min videos.

Outcomes

Outcome measures were divided into four categories depending on the focus of the measurement: gait performance, components of gait, psychological components, and other measurements. Outcome measures for gait performance were measures that directly assessed the performance or quality of walking. In the included articles, the 10-m walk test was used to measure walking speed, the 6-min walk test was used to assess cardiovascular endurance during gait task, the Timed Up and Go test was used to assess mobility performance, the functional gait assessment was used to assess postural stability during the walking task, and gait speed was measured separately from the 10-m walk test in some studies. The second category includes the components of walking. This category includes measurements that assess body components related to gait ability. Measurements included lower extremity muscle strength and kinematic functions such as speed, spatial error, gait length, balance, and motor function assessments such as the Fugl–Meyer Assessment and the Modified Ashworth Scale. The third category includes psychological components. In this study, some items included psychological aspects as outcome measures, such as intrinsic motivation, anxiety and depression, mood, and adverse event safety measures. The other measurement categories were activity of daily living measures such as the Barthel Index, Functional Independence Measure, and heart rate.

DISCUSSION

The aim of this review was to summarize the current literature on VR-based interventions for gait training in stroke patients to identify potential avenues for future research. Thirteen articles met the inclusion criteria. Existing literature suggests that incorporating VR-based rehabilitation into conventional physiotherapy may be effective in improving gait ability in stroke patients, particularly in the chronic stage

Based on these findings, many commercial VR systems have been used. The use of commercial VR for neurorehabilitation is gaining interest. It was also seen as a cost-effective intervention for home-based programs and reduced therapist time (Aliprandi et al., 2022).

Consistent with the principles of neurorehabilitation based on motor learning and brain plasticity mechanisms, elements such as repetitive practice, spaced practice, dosage, task-specific, goal-oriented practice, variable practice, increasing difficulty, multisensory stimulation, and explicit/implicit feedback (Maier et al., 2019b) were used to some degree in VR-based interventions in all included studies.

With respect to walking tasks in VR-based intervention, such as stationary walking, walking on a treadmill, or robot-assisted walking, improved gait function outcomes were obtained. This could be due to the influence of task-specific or goal-directed training, in which patients practice context-specific motor tasks and receive some form of feedback (Teasell et al., 2008). Thus, task specificity seems to be a crucial, but not the only, factor in the use of VR-based interventions (Darekar et al., 2015). In addition, the intensity of the intervention could be considered as a dosage and timed exercise. In this study, the intensity of VR intervention ranged from 10–60 min per session for a total duration of 9–30 sessions. Additionally, some studies have used VR-based interventions in conjunction with conventional physical rehabilitation. Studies from neuroscience show that high-intensity rehabilitation protocols with prolonged training times can induce neuronal plasticity (Kwakkel et al., 2015) and reorganization of neural networks and improve motor functions (Veerbeek et al., 2014). In contrast to the previous scoping review (Darekar et al., 2015), this review also found that many studies included psychological outcomes such as immediate intrinsic motivation, anxiety, depression, and mood. These outcomes showed improvements in all participants. This could mean that the potential advantage of VR is that it provides highly repetitive training with great variability, which helps to maintain the patient's motivation, limit their perception of effort, and improve their adaptability (Selves et al., 2020). Finally, regarding feedback, the majority of included studies used explicit feedback in the form of visual (e.g., success scores, stars) or auditory (e.g., cheers, feelings of success, and other sounds) feedback. Explicit feedback appears to activate explicit learning mechanisms while having minimal effects on implicit learning mechanisms (Taylor et al., 2014). Reinforcement of positive outcomes appears to promote a success-oriented learning system that limits decay after learning, possibly by mobilizing the dopaminergic system (Wickens et al., 2003). Implicit feedback was presented in the form of the quality of the movement, e.g., a graph or motion capturing system. Implicit sensory feedback enhances learning from sensorimotor prediction errors, which may aid in adaptation to unexpected perturbations (Shadmehr et al., 2010), possibly by contributing to implicit learning mechanisms (Taylor et al., 2014).

This is consistent with previous arguments that VR can provide meaningful and realistic experiences that facilitate rehabilitation success (Levac et al., 2019; Levin, 2011). The main advantages of VR are the accessibility of repeated practice, multisensory feedback, increasing task difficulty, and task specificity (Levac et al., 2019; Levin, 2011). Additionally, evidence from moderation analysis suggests that tailoring VR systems to patient needs can improve rehabilitation outcomes (Voinescu et al., 2021).

Overall, VR-based gait rehabilitation had a positive effect on gait components, gait performance, and psychological outcomes. However, one study reported that gait speed could not be measured due to the ground effect of the baseline performance. Serious adverse effects were not observed. In this study, it was found that the majority of stroke patients were in the chronic phase. Although spontaneous recovery usually reaches its limits in the chronic phase (Grefkes and Fink, 2020), this study found that positive improvement also occurs in participants in the chronic phase. This is consistent with previous systematic research that suggested that supplementing gait training with VR-based training could result in greater improvement in walking speed than non-virtual walking interventions (Rodrigues-Baroni et al., 2014).

However, this review was a scoping study and not a systematic review because no quality assessment of the included studies was performed. We found heterogeneity in the included studies in terms of participants, VR systems, VR-based intervention content, and outcome measures. Despite these limitations, initial findings were positive. The use of VR-based physiotherapy interventions for gait rehabilitation in stroke patients appear to be effective in improving gait components, gait performance, and psychological aspects.

https://doi.org/10.12965/jer.2346114.057

In conclusion, existing literature suggests that VR-based rehabilitation combined with conventional physiotherapy can improve gait ability in people with stroke, especially in the chronic stage. The duration of the programs should be customized to avoid stimulation disease. Further research is needed to investigate the long-term effects of this approach.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENTS

The authors received no financial support for this article.

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 https://doi.org/10.12965/jer.2346114.057