THE EFFECTS OF VIRTUAL REALITY TRAINING FOR IMPROVING STANDING BALANCE IN CHRONIC STROKE PATIENTS

LITERATURE REVIEW

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Date: 20/04/2023

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Contents

Preface

The following literature review is a thesis for the bachelor of physiotherapy graduation assignment at Hanze University of Applied Science, Groningen. Throughout my studies, I took a particular interest in central neurological disorders. One such disorder that I had personal experiences with in the past was Cerebral Vascular Accidents, more commonly known as strokes. Furthermore, I gained real exposure with these patients during my internships. An aspect of this condition that I became quite interested in was the different types of intervention that could be administered depending upon a given patients stage of poststroke recovery. I had the opportunity to treat patients in different stages, applying various interventions that were deemed suitable to each individual patient. From what we were taught in my studies, and based on current evidence, a functional approach is optimal in the rehabilitation of strokes. It is important to note that I am in agreeance with this idea, but to what extent could also focusing on specific aspects, such as training one's standing balance, be an improvement on simply training functionally? Would training specific aspects, along with functional training, yield a better overall functioning rather than a generalised functional training program? This led me to think about specific interventions when it comes to this. More specifically, I was curious to see if novel, up-and-coming techniques were effective in achieving this. It was at this point, when researching interventions to treat balance, that I came across the concept of Virtual Reality training. I became eager to find out if Virtual Reality training is effective for training balance, and if so, to what extent and is it worth including in a rehabilitation program. With this idea, I was curious to find out if such an intervention would be beneficial depending on a patient's phase of recovery. That phase being the chronic phase, as that is where most of my personal experiences lay. Depending on the results of this review, I hope that I can carry this knowledge forward in my career as a physiotherapist.

Abstract

Introduction: Strokes are one of the most common causes for chronic disability worldwide and its prevalence is increasing at a worrying rate. Millions of stroke patients are burdened with permanent neurological deficits, mainly motor and psychological. Balance deficits play a major role in patients who have suffered strokes. It is estimated that 30% of patients cannot walk independently 6 months post-stroke, usually caused by impaired standing balance due to hemiplegia or hemiparesis that is experienced. Balance as a whole is a key factor when it comes to achieving ADL independence post-stroke. While several treatment options are available, in recent years, Virtual Reality has gained attention and traction for a number of reasons. Firstly, through its ability to deliver a customized training session and to increase patients' engagement, allowing the patient to perform a therapeutic program tailored to their needs while interacting with a safe, computer-simulated environment. Secondly, it has also been shown to increase neuroplasticity in the affected area(s) of the brain, by evoking visual, sensory and cognitive interactions at the intercortical level. The unique game-based or immersive/semi immersive aspect of the intervention also adds an enjoyable element to the training, which will increase patient's motivation.

Aim: To add knowledge to this up-and-coming intervention and, in turn, bring value to more modern interventions in this field in the coming future. More specifically, its effect on improving overall standing balance in chronic stroke patients.

Method: A search from PubMed and PEDro databases was carried out between January and March 2023. To aid in selecting articles, the search was based on eligibility criteria. Once these were chosen, their methodological quality was assessed using the PEDro Scale. The data extracted from each article was as follows: Population, Patient type, Intervention, Control/Comparison intervention, Duration of intervention, Outcome, Outcome measure, Results and Follow-up was extracted. With regards to data analysis, $P < 0.05$ was used to determine statistical significance, while Cohens' d was used to calculate effect size.

Results: Across 10 selected RCT's, there was a total population of 311 chronic stroke patients. A variety of Virtual Reality interventions seen. 5 studies used game-based Virtual Reality, 2 studies used treadmill-based Virtual Reality and the remaining 3 studies used other semi-immersive Virtual Reality interventions. 7 articles performed Virtual Reality in combination with conventional rehabilitation, with a control group of conventional rehabilitation only. At least one measurement tool(s) for static and/or dynamic balance were used in each study. They included: Berg Balance Scale; Performance Orientated Mobility Assessment-balance; Functional Reach Test; Timed Up-and-Go; Postural Sway. Results showed statistically significant differences within one or both groups in at least one outcome measure in each study, and between group differences in 8 out of the 10 included articles in favour of Virtual Reality intervention. Generally, there was a medium to large clinical effect.

Conclusion: From the available literature, there is evidence to suggest that Virtual Reality training can be beneficial with regards to improving balance in chronic stroke patients. When included in a general rehabilitation program, results have shown to have a medium to large clinical effect.

Key Words: Virtual Reality, Virtual Reality training, Chronic Stroke, Static, Dynamic, Standing Balance, Rehabilitation, Neural Plasticity.

Introduction

Strokes are one of the most common causes for chronic disability worldwide and its prevalence is increasing at a worrying rate. The World Health Organization (WHO) estimates that stroke events in EU countries are likely to increase by 30% between 2000 and 2025 (Hatem, et al., 2016). Another study stated that by 2030, it is estimated that 4% of the population will have experienced a stroke during their lifetime, amounting to medical costs of up to $183.13 billion (Anwar, et al., 2021). Millions of stroke patients are burdened with permanent neurological deficits, mainly motor and psychological. In most cases, post-stroke recovery requires long-time interventions in a multidisciplinary team, primarily depending on a number of prognostic factors. These include the severity of the stroke, the associated pathologies, the patient's age, the time since stroke and the beginning of rehabilitation (Miclaus, 2021).

Ischemic strokes occur due to the loss of blood supply to an area of the brain due to a blockage or occlusion. It is a common type of stroke (Unnithan, 2022). Haemorrhagic strokes occur due to bleeding into the brain by the rupture of a blood vessel, meaning it is associated with severe morbidity and high mortality (Unnithan, 2022). Three main stages are used to describe the CT scan manifestations of stroke: the first 2 weeks are defined as the acute stage; 3–11 weeks post-stroke is termed the subacute stage in which most changes occur; 12–24 weeks post-stroke is the early chronic stage; and more than 24 weeks post-stroke is the chronic stage (Wu, et al., 2015). The early and late chronic phases can be grouped together to simply be known as the chronic phase (12-24+ weeks). There can be some variety throughout the literature when classifying these stages, however, the above timeframe is usually a good conservative estimate. It is important to note, that "post-stroke rehabilitation in the subacute phase begins when the patients' are clinically balanced and stable, especially with regards to cardiorespiratory functions, and last but not least, when the tasks can be understood and supported by the patients' participation and involvement in the rehabilitation program" (Miclaus, 2021). The most commonly used post-stroke rehabilitation techniques usually refer to correct posture, avoiding synkinesis, increasing muscle strength, active mobilization, proprioception, gait, balance, and daily activities training (Miclaus, 2021). Rehabilitation in the chronic phase consists of constant and consistent rehabilitation of a similar nature, that is continued for the remainder of their lives. Depending on the severity of the stroke, it is during the early or late chronic phase where the maximum level of the physiotherapy program is reached (Miclaus, 2021).

Balance deficits play a major role in patients who have suffered strokes. It is estimated that 30% of patients cannot walk independently 6 months post-stroke (Sheehy, et al., 2016). This can be caused by impaired standing balance due to hemiplegia or hemiparesis that is experienced post stroke. Standing balance can be split further into static and dynamic balance. Static balance is defined as the ability to maintain an upright posture and to keep the line of gravity within the limits of the base of support, while dynamic balance is defined as the ability to maintain stability during weight shifting, often while changing the base of support (Dunsky, Zeev, & Netz, 2017). Regardless, balance as a whole is a key factor when it comes to achieving ADL independence post-stroke. A systematic review stated "impaired balance early after stroke is strongly associated with future function and recovery" (Lubetsky-Vilnai & Kartin, 2010). This same systematic review stated that recent literature "have not established a significant improvement in balance as a result of resistance training in older adults or gait-oriented training in individuals poststroke". That being said, The KNGF Stroke

Guideline of 2014 recommends several ways to train standing balance. Exercises with or without visual feedback from a force platform is recommended (Royal Dutch Society for Physical Therapy, 2014). Several exercises like these aim to increase balance, however, so far there is no clear balance training programme that has been proven most effective.

While several treatment options are available, in recent years, technology has become much more prevalent in the physiotherapeutic field and in the medical science field as a whole. Virtual Reality (VR) has gained attention for a number of reasons. Firstly, through its ability to deliver a customized training session and to increase patients' engagement, while allowing the patient to perform a therapeutic program tailored to their needs while interacting with a computer-simulated environment (Patsaki, et al., 2022). As stated in the KNGF Guideline, (2014), “The training effort for stroke patients should as much as possible be aimed at learning or re-learning skills that are important for the patient’s everyday life. The principle of the specificity of treatment effects in patients with a stroke relates not only to the actual movements made while exercising, but also to the environment or context in which they are practiced”. Secondly, it has also been shown to increase neuroplasticity in the affected area(s) of the brain, by evoking visual, sensory and cognitive interactions at the intercortical level (Anwar, et al., 2021). Again, this could be attributed to the fact that they can gain “access in a safe environment to real-life situations, otherwise inaccessible to patients due to cognitive, motor and psychological limitations” (Miclaus, 2021). The unique game-based or immersive/semi immersive aspect of the intervention also adds an enjoyable element to the training, which will increase patient’s motivation (Jang, et al., 2005). As this is a novel intervention, the current evidence available is still quite limited. However, recent studies have shown this to be positive in the context of overall balance performance in stroke patients. This concept will be explored in detail throughout this review.

This literature review aims to come to a conclusive answer with regards to the following research question: What is the effect of Virtual Reality training for improving standing balance in chronic stroke patients?

The aim of this literature review is to add knowledge to this up-and-coming intervention and, in turn, bring value to more modern interventions in this field in the coming future. More specifically, its effect on improving overall standing balance in chronic stroke patients. Ideally, it will bring attention to this treatment method in later stage strokes, as much focus within current literature is put on early intervention, in the acute and subacute phases. Moreover, in the acute phase, and subacute phase to an extent, much of the improvement displayed is spontaneous, therefore, it is difficult to attribute improvement in standing balance to be as a result of specific balance related intervention (Lubetsky-Vilnai & Kartin, 2010; Wu, et al., 2015). If VR training is shown to be of benefit in the context of standing balance, it could possibly decrease or slow down the condition’s deterioration, allowing people who have suffered strokes to be more ADL independent, with less at risk of falls, for a longer, sustained period of time. Therefore, inclusion of this intervention, either in physiotherapeutic or home settings, could be of financial benefit to the healthcare system in the long term.

Methods

Research design

This literature review is based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). Between January and March 2023, an independent article search was carried out in order to conduct a literature review. A preliminary search was carried out in January 2023, with the aim of establishing suitable search terms. This was followed by an advanced search strategy in February and March 2023, where a search string could be created to find and select the appropriate articles. This was done to assess the effectiveness of VR training for improving standing balance in chronic stroke patients. This research took the form of a PIO question: The Patient is chronic stage stroke patients; the Intervention is Virtual Reality training and the Outcome is improving standing balance. It was not necessary to follow ethical protocol prior to carrying out this literature review, as there were no participants that were known to the author, nor were there any participants recruited as part of this research.

Search strategy

There were two online databases used in the search process; PubMed and PEDro. PubMed was selected as it is a database which contains a broad range of high-quality data related to medical science. PEDro was also selected as it contains high quality evidence related specifically to the field of physiotherapy. Based on the established search terms, the following search strings for both databases were created:

Table 1. *Search strings*

Database	Filter	Search string
PubMed	Full text available, Human trials, RCT’s & Clinical trials, artilces published within the past 10 years	(((((stroke)[MeSH Terms] OR (chronic stroke)) OR (CVA)) OR (cerebral apoplexy)) AND (((Virtual Reality training)[MeSH Terms] OR (VR training)) OR (immersive Virtual Reality training))) AND (((((balance) OR (standing balance)) OR (postural control)) OR (static balance)) OR (dynamic balance))
PEDro	Clinical trials	“Virtual Reality”, “balance”, “stroke”

Eligibility criteria

The selection criteria were chosen independently by the author. This was done in order to exclude any irrelevant data for this literature review. From the results of each search string, the relevancy of the subsequent titles was screened, followed by a screening of the abstracts. After this selection process, scientific articles were chosen to include in this review based on the following criteria presented in

Table 2. *Eligibility criteria*

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Inclusion criteria	Exclusion criteria
- English articles with full text available - Human trials - RCT's or CT's - Published within past 10 years - Chronic stroke patients - Immersive VR or semi immersive/exergaming VR - Standing, static or dynamic, balance outcome measures	- No full text articles available - Animal trials - Studies of a lower level of evidence than RCT's or CT's (cohort studies, case studies, etc.) - Published >10 years ago - Acute stroke patients, subacute stroke patients or other Central Neurological Disorders (MS, Parkinson's, TBI/ABI, etc.) - Robot assisted interventions - Outcome measures that measure sitting balance or do not include balance whatsoever (only gait, mobility, fall risk, etc.)

Abbreviations: RCT – *randomised controlled trial;* CT – *clinical trial;* MS – *multiple sclerosis;* TBI – *traumatic brain injury;* ABI – *acquired brain injury*

Methodological quality analysis

The PEDro scale is a commonly used tool to assess the quality, along with internal validity, external validity and statistical reporting of Randomised Controlled Trials (RCT's) and Clinical Trials (CT's). Articles are assessed and scored based on a 10 point scale; eligibility criteria and source; random allocation; concealed allocation; baseline comparability; blinding of participants; blinding of therapists; blinding of assessors; adequate follow up (>85%); intention to treat analysis; between group statistical comparisons; reporting of point measures and measures of variability. It is important to note that the eligibility criteria and source is not scored. Authors have suggested that scores of: < 4 are considered 'poor', 4 to 5 are considered 'fair', 6 to 8 are considered 'good' and 9 to 10 are considered 'excellent' (Cashin & McAuley, 2020). The PEDro score has demonstrated 'fair' to 'excellent' inter-rater reliability (intraclass correlation coefficient [ICC] = 0.53 to 0.91) for clinical trials of physiotherapy-related interventions, and 'excellent' inter-rater reliability (ICC = 0.80 to 0.89) (Cashin & McAuley, 2020). With regards to its validity, "The PEDro scale is a valid measure of the methodological quality of clinical trials" (de Morton, 2009). The PEDro scale was applied to each selected article and can be found in Appendix 1.

Data extraction

Initially, a general data extraction was performed for each chosen article, which included the author, year, type of study and the aim of each study. Along with this, Population, Patient type, Intervention, Control/Comparison intervention, Duration of intervention, Outcome, Outcome measure, Results and Follow-up was extracted. Also included was the quality assessment (PEDro Scale score) of each article. An overview of this information is given in

Appendix 2.

Data analysis

The statistical results from the selected studies were not altered in any way and analysed as they were. A result was considered statistically significant when ($P < 0.05$), meaning there is a 5% chance, or less, that the result is incorrect. In other words, a P-value of ≤ 0.05 indicates strong evidence against the null hypothesis, whereas a p-value of > 0.05 indicates weak evidence against the null hypothesis (Dahiru, 2008). Along with this, the effect size of the results was also analysed, in order to determine the clinical relevance of the results. While a P-value can inform the reader whether an effect exists, the P-value will not reveal the size of the effect. In reporting and interpreting studies, both the substantive significance (effect size) and statistical significance (P-value) are essential results to be reported (Sullivan & Feinn, 2012). For the effect size, the Cohen's model for effect size (d) is interpreted as a small effect size ($d = 0.2$), medium effect size ($d = 0.5$) and large effect size ($d = 0.8$) (Portney & Watkins, 2013; Page, 2014).

Results

Included studies

In February and March 2023, a search, using the search strings described in Table 1, was carried out across two databases: PubMed and PEDro. Filters applied to the PubMed search were RCT's/CT's, human trials, published within the past 10 years. Filters applied to the PEDro search were clinical trials. With these filters, a total of 77 results between both databases were identified to be screened. From here, 36 articles were excluded based on irrelevancy of titles, leaving 41 articles to be further screened based on their abstracts and the eligibility criteria mentioned in Table 2. From here, 25 articles were excluded based on abstract and eligibility criteria, leaving 16 remaining articles eligible for inclusion. Within the remaining articles, 6 results were duplicates across both databases. Therefore, 10 articles were chosen to be included in this literature review. A visual overview of the selection process can be seen in Figure 1.

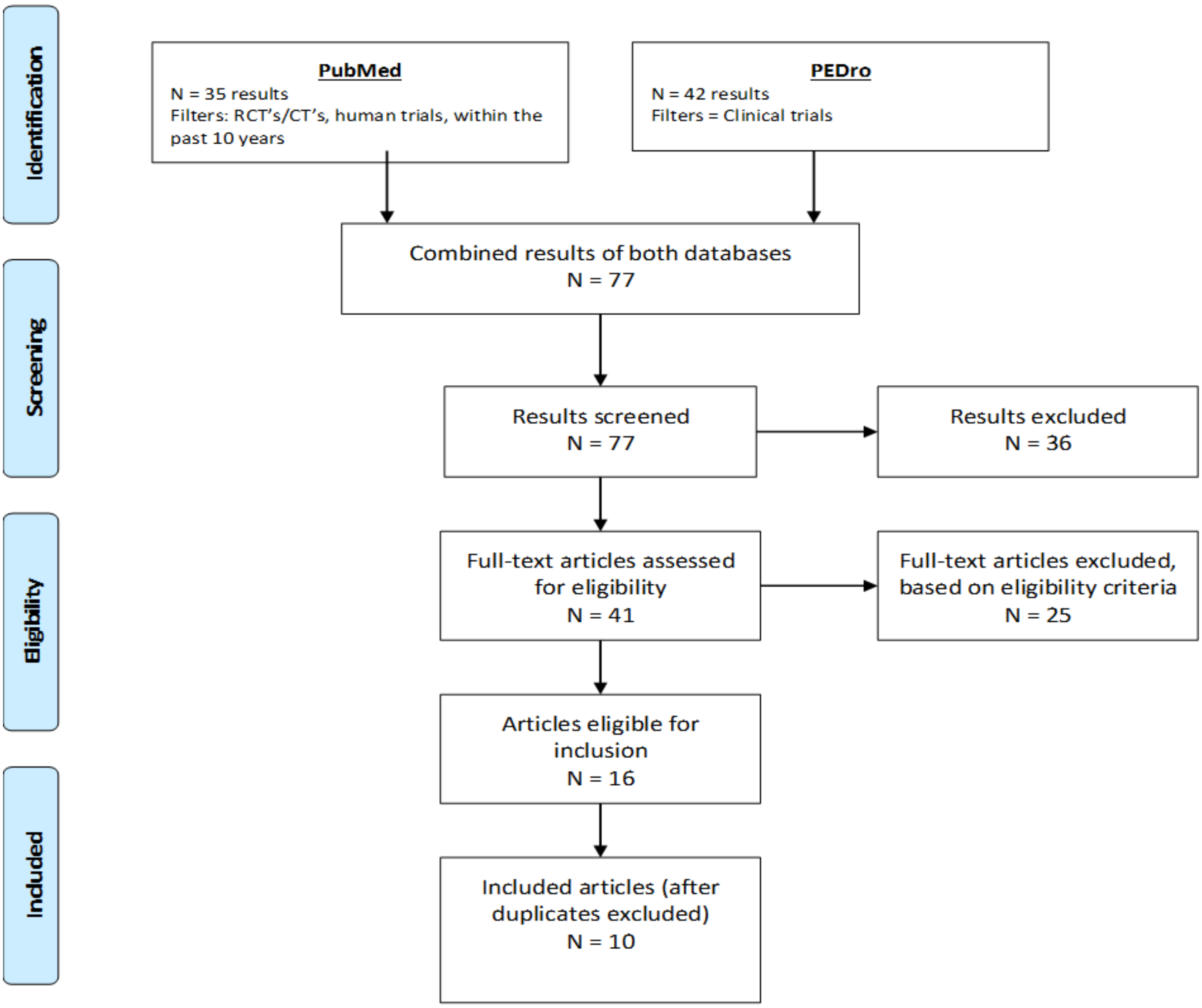

Figure 1. *Flow Diagram* (Moher D, 2009)

Population Characteristics

This literature review contained a total population of 311 chronic stroke patients across the 10 included studies, with the ages ranging from an average of 51.35 to 78.10. Each study generally had a small population size, ranging from a population of 20 to a population of 68. This included a total of 143 males and 100 females, leaving the sex of 68 participants unaccounted for. It is important to note that the study of Anwar et al, (2022), did not specify the sex of the participants. A total of 111 ischemic strokes and 61 haemorrhagic strokes were included, with 4 studies not specifying the aetiology of the participants. A detailed overview of each study's participants age, sex, chronicity of stroke and aetiology is shown in Table 3.

Table 3. Population characteristics

Study	Age (years)		Male		Female		Chronicity of stroke (months)		Aetiology	
	EG	CG	EG	CG	EG	CG	EG	CG	EG	CG
Anwar et al.	51.56(±) 7.199	51.35(±) 5.787	NS	NS	NS	NS	NS	NS	I-NS H-NS	I-NS H-NS
Yom et al.	64.60	78.10	6	5	4	5	11.14	11.63	I-NS H-NS	I-NS H-NS
In et al.	57.31(±) 10.53	54.42(±) 11.44	8	7	5	5	12.54(±) 4.14	13.58(±) 5.28	I-8 H-5	I-8 H-4
Marques-Sule et al.	61.5(±) 8.4	58.2(±) 7.4	9	6	9	5	>12	>12	I-NS H-NS	I-NS H-NS
Llorens et al. (2014)	58.3(±) 11.6	55.0(±) 11.6	4	5	6	5	13.58(±) 7.75	19.6(±) 7.4	I-7 H-3	I-6 H-4
Llorens et al. (2015)	55.47(±) 9.63	55.60(±) 7.29	10	7	5	8	11.14(±) 2.03	10.56(±) 1.66	I-9 H-6	I-10 H-5
Fishbein et al.	64.36	66	10	7	1	4	102.84	114.6	I-NS H-NS	I-NS H-NS
Park et al.	62.0(±) 17.14	65.30(±) 10.51	5	5	5	5	10.78(±) 7.06	14.10(±) 7.73	I-8 H-2	I-5 H-5
Cho et al.	65.86(±) 5.73	63.53(±) 5.54	7	8	8	7	13.81(±) 5.01	15.34(±) 6.23	I-10 H-5	I-10 H-5
Lee et al.	59.35(±) 8.95	55.76(±) 9.59	16	18	10	3	27.99(±) 23.97	21.77(±) 19.65	I-16 H-10	I-14 H-7

Age and chronicity of stroke are defined in terms of mean (±) SD
Abbreviations: NS – *not specified;* EG – *experimental group;* CG – *control group;* I – *ischemic;* H – *haemorrhagic.*

Intervention

Throughout the studies, the intervention period ranged from twice a week to daily, for 4 weeks to 7 weeks. The intervention period averaged 3-4 days per week, for an average of 5 weeks. Furthermore, the duration of each VR intervention session ranged from 30 minutes to 60 minutes. Only 3 studies specified a post intervention follow up period. 2 studies followed up 4 weeks post intervention and 1 study followed up 3 months post intervention.

Each article included VR as the experimental intervention. There was, however, slight variance in the way the VR was applied throughout the studies.

Game based VR

Of the included studies, Anwar et al, (2022), Marques-Sule, et al (2021), Llorens et al, (2015), Park et al, (2017) and Lee et al, (2017) used game-based VR interventions. The instruments used were the Nintendo Wii and Xbox Kinect. Wii comes with a console, adapter, infrared sensor bar, 2 wireless nun chucks, remote with wrist straps, sensor bar, Wii balance board, and Wii Sports kit (Anwar, et al., 2022). The console, adaptor and sensor bar are connected to a TV. The remotes, nun chucks and balance board are calibrated to limb movements and bodyweight shifting via the sensors. This allows the participant to directly control the movements of the avatar on the screen. The Wii Sports kit are attachable to the remote depending on the game being played. Games included tennis, boxing, cooking, (Anwar, et al., 2022), heading footballs, ski slalom, tilt table, tightrope tension, downstream, sub-zero fishing (Marques-Sule, et al., 2021). The Xbox Kinect system works in a very similar way. It consists of a console and Kinect sensor, which connect to the TV. However, the Xbox sensor contains an in-built infrared camera which recognises tracks the participants movements and body position, which is once again, relayed directly to the on-screen avatar. This means that a handheld remote or nun chuck is not required. Games included boxing, table tennis, soccer, golf, ski, American football, (Park, Lee, Lee, & Lee, 2017), darts, bowling, golf, virtual smash, light race, space pop, rally ball, river rush and table tennis (Lee, Huang, Ho, & Sung, 2017).

Treadmill based VR

Of the included studies Fishbein et al, (2019), and Cho et al, (2014), used a treadmill-based VR intervention. The key instrument used in both of these studies was a treadmill that included an emergency stop mechanism, while being attached to a safety harness that did not support bodyweight. They would walk at a comfortable pace, based on their ability. Fishbein et al, (2019), used a dual task walking intervention. This included walking, while simultaneously participating in mini-games using the SeeMe system. This entails a projected video-capture VR system that works with a standard PC and a single, standard web video camera. Participants were positioned on the treadmill in a demarcated area in front of a large television screen, on which the games were displayed (Fishbein, Hutzler, Ratmansky, Treger, & Dunsky, 2019). The mini-games included: a ball game, which required the participant to strike virtual balls with their arms from different targets; reactive boxing, where boxes appear at random on either side of the screen that need to be touched within the allocated time; and cleaning windows, where they would have to wipe virtual dirt off the screen as quickly as possible. Cho, et al, used screenshots of real-world video recordings. They were captured using a video camera and a Steadicam camera stabilizing system. Real-world video recording, composed of six screen shots, was projected onto a big screen in front of the treadmill (2 m) using a projector and a laptop. At the same time, auditory input, which recorded real-sound during real-world video recording, was provided using a loud speaker (Cho & Lee, 2014). While walking on the treadmill, participants viewed a virtual environment using the real-world video recording. Each screenshot was depicted in the following order: a sunny 400-m walking track; a rainy 400-m walking track; a 400- m walking track with obstacles; daytime walks in a community; night-time walks in a community; and walking on trails (Cho & Lee, 2014). This was progressed on a weekly basis.

Other semi-immersive VR interventions

The remaining 3 studies, Llorens et al, (2014), Yom et al, (2015), and In et al, (2016), used separate VR interventions that did not include gaming or treadmill activity.

Llorens et al, used a stepping-based VR intervention. The set-up consisted of a standard computer, an audio-visual output system consisting of a video display, and a motion tracking system. With regards to the motion tracking system, two OptiTrack cameras at 100 Hz were used to estimate the 3D position of two reflective spherical markers, which were fixed to the participants' insteps using Velcro strips. The exercise immersed the participants in a 3D virtual environment. In the virtual world, the participants' feet were represented by two shoes that mimicked their movement in the real world. In this virtual display, blocks came up from the ground around them, to which the participant had to step onto with one foot while keeping the other foot on the ground. It could be made more difficult by increasing the repetitions and size of the blocks (Llorens, Gil-Gomez, Alcaniz, Colomer, & Noe, 2014).

Yom et al, used an ankle-based VR intervention. To create the virtual reality environment, a virtual reality-based ankle exercise program, safety belt, notebook computer, beam projector and screens were used. The screen was installed, and the beam projector was used for people and computers to interface through the camera, which installed equipped on the computer. One screen showed the virtual reality-based ankle exercise program while the other screen showed the target. The four virtual reality-based ankle exercises trained the subjects in a back and forth movement of the ankles in standing without any movement from the body or hip joints. They were as follows: exercising on the floor; exercising on a balance board; exercising on a cushion ball and standing on one foot (Yom, Cho, & Lee, 2015).

In et al, utilised a VR reflection therapy (VRRT) intervention. The set up consisted of a laptop, camera and LCD monitor. Participants were seated on a bench with no back support and feet on the ground. Participants placed their affected lower limb into the VRRT box to observe the projected movement of the unaffected lower limb without visual asymmetry. The unaffected lower limb of each participant was placed so that the centre of the camera was over the limb. Participants then adjusted the lower extremities so that the image was projected in the location of the affected lower extremities. When the program started, the participants were asked to watch the movements of the lower limbs on the monitor only (In, Lee, & Song, 2016). Leg movements or tasks started off basic and got increasingly more complex as the weeks went on.

Outcome measures

Each article used between 1 and 4 measurement tools that measured static and/or dynamic balance. Every article, with the exception of the study by Yom et al, (2015), used the Berg Balance Scale (BBS). This is one of the most consistent and reliable measurement tools that assesses both static and dynamic balance in people with central neurological disorders (Blum & Korner-Bitensky, 2008). It was also the primary balance outcome measure throughout the 9 studies in which it was included. Marques-Sule et al, (2021), Llorens et al, (2015), and Llorens et al, (2014), used Performance Orientated Mobility Assessment-balance (POMA/Tinetti Test). Like the BBS, the POMA also measures both static and dynamic balance. As this test contains both a gait and balance component, only the results of the balance component were compared. Cho et al, (2014), Yom et al, (2015), In et al, (2016), and Lee et al, (2017), used the Timed Up-and-Go (TUG) as a measurement of dynamic balance. However, Lee et al used the TUG-Cognition, or TUG-cog, which is a modified version of the traditional TUG. In the TUG-cog, participants were asked to complete the test as normal, while counting backward by 3 from a randomly selected number between 20 and 100 (Lee, Huang, Ho, & Sung, 2017). Another test that measures dynamic balance is the Functional Reach Test (FRT). The FRT was used by Fishbein et al, (2019), Lee et al, (2017), and In et al, (2016). Finally, 1 study included Postural sway as a measure of static balance (Cho & Lee, 2014).

Main outcomes

Game based VR

Anwar et al reported a significant difference between the two groups in the BBS score ($P<.001$). This was in favour of the VR group with a mean value of 36.62 (SD 7.76) compared to the routine physical therapy group, with a mean value of 26.94 (SD 6.46) (Anwar, et al., 2022). This was also the case in the study by Park et al, (2017), in which the intervention group demonstrated a significant improvement in BBS scoring compared to the control group ($P<0.05$). Marques-Sule et al, (2021), reported significant differences within ($P < 0.001$, $P < 0.05$) and between ($P < 0.001$, $P< 0.05$) experimental and control groups based on the BBS and POMA-balance respectively. Likewise, Llorens et al also used the BBS and POMA-balance. Within both groups, significant effect in the BBS ($P = 0.001$) and POMA-balance ($P = 0.006$) was observed, however, no significant improvement was detected from the final to the follow-up assessment in any of them, nor were there any significant differences between the groups (Llorens, Noe, Colomer, & Alcaniz, 2015). Lee et al observed a significant difference within both groups in BBS ($P = 0.000$) and TUG-cog ($P = 0.009$). The post hoc analysis revealed significantly improved BBS scores from the pre- to postintervention ($P = 0.000$) and follow-up test ($P = 0.003$). TUG-cog time had significantly decreased from the pre- to postintervention ($P = 0.003$) and follow-up test ($P = 0.006$). However, a nonsignificant time effect was observed in both the groups in the FRT ($P = 0.187$). Although both groups showed partial improvement in scores, no significant group-by-time interaction was observed in any scale (Lee, Huang, Ho, & Sung, 2017).

Treadmill based VR

Fishbein et al showed there to be a significant difference in BBS ($P < 0.001$) and FRT ($P < 0.05$) scores between the groups in favour of the experimental group from pre to post intervention, as well as pre intervention to follow up 4 weeks post intervention. However, no difference was observed between post intervention and follow up period (Fishbein, Hutzler, Ratmansky, Treger, & Dunsky, 2019). In the study by Cho et al, both groups showed significant differences between pre and post testing, however, the intervention group showed more improvements in both BBS score and TUG ($P < 0.05$). Furthermore, both groups demonstrated significant improvements in the BBS and TUG ($P = 0.000$), along with significant differences between both groups in the BBS and TUG ($P = 0.001$). However, there was no within or between differences in postural sway (Cho & Lee, 2014).

Other semi immersive VR interventions

Yom et al, (2015), observed significant improvement of the intervention group in TUG ($P < 0.05$), whereas the control group did not. Also, there was a significant difference in TUG between both groups in favour of the intervention ($P < 0.05$). In et al, (2016), recorded a significant difference in BBS, FRT and TUG within and between groups in favour of the intervention group ($P <0.05$). As for the control group, only a significant difference was observed within the group for BBS (P < 0.05). Llorens et al, (2014), found there to be a significant improvement in both groups with regards to the BBS (P < 0.01). However, the experimental group showed greater gains in comparison with the control group. With regards to the POMA-balance, the improvement was non-significant for both groups.

Quality of evidence

As each included article was either an RCT or CT, the PEDro scale was used to assess their methodological quality. 8 out of the 10 articles were scored between 6 and 8 on the PEDro scale, which is considered as 'good'. One article scored a 9, which is considered 'excellent', and one article scored a 5, which is considered 'fair' (Cashin & McAuley, 2020). Therefore 90% of the included articles in this literature review can be considered either good or excellent. The scoring of each individual article can be found in Appendix 1.

Summary of results

Below, is a summary of the results based off the aforementioned main outcomes.

Table 4. *Summary of Results*

Game-based VR interventions					
Study	Intervention group [mean (SD)]	Control group [mean (SD)]	Differences within groups (95% CI)	Difference between groups	Effect size (Cohens' d)
Marques-Sule et al.	**BBS (score)** Pre: 41.7 (10.2) Post: 47.0 (8.1)	**BBS (score)** Pre: 41.7 (10.6) Post: 40.5 (8.0)	IG = -5.3^ CG = 1.2	6.5*	d= 0.80
	POMA-balance (score) Pre: 12.6 (3.2) Post: 14.4 (2.2)	**POMA-balance (score)** Pre: 12.1 (4.4) Post: 11.9 (3.5)	IG= -1.8^ CG= 0.2	2.5*	d= 0.85
Anwar et al.	**BBS** Pre: 18.38 (5.19) Post: 36.62 (7.76)	**BBS** Pre: 19.68 (5.23) Post: 26.94 (6.46)	IG = 18.24^ CG = 7.26^	10.98^	d= 1.36
Llorens et al.	**BBS** Pre: 47.53 (3.85) Post: 51.20 (2.11) Follow up: 51.53 (2.07)	**BBS** Pre: 48.80 (5.01) Post: 51.07 (5.09) Follow up: 51.27 (5.12)	IG = 3.66^ CG = 2.26^ FUI = 0.33 FUC = 0.67	1.4	d= 0.03
	POMA-balance Pre: 14.53 (1.68) Post: 15.40 (0.82) Follow up: 15.47 (0.74)	**POMA-balance** Pre: 15.07 (1.10) Post:15.33 (0.72) Follow up: 15.53 (0.74)	IG = 0.86* CG = 0.26* FUI = 0.67 FUC = 0.20	0.6	d= 0.09
Park et al.	**BBS** Pre: 35.8 (8.61) Post: 50.0 (6.27)	**BBS** Pre: 37.3 (11.98) Post: 44.7 (7.47)	IG = 14.20* CG = 7.40*	6.80*	d= 0.76
Lee et al.	**BBS** Pre: 43.35 (6.23) Post: 46.19 (5.57) Follow up: 46.31 (5.80)	**BBS** Pre: 43.48 (6.62) Post: 45.71 (6.64) Follow up: 45.00 (5.06)	IG = 2.84^ CG = 2.23^ FUI = 0.12* FUC =-0.71	0.61	d= 0.08
	FRT (cm) Pre: 21.43 (7.62) Post: 22.63 (5.07) Follow up: 22.48 (5.87)	**FRT (cm)** Pre: 22.05 (8.27) Post: 21.84 (7.46) Follow up: 18.74 (5.88)	IG = 1.2 CG = -0.21 FUI = -0.15 FUC = -3.1	1.41	d= 0.12
	TUG-cog (seconds) Pre: 27.18 (14.90) Post: 24.15 (10.87) Follow up: 23.52 (10.96)	**TUG-cog (seconds)** Pre: 32.13 (24.63) Post: 28.48 (21.53) Follow up: 28.67 (18.73)	IG = -3.03* CG = -3.65* FUI =-0.63* FUC = 0.19	0.62	d= 0.25

Treadmill-based VR interventions					
Fishbein et al.	**BBS** Pre: 40.55 (6.04) Post: --- Follow up: --- **FRT** Pre: 20.64 (7.01) Post: --- Follow up: ---	**BBS** Pre: 43.18 (10.02) Post: --- Follow up: --- **FRT** Pre: 21.05 (7.07) Post: --- Follow up: ---	IG = x^ CG = x FUI = x^ FUC = x IG= x* CG = x FUI = x* FUC = x	x^ x^	η_p^2= 0.52 η_p^2= 0.27
Cho et al.	**BBS** Pre: 39.26 (4.13) Post: 42.60 (3.06) **TUG (seconds)** Pre: 22.43 (3.25) Post: 20.01 (2.78) **Postural sway (mm^2)** Pre: 20.29 (11.00) Post: 19.82 (11.05)	**BBS** Pre: 39.53 (5.69) Post: 41.06 (5.29) **TUG seconds)** Pre: 21.45 (4.78) Post: 20.29 (4.82) **Postural sway (mm^2)** Pre: 20.82 (10.50) Post: 20.68 (13.49)	IG = 3.34* CG = 1.53* IG = -2.42* CG = -1.16* IG = -0.47 CG = -0.14	1.81* 1.26* 0.33	d= 0.35 d= 0.071 d= 0.07
Other semi immersive VR interventions					
Llorens et al.	**BBS** Pre: 47.2 (6.7) Post:51.0 (4.6) **POMA-balance** Pre: 14.0 (3.0) Post: 15.2 (0.8)	**BBS** Pre: 44.4 (7.0) Post: 46.2 (5.7) **POMA-balance** Pre: 13.8 (1.7) Post: 13.2 (1.9)	IG = 3.8^ CG = 1.8^ IG = 1.2 CG = -0.6	2.0* 1.8	d= 0.9 d= 1.37
Yom et al.	**TUG** Pre: 24.59 (14.42) Post: 19.09 (12.73)	**TUG** Pre: 35.96 (16.50) Post:34.74 (16.20)	IG = -5.50* CG = -1.22	4.28*	d= 1.07
In et al.	**BBS** Pre: 45.46 (4.12) Post: 49.08 (2.72) **FRT (mm)** Pre: 194.16 (58.89) Post: 200.83 (58.83) **TUG** Pre: 21.82 (5.70) Post:18.01 (3.70)	**BBS** Pre: 44.75 (3.02) Post: 46.08 (2.97) **FRT (mm)** Pre: 197.10 (71.07) Post: 196.13 (70.90) **TUG** Pre: 20.39 (4.11) Post: 19.30 (3.72)	IG = 3.62* CG = 1.33* IG = 5.14* CG = -0.81 IG = -3.80* CG = -1.09	2.29* 5.95* 2.71*	d= 1.05 d= 0.07 d= 0.35

Abbreviations: SD – *standard deviation;* CI – *confidence interval;* IG – *intervention group;* CG – *control group;* BBS – *Berg Balance Scale;* FRT – *Functional Reach Test;* TUG – *Timed Up-and-Go;* POMA – *Performance Orientated Mobility Assessment (Tinetti Test);* VR – *Virtual Reality;* x – *results not provided by study*
*- significant when $P < 0.05$
^- significant when $P < 0.001$

Discussion

Interpretation of results

The aim of this literature review was to explore the effects of VR training on improving standing balance in chronic stroke patients. 10 RCT's were selected, all of which compared various types of VR intervention in combination with conventional physiotherapy, with a control group consisting of conventional physiotherapy only. Exceptions to this was Anwar et al, (2022), who used only VR as an intervention and conventional as a control; Fishbein et al, (2019), who used dual task treadmill walking with VR tool as an intervention and single task treadmill walking as a control; and Llorens et al, (2015), who used an intervention of in-home VR with conventional physiotherapy and in-clinic VR with conventional physiotherapy as a control. Generally, the included studies found the improvements in the intervention groups to be statistically significant, clinically effective and worth including in a rehabilitation program alongside conventional treatment. Moreover, each study observed significant improvements in at least one of the balance outcome measurements used.

With regards to the game-based VR interventions, the findings in this literature review are promising. Anwar et al, (2022), Marques-Sule et al, (2021), and Park et al, (2017), displayed between group differences in favour of the intervention, along with a high medium to large effect size. Llorens et al, (2015), and Lee et al, (2017), did not display this in any outcome measurement. Interestingly, they were the only two game-based VR studies that included a follow up measurement. A possible reason for the lack of significant difference and effect size in the study of Llorens et al could be due to the fact that both groups performed VR training and conventional physiotherapy, except in different environments. Improvements within both groups reveals that VR training can be effective both in a clinical setting and in the home. The lack of significant difference between groups and effect size in the study of Lee et al may be explained by the fact that the intervention was only administered twice a week. Park et al, (2017), performed a similar Xbox intervention daily and yielded significant improvements between groups ($P < 0.05$) and medium effect size ($d = 0.76$). This suggests that frequency may have a positive effect. Not only that, the chronicity of the stroke may have also affected this. Lee et al, (2017), had a population average of 27.99 months post stroke in the intervention group and 21.77 months post stroke in the control group. This level of chronicity is much greater than the majority of the other studies included in this review (average range of 13.15 months). This may suggest that VR intervention is more effective on stroke patients < 2 years post-stroke. However, this is unclear and requires further research.

From the two included studies from Fishbein et al, (2019), and Cho et al, (2014), treadmill-based VR training appears to yield positive results, however the consistency is still up for debate. Both showed statistically significant differences within and between both groups in favour of the intervention (with the exception of postural sway performed by Cho et al). However, its clinical effectiveness is divided. Fishbein et al observed a large effect size based on BBS and FRT (η_p^2= 0.52, η_p^2= 0.27 respectively), whereas Cho et al only observed a negligible (d= 0.071, d= 0.07 in TUG and Postural sway respectively) to small (d= 0.35 in BBS) effect. It is important to note that Fishbein et al did not provide mean and SD values for post intervention and follow up, therefore Cohens' d could not be calculated. Nevertheless, Partial Eta Squared (η_p^2) was the method Fishbein et al used to calculate effect size. It can be interpreted as follows: small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), and large ($\eta^2 = 0.14$) effects (Cohen, 1988). With reference to existing literature on treadmill-based VR, a pilot study by Cho et al, (2013), a direct precursor to the his RCT included in this review, similarly showed significant differences in BBS and TUG within both groups and between groups in favour of the intervention ($P < 0.05$). Interestingly, while the effect size on the TUG was also negligible ($d= 0.1$), the BBS showed a much larger effect size ($d= 1.5$) (Cho & Lee, 2013). Furthermore, a recent study involving treadmill-based VR training and chronic Traumatic Brain Injury (TBI) patients showed promising results on balance and mobility measures following a 4-week intervention (Tefertiller, 2022). Due to the fact that the neurological mechanism of a TBI differs from a stroke, they cannot be directly compared. It can, however, give a good idea of the interventions effects on CNS patients and should pave way for further research for treadmill-based VR interventions in the future.

Outcome measures that did not show a significant statistical difference between pre and post intervention include the POMA-balance (Llorens, Gil-Gomez, Alcaniz, Colomer, & Noe, 2014), Postural sway (Cho & Lee, 2014), and FRT (Lee, Huang, Ho, & Sung, 2017). However, in these 3 studies, every other outcome measure displayed significant differences. In the other studies, interestingly, the POMA and FRT showed significant differences. Llorens et al, (2014), suggested that the possible non significance of the POMA was due to the fact that 5 of the 20 participants had already reached the maximum value of the balance subscale in the initial assessment. With regards to the FRT, all other included studies that used this measurement, along with another study that focused on the effects of exergaming on chronic stroke patients, (Hung, et al., 2014), displayed improvements in measurements. Lee et al, (2017), proposed the reasoning for lack of significant results was due the similarities in movements (stepping and weight shifting) of both intervention and control groups. They also suggested the possibility of greater FRT improvements when using the Nintendo Wii as a VR intervention rather than the Xbox Kinect, as the Wii focuses more on static weight shifting on the Wii balance board, compared to the less restrictive Xbox Kinect. In other words, it is more specific to the FRT. Cho et al also proposed similar reasoning for postural sway in their research. The dynamic treadmill-based intervention may not translate to results in a static balance test (Cho & Lee, 2014).

Points of discussion

As mentioned above, the effects of VR intervention on static balance seem to be inconclusive. However, a study by Yang et al, (2011), which also utilised a dynamic treadmill-based VR intervention, showed significant differences in postural sway in the experimental group ($P = 0.046$). Likewise, a study by Kim et al, (2015), also used treadmill-based VR interventions on chronic stroke patients. Their results displayed significant differences in total postural sway within ($P < 0.05$) and between ($P < 0.01$) groups in favour of the VR intervention. That being said, a systematic review by Cano Porras et al, (2018), stated that VR had much greater effect on dynamic balance than static balance. Still, it is also important to consider that the BBS and POMA-balance measures both static and dynamic balance. The fact that the VR intervention group in each included study showed statistically significant improvements and generally a medium to large effect size based in both measurement tools, shows that both static and dynamic balance may have improved post intervention. However, this is difficult to ascertain based on the information that is supplied in each study. Further research is necessary to determine if dynamic balance interventions, such as the various forms of VR balance training, influence static balance measurements.

While the results generally showed a statistically significant improvement in favour of the intervention between pre and post intervention, little can be determined regarding this in the long term. Fishbein et al, (2019), Lee et al, (2017), and Llorens et al, (2015), all displayed no statistically significant differences between post and follow up measurements. However, there is evidence from those 3 studies to suggest that the improvements can be maintained 4 weeks (Fishbein, Hutzler, Ratmansky, Treger, & Dunsky, 2019; Llorens, Noe, Colomer, & Alcaniz, 2015), and 3 months (Lee, Huang, Ho, & Sung, 2017), post intervention. A systematic review by Lee et al, (2019), which looked at overall function including balance outcomes in chronic stroke patients, concluded that a VR intervention period should last at least 8 weeks to gain a long-term effect. Out of the 10 included articles in this review, the longest intervention period was 7 weeks (Llorens, Noe, Colomer, & Alcaniz, 2015). Based on this information, a recommendation could be made for a longer intervention period in order to yield more significant long-term results.

With regards to other Central Neurological Diseases (CND), the effects of VR training have also shown to be beneficial. A recent systematic review was performed on Stroke, Parkinson's and MS patients, where home-based VR training (Nintendo Wii & Xbox Kinect) was administered and balance was assessed using the BBS. Results found there to be "a significant improvement in BBS scores over time in both experimental and control groups ($P < 0.05$), and the effect remained at follow-up for both groups" (Truijen, et al., 2022). There was, however, no significant effects between groups ($P = 0.45$). Furthermore, the systematic review by Cano Porras et al, (2018), confirmed that VR rehabilitation, or its inclusion alongside conventional rehab, may have benefits on balance for patients with MS, TBI, Cerebral Palsy, but interestingly, more so in Parkinson's and both acute and chronic stroke. The included studies mainly used BBS and TUG as outcome measurements. The fact that the most significant improvements were observed in Parkinson's and stroke patients may be due to the fact that neural plasticity, elicited by an intervention such as VR, has greater effect on neurodegenerative diseases such as these (Dorszewska, Kozubski, Waleszczyk, Zabel, & Ong, 2020; Hao, Xie, Harp, Chen, & Siu, 2022). Conversely, this could perhaps explain why VR intervention is not superior to traditional physiotherapy interventions in improving balance and mobility post- TBI (Alashram, Padua, & Annino, 2022). To sum up, the results from this literature review largely agree with the reviews of Truijen et al and Cano Porras et al.

In relation to the cost and usability of the VR tools for patients at home, Llorens et al, (2015), accounted for both. Usability of the equipment was measured using the System Usability Scale (SUS) and the Intrinsic Motivation Inventory (IMI) for subjective experiences. Scores for both were high and no significant difference between the in-home VR group in-clinic VR group. This means patients found it easy to use, while also finding it enjoyable and motivating, regardless of location. With regards to cost, it was concluded that implementing in-home VR rehabilitation programs would be much more cost efficient, as much of the total cost of the in-clinic group was spent on transportation/commuting (87.77% or $1308.11) (Llorens, Noe, Colomer, & Alcaniz, 2015). Another study also supported this, by concluding that reducing contact time under supervision from the therapist and by not commuting to a clinic, can counterbalance the initial cost of equipment (Islam & Brunner, 2019). Potential exists for a future where, given adequate guidance and instruction, patients can carry out this training from their own home, saving money for both the patients and their respective clinics.

Strengths and limitations

In this Literature Review, there were multiple strengths and limitations that need to be factored in when reviewing the results.

The main strength was the methodological quality of the chosen articles. 8 out of the 10 included articles scored between 6 and 8 on the PEDro scale, rendering the articles as 'good' quality. 1 article scored a 9, meaning it had 'excellent' quality and 1 article scored 5, giving it a 'fair' quality. Every article was published within the past 10 years, meaning the information and interventions in each study was generally up to date. Furthermore, each study also made use of standardised balance assessment tools, measuring static and/or dynamic balance, making results easier to report and interpret across each study.

One limitation was generally a low sample size across the included studies. Every article, with the exception of Lee et al, (2017), and Anwar et al, (2022), had 30 or less participants. Low sample size can hinder results from being extrapolated, and also makes it difficult to achieve true statistical significance (Faber & Fonseca, 2014). With regards to population, 6 of the included studies were carried out in Asia (Korea x4, Pakistan and Taiwan). The remaining 4 were carried out in Europe (Spain x3 and Israel). The fact that 7 out of 10 studies were carried out between 2 countries, means that the results may not translate similarly to the broader population. Only two databases were used to attain articles. While PubMed and PEDro do provide high quality medical and physiotherapeutic related articles, there are still other databases available, which would have made the search strategy much more comprehensive in terms of selecting articles for screening. Finally, the review was written by only one researcher with little experience, therefore human error may have played a part during the method process or data interpretation. Additionally, no authors were contacted to retrieve any missing information from the included studies.

Conclusion

From the available literature, there is evidence to suggest that VR training can be beneficial with regards to improving balance in chronic stroke patients. When included in a general rehabilitation program, results have shown to have a medium to large clinical effect. Additionally, most of the current VR training for chronic stroke patients seems to be game-based, and is shown to be the most effective form of VR training based on this fact. Long term, intensive implementation of the intervention, e.g. for at least 8 weeks, may yield long term effects. It can also be concluded that VR training may improve dynamic balance more so than static balance, although as discussed, this is difficult to fully establish. VR intervention is effective both in-clinic and in-home, however, in home may be more cost efficient in the long term. Finally, it cannot be determined whether VR interventions are more or less effective depending on the patients age and chronicity of stroke.

Recommendation for future research

VR training is still in its pioneering stage, leaving much room for further high-quality research to be carried out. First, studies with larger sample sizes should be implemented, in order to achieve true statistical significance in the results. Second, more studies should include follow up measurements. Not only that, but longer intervention periods with scope for long term effects, as this is unclear within current literature. Third, a broad population should be trialled going forward, in terms of age groups, chronicity and severity of stroke, meaning outcomes will not be generalised. Fourth, more research should be executed to determine the extent of how VR training can improve solely static balance, as oftentimes it can become merged with dynamic balance measures in tests like the BBS and POMA-balance. More studies are required to analyse the long-term maintenance and cost of for both clinics and in-home setups. While current literature can deem this intervention as relatively low cost, it is wise to compile additional data in order to properly benefit the healthcare system in the long term. In addition, the possibility of including functional MRI scans should be explored. This would give an objective assessment of brain reorganisation pre and post intervention. However, its accessibility presents its own financial complications. Finally, where possible, more research should be carried out in different regions around the world, such as African, Oceanic, North American and South American countries. This will help discover the effect of VR training across a wider population, rather than in specific regions.

Acknowledgements

I would like to thank Hanze University of Applied Sciences for their support and guidance throughout my studies. More specifically, I want to express thanks to my supervisor of this graduation assignment, whose advice and counselling facilitated my learning during this period. Finally, I would like to give a special acknowledgement to my Grandmother, Mary O'Shea, who was a large part of the inspiration behind this research topic.

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Appendices

Appendix 1. *PEDro Scale*

Study	Marques-Sule et al.	Llorens et al.	Llorens et al.	Anwar et al.	Fishbein et al.	Park et al.	Yom et al.	In et al.	Lee et al.	Cho et al.
1. Eligibility criteria were specified	+	+	+	+	-	+	+	+	+	-
2. Subjects were randomly allocated to groups	+	+	+	+	+	+	+	+	+	+
3. Allocation was concealed	+	+	+	-	-	+	-	-	+	+
4. The groups were similar at baseline regarding the most important prognostic indicators	+	+	+	+	+	+	+	+	+	+
5. There was blinding for all subjects	+	-	-	-	-	-	-	-	-	-
6. There was blinding of all therapists who administered the therapy	-	-	-	-	-	-	-	-	-	-
7. There was blinding of all assessors who measured at least one key outcome	+	+	+	+	+	+	+	+	+	+
8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups	+	+	+	+	+	-	+	-	+	+
9. All subjects from who outcome measures were available received the treatment or control condition as allocated, or, where this not the case, data for at least one key outcome was analysed by "intention to treat)	+	+	+	-	-	-	-	-	-	-
10. The results of between-group statistical comparison are reported for at least one key outcome	+	+	+	+	+	+	+	+	+	+
11. The study provides both point measures and measures of variability for at least one key outcome.	+	+	+	+	+	+	+	+	+	+
Total	**9**	**8**	**8**	**6**	**6**	**6**	**6**	**5**	**7**	**7**

Appendix 2. *Data extraction*

Author, Year, Study design	Aim of study	population	Patient type	Intervention (EG and CG)	Outcome measure	Duration of intervention	Results	Outcomes	Follow up	Quality assessment (PEDro scale)
Marques-Sule et al. 2021 Single blind RCT	The aim of this study was to assess whether a virtual rehabilitation program using Nintendo Wii added to conventional physical therapy improved functionality, balance, and daily activities in chronic stroke survivors, when compared with conventional physical therapy.	N = 29 EG = 15 CG = 14	Chronic stroke	30-minute session of virtual reality with Nintendo Wii (VRWiiG), which included balance training with the Wii Balance Board and upper limb exercises with the Wii Sports package, added to conventional physical therapy. The CG only performed conventional physical therapy.	BBS POMA	2 sessions per week for 4 weeks	Regarding POMA and BBS, post hoc analysis showed within-group differences only in the VRWiiG ($P < .001$, $d = 0.76$; $P < .001$, $d = 0.57$, respectively) and between-group differences ($P < .012$, $d = 1.00$; $P < .042$, $d = 0.79$, respectively)	Results showed promising results in functionality, balance, and activities of daily living when adding virtual reality with Nintendo Wii to conventional physical therapy in chronic stroke survivors.	N/A	9/10
Llorens et al. 2015 Single blind RCT	To evaluate the clinical effectiveness of a virtual reality-based telerehabilitation program in the balance recovery of hemiparetic individuals' post-stroke in comparison to an in-clinic program	N = 30 EG = 15 CG = 15	Chronic stroke	Twenty 45-minute training sessions with the telerehabilitation system, in clinic (CG) or in-home setting (EG), with conventional physiotherapy administered to both groups in the clinic twice a week	BBS POMA (balance)	3 times a week for 7 weeks	Significant improvement in both groups from the initial to the final assessment in the Berg Balance Scale ($p=0.001$, $\eta^2_p = 0.68$), in the balance subscale of the POMA ($p=0.006$, $\eta^2_p = 0.24$). However, no significant	Virtual reality-based telerehabilitation interventions can promote the reacquisition of locomotor skills associated with balance in a similar way that in-clinic interventions, both complemented with a	Yes – 4 weeks post treatment	8/10

							differences between groups	conventional therapy program		
Llorens et al. 2014 RCT	To study the clinical effectiveness and the usability of a virtual reality-based intervention compared with conventional physical therapy in the balance recovery of individuals with chronic stroke.	N = 20 EG = 10 CG = 10	Chronic stroke	20 one-hour sessions. The experimental group combined 30minutes with the virtual reality-based intervention with 30minutes of conventional training. The control group underwent one-hour conventional therapy.	BBS POMA (balance)	5 sessions per week for 4 weeks	The results revealed a significant group-by-time interaction in the scores of the Berg Balance Scale ($p < 0.05$). Post-hoc analyses showed greater improvement in the experimental group: 3.8 ±2.6 vs. 1.8 ±1.4 in the Berg Balance Scale	Virtual reality interventions can be an effective resource to enhance the improvement of balance in individuals with chronic stroke.	N/A	8/10
Cho et al. 2014 RCT	The purpose of this study was to determine the role of treadmill training based real-world video recording (TRWVR) for balance and gait ability in chronic stroke patients.	N = 30 EG = 15 CG = 15	Chronic stroke	Both groups participated in a standard rehabilitation program, with each session lasting 30 minutes. In addition, the TRWVR group participated in TRWVR for 30 minutes	BBS TUG Postural sway	Three times per week for 6 weeks	Significant differences in the time factor for dynamic balance and gait ($P < 0.05$) were observed in the TRWVR and control group, with the exception of static balance. For the group time interaction, significant improvements in dynamic balance and gait ($P < 0.05$).	This study demonstrated that the real-world video recording has an effect on dynamic balance and gait in chronic stroke patients when added to treadmill walking.	N/A	7/10
Lee et al. 2017	The aim of this study was to investigate the effects of virtual reality (VR) balance training conducted using Kinect for	N = 47 EG = 26 CG =21	Chronic stroke	VR plus standard treatment group and standard treatment (ST) group. In total, 12 training sessions, 90 minutes a session. The	BBS FRT TUG-cog	Twice per week for 6 weeks	Both groups exhibited significant improvement over time in the BBS ($P = 0.000$) However,	VR balance training by using Kinect for Xbox games plus the traditional	Yes – 3 months post interventi on	7/10

Prospective RCT	Xbox games on patients with chronic stroke			VR group performed 45 mins VR training; 45 mins conventional. Whereas the control group received 90 mins conventional			no significant difference was observed within or between the groups	method had positive effects on the balance ability of patients with chronic stroke.		
Anwar et al. 2022 Single blind RCT	To compare the effects of VR training and routine physical therapy on balance and upper extremity sensorimotor function in patients with stroke.	N = 68 EG = 34 CG = 34	Chronic stroke	1-hour session of VR training. The control group received different stretching and strengthening exercises.	BBS	3 weekdays over 6 weeks	A significant difference between the two groups was found in the Berg Balance Scale score (*P*<.001)	VR training is helpful for improving balance. VR training can be a better option in a rehabilitation plan designed to increase functional capability.	N/A	6/10
Fishbein et al. 2019 Preliminary single blind RCT	To investigate the feasibility of using a Virtual Reality-based dual task of an upper extremity while treadmill walking, to improve gait and functional balance performance of chronic poststroke survivors.	N = 22 EG = 11 CG = 11	Chronic stroke	Participants were divided into 2 groups (each group performing an 8-session exercise program using virtual reality): the EG participated in dual-task walking (DTW). The CG participated in single-task treadmill walking (TMW)	BBS FRT	Twice a week for 4 weeks	Improvements were observed in balance variables: BBS, FRT (P < .01) favouring the DTW group	The results of this study demonstrate the potential of VR-based DTW to improve walking and balance in people after stroke; thus, it is suggested to combine training sessions that require the performance of multiple tasks at the same time.	Yes – 4 weeks post treatment	6/10

Park et al. 2017 Preliminary RCT	This study aimed to investigate the effects of VR training, using the Xbox Kinect-based game system, on the motor recovery of patients with chronic hemiplegic stroke.	N = 20 EG = 10 CG = 10	Chronic stroke	The intervention group participated in a 30-minute VR training session using Xbox Kinect, followed by a 30-minute session of conventional physical therapy. The control group participated in a 30-minute conventional physical therapy session only	BBS	Daily for 6 weeks	The scores on the BBS improved significantly from baseline to post intervention in both groups after training. The pre-to-post difference scores on BBS for the intervention group were significantly more improved than those for the control group ($P < .05$).	The present study supports the use of additional VR training with the Xbox Kinect gaming system as an effective therapeutic approach for improving motor function during stroke rehabilitation.	N/A	6/10
Yom et al. 2015 RCT	The purpose of this study was to investigate the therapeutic effects of virtual reality-based ankle exercise on the dynamic balance, muscle tone, and gait ability of stroke subjects.	N = 20 EG = 10 CG = 10	Chronic stroke	30-minute session of Virtual Reality-based Ankle Exercise. The control group watched a video for 30 mins	TUG	5 times per week over a 6-week period.	An improvement in dynamic balance was more significant in the EG (5.50±2.57) than in the CG (1.22±2.05). There were also significant differences found between the groups in post-test values ($p < 0.05$)	virtual reality-based ankle exercise effectively improves the dynamic balance ability of stroke patients.	N/A	6/10
In et al. 2016 RCT	The aim of this study was to investigate whether VRRT could improve the postural balance and gait ability of patients with chronic stroke.	N = 25 EG = 13 CG = 12	Chronic stroke	30-minute session of virtual reality reflection therapy, along with 30 minutes of conventional rehabilitation. The control group performed conventional rehabilitation program	BBS FRT TUG	5 times per week for 4 weeks	There were statistically significant improvements in the VRRT group compared with the control group for BBS, FRT, TUG. ($p<0.05$)	Applying VRRT (even as a home treatment) along with a conventional rehabilitation program for patients with chronic stroke might be even	N/A	5/10

				and a placebo VRRT program for the same time frame.				more beneficial than conventional rehabilitation program alone in improving affected lower limb function.		

Abbreviations: N/A – *not applicable;* RCT – *Randomised Controlled Trial;* VR – *Virtual Reality;* VRRT – *Virtual Reality Reflection Training;* N – *total number;* EG – *experimental group;* CG – *control group;* BBS – *Berg Balance Scale;* FRT – *Functional Reach Test;* TUG – *Timed Up-and-Go;* POMA – *Performance Orientated Mobility Assessment (Tinetti Test)*