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Virtual reality for stroke rehabilitation (Review)

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Virtual reality for stroke rehabilitation (Review)

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[Intervention Review]

Virtual reality for stroke rehabilitation

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ABSTRACT

Rationale

Virtual reality applications have emerged as a treatment approach in stroke rehabilitation, with the first randomised trial published in 2004. A wide range of applications have been tested in research studies and adopted in clinical practice, from non-immersive, non-customised, interactive game-based applications to immersive applications specifically designed for rehabilitation settings. This is an update of a Cochrane review first published in 2011 and then again in 2015 and 2017.

Objectives

Primary objective: to assess the effects of virtual reality compared with an alternative intervention or no intervention for upper limb function and activity in people after stroke.

Secondary objectives: to assess the effects of virtual reality compared with an alternative intervention or no intervention on gait and balance, global motor function, cognitive function, activity limitation, participation restriction and quality of life, and adverse events in people after stroke.

Search methods

We searched the Cochrane Stroke Group Trials Register, CENTRAL, MEDLINE, Embase, and four additional databases. We also searched trials registries up to September 2023.

Eligibility criteria

We included randomised trials in adults after stroke comparing virtual reality (an advanced form of human-computer interface that allows the user to 'interact' with a computer-generated environment in a naturalistic fashion) with alternative or usual care. We excluded studies that compared two different types of virtual reality without an alternative group and studies of participants with mixed aetiology (e.g. participants with acquired brain injury) unless data were available relating to people with stroke only.

Outcomes

The critical outcome of interest was upper limb function and activity. Important outcomes included mobility outcomes (gait speed, balance), global cognitive function, activity limitation, participation restriction and quality of life, and adverse events.

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Risk of bias

We used the Cochrane RoB 1 tool to assess risk of bias.

Synthesis methods

We conducted meta-analysis using a fixed-effect model to calculate the standardised mean difference (SMD) and 95% confidence intervals (CI) for the critical outcome. We assessed the certainty of the evidence using GRADE.

Included studies

We included 190 trials involving a total of 7188 participants, of which 119 studies are newly included in the current update. The majority of studies were small, with only 36 (19%) studies involving more than 50 participants, and the largest study recruiting 152 participants. Interventions varied in terms of both the goals of treatment and the virtual reality applications used. Control groups usually received the same amount of an alternative form of therapy. In many studies risk of bias was unclear due to poor reporting. Thus, while there is a very large number of randomised controlled trials included in the review, the evidence remains mostly low or moderate certainty when rated using the GRADE system.

Synthesis of results

When comparing virtual reality with alternative therapy approaches, results suggest that virtual reality may be beneficial in slightly improving upper limb function and activity (SMD 0.20, 95% CI 0.12 to 0.28; 67 studies, 2830 participants; low-certainty evidence). When compared with alternative therapy approaches, virtual reality may have little to no effect on gait speed, but the evidence is very uncertain (10 studies, 304 participants; very low-certainty evidence). Compared to alternative therapy approaches, virtual reality may be slightly beneficial for balance (SMD 0.26, 95% CI 0.12 to 0.40; 24 studies, 871 participants; low-certainty evidence) and probably reduces activity limitation (SMD 0.21, 95% CI 0.11 to 0.32; 33 studies, 1495 participants; moderate-certainty evidence). However, there may be little to no effect on participation and quality of life (SMD 0.11, 95% CI -0.02 to 0.24; 16 studies, 963 participants; low-certainty evidence).

The addition of virtual reality to usual care or rehabilitation (resulting in an increased amount of time spent in therapy for those in the intervention group) probably increases upper limb function and activity compared to usual care alone (SMD 0.42, 95% CI 0.26 to 0.58; 21 studies, 689 participants; moderate-certainty evidence). However, there may be no apparent benefit in gait speed, but the evidence is very uncertain (3 studies, 57 participants; very low-certainty evidence). Virtual reality in addition to usual care may be beneficial for balance (SMD 0.68, 95% CI 0.46 to 0.91; 12 studies, 321 participants; low-certainty evidence) and is probably beneficial for activity limitation (SMD 0.22, 95% CI 0.04 to 0.41; 15 studies, 513 participants; moderate-certainty evidence). The evidence suggests that virtual reality in addition to usual care may not have a beneficial effect on participation and quality of life (2 studies, 76 participants; low-certainty evidence).

Fifty-nine studies in this review reported that they monitored for adverse events; across these studies there were few adverse events, and those reported were relatively mild.

Authors' conclusions

We found moderate- to low-certainty evidence that the use of virtual reality and interactive video gaming is slightly more beneficial than alternative therapy approaches in improving upper limb function, balance, and activity limitation. Furthermore, greater benefits were seen for upper limb function when virtual reality was used in addition to usual care (to increase overall therapy time). There was mixed evidence on the effects on mobility outcomes including gait speed, and insufficient evidence to reach any conclusions about the effect of virtual reality and interactive video gaming on participation restriction and quality of life.

Funding

This Cochrane review had no dedicated funding.

Registration

Protocol: doi.org/10.1002/14651858.CD008349

Original review (2011): doi.org/10.1002/14651858.CD008349.pub2

Review update (2015): doi.org/10.1002/14651858.CD008349.pub3

Review update (2017): doi.org/10.1002/14651858.CD008349.pub4

PLAIN LANGUAGE SUMMARY

Virtual reality for stroke rehabilitation

Key messages

Virtual reality for stroke rehabilitation (Review)

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- Virtual reality may be slightly better than alternative therapy approaches in improving the ability to use one's arm. A very small number of people reported unwanted effects including pain, headaches, or feeling faint or dizzy.
- Virtual reality may be better than alternative therapy in terms of slightly improving balance, and probably reduces activity limitation.
- Very few studies included virtual reality applications that were considered immersive (for example, where the virtual environment was viewed through a head-mounted device).

What are the benefits of virtual reality compared with alternative therapy approaches or no therapy after stroke?

We wanted to compare the effects of virtual reality versus an alternative treatment or no treatment on recovery after stroke using arm function and other outcomes such as walking speed, cognitive function (thinking), independence, and quality of life after stroke.

What is virtual reality, and why might it be used to help stroke recovery?

Many people have difficulty moving, thinking, and sensing after a stroke. This often results in problems with everyday activities such as writing, walking, and driving. Virtual reality is a broad term used to describe the use of computer-based programs designed to mimic real-life objects and events. Virtual reality-based therapy may have some advantages over traditional therapy approaches, as the applications can allow people to practise everyday activities that are not or cannot be practised within the hospital or clinic environment. In addition, there are several features of virtual reality programmes that might get patients to spend more time in therapy, for example the activity might be more motivating.

What did we want to find out?

We wanted to know whether using virtual reality in stroke recovery programmes was more effective than traditional approaches to therapy. We wanted to understand the effects on various outcomes (including movement, cognition, and activity limitation). We were most interested in outcomes related to arm function, as this is the focus of most studies in this area. We also wanted to understand how we can use virtual reality most effectively (in terms of how much therapy to provide and when) and which types of virtual reality programmes might be most beneficial.

What did we do?

We searched for studies that compared virtual reality with either an alternative form of therapy (for example, traditional physical therapy approaches to improving strength and movement) or no therapy. We included studies that recruited adults at all stages of recovery following a stroke.

What did we find?

We identified 190 studies involving 7188 people after stroke. A wide range of virtual reality programmes were used; most aimed to improve either arm function or mobility (walking speed and balance).

- Sixty-seven trials looked at whether the use of virtual reality compared with alternative therapy resulted in improved ability to use one's arm, and found that the use of virtual reality may result in slightly improved function.
- People who use virtual reality (in comparison to alternative therapy approaches) may experience slight benefits in balance and probably experience benefits in activity limitation, but may not experience benefits in walking speed or quality of life.
- The addition of virtual reality to usual care or rehabilitation (resulting in an increased amount of time spent in therapy) probably increases arm functioning.
- Virtual reality may be most beneficial when people spend many hours using the programme.
- A small number of people using virtual reality reported pain, headaches, or feeling faint or dizzy. No serious unwanted effects were reported.

What are the limitations of the evidence?

There is now a large number of studies; however, the studies were generally small and not of high quality. Also, not all the studies provided information about everything we were interested in. As such, we have moderate to very low confidence in the evidence.

How up-to-date is this evidence?

The evidence is current to September 2023.

SUMMARY OF FINDINGS

Summary of findings 1. Virtual reality compared to alternative therapy approaches for stroke rehabilitation

Virtual reality compared to alternative therapy approaches for stroke rehabilitation

Patient or population: people receiving stroke rehabilitation

Settings: hospital, clinic, or home

Intervention: virtual reality

Comparison: alternative therapy approach

Outcomes*	Illustrative comparative risks** (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Control	Virtual reality				
Upper limb function (immediately after the intervention period)	Same amount of an alternative therapy approach	The mean upper limb function in the intervention groups was 0.20 standard deviations higher (0.12 to 0.28 higher).	-	2830 (67 studies)	⊕⊕⊕⊕ low ^{a,b}	SMD of 0.20 represents a small effect in favour of those receiving virtual reality intervention.
Gait speed (immediately after the intervention period (m/s))	Same amount of an alternative therapy approach	No benefit found of VR over alternative therapy.	-	304 (10 studies)	⊕⊕⊕⊕ very low ^{a,c,d}	No difference between groups (MD 0.05, 95% CI -0.02 to 0.13)
Balance (immediately after the intervention period)	Same amount of an alternative therapy approach	Balance in the intervention group was 0.26 standard deviations higher (0.12 to 0.40 higher).	-	871 (24 studies)	⊕⊕⊕⊕ low ^{a,b}	SMD of 0.26 represents a small effect in favour of those receiving virtual reality intervention.
Activity limitation (immediately after the intervention period)	Same amount of an alternative therapy approach	The outcome in the intervention groups was 0.21 standard deviations higher (0.11 to 0.32 higher).	-	1495 (33 studies)	⊕⊕⊕⊕ moderate ^a	SMD of 0.21 represents a small effect in favour of those receiving virtual reality intervention.
Participation restriction and quality of life	Same amount of an alternative therapy approach	No apparent benefit found of VR over alternative therapy.	-	963 (16 studies)	⊕⊕⊕⊕ low ^{a,b}	No apparent benefit (SMD 0.11, 95% CI -0.02 to 0.24). Other studies could not be pooled but reported consistent findings.

(immediately after the intervention period)	
Adverse events	There were few adverse events reported across studies, and those reported (transient dizziness, headache, pain) were relatively mild.

*All outcomes (except for gait speed) are composite in nature and were obtained by pooling different outcome measurement tools.

The basis for the **assumed risk (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **SMD:** standardised mean difference; **VR:** virtual reality

GRADE Working Group grades of evidence

High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.

Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of effect, but there is a possibility that it is substantially different.

Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.

Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

^aDowngraded by one level due to study limitations (one or more risk of bias domains were considered unclear in a number of studies in the analysis).

^bDowngraded by one level due to inconsistency in findings across studies (evident by the I² value being > 50% or confidence intervals which do not overlap).

^cDowngraded by one level due to indirectness (use of a surrogate outcome).

^dDowngraded by one level due to imprecision (small total population size included in analysis).

Summary of findings 2. Virtual reality plus usual care compared with usual care alone for stroke rehabilitation

Virtual reality plus usual care compared with usual care alone for stroke rehabilitation

Patient or population: people receiving stroke rehabilitation

Settings: hospital, clinic, or home

Intervention: virtual reality provided in addition to usual care

Comparison: usual care

Outcomes*	Illustrative comparative risks** (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				

	Control	Virtual reality in addition to usual care				
Upper limb function (immediately after the intervention period)	Usual care	The SMD in the intervention groups was 0.42 standard deviations higher (0.26 to 0.58).	-	689 (21 studies)	⊕⊕⊕⊖ moderate ^{b,e}	SMD of 0.42 represents a moderate effect in favour of providing virtual reality intervention in addition to usual care.
Gait speed (immediately after the intervention period (m/s))	Usual care	There was no mean difference in the intervention group, SMD 0.08 metres per second faster (-0.05 to 0.21).	-	57 (3 studies)	⊕⊕⊕⊖ very low ^{a,c,d}	No difference between groups (SMD 0.08, 95% CI -0.05 to 0.21)
Balance (immediately after the intervention period)	Usual care	The SMD in the intervention groups was 0.68 standard deviations higher (0.46 to 0.91).	-	321 (12 studies)	⊕⊕⊕⊖ low ^{a,d}	SMD of 0.68 represents a moderate effect in favour of providing virtual reality intervention in addition to usual care.
Activity limitation (immediately after the intervention period)	Usual care	The SMD in the intervention groups was 0.22 standard deviations higher (0.04 to 0.41).	-	513 (15 studies)	⊕⊕⊕⊖ moderate ^a	SMD of 0.22 represents a small effect in favour of virtual reality intervention.
Participation restriction and quality of life (immediately after the intervention period)	Usual care	There was no apparent difference between groups, SMD 0.22 (95% CI -0.24 to 0.67).	-	76 (2 studies)	⊕⊕⊕⊖ low ^{a,d}	No difference between groups (SMD 0.22, 95% CI -0.24 to 0.67)
Adverse events	There were few adverse events reported across studies, and those reported (transient dizziness, headache, pain) were relatively mild.					

*All outcomes (except for gait speed) are composite in nature and were obtained by pooling different outcome measurement tools.

The basis for the **assumed risk (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **SMD:** standardised mean difference

GRADE Working Group grades of evidence

High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.

Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of effect, but there is a possibility that it is substantially different.

Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.

Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

- ^aDowngraded by one level due to study limitations (one or more risk of bias domains were considered unclear in a number of studies in the analysis).
- ^bDowngraded by one level due to inconsistency in findings across studies (evident by the I^2 value being > 50% or confidence intervals which do not overlap).
- ^cDowngraded by one level due to indirectness (use of a surrogate outcome).
- ^dDowngraded by one level due to imprecision (small total population size included in analysis).
- ^eSensitivity analysis showed similar results when studies at risk of bias were omitted from the analysis.

BACKGROUND

Description of the condition

Stroke is one of the leading causes of death and disability globally. In 2021, it was the third most common cause of death (7.3 million) and the fourth most common cause of disability-adjusted life years [1]. Stroke has considerable economic consequences due to the associated healthcare costs, social care costs, and lost productivity [2]. The estimated direct (e.g. treatment and rehabilitation) and indirect (considering productivity loss) costs of stroke globally are in excess of USD 891 billion (891,000 million) annually [3]. The burden of stroke has increased over the last 20 years due to population growth, ageing, and limited effectiveness of disease prevention strategies [1]. Most stroke burden is in low- and middle-income countries [4], and increasingly impacts younger populations under 70, reflecting growing risk among middle-aged adults, especially in Southeast Asia and parts of Oceania [3]. The effects of a stroke may include sensory, motor, and cognitive impairment as well as a reduced ability to perform self-care and participate in social and community activities [5]. While most recovery is thought to be made in the first few weeks after stroke [6], patients may make improvements on functional tasks many months after having a stroke [7]. Many stroke survivors report long-term disability and reduced quality of life [8][9]; approximately 40% of survivors have moderate-to-severe disability, affecting independence in daily activities [10][11].

Description of the intervention and how it might work

Virtual reality is considered an umbrella term describing a range of different technology-based treatment approaches. Consensus around an agreed definition of virtual reality is lacking, although definitions most commonly include the terms 'computer', 'environment', 'user', and 'interactive' [12]. It is generally accepted that virtual reality is the use of "interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear and feel similar to real-world objects and events" [13].

In stroke rehabilitation settings, users usually move, hold, or touch objects in their interactions within the virtual environment. The user is provided with visual and often auditory and haptic feedback. Visual feedback may be presented on a computer or television screen, projection, or viewed while wearing a head-mounted device. Depending on the intervention and the virtual reality application, the user's level of physical activity may range from relatively inactive (e.g. using hand movements on a touchscreen) to highly active (e.g. challenging, full-body movements).

Virtual environments are often described in terms of their level of immersion and the sense of presence they create [14]. Immersive systems relate specifically to the hardware that is used to deliver the environment. Immersive environments allow the user to view the virtual environment in all directions; for example, the user wears a head-mounted display where the vision of the outside world is completely occluded. Non-immersive systems offer a limited field of view and include applications where the environment is presented on a single screen (e.g. a computer) [15]. The degree of immersion promotes but does not guarantee the degree of presence, which is the psychological experience of "feeling like you are in the environment" [16][14]. A number of factors are thought to influence presence including the technology

(realistic visual imagery, spatial audio), the user's personality and immersive tendencies, and the sense of control they have over their environment [17].

The use of virtual reality is becoming more widespread within the field of health care. Virtual reality is commonly used as a training tool for health professionals; for example, applications exist focused on training health professionals how to perform surgical procedures or enhance teamwork or clinical decision-making [18]. The ability to expose users to a highly controlled virtual environment that feels real means that virtual reality is also commonly used in the treatment of mental health conditions including treatment of anxiety and post-traumatic stress disorder [19]. Another big area of practice is pain management/therapy.

Virtual reality applications have become more sophisticated over time, and most studies included in the previous version of this review involved relatively simple software programs which were limited in both the level of immersion and degree of naturalistic interaction between the user and the environment. These programs often relied on 'gaming' features which helped to engage and motivate the person to participate. Highly immersive programs are increasingly being used due to the improved accessibility of head-mounted devices. The degree to which the environments feel naturalistic continues to improve.

Virtual reality in stroke rehabilitation may be advantageous as it offers several features, such as goal-oriented tasks and repetition, shown to be important in neurological rehabilitation [20, 21]. The enriched nature of the environment may also be beneficial, as much animal research has shown that training in enriched environments results in better problem-solving and performance of functional tasks than training in basic environments [22]. Virtual reality applications have been described as more interesting and enjoyable than usual rehabilitation activities by children and adults, thereby they may enhance motivation to participate, encouraging higher numbers of repetitions [23].

Evidence of neuroplasticity as a result of training in virtual reality is emerging. To date, studies have suggested that virtual reality may result in enhanced cortical connectivity, increased cortical mapping of affected limb muscles, increased activation of regions in the frontal cortex, and potential involvement of the mirror neuron system [24].

One major advantage of virtual reality applications, which has been underutilised to date, is that they allow clinicians to trial tasks that are unsafe to practise in the real world, such as crossing the street. In addition, some applications are designed to be used without supervision (e.g. at home), also meaning that an increased amount of therapy can be provided without increased staffing levels.

Why it is important to do this review

As technology use has become an integral part of daily living, and virtual reality applications are now widely used in clinical rehabilitation settings, it is important to evaluate if, when, and how virtual reality can be applied as an effective therapeutic intervention. Furthermore, therapeutic interventions that increase the amount of task-specific training without increasing staffing will be sought after.

There are now over 40 systematic reviews examining the benefits of virtual reality for stroke rehabilitation (e.g. [25]) or, more

specifically, commercial gaming devices for upper limb stroke rehabilitation [26]. Our initial review, published in 2011, identified 19 studies and a number of ongoing studies. An update published in 2015 resulted in the inclusion of more studies, bringing the total to 37 studies. An update published in 2017 included a total of 72 trials. The area is rapidly expanding, therefore an update of our review was warranted.

OBJECTIVES

Primary objective

To assess the effects of virtual reality compared with an alternative intervention or no intervention for upper limb function and activity in people after stroke.

Secondary objectives

To assess the effects of virtual reality compared with an alternative intervention or no intervention on gait and balance, global motor function, cognitive function, activity limitation, participation restriction and quality of life, and adverse events in people after stroke.

METHODS

Since publication of our protocol some of our methods have been updated; see [Supplementary material 7](#). We followed the Methodological Expectations of Cochrane Intervention Reviews (MECIR) [27] when conducting the review and PRISMA 2020 for the reporting [28].

Criteria for considering studies for this review

Types of studies

We included randomised controlled trials (RCTs). We did not include quasi-randomised trials. We looked for studies that compared virtual reality with either an alternative intervention or no intervention. We did not include studies that compared two different types of virtual reality without an alternative group. We included trials that evaluated any intensity and duration of virtual reality that exceeded a single treatment session.

Types of participants

The study participants had a diagnosis of stroke, defined by the World Health Organization as "a syndrome of rapidly developing symptoms and signs of focal, and at times global, loss of cerebral function lasting more than 24 hours or leading to death with no apparent cause other than that of vascular origin" [29], diagnosed by imaging or neurological examination. We included people who were 18 years and older with all types of stroke, all levels of severity, and at all stages poststroke, including those with subarachnoid haemorrhage. We excluded studies of participants with mixed aetiology (e.g. participants with acquired brain injury) unless data were available relating to people with stroke only.

Types of interventions

We included studies using virtual reality interventions that met the following definition: an advanced form of human-computer interface that allows the user to 'interact' with a computer-generated environment in a naturalistic fashion [30].

We included studies using any form of non-immersive or immersive virtual reality, including studies that used commercially available gaming consoles.

The comparison group received either an alternative intervention or no intervention. Given the broad range of alternative interventions, these included any activity designed to be therapeutic at the impairment, activity, or participation level that did not include the use of virtual reality.

Outcome measures

Critical and important outcomes were measured following intervention.

Critical outcomes

As one of the most common applications of virtual reality in stroke rehabilitation is upper limb rehabilitation, we selected upper limb function and activity as our critical outcome. Improving upper limb function is also reported as being of great importance to stroke survivors. We used a predefined hierarchy of outcome measurement tools for inclusion in meta-analysis.

1. Upper limb function and activity at the conclusion of the intervention period
 - a. Upper limb function and activity: Fugl Meyer Upper Extremity, Motor Assessment Scale (upper limb), Action Research Arm Test, Wolf Motor Function Test, Box and Block Test, Modified Motor Assessment Scale, Chedoke Arm and Hand Activity Inventory, UL Motricity Index, Jebsen Taylor Hand Function Test, Rancho Functional test UE, Stroke Upper Limb Capacity Scale (SULCS), Rancho Functional Test for the hemiplegic UE, Nine Hole Peg Test
 - b. Grip strength
 - c. Amount of use (self-reported): Motor Activity Log
 - d. Upper limb function and activity: short-term follow-up (one to six months after the end of the intervention period)

Important outcomes

1. Gait and balance
 - a. Mobility: gait speed
 - b. Mobility: Timed Up and Go test
 - c. Balance: Berg Balance Scale, Functional Reach Test, Forward Reach Test, Tinetti Performance Oriented Mobility Assessment, Brunel Balance Assessment, Four Step Square Test
 - d. Mobility: endurance
2. Global motor function: including assessments such as the Motor Assessment Scale
3. Cognitive function: Mini Mental State Examination, Montreal Cognitive Assessment, Trail Making Tests, Loewenstein Occupational Therapy Cognitive Assessment (LOTCA), Wechsler Memory Scale, Rey Complex Figure Test
4. Activity limitation: Functional Independence Measure (FIM), Barthel, Modified Barthel, Frenchay, Nottingham
5. Participation restriction and quality of life: SF-36, SF-12, Stroke-Specific Quality of Life Scale, Stroke Impact Scale, EQ-5D
6. Adverse events: including motion sickness, pain, injury, falls, and death

All important outcomes will be assessed at the conclusion of the intervention period.

Search methods for identification of studies

Search methods and strategies are presented in [Supplementary material 1](#). This update includes searches up to September 2023.

Electronic searches

We identified trials from the following electronic bibliographic databases:

- Cochrane Central Register of Controlled Trials (CENTRAL; 2023, Issue 8) in the Cochrane Library (searched 26 September 2023);
- MEDLINE (Ovid) (1950 to 26 September 2023);
- Embase (Ovid) (1980 to 26 September 2023);
- CINAHL (EBSCO) (1982 to 26 September 2023);
- PsycINFO (Ovid) (1840 to 26 September 2023);
- PsycBITE (now NeuroBITE) (neurorehab-evidence.com/) (2004 to 26 September 2023);
- COMPENDEX (1970 to 26 September 2023).

We searched the following ongoing trial registers on 26 September 2023:

- US National Institutes of Health Ongoing Trials Register ClinicalTrials.gov (www.clinicaltrials.gov);
- World Health Organization International Clinical Trials Registry Platform (WHO ICTRP) (apps.who.int/trialsearch/).

We searched all databases from their inception to September 2023 with no restrictions on language of publication.

Searching other resources

We used additional strategies (handsearching conference proceedings and contacting virtual reality manufacturers) in previous versions of this review that we did not continue to use in this review. We did not continue handsearching conference proceedings due to the publication of the majority of conference abstracts and the ability to find these in electronic databases. We did not contact manufacturers, as this method had not been beneficial in identifying research studies in previous versions of the review ([Supplementary material 8](#)). We searched the Cochrane Stroke Group Trials Register in previous versions of this review.

Data collection and analysis

Selection of studies

In this review update we used Cochrane's Screen4Me workflow to help assess the search results. The three components of Screen4Me are: known assessments (which match records in the search results to records that have already been screened in Cochrane Crowd and labelled as an RCT or not); the RCT classifier (a machine learning model that distinguishes RCTs from other study designs); and Cochrane Crowd (Cochrane's citizen science platform where the Crowd help to identify and describe health evidence). More information about Screen4Me and the evaluations that have been conducted can be found on the Cochrane Information Specialist's portal and in the published literature [31, 32, 33, 34].

Two review authors (KL and BL or MCh) independently reviewed the titles and abstracts identified as a result of the search to assess their potential relevance with respect to the predefined inclusion criteria. We obtained potentially relevant articles in full text; KL or MCh contacted study authors for more information as needed to determine study eligibility. KL and BL or SG or MCh then independently assessed the full-text articles and correspondence with investigators to determine study eligibility. JD made the final decision on studies in the case of disagreement. We documented the reasons for the exclusion of studies. Where studies published in non-English languages appeared relevant, we sought the full text of the study and used translation software to determine whether the study met the inclusion criteria. Where an author on our team was also an author on an included study, they did not make study eligibility decisions about, extract data from, or perform risk of bias or GRADE assessments for that study.

Data extraction and management

Two review authors (KL and SG, JD, GS, MCh, or MC) independently extracted data for each selected study. Data extracted included citation details, trial setting, inclusion and exclusion criteria, study population, participant flow, intervention details, outcome measures and results, and methodological quality. We resolved any disagreements by discussion or by referral to a third review author (BL) as necessary. The review authors contacted study authors by email to request any missing information (e.g. information about risk of bias) or data necessary for the review.

Risk of bias assessment in included studies

Two review authors (KL and SG, JD, GS, MC, or MCh) used Cochrane's RoB 1 tool to independently assess the methodological quality of the included studies ([Supplementary material 6](#); [35]). The tool covers the domains of sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, incomplete outcome data, selective reporting, and other bias. We classified the domains as at low, high, or unclear risk of bias. We contacted the authors of the included studies for more information to assess risk of bias as needed. We resolved any disagreements with help from a third review author (BL).

Measures of treatment effect

Two review authors (KL and SG, JD, GS, MCh, or MC) independently classified outcome measures in terms of the domain assessed (upper limb function and activity, gait and balance, global motor function, cognitive function, activity limitation, participation restriction and quality of life, and adverse events). When a study presented more than one outcome measure for the same domain, we used a predetermined hierarchy to decide which measure to use in the analysis. The hierarchy was determined based on how commonly and widely accepted outcome measures were and agreed upon by all authors. We planned to calculate risk ratios (RR) with 95% confidence intervals (CIs) for any dichotomous outcomes, if recorded. We calculated mean differences (MD) or standardised mean differences (SMD) for continuous outcomes as appropriate.

Unit of analysis issues

The unit of randomisation was the individual participant. We did not include any cluster-RCTs. Seventeen studies were three-armed trials. We used the approach of splitting the 'shared' group into two or more groups with smaller sample size and including two

(reasonably independent) comparisons (as described in part 16.5.4 of the *Cochrane Handbook for Systematic Reviews of Interventions* [36]).

Dealing with missing data

We contacted study authors to obtain any missing data and converted available data when possible (e.g. we converted gait speed reported as metres per minute to metres per second (Jaffe 2004 [37])). We used the actual denominator of the participants contributing the data.

Reporting bias assessment

Our search of clinical trials registers assisted in reducing publication bias. We also investigated selective outcome reporting through the comparison of the methods section of papers with the results reported and by contacting study authors to check whether additional outcomes had been collected.

Synthesis methods

Where there were acceptable levels of heterogeneity, we pooled results to present an overall estimate of the treatment effect. We used the fixed-effect model with 95% CI using RevMan [38]. We used a random-effects model as part of a sensitivity analysis in the presence of heterogeneity [39]. Where meta-analysis was not appropriate due to unacceptable heterogeneity, we presented a narrative summary of study results. We assessed heterogeneity by visual inspection of the forest plot. We quantified inconsistency among studies using the I^2 statistic [40], considering an I^2 value greater than 50% as substantial heterogeneity. We pooled outcomes measured with different instruments using the SMD. We interpreted SMDs of 0.2 to 0.5 as small, 0.5 to 0.8 as medium, and > 0.8 as large [41].

Investigation of heterogeneity and subgroup analysis

We attempted to perform subgroup analyses to determine whether outcomes varied according to age, severity of stroke, time since onset of stroke, amount of therapy (total hours of therapy), and type of intervention (customised programme designed for rehabilitation versus non-customised programme (e.g. commercial gaming console)). However, not all of these analyses were possible due to the homogeneity of trial participants. We were able to undertake subgroup analysis in some cases for:

- amount of therapy (for upper limb function we compared less than 15 hours' intervention with more than 15 hours' intervention, and for lower limb function we compared less than 10 hours' intervention with more than 10 hours' intervention). We selected the amounts of 10 and 15 hours based on our examination of the included studies and their characteristics, choosing a threshold that appeared to separate the studies approximately in half (to enable comparisons of higher- and lower-amount treatments);
- time since onset of stroke (less than or more than six months);
- type of intervention (customised programme designed for rehabilitation or non-customised programme (e.g. commercial gaming console with commercial games used))

In this review update we performed a new subgroup analysis where we explored differences in effects based on the level of immersion offered by the virtual reality application. Virtual reality

was considered immersive if the user could view virtual content in all directions (for example, while using a head-mounted device). Virtual reality was considered non-immersive if this was not possible.

Equity-related assessment

We did not investigate equity-related characteristics in this review. We note that virtual reality intervention as part of stroke rehabilitation seems to be more available in upper-middle-income and high-income countries.

Sensitivity analysis

We performed sensitivity analyses to determine whether there was a difference in using a fixed-effect model versus a random-effects model. We conducted sensitivity analyses where possible to explore the effects of the methodological quality of the included studies on overall effect.

Certainty of the evidence assessment

We employed GRADE to interpret findings [42] and used GRADEpro GDT to create summary of findings tables [43]. Two review authors (KL and SG) performed assessments of the certainty of evidence, with any disagreements resolved through discussion. The summary of findings tables provide outcome-specific information concerning the overall certainty of evidence from studies included in the comparisons, the magnitude of effect of the intervention, and the sum of available data on the outcomes considered. When using GRADE, we downgraded the evidence from 'high certainty' by one level for serious (or by two for very serious) study limitations (risk of bias), indirectness of evidence, serious inconsistency, imprecision of effect estimates, or potential publication bias.

We generated summary of findings tables that evaluated the overall certainty of the body of evidence for the main review outcomes (upper limb function, gait speed, balance, activity limitation, participation restriction and quality of life, and adverse events), using GRADE criteria (study limitations (i.e. risk of bias), consistency of effect, imprecision, indirectness, and publication bias). We described, documented, and considered judgements about the certainty of the evidence (high, moderate, low, or very low) in our reporting of the results.

We produced two summary of findings tables.

- Virtual reality compared to alternative therapy for stroke rehabilitation
- Virtual reality plus usual care compared with usual care alone for stroke rehabilitation

Consumer involvement

Consumers were not involved in the conduct of this review, as our methods were established in 2010 [44], a time when consumer involvement and participation in systematic reviews was rare. However, this review has benefited from consumer perspectives in both previous versions and the current version through the editorial process. Furthermore, our summary of findings tables present outcomes that have been shown to be important to consumers [45].

RESULTS

Description of studies

Results of the search

In the previous version of this review we searched up until April 2017 and screened 11,940 records, of which 72 studies were included. One of these studies was excluded from this update as it was quasi-randomised, resulting in 71 studies from the previous review being included in this update.

In this update, we searched databases in May 2021 and identified 10,163 records through database searching and 321 records

through other searches including the trial registries. We then used Screen4Me methods to update our search in September 2023, which identified a further 4989 records ([Figure 1](#)). Of the 15,473 records screened, a total of 529 articles were reviewed in full text. We grouped articles reporting the same study. We removed articles that did not meet the inclusion criteria, such as studies that used interventions that were not considered virtual reality and non-RCTs. We included 119 new studies, resulting in a total of 190 studies. Details on excluded studies that were closest to meeting the inclusion criteria but did not are provided in [Supplementary material 3](#). The screening process is presented in [Figure 2](#).

Figure 1. Screen4Me summary diagram.

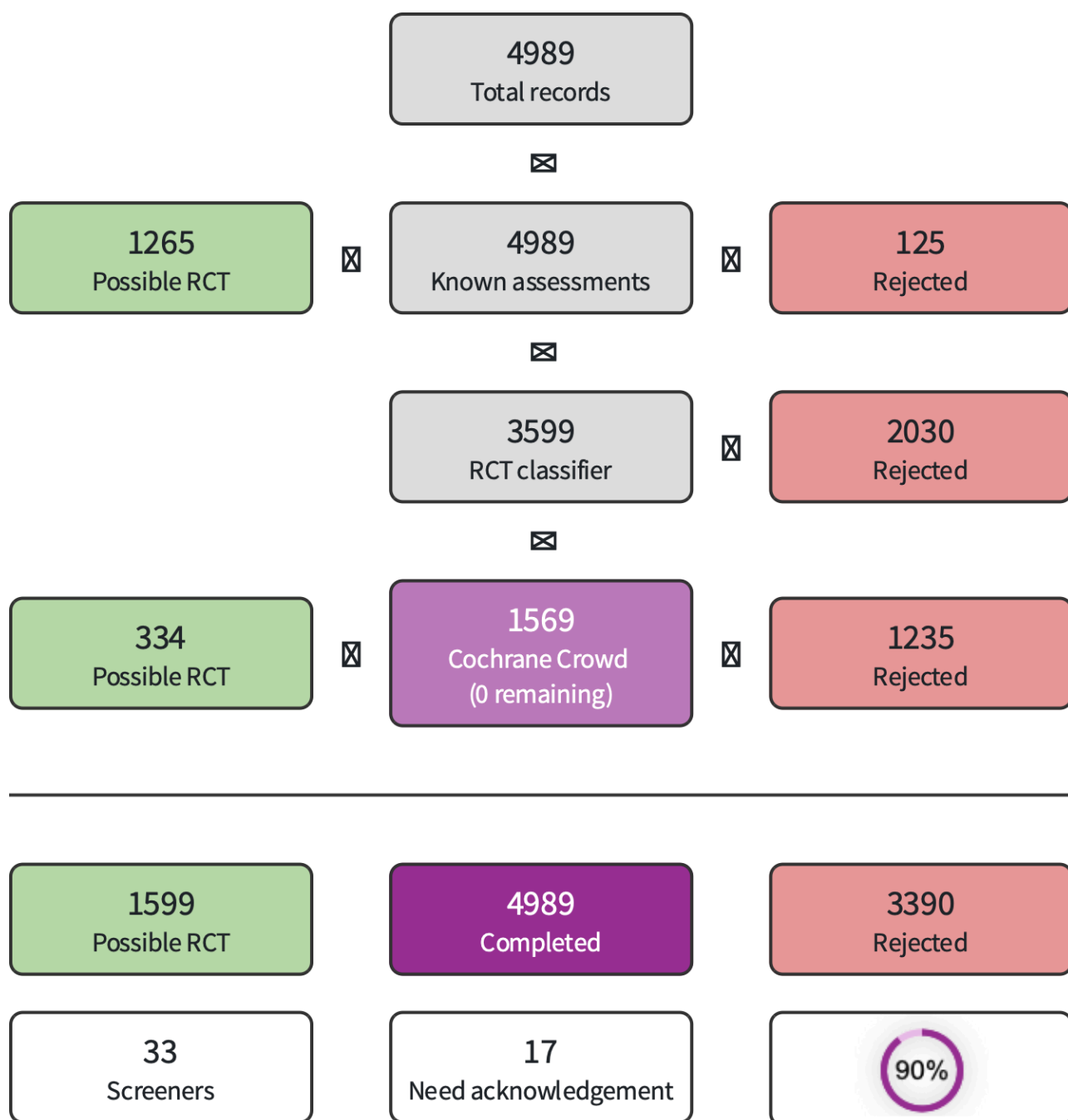


Figure 2. PRISMA flow diagram.

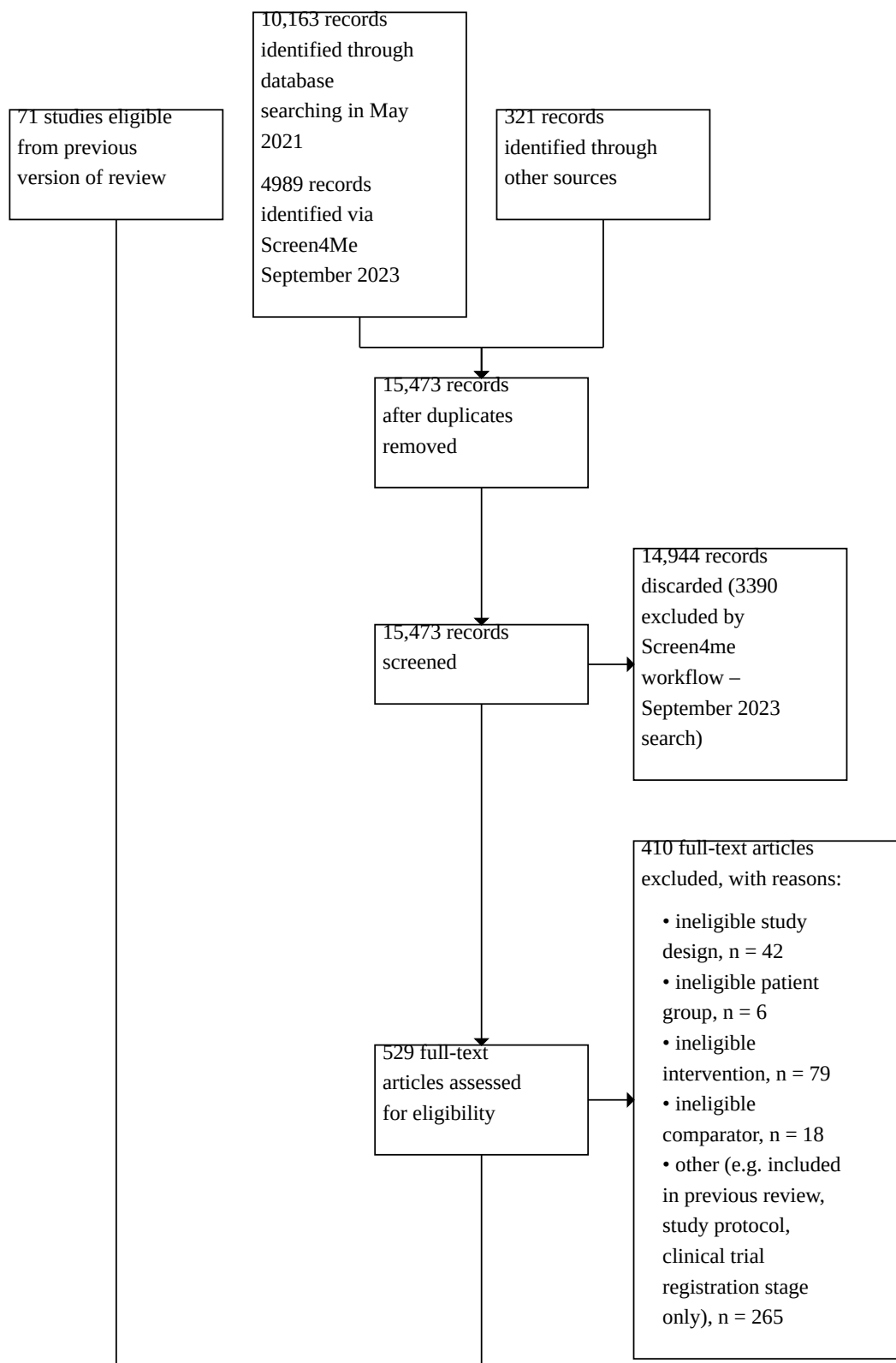
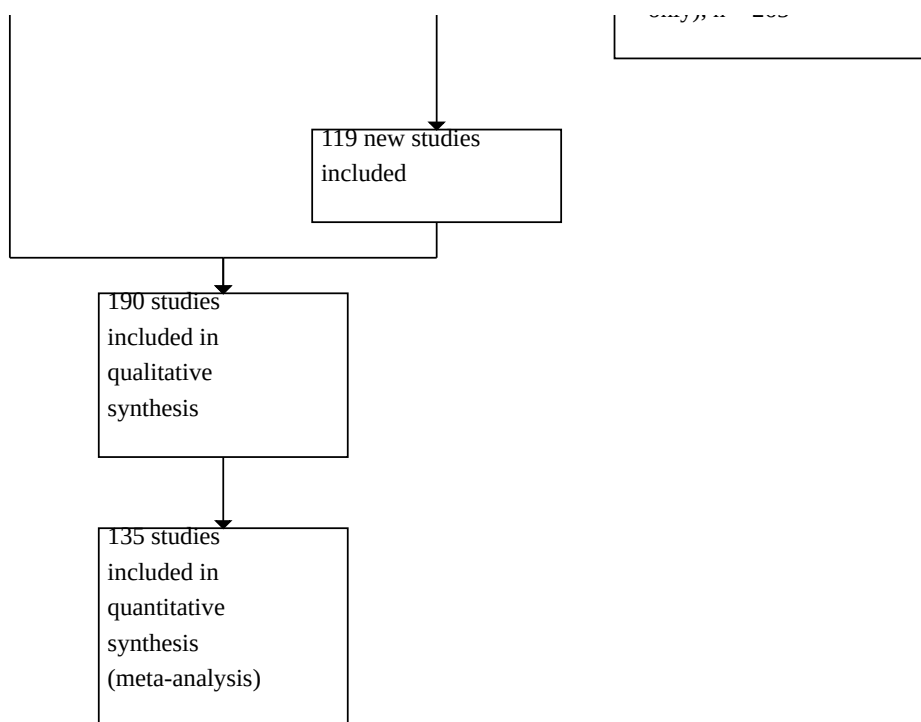


Figure 2. (Continued)



Included studies

One hundred and ninety RCTs with a total of 7188 participants met the inclusion criteria; these are summarised in [Supplementary material 2](#) (Adams 2023 [46]; Adie 2017 [47]; Afsar 2018 [48]; Ain 2021 [49]; Akinci 2023 [50]; Akinwuntan 2005 [51, 52, 53, 54]; Ali 2022 [55]; Allegue 2023 [56]; Alves 2018 [57]; Anjum 2021 [58]; Anwar 2022 [59, 60]; Arshad 2022 [61]; Askin 2018 [62]; Aslam 2021 [63]; Assadi 2016 [64]; Bai 2022 [65]; Ballester 2017 [66]; Bang 2016 [67]; Barcala 2013 [68]; Bergmann 2018 [69]; Bian 2022 [70]; Bower 2015 [71]; Brunner 2017 [72, 73, 74]; Byl 2013 [75]; Calabro 2017 [76]; Cannell 2018 [77, 78]; Cano-Manas 2020 [79]; Chen 2021 [80]; Chen 2022 [81]; Cho 2012 [82]; Cho 2019 [83]; Cho 2021 [84]; Choi 2014 [85]; Choi 2017 [86]; Choi 2021 [87]; Chow 2013 [88]; Cikajlo 2020 [89]; Cinakli 2024 [90]; Coupar 2012 [91]; Crosbie 2008 [92, 93]; da Silva Cameirao 2011 [94]; da Silva Ribeiro 2015 [95, 96]; De Luca 2018 [97]; De Luca 2023 [98]; de Rooij 2021 [99]; de Souza Filho 2020 [100]; Deutsch 2017 [101]; Dhanusia 2023 [102]; El Kafy 2022 [103]; El-Kafy 2021 [104]; Esquenazi 2021 [105]; Fan 2014 [106]; Faria 2016 [107]; Faria 2018 [108]; Faria 2020 [109]; Fishbein 2019 [110]; Galvao 2015 [111]; Gamito 2017 [112]; Giachero 2020 [113]; Givon 2016 [114, 115]; Grechuta 2019 [116]; Gueye 2021 [117]; Guo 2023 [118]; Han 2013 [119]; Hegazy 2022 [120]; Henrique 2019 [121]; Heo 2016 [122]; Hernandez 2022 [123]; Housman 2009 [124]; Huang 2022 [125]; Hung 2014 [126]; Hung 2017 [127]; Hung 2019 [128]; Jaffe 2004; Jang 2005 [129]; Jannink 2008 [130]; Johnson 2020 [131]; Jung 2012 [132]; Junior 2019 [133]; Kang 2009 [134]; Kaur 2020 [135]; Kayabinar 2021 [136]; Kim 2009 [137]; Kim 2011a [138]; Kim 2011b [139]; Kim 2012a [140]; Kim 2018a [141]; Kim 2018b [142]; Kiper 2011 [143]; Kiper 2018 [144]; Kiper 2022 [145]; Klamroth-Marganska 2014 [146]; Ko 2015 [147]; Kong 2014 [148, 149, 150]; Kong 2016 [151]; Kottink 2014 [152]; Kuo 2023 [153]; Kwon 2012 [154]; Lam

2006 [155]; Lee 2013 [156]; Lee 2014a [157]; Lee 2015a [158]; Lee 2015b [159, 160]; Lee 2016a [161]; Lee 2016b [162]; Lee 2017a [163]; Lee 2017b [164]; Lee 2018 [165]; Lee 2019 [166]; Lee 2020 [167]; Leng 2022 [168]; Levin 2012 [169]; Lin 2020 [170]; Lin 2021 [171]; Linder 2015 [172]; Liu 2023 [173]; Llorens 2015 [174]; Long 2020 [175]; Low 2012 [176]; Luo 2023 [177]; Maggio 2021 [178]; Maier 2020 [179]; Malik 2017 [180]; Malik 2021 [181]; Manlapaz 2010 [182, 183]; Manuli 2020 [184]; Mao 2015 [185]; Marques-Sule 2021 [186]; Marshall 2020 [187]; Matsuo 2013 [188]; Mazer 2005 [189, 190]; McNulty 2015 [191, 192]; Mekbib 2021 [193]; Miclaus 2020 [194]; Miranda 2019 [195]; Mirelman 2008 [196, 197]; Morone 2014 [198]; Nara 2015 [199]; Norouzi-Gheidari 2019 [200]; Ogun 2019 [201]; Oh 2019 [202]; Park 2018 [203]; Park 2021 [204]; Pedreira da Fonseca 2017 [205]; Pelaez-Velez 2023 [206]; Piron 2007 [207]; Piron 2009 [208]; Piron 2010 [209]; Prange 2015 [210]; Rajaratnam 2013 [211]; Rand 2017 [212, 213]; Reinkensmeyer 2012 [214]; Rodríguez-Hernández 2021 [215, 216]; Rodríguez-Hernandez 2023 [217]; Sana 2023 [218]; Saposnik 2010 [219]; Saposnik 2016 [220]; Schuster-Amft 2018 [221]; Shin 2014 [222]; Shin 2015 [223, 224]; Shin 2022 [225]; Simsek 2016 [226]; Sin 2013 [227]; Song 2014 [228]; Song 2015 [229]; Song 2021 [230]; Standen 2017 [231, 232]; Stockley 2017 [233]; Subramanian 2013 [234]; Sultan 2023 [235]; Térémetz 2022 [236]; Thielbar 2014 [237]; Tramontano 2020 [238]; Turkbey 2017 [239]; Ucar 2014 [240]; Utkan Karasu 2018 [241]; Velmurugan 2023 [242]; Wang 2017 [243]; Xiang 2014 [244]; Xiang 2022 [245]; Xie 2021 [246]; Xu 2021 [247]; Yaman 2022 [248]; Yang 2008 [249]; Yang 2011 [250]; Yavuzer 2008 [251]; Yin 2014 [252]; You 2005 [253]; Zhang 2017 [254]; Zucconi 2012 [255]).

Of the 190 included studies, we included 19 (with 565 participants) in the original version of the review, 18 new studies (with 454 participants) in the 2015 update, 35 new studies (with 1451

participants) in the 2017 update, and 119 new studies (with 4740 participants) in the current review.

Sample characteristics

All trials took place from 2004 onwards. All but five were published in English (de Souza Filho 2020; Galvao 2015; Heo 2016; Xiang 2014; Xiang 2022). Only 36 (19%) studies involved more than 50 participants. A total of 7188 participants poststroke were included in the trials.

All studies except for three (Akinci 2023; Ucar 2014; Utkan Karasu 2018) reported that they included both men and women. Although not always clearly reported, it appears that participants in the included studies were relatively young, with all studies reporting the average age of participants ranging from 34 to 75 years.

Across studies, recruitment ranged from the acute to chronic stages following stroke. Recruitment timeframes for each of the studies focused on upper limb training (critical outcome of interest) are presented in [Table 1](#).

Several trials excluded people who were deemed medically unstable, though how this was determined was often unclear. Many trials specified that people with a history of epilepsy or seizures would be excluded (Afsar 2018; Akinwuntan 2005; Assadi 2016; Cano-Manas 2020; Choi 2014; Fan 2014; Givon 2016; Kim 2012a; Kong 2016; Lee 2018; Mazer 2005; Pedreira da Fonseca 2017; Rand 2017; Saposnik 2010; Saposnik 2016; Sin 2013; Térémetz 2022; Turkbey 2017; Ucar 2014; Yin 2014; Zhang 2017). Most studies reported that people with significant cognitive impairment would be excluded; however, this criterion was often poorly defined. Several studies listed the presence of aphasia, apraxia, and visual impairment as exclusion criteria.

Interventions

Intervention approaches

Four main intervention approaches were used: upper limb training (92 trials), lower limb, balance, and gait training (59 trials), global motor function training (15 trials), and cognitive and/or communication training (17 trials).

Sixty-six (35%) of the studies used commercially available gaming consoles: one study used the Playstation EyeToy; 40 studies used the Nintendo Wii; and 22 studies used the Microsoft Kinect. Five studies used a mix of gaming consoles (Assadi 2016; Bian 2022; Bower 2015; Givon 2016; Rand 2017). Nine studies used GestureTek IREX. Five studies used the Armeo (Coupar 2012; El Kafy 2022; El-Kafy 2021; Esquenazi 2021; Gueye 2021); one used the CAREN system (Subramanian 2013); and six used the Lokomat (Bergmann 2018; Calabro 2017; Maggio 2021; Manuli 2020; Park 2018; Ucar 2014). The remaining studies used customised virtual reality programmes which are not commercially available.

Setting

The majority of interventions were delivered in either an inpatient or outpatient setting, although 15 of the studies delivered the intervention in the participant's own home (Adie 2017; Afsar 2018; Ain 2021; Ballester 2017; Linder 2015; Marshall 2020; McNulty 2015; Piron 2009; Rand 2017; Standen 2017; Thielbar 2014; Adams 2023; Allegue 2023; Hernandez 2022; Huang 2022).

Amount of therapy provided

The total amount of therapy provided varied between studies. Characteristics of the studies focused on upper limb training are presented in [Table 1](#).

Comparison interventions

Most of the trials compared virtual reality intervention with a comparable alternative intervention. The alternative intervention was often described as therapy using an alternative approach such as traditional exercises to build strength and co-ordination. Thirty-seven studies compared the effect of virtual reality with usual care (where the control group received either no intervention or usual care), thus there was a discrepancy in the amount of therapy received between the intervention and control groups (Afsar 2018; Alves 2018; Barcala 2013; Bower 2015; Cho 2012; Gamito 2017; Jang 2005; Johnson 2020; Kim 2011a; Kim 2012a; Kong 2014; Kong 2016; Kwon 2012; Lee 2013; Lee 2014a; Lin 2020; Long 2020; Low 2012; Marques-Sule 2021; Marshall 2020; Matsuo 2013; Mazer 2005; Norouzi-Gheidari 2019; Shin 2014; Sin 2013; Standen 2017; Ucar 2014; Xu 2021; You 2005; Adams 2023; Akinci 2023; Bai 2022; Cinakli 2024; Malik 2021; Park 2021; Pelaez-Velez 2023; Xiang 2022). Details of three-armed studies related to the critical outcome of interest are presented in [Table 1](#).

Outcomes

As a result of the diverse intervention approaches, a wide range of outcome measures were used. Due to the heterogeneity of outcome measures, we were unable to include all of them in the analyses. Few studies involved longer-term follow-up.

Excluded studies

We have provided details of excluded studies. We listed studies as excluded if they were obtained in full text and required discussion between authors to confirm exclusion ([Supplementary material 3](#)). Common reasons for exclusion were: studies compared different forms of virtual reality, or the interaction between the virtual environment and the user was not genuine (e.g. the person walked on a treadmill while viewing a virtual environment, but there was no interaction between the user and the environment, and changes in speed of walking in the user did not impact on movement in the virtual world).

Risk of bias in included studies

Refer to [Figure 3](#) and [Figure 4](#).

Figure 3. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of outcome assessment (detection bias): All outcomes	Incomplete outcome data (attrition bias): All outcomes	Selective reporting (reporting bias)	Blinding of participants and personnel (performance bias)
Adams 2023	+	+	+	+	+	-
Adie 2017	+	+	+	+	+	-
Afsar 2018	+	?	+	+	?	-
Ain 2021	+	?	+	+	-	-
Akinci 2023	+	+	+	+	+	-
Akinwuntan 2005	+	+	+	+	+	-
Ali 2022	?	?	?	?	?	-
Allegue 2023	+	+	+	-	+	-
Alves 2018	?	+	+	-	?	-
Anjum 2021	+	?	?	?	?	-
Anwar 2022	+	?	+	-	+	-
Arshad 2022	+	+	+	+	?	-
Askin 2018	+	?	+	+	?	-
Aslam 2021	?	?	+	?	?	-
Assadi 2016	?	?	+	+	?	-
Bai 2022	?	?	?	?	?	-
Ballester 2017	?	?	-	?	-	-
Bang 2016	?	?	?	?	?	-
Barcala 2013	+	+	+	+	?	-
Bergmann 2019	+	+	+	-	-	-

Figure 3. (Continued)

Barcala 2013	+	+	+	+	?	-
Bergmann 2018	+	+	+	-	-	-
Bian 2022	+	+	+	-	+	-
Bower 2015	+	+	+	+	+	-
Brunner 2017	+	+	+	-	+	-
Byl 2013	+	+	+	+	+	-
Calabro 2017	?	?	+	+	+	-
Cannell 2018	+	+	+	+	+	-
Cano-Manas 2020	+	?	+	-	+	-
Chen 2021	?	?	?	+	+	-
Chen 2022	+	?	+	+	?	-
Cho 2012	+	?	?	-	?	-
Cho 2019	+	?	?	+	?	-
Cho 2021	?	?	+	+	?	-
Choi 2014	?	?	+	+	?	-
Choi 2017	?	+	+	+	?	-
Choi 2021	?	+	+	+	?	-
Chow 2013	?	?	?	?	?	-
Cikajlo 2020	+	+	-	+	+	-
Cinakli 2024	?	+	+	+	?	-
Coupar 2012	+	+	+	+	+	-
Crosbie 2008	+	+	+	+	+	-
da Silva Cameirao 2011	+	+	+	-	+	-
da Silva Ribeiro 2015	+	?	+	?	?	-
De Luca 2018	+	?	?	?	?	-
De Luca 2023	?	?	?	?	?	-
de Rooij 2021	?	+	+	+	+	-
de Souza Filho 2020	+	+	+	-	?	-
Deutsch 2017	?	?	+	+	?	-
Dhanusia 2023	?	?	?	?	?	-
El-Kafy 2021	+	?	+	+	+	-
El Kafy 2022	+	+	+	+	+	-
Esquenazi 2021	+	+	+	-	?	-
Fan 2014	+	?	+	-	?	-
Faria 2016	+	+	-	+	?	-
Faria 2018	+	+	-	+	?	-

Figure 3. (Continued)

Faria 2018	+	+	-	+	?	-
Faria 2020	+	?	-	-	?	-
Fishbein 2019	+	+	+	+	?	-
Galvao 2015	+	+	+	?	?	-
Gamito 2017	+	?	-	+	?	-
Giachero 2020	+	+	+	+	?	-
Givon 2016	?	?	+	+	-	-
Grechuta 2019	+	+	?	+	+	-
Gueye 2021	?	?	?	+	?	-
Guo 2023	+	?	?	-	+	-
Han 2013	?	?	?	?	?	-
Hegazy 2022	?	?	+	+	?	-
Henrique 2019	?	?	?	?	?	-
Heo 2016	+	+	?	-	?	-
Hernandez 2022	+	+	+	+	+	-
Housman 2009	+	-	+	+	+	-
Huang 2022	+	?	+	+	+	-
Hung 2014	+	+	+	+	?	-
Hung 2017	+	+	+	+	?	-
Hung 2019	+	+	+	+	?	-
Jaffe 2004	+	-	+	+	?	-
Jang 2005	?	?	?	?	?	-
Jannink 2008	?	?	?	?	?	-
Johnson 2020	+	?	+	+	+	-
Jung 2012	+	?	+	?	?	-
Junior 2019	+	+	+	-	+	-
Kang 2009	+	?	+	+	?	-
Kaur 2020	+	?	+	?	+	-
Kayabinar 2021	+	?	+	-	+	-
Kim 2009	+	+	+	+	+	-
Kim 2011a	?	?	-	+	+	-
Kim 2011b	?	?	+	+	+	-
Kim 2012a	?	?	?	?	?	-
Kim 2018a	+	+	+	+	+	-
Kim 2018b	+	+	?	?	?	-
Kiper 2011	+	+	+	+	+	-

Figure 3. (Continued)

Kim 2010	+	+	+	+	+	+	+
Kiper 2011	+	+	+	+	+	+	-
Kiper 2018	+	+	+	+	?	+	-
Kiper 2022	+	+	+	-	+	+	-
Klamroth-Marganska 2014	+	+	+	+	+	+	-
Ko 2015	?	?	?	?	?	?	-
Kong 2014	+	+	+	+	+	+	-
Kong 2016	+	+	+	+	?	+	-
Kottink 2014	?	?	+	+	?	+	-
Kuo 2023	?	+	+	-	?	+	-
Kwon 2012	?	?	+	?	?	+	-
Lam 2006	+	+	+	+	+	+	-
Lee 2013	+	?	?	-	?	+	-
Lee 2014a	-	-	+	+	?	+	-
Lee 2015a	?	?	?	?	?	+	-
Lee 2015b	?	?	?	?	?	+	-
Lee 2016a	+	+	+	+	?	+	-
Lee 2016b	?	+	+	+	?	+	-
Lee 2017a	+	?	+	+	+	+	-
Lee 2017b	+	+	+	+	?	+	-
Lee 2018	+	+	+	+	?	+	-
Lee 2019	+	+	+	+	?	+	-
Lee 2020	?	?	?	?	?	+	-
Leng 2022	+	?	+	-	+	+	-
Levin 2012	-	+	+	+	+	+	-
Lin 2020	+	+	+	+	?	+	-
Lin 2021	+	+	+	+	?	+	-
Linder 2015	+	+	+	+	-	+	-
Liu 2023	?	?	?	+	+	+	-
Llorens 2015	+	?	+	+	?	+	-
Long 2020	+	+	+	+	+	+	-
Low 2012	?	?	?	?	?	+	-
Luo 2023	?	?	?	+	?	+	-
Maggio 2021	?	?	?	?	?	+	-
Maier 2020	+	-	-	+	+	+	-
Malik 2017	?	?	?	?	?	+	-

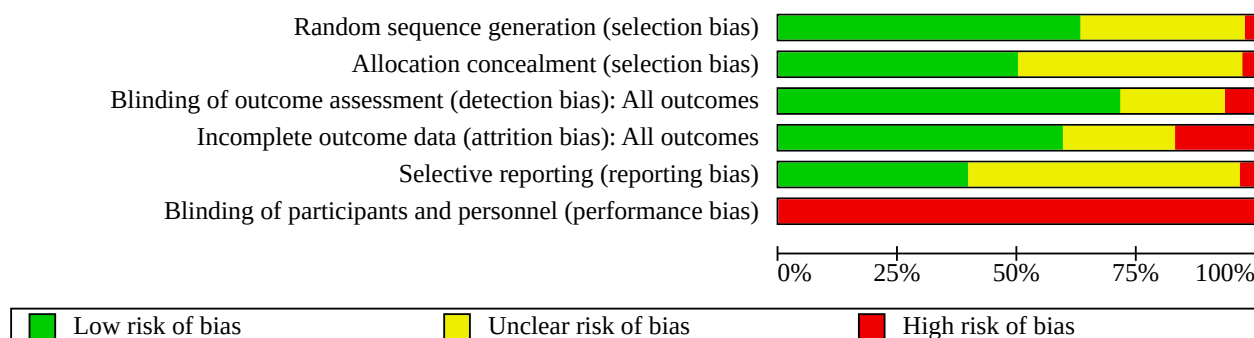
Figure 3. (Continued)

Malik 2017	?	?	?	?	?	-
Malik 2021	?	+	?	+	+	-
Manlapaz 2010	?	+	+	+	?	-
Manuli 2020	+	+	+	+	?	-
Mao 2015	+	+	?	?	+	-
Marques-Sule 2021	+	+	+	+	+	-
Marshall 2020	+	?	+	-	+	-
Matsuo 2013	?	?	?	?	?	-
Mazer 2005	+	+	+	+	+	-
McNulty 2015	+	+	+	+	?	-
Mekbib 2021	+	+	+	-	?	-
Miclaus 2020	+	+	+	+	+	-
Miranda 2019	+	+	?	?	?	-
Mirelman 2008	+	+	+	+	+	-
Morone 2014	+	?	+	-	?	-
Nara 2015	?	?	?	-	?	-
Norouzi-Gheidari 2019	?	?	+	-	?	-
Ogun 2019	+	+	+	-	+	-
Oh 2019	+	?	+	+	+	-
Park 2018	?	?	?	?	?	-
Park 2021	?	?	?	+	?	-
Pedreira da Fonseca 2017	+	+	+	+	+	-
Pelaez-Velez 2023	+	?	+	+	+	-
Piron 2007	+	+	+	-	+	-
Piron 2009	+	+	+	+	+	-
Piron 2010	+	+	+	+	+	-
Prange 2015	?	+	+	+	+	-
Rajaratnam 2013	+	?	+	?	?	-
Rand 2017	?	?	+	+	+	-
Reinkensmeyer 2012	+	?	+	?	?	-
Rodríguez-Hernández 2021	+	+	+	+	+	-
Rodriguez-Hernandez 2023	+	+	+	-	+	-
Sana 2023	?	?	+	+	+	-
Saposnik 2010	+	?	+	+	+	-
Saposnik 2016	+	+	+	+	+	-
Schuster-Amft 2018	+	+	+	+	+	-

Figure 3. (Continued)

	+	+	+	+	+	-
Schuster-Amft 2018	+	+	+	+	+	-
Shin 2014	+	+	+	+	+	-
Shin 2015	+	?	+	+	?	-
Shin 2022	+	+	+	-	+	-
Simsek 2016	?	+	+	+	?	-
Sin 2013	+	?	+	?	?	-
Song 2014	?	?	?	?	?	-
Song 2015	?	?	?	?	?	-
Song 2021	?	+	?	+	?	-
Standen 2017	+	+	+	-	+	-
Stockley 2017	+	+	+	+	?	-
Subramanian 2013	+	+	+	+	+	-
Sultan 2023	?	+	+	+	+	-
Térémetz 2022	+	?	+	+	+	-
Thielbar 2014	-	+	+	+	?	-
Tramontano 2020	+	?	+	+	?	-
Turkbey 2017	+	+	+	+	+	-
Ucar 2014	?	?	-	?	?	-
Utkan Karasu 2018	+	+	+	+	?	-
Velmurugan 2023	?	?	+	?	?	-
Wang 2017	+	?	+	+	+	-
Xiang 2014	?	?	-	?	?	-
Xiang 2022	?	+	+	+	?	-
Xie 2021	+	+	+	+	?	-
Xu 2021	?	?	+	+	?	-
Yaman 2022	+	+	+	?	?	-
Yang 2008	+	?	+	?	?	-
Yang 2011	?	?	+	?	?	-
Yavuzer 2008	+	+	+	+	?	-
Yin 2014	?	+	-	+	?	-
You 2005	?	?	+	?	?	-
Zhang 2017	?	?	?	?	?	-
Zuconi 2012	+	+	+	+	+	-

Figure 4. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.



Not all included studies followed the CONSORT guidelines [256]; in such cases we contacted the corresponding authors for clarification of study methodology. If we received no response, we assessed the risk of bias criterion as 'unclear'.

We assessed random sequence generation as being adequate in 64% of trials. Allocation concealment was reported as adequate in 51% of trials.

Seventy-two per cent of studies reported blinding of the outcome assessor. No trials were able to blind participants or personnel.

We deemed 16% of studies to be at high risk of bias regarding incomplete outcome data, and 24% of studies as at unclear risk of bias for this criterion. Dropouts from studies appeared to be generally balanced across groups.

We judged 40% of studies to be free of selective reporting by comparing the published results with trials register entries or protocol papers, or through correspondence with study authors. It was unclear whether selective reporting was present in most other studies.

Synthesis of results

Results are presented by comparison and then by outcome (critical outcome, important outcomes). The first comparison is virtual reality versus alternative therapy, in which groups received different types of therapy but the same amount of therapy. All analyses are presented in [Supplementary material 4](#) and [Supplementary material 5](#).

Virtual reality versus alternative therapy approaches

Critical outcome: Upper limb function and activity

Results are presented for upper limb function and activity and hand function. All outcomes were taken within days of the end of the intervention programme.

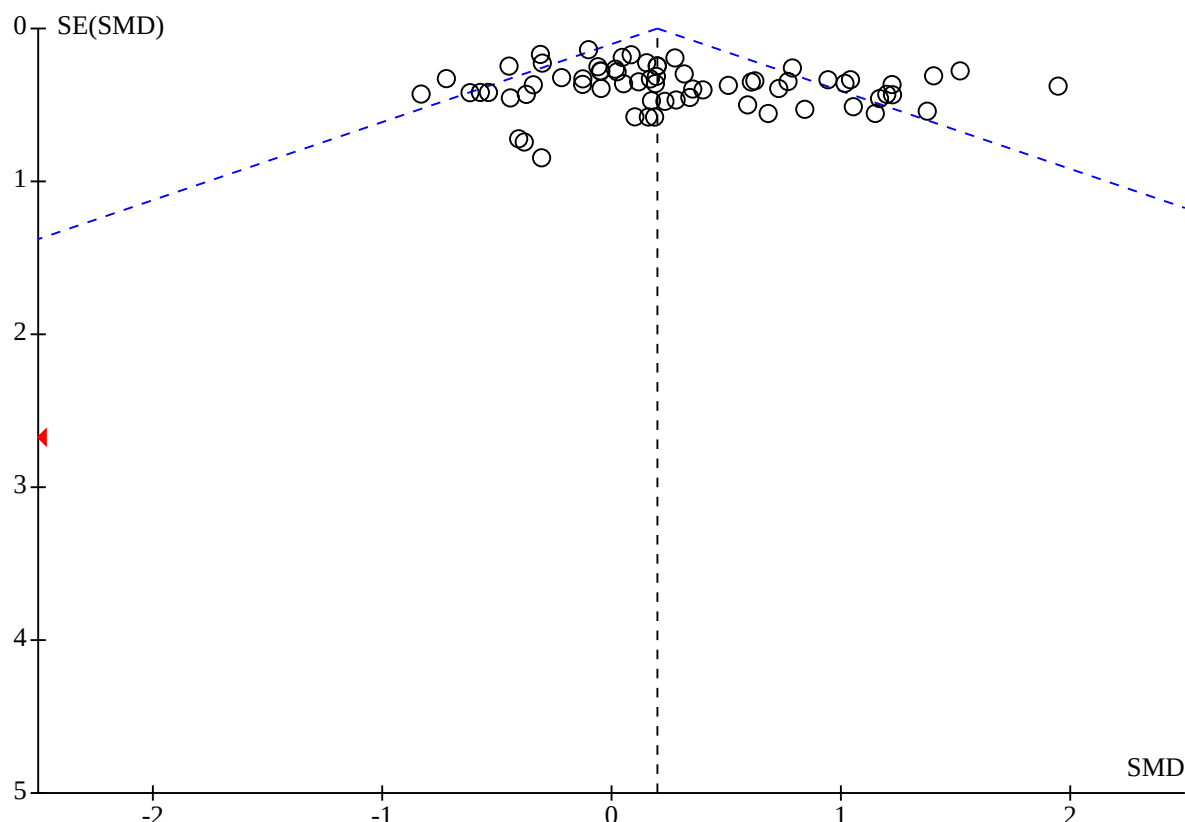
Analysis 1.1: Upper limb function and activity postintervention

Sixty-seven studies presented outcomes for upper limb function and activity in a form suitable for inclusion in the meta-analysis (with 2830 participants). The impact of virtual reality on upper limb function was found to be beneficial (SMD 0.20, 95% CI 0.12 to 0.28; low-certainty evidence; Analysis 1.1). Statistical heterogeneity was present ($I^2 = 68\%$).

We were unable to obtain data in a suitable format for pooling for eight studies (Assadi 2016; Ballester 2017; Chen 2022; El-Kafy 2021; Fan 2014; Luo 2023; McNulty 2015; Shin 2015). Fan 2014 reported that there were no differences between groups for outcomes on the Jebsen Taylor Hand Function Test; McNulty 2015 reported no differences between virtual reality and constraint-induced movement therapy on the Wolf Motor Function Test. Shin 2015, Assadi 2016, Ballester 2017, and Luo 2023 found no differences between groups on the Fugl Meyer Assessment. The other studies reported that those in the virtual reality group improved more than those in the alternative therapy group on the Fugl Meyer Assessment (Chen 2022) and the Action Research Arm Test (El-Kafy 2021).

A funnel plot related to this analysis displayed an atypical distribution of study effects relative to sample size; however, it was not clear if this was due to publication bias ([Figure 5](#)).

Figure 5. Funnel plot examining potential publication bias in Analysis 1.1.



Sensitivity analysis for Analysis 1.1

Excluding those studies judged to be unclear or at high risk of bias in two or more categories left 17 studies. This analysis showed no beneficial effect for virtual reality when compared to alternative therapy (SMD 0.04, 95% CI -0.09 to 0.16). Statistical heterogeneity was slightly lower ($I^2 = 52\%$). We also conducted a sensitivity analysis involving use of a random-effects model. The difference was minor (SMD 0.27, 95% CI 0.13 to 0.41).

Analysis 1.2: Hand function postintervention (grip strength)

Sixteen trials measured the effect of virtual reality versus alternative therapy on grip strength (556 participants). The impact of virtual reality compared to alternative therapy was not shown to be beneficial (SMD 0.09, 95% CI -0.08 to 0.26; Analysis 1.2). Statistical heterogeneity was high ($I^2 = 61\%$). One study that could not be pooled found that grip strength improved more in the virtual reality group (Assadi 2016).

Analysis 1.3: Upper limb function postintervention: amount of use

We pooled 11 studies (with 479 participants) to examine the effect on amount of use of the upper limb (self-reported component of the Motor Activity Log). There was no difference between the groups receiving virtual reality and alternative therapy (SMD -0.08, 95% CI -0.26 to 0.10; Analysis 1.3). Data from three further studies could not be pooled; two of these studies both reported that there were greater improvements in the intervention group than the control group on the amount-of-use scale (Jang 2005; Standen 2017). The

remaining study found no differences between virtual reality and constraint-induced movement therapy (McNulty 2015).

Analysis 1.4: Upper limb function and activity: short-term follow-up

We pooled 17 studies ($n = 749$ participants) that reported follow-up assessments of arm function taken between two weeks and three months after the end of intervention. The difference in performance between the virtual reality and alternative therapy groups at this later follow-up point remained present (SMD 0.18, 95% CI 0.04 to 0.33; Analysis 1.4). A further three studies measured outcomes six months after the end of intervention. Housman 2009 reported that participants in the virtual reality group had improved more on the Fugl Meyer UE Scale at the six-month follow-up assessment than participants in the alternative treatment group ($P = 0.045$). Participants in the virtual reality group improved by 3.6 points (standard deviation (SD) 3.9), whereas participants in the alternative treatment group improved by 1.5 points (SD 2.7). However, the trial found no other differences between groups at six months on the other outcome measures used (Rancho Functional Test, grip strength, and Motor Activity Log). In contrast, Adie 2017 reported no differences between groups on the Action Research Arm Test or Motor Activity Log at six-month follow-up, and McNulty 2015 reported that upper limb function at six months was not different between participants in the Wii-based movement therapy group and those in the modified constraint-induced movement therapy group.

Analysis 1.5: Upper limb function: subgroup analysis based on amount of therapy

We compared trials providing under 15 hours of intervention with trials providing 15 hours or more of intervention. Both subgroups showed an effect, although the effect size was larger in the group with the higher amount of therapy (SMD 0.30, 95% CI 0.20 to 0.41 compared with SMD 0.13, 95% CI 0.01 to 0.24). There was a difference between groups ($\text{Chi}^2 = 4.95$, $\text{df} = 1$, $P = 0.03$; Analysis 1.5).

Analysis 1.6: Upper limb function: subgroup analysis based on time since onset of stroke

We classified trials based on whether participants had been recruited within six months of stroke or more than six months poststroke. There was no difference between groups ($\text{Chi}^2 = 1.95$, $\text{df} = 1$, $P = 0.16$; Analysis 1.6).

Analysis 1.7: Upper limb function: subgroup analysis based on virtual reality application being customised or non-customised for rehabilitation settings

Studies utilising customised virtual reality programmes specifically designed for rehabilitation settings demonstrated benefits over alternative intervention, as did non-custom programmes (Analysis 1.7). The test for subgroup differences indicated no difference between subgroups ($P = 0.32$).

Analysis 1.8: Upper limb function: subgroup analysis based on level of immersion of customised virtual reality application

Studies using a virtual reality application customised for rehabilitation settings and immersive showed a beneficial effect (SMD 0.68, 95% CI 0.32 to 1.04). The effect size for non-immersive virtual reality applications was smaller (SMD 0.20, 95% CI 0.10 to 0.30). There was a difference between groups ($\text{Chi}^2 = 6.15$, $\text{df} = 1$, $P = 0.01$) (Analysis 1.8).

We did not undertake other planned subgroup analyses due to similarities in these studies regarding the age of participants and frequency of intervention sessions.

Important outcomes

Analysis 1.9: Mobility: Gait speed postintervention

Ten studies provided data on gait speed (304 participants). There did not appear to be an effect of virtual reality on gait speed (MD 0.05, 95% CI -0.02 to 0.13; very low-certainty evidence; Analysis 1.9). Moderate statistical heterogeneity was indicated ($I^2 = 39\%$).

Jaffe 2004 examined the effect of virtual reality on comfortable walking speed and fast walking speed. We included data relating to comfortable walking speed in the meta-analysis. The effect on fast walking speed was found to be greater in the virtual reality intervention group than the comparative group. Five studies could not be pooled due to an inability to obtain data in a suitable format for pooling. Few participants in the study by Bergmann 2018 were able to complete the test of walking speed due to significantly impaired mobility. Two studies (Kayabinar 2021; Morone 2014) found no differences between groups in walking speed. In contrast, two studies reported that virtual reality was more beneficial than alternative therapy for gait speed (Fishbein 2019; Ucar 2014); one of these studies used the Lokomat (Ucar 2014).

Analysis 1.10: Mobility: Timed Up and Go test postintervention

We pooled 10 studies (400 participants) reporting data for the Timed Up and Go (TUG) test. There was a difference between those in the virtual reality and alternative therapy groups (MD -4.66, 95% CI -5.79 to -3.53), and statistical heterogeneity was present ($I^2 = 49\%$) (Analysis 1.10). Five studies could not be included in the analysis, as means and SDs were not available (Chen 2021; de Rooij 2021; Fishbein 2019; Sana 2023; Ucar 2014). Authors of one study reported that those receiving therapy on the Lokomat had better performance on the TUG test than those receiving alternative therapy ($P = 0.035$, Ucar 2014), whereas Chen 2021, de Rooij 2021, and Fishbein 2019 reported no differences between groups. Sana 2023 reported that the intervention group had an improvement in scores on the TUG following training; however, no between-groups analysis was reported.

Analysis 1.11: Balance postintervention

Twenty-four studies with 871 participants examined the effect of virtual reality intervention compared to alternative therapy on balance. Balance was most commonly assessed using the Berg Balance Scale or the Functional Reach Test. The effect of virtual reality was shown to be beneficial (SMD 0.26, 95% CI 0.12 to 0.40; low-certainty evidence; Analysis 1.11); heterogeneity was high ($I^2 = 85\%$). We could not include five studies in the analyses because we were unable to obtain data in the format required. Two of these studies reported that there was no difference between groups in balance (Chen 2021; Han 2013), whereas Morone 2014 and Fishbein 2019 reported that virtual reality was more effective than alternative balance therapy in improving performance on the Berg Balance Scale, and Malik 2017 reported an effect between groups favouring virtual reality on the Forward Reach Test at the end of treatment.

Six studies compared use of the Lokomat with an alternative therapy approach (Bergmann 2018; Calabro 2017; Maggio 2021; Manuli 2020; Park 2018; Ucar 2014). However, these studies used a range of outcome assessments, preventing pooling. Furthermore, one study did not report data in a suitable format for pooling (Ucar 2014), and another study reported that participants had difficulty completing the outcome assessment and therefore data were incomplete (Bergmann 2018).

Mobility: endurance postintervention

No studies compared virtual reality with an alternative therapy and reported outcomes related to endurance.

Global motor function postintervention

No studies compared virtual reality with an alternative therapy approach and reported outcomes related to global motor function.

Analysis 1.12: Cognitive function postintervention

We examined the effect of virtual reality on cognitive function (assessed using such tools as the Montreal Cognitive Assessment) by pooling nine studies with 279 participants. There was an effect in favour of virtual reality (SMD 0.32, 95% CI 0.08 to 0.56; heterogeneity $I^2 = 47\%$; Analysis 1.12). Data for three studies were not in a suitable format for pooling and therefore could not be included in the meta-analysis. Cho 2019 reported that participants in the virtual reality group improved on the LOTCA after intervention (but did not present data on between-group differences). De Luca 2018 reported

that the virtual reality group improved on the MOCA (whereas the control group did not). Gamito 2017 reported improvement in the virtual reality group on the Wechsler Memory Scale but no improvement in the alternative therapy group.

Analysis 1.13: Activity limitation postintervention

We pooled 33 studies with 1495 participants that examined the difference between virtual reality intervention and alternative intervention on activity limitation performance. There was a small effect (SMD 0.21, 95% CI 0.11 to 0.32; moderate-certainty evidence) and a small amount of statistical heterogeneity ($I^2 = 30\%$) (Analysis 1.13). Several studies could not be included in the analysis due to our inability to obtain data in a suitable format for pooling (Ballester 2017; Cho 2019; De Luca 2018; de Souza Filho 2020; Han 2013; Kiper 2022; Liu 2023; Manuli 2020; Morone 2014). Morone 2014 presented a graph indicating that those in the Nintendo Wii group had better scores on the Barthel Index postintervention than those in the alternative therapy group, and Cho 2019 found that participants in the virtual reality group improved more on the FIM than those in the control group. In contrast, seven studies reported no differences between groups (Ballester 2017; De Luca 2018; de Souza Filho 2020; Han 2013; Kiper 2022; Liu 2023; Manuli 2020).

Akinwuntan 2005 reported results from the follow-up assessments, which were completed at six months and five years postintervention. They found that at six months postintervention, participants in the virtual reality intervention group had improved more in their on-road performance (measured by the Test Ride for Investigating Practical fitness to drive checklist) than participants in the alternative intervention group ($P = 0.005$). Furthermore, 73% of the virtual reality group compared with 42% of the group that participated in driving-related cognitive tasks were classified by driving assessors as 'fit to drive' at six months. At five years, there was no difference between groups in 'fitness to drive' or resumption of driving.

Sensitivity analysis for Analysis 1.13

We explored the effects of methodological quality on the overall effect by excluding studies deemed to be at unclear or high risk of bias in two or more categories from the analysis. The results were similar, with a slight difference in confidence interval (SMD 0.24, 95% CI 0.04 to 0.43).

Analysis 1.14: Participation restriction and quality of life

We pooled 16 studies with 963 participants to examine the effect of virtual reality on participation restriction and quality of life compared to alternative therapy. No apparent difference was observed (SMD 0.11, 95% CI -0.02 to 0.24; low-certainty evidence; Analysis 1.14).

Of the seven studies that could not be pooled, Shin 2015 reported that participants in the virtual reality group reported better scores in terms of role limitations due to physical problems, whereas the remaining six studies reported no differences between groups (Fan 2014; Klamroth-Marganska 2014; Manuli 2020; Saposnik 2010; Schuster-Amft 2018; Térémetz 2022).

Virtual reality in addition to usual care compared to usual care alone

The second comparison is virtual reality intervention compared with no intervention (usual care) and used to augment standard

care (i.e. people in the virtual reality intervention group received additional therapy time relative to the control group).

Critical outcome: Upper limb function and activity

Analysis 2.1: Upper limb function and activity postintervention

Twenty-one studies with a total of 689 participants presented outcomes for upper limb function. There was a moderate effect demonstrating that additional treatment with virtual reality intervention was more effective than usual care alone (SMD 0.42, 95% CI 0.26 to 0.58; moderate-certainty evidence; Analysis 2.1). Statistical heterogeneity was present ($I^2 = 61\%$).

Six studies could not be included in the analysis due to our inability to obtain data in a suitable format for pooling (Askin 2018; Bai 2022; Long 2020; Low 2012; Xiang 2022; Yin 2014). Four of these studies (Long 2020; Low 2012; Xiang 2022; Yin 2014) reported that there were no differences between groups on the Fugl Meyer score. The remaining studies (Askin 2018; Bai 2022) found those in the virtual reality group improved more on the Fugl Meyer than those in the usual care group.

Sensitivity analysis for Analysis 2.1

We excluded trials deemed to be at high risk of bias in two or more domains. The result was similar (SMD 0.41, 95% CI 0.24 to 0.59), therefore we assessed the certainty of the evidence to be moderate for this outcome.

Grip strength

No studies where virtual reality was used in addition to usual care reported outcomes related to grip strength.

Analysis 2.2: Upper limb function postintervention: amount of use (self-reported)

Pooling of four studies examining the amount of use of the upper limb using the Motor Activity Log (five-point scale) found an effect in favour of virtual reality intervention (MD 0.53, 95% CI 0.29 to 0.77; Analysis 2.2). Statistical heterogeneity was low ($I^2 = 29\%$).

Upper limb function and activity: short-term follow-up

Insufficient data precluded pooling of studies using virtual reality in addition to usual care compared to usual care alone on follow-up outcomes.

Analysis 2.3: Upper limb function: subgroup analysis based on amount of therapy

We compared trials providing less than 15 hours of intervention with trials providing 15 hours or more of intervention. There was no difference between groups ($\text{Chi}^2 = 2.30$, $\text{df} = 1$, $P = 0.13$; Analysis 2.3).

Analysis 2.4: Upper limb function: subgroup analysis based on time since onset of stroke

We completed analysis for 10 trials recruiting participants within six months of stroke compared with 10 trials recruiting participants more than six months poststroke. Analysis of trials recruiting within six months did not reveal an effect (SMD 0.20, 95% CI -0.01 to 0.40), whereas those recruiting people in the chronic phase of stroke showed benefits (SMD 0.77, 95% CI 0.50 to 1.04). There was a difference between groups ($P < 0.001$) (Analysis 2.4).

Analysis 2.5: Upper limb function: subgroup analysis based on virtual reality application being customised or non-customised for rehabilitation settings

We compared nine trials evaluating the benefits of non-custom devices with 12 trials evaluating the benefits of customised systems specifically designed for rehabilitation. There was no difference between groups ($\text{Chi}^2 = 0.30$, $\text{df} = 1$, $P = 0.58$; Analysis 2.5).

Important outcomes

Analysis 2.6: Mobility: Gait speed postintervention

Pooling of three studies with 57 participants utilising virtual reality intervention as an adjunct to usual care did not identify beneficial effects (SMD 0.08, 95% CI -0.05 to 0.21; very low-certainty evidence) (Bower 2015; Lee 2014a; Xiang 2014). There was no statistical heterogeneity (Analysis 2.6). Two studies could not be included in the analysis due to our inability to obtain data in a suitable format for pooling (Chow 2013; Low 2012). Both papers (presented as conference abstracts only) reported no differences between groups in gait speed following intervention.

Analysis 2.7: Mobility: Timed Up and Go test postintervention

Pooling of eight studies with 236 participants identified a difference favouring those who had received virtual reality in comparison to usual care (MD -1.85, 95% CI -2.8 to -0.9), although statistical heterogeneity was present ($I^2 = 63\%$). Sensitivity analysis omitting studies at risk of bias for two or more domains altered this analysis, resulting in no effect between interventions (Analysis 2.7).

Analysis 2.8: Balance postintervention

We pooled 12 studies (with 321 participants) to examine the effect of providing virtual reality as an adjunct to usual care on balance. There was a beneficial effect of virtual reality, and the effect size was moderate (SMD 0.68, 95% CI 0.46 to 0.91; $I^2 = 13\%$; low-certainty evidence; Analysis 2.8).

Four studies could not be included in the analysis due to our inability to obtain data in a suitable format for pooling. Two papers (presented as conference abstracts only: Chow 2013; Low 2012) reported no differences between groups, whereas Lee 2018 reported that the experimental group had improved performance on the modified Functional Reach Test in comparison to the control group, and Bai 2022 reported improved performance on the Berg Balance scale in participants in the virtual reality group.

Mobility: endurance

No studies compared virtual reality in addition to usual care versus usual care alone and reported endurance outcomes.

Analysis 2.9: Global motor function postintervention

We pooled three studies (with 43 participants) that examined the effect of virtual reality on global motor function when used in addition to usual care. There did not appear to be an effect on global motor function (SMD 0.01, 95% CI -0.60 to 0.61; Analysis 2.9).

Cognitive function postintervention

Only one study compared virtual reality in addition to usual care versus usual care alone and reported on cognitive function outcomes (Oh 2019). This study reported that both the intervention and control groups experienced a small improvement in performance on the Korean Mini Mental State Examination test.

Analysis 2.10: Activity limitation postintervention

Analysis of 15 studies (with 513 participants) showed that those who received virtual reality intervention in addition to usual care had an improvement in activity limitation (measured using a global scale such as the Functional Independence Measure) (SMD 0.22, 95% CI 0.04 to 0.41; moderate-certainty evidence). Heterogeneity was low ($I^2 = 16\%$) (Analysis 2.10).

We could not include five studies in the analysis due to our inability to obtain data in a suitable format for pooling. Three studies (Chow 2013; Low 2012; Yin 2014) reported no difference between groups in activity limitation. The fourth study (Long 2020) found a difference between groups, with the control group performing better on the Barthel Index. The fifth study (Bai 2022) reported superior outcomes in the virtual reality group on the Barthel Index.

Analysis 2.11: Participation restriction and quality of life postintervention

Pooling of two studies (Johnson 2020; Norouzi-Gheidari 2019) with 76 participants revealed no beneficial effect on participation restriction and quality of life (SMD 0.22, 95% CI -0.24 to 0.67; low-certainty evidence; Analysis 2.11).

Adverse events

Fifty-nine studies included in this review monitored and reported on adverse events. Forty-six studies reported no major adverse events linked to study participation (Adie 2017; Adie 2017; Askin 2018; Brunner 2017; Byl 2013; Calabro 2017; Cannell 2018; Cano-Manas 2020; Chen 2021; Choi 2014; Coupar 2012; de Rooij 2021; Givon 2016; Hernandez 2022; Housman 2009; Hung 2019; Jaffe 2004; Johnson 2020; Kiper 2011; Kiper 2018; Kiper 2022; Lee 2017b; Levin 2012; Lin 2021; Llorens 2015; Long 2020; Maggio 2021; Marques-Sule 2021; Marshall 2020; McNulty 2015; Norouzi-Gheidari 2019; Oh 2019; Pedreira da Fonseca 2017; Piron 2007; Piron 2010; Rand 2017; Reinkensmeyer 2012; Saposnik 2010; Saposnik 2016; Schuster-Amft 2018; Shin 2015; Stockley 2017; Subramanian 2013; Wang 2017; Yavuzer 2008; Yin 2014). Studies that reported adverse events are presented in [Table 2](#).

We were not able to pool data for adverse events due to different comparisons, intervention approaches and events reported, and insufficient detail reported in the studies regarding type and number of events. For example, for our main comparison (virtual reality versus alternative therapy) and critical outcome of upper limb function and activity, only seven studies reported on adverse events (as presented in [Table 2](#)). The nature of adverse events spanned upper limb fatigue, dizziness, headache, general fatigue, falls, pain, eye strain, blurred vision, dizziness, and shoulder soreness.

Equity assessment

We did not investigate equity-related characteristics in this review.

Reporting biases

None reported.

Virtual reality for stroke rehabilitation (Review)

DISCUSSION

Summary of main results

This review included 190 trials with 7188 participants. The main results are presented in [Summary of findings 1](#) and [Summary of findings 2](#). There were few adverse events reported across studies, and those reported (transient dizziness, headache, pain) were relatively mild.

Comparison: Virtual reality compared to alternative therapy approaches for stroke rehabilitation

Critical outcome: Upper limb function and activity

Our first analysis found a total of 67 studies with 2830 participants comparing a virtual reality intervention with an alternative therapy intervention and measured effects on upper limb function and activity. Overall, the effect of virtual reality was small but beneficial (low-certainty evidence). These trials used a variety of different customised and non-customised virtual reality programmes and were delivered with a range of different amounts of therapy at different time points after stroke. Subgroup analyses suggested that higher amounts of therapy were more beneficial for upper limb function. Pooling of a smaller number of studies revealed that the effects of virtual reality compared to alternative therapy were not beneficial for grip strength (16 studies) or amount of use (measured subjectively in 11 studies).

In summary, the use of virtual reality may result in improvements in overall upper limb function and activity. However, the virtual reality intervention was only slightly more effective than alternative interventions. This finding is in contrast with the previous version of this review published in 2017 where meta-analysis revealed no significant benefit associated with virtual reality intervention when compared with alternative therapy approaches. The current review includes many more studies comparing virtual reality with alternative therapy and thus provides more information about the benefits of virtual reality.

Important outcomes

Our analyses showed that virtual reality may be more beneficial than alternative therapy for TUG score (10 studies), balance (24 studies; low-certainty evidence), cognitive function (9 studies), and activity limitation (33 studies; moderate-certainty evidence), and effect sizes ranged from small to moderate. There may be no advantage of virtual reality over alternative therapy for gait speed (10 studies; very low-certainty evidence) or participation restriction and quality of life (16 studies; low-certainty evidence).

Comparison: Virtual reality plus usual care compared with usual care alone

Critical outcome: Upper limb function and activity

We examined the effect of a virtual reality intervention on upper limb function when the intervention was provided to augment the usual amount of therapy (meaning that participants received extra therapy which was delivered using virtual reality). Thus, the intervention group received more therapy time than the control group. A total of 21 studies with 689 participants found a moderate effect in favour of the virtual reality intervention (moderate-certainty evidence). Twelve of these studies involved the use of

custom virtual reality programmes, whereas the remaining nine studies used non-custom devices.

Important outcomes

When virtual reality was used in addition to usual care (providing an increased amount of therapy for participants in the experimental group), there may be a positive effect on balance (12 studies; low-certainty evidence) and a likely positive effect on activity limitation (15 studies; moderate-certainty evidence). We were unable to draw conclusions about the effect on gait speed (3 studies; very low-certainty evidence), global motor function (3 studies), or participation restriction and quality of life (2 studies; low-certainty evidence), as few studies could be pooled.

Heterogeneity of included studies

There was considerable clinical heterogeneity between the studies included in the review, particularly with regard to the variety of intervention approaches used to address a variety of different patient needs. Some of these interventions were very specific (e.g. retraining participants to use the local public transport system), and therefore studies were not comparable in many circumstances. Even the same device could be used in different ways. For example, although the Nintendo Wii was used in 40 studies, it was sometimes used to improve balance and sometimes used to improve upper limb function. In addition, a wide variety of outcome measures were used, which also limited our ability to pool results. Work has been done among leading stroke rehabilitation researchers to achieve consensus on outcome measures that should be included in research trials to enable data synthesis [257, 258]. Researchers planning to conduct trials of virtual reality should consult these consensus-based recommendations.

The use of meta-analysis in cases where such heterogeneity is present can be considered controversial [39], and our analyses often contained substantial statistical heterogeneity ($I^2 > 50\%$); however, we felt that meta-analysis in this review was justified, and we were careful to only pool studies that were relatively comparable (with clinical heterogeneity) in terms of participants, interventions, comparison, and outcome measures. Meta-analysis of the individual studies enabled us to explore the overall treatment effect of the intervention when compared with an alternative, more traditional intervention or no intervention. Our sensitivity analyses suggested that there were no notable differences between using random-effects and fixed-effect models.

Limitations of the evidence included in the review

We were able to include a very large number of studies in the current version of the review. However, the quality of evidence in the field is limited due to small sample sizes and risk of bias present in the majority of studies. The largest study recruited 152 participants. Thus, while there is a large number of RCTs, the certainty of evidence remains mostly moderate or low. Conducting more small trials using the same intervention approaches will not further advance our knowledge in this field and does not appear to be a good use of research resources.

Our primary analysis showed that virtual reality was slightly more beneficial than alternative therapy approaches in upper limb function and activity. However, when we excluded studies from this analysis which were considered to be at high risk of bias, the analysis failed to show benefit. The largest studies included in this

analysis also failed to show that virtual reality was more beneficial than alternative therapy approaches. Accordingly, our confidence in the effect estimate is limited.

The number of studies in this version of the review has more than doubled, with the current inclusion of 190 studies. There are now studies recruiting participants in both the earlier phases poststroke, as well as the chronic phase. People with cognitive impairment, or communication or visual deficits, remain excluded in many studies, thereby raising questions about how applicable this intervention is to a wide range of stroke survivors. Furthermore, the average age of participants in the included studies was relatively young, therefore information about use with older stroke survivors is limited.

Researchers involved in future studies should provide more detail in their reporting, ensuring that they clearly describe their eligibility criteria, consent rate, and the adherence and satisfaction of participants with the intervention. These details will be of interest to clinicians who will need to balance the cost of the virtual reality programme with the potential benefits and the number of clients who may benefit from use. Researchers should also consult guidance on selection of outcome measures (which will enable improved data synthesis) [257, 258] and ensure that the treatment of the control group is appropriate and addresses the study aims [259].

We found that many studies used virtual reality intervention later in the recovery process, such as more than six months after stroke. The reason for this is unclear; it could be that people in the later stages of recovery find virtual reality to be novel and more motivating and challenging than early rehabilitation approaches and therefore are more engaged in therapy. There are a number of studies suggesting that virtual reality training is motivating and enjoyable, with some studies finding the intervention to be more engaging than usual therapy exercises (McNulty 2015; [260, 261]). Although there is a perception that people undergoing rehabilitation programmes will find the technology difficult to use, research suggests that a number of studies report the technology as acceptable and easy to use [262].

In this review we added a new subgroup analysis that compared the effects of customised rehabilitation programmes using immersive and non-immersive technologies. Very few of the studies included in this analysis were considered to be immersive, and therefore we are currently unable to draw any conclusions about the effects of immersive virtual reality and how this compares to the effects of non-immersive virtual reality. Furthermore, within the included studies, the level of interaction in the virtual environment ranged in terms of sophistication, and many interactions were quite simple (e.g. reaching for virtual objects). As the number of immersive studies in the field increases, it may be possible to gain more information about the types of virtual reality that are likely to be effective through this type of subgroup analysis [15]. In the interim, our findings suggest that benefits arising from virtual reality may be partially due to gamification of therapy, which may increase motivation, adherence, and participation.

Several trials reported the presence or absence of adverse events. There were few events reported; the small number of events were mild and limited to dizziness, headaches, and pain.

Limitations of the review processes

Despite a comprehensive search strategy, it is possible that we did not identify some studies in the search process, for example studies where there was no published abstract in English. While in previous versions of this review we contacted manufacturers of virtual reality equipment and searched conference proceedings, we opted not to do so in this update, as this method was not previously effective in eliciting original studies. However, this does mean that unpublished data may not have been identified. Furthermore, although we contacted all corresponding authors of included studies, few authors responded. This resulted in the study methodology of many trials being unclear and thus prevented the inclusion of some data in the analyses. The process of two review authors independently reviewing abstracts and extracting data (with a third review author to moderate disagreements) enabled us to minimise bias. The search date of this review was September 2023. As this field is rapidly expanding, there are likely to be more studies now eligible for inclusion, although we are unaware of any major new studies underway.

Agreements and disagreements with other studies or reviews

Previous systematic reviews have reported that virtual reality appears promising [263, 264, 265, 266, 267, 268, 269]. This review is generally consistent with these reviews; however, due to the more recent and comprehensive search strategy, we were able to identify a greater number of studies and conduct subgroup analyses. The various reviews have drawn different conclusions about the benefits of virtual reality; most of the differences are due to different inclusion and exclusion criteria. For example, in this review we excluded studies where the interaction between the study participant and the virtual environment was mediated by the therapist rather than directly by the participant, such as when speed of movement through a virtual environment was controlled by the therapist during treadmill training. Other reviews did not make this distinction and included these types of studies. We were also careful to conduct separate analyses based on the treatment of the control group and the type and amount of therapy received.

In the previous version of this review, the main analysis examining the effect on upper limb function included 22 studies and found that virtual reality intervention was not more effective than alternative therapy [270]. There have been many studies published in the last couple of years, and the analysis in this updated version of the review included 67 studies with 2830 participants. The analysis of the effect on upper limb function showed a benefit of virtual reality, although the effect size was small; this finding is a change in the direction of results with practical implications for clinicians.

AUTHORS' CONCLUSIONS

Implications for practice

We found that virtual reality therapy may be more beneficial than alternative therapy for a range of outcomes after stroke, including upper limb function, balance, and activity limitation. We also found that adverse events may be similar across virtual reality and alternative therapy groups. A greater improvement was seen with a higher amount of therapy. The gains made appear to be clinically relevant, with analyses showing small to moderate

effect sizes (i.e. a moderate effect on upper limb function when virtual reality was used to augment usual care (standardised mean difference (SMD) 0.42, moderate-certainty evidence), a moderate effect on balance (SMD 0.68), and a small effect on activity limitation (SMD 0.22), moderate-certainty evidence). However, there is substantial heterogeneity between studies at present. For example, only two studies examined the use of a virtual reality driving simulation programme, and thus it is unclear how effective virtual reality may be for driver rehabilitation after stroke. In addition, as virtual reality interventions may vary greatly (from inexpensive commercial gaming consoles to expensive customised programmes), it is unclear which characteristics of the intervention are most important. Our analyses did not provide clear direction as to which virtual reality programmes are superior to others. As very few of the included studies involved highly immersive, naturalistic virtual reality programmes, our results suggest that gamification of therapy may play a role in enhancing engagement and participation and may explain positive findings. Highly immersive programmes which use a head-mounted display and promote a sense of presence may be beneficial for patients undertaking therapy to improve performance in complex real-world activities (e.g. driving); however, this is currently unclear in our review. While such programmes are increasingly used in practice, research studies using head-mounted displays are lagging.

The lack of adverse events, including motion sickness, nausea, headache, or pain, suggests that these factors should not be of great concern to clinicians; however, this may vary depending on the characteristics of the person, the virtual reality hardware and software, and the task. Clinicians who currently have access to virtual reality programmes should be reassured that their use as part of a comprehensive rehabilitation programme can be beneficial, taking into account the patient's goals, abilities, and preferences. Virtual reality programmes may have more utility later in the recovery process (more than six months after stroke), as programmes are designed to be motivating, and therapy can be largely self-directed.

Implications for research

This updated version of the review revealed that 119 new randomised controlled trials (RCTs) were published over approximately six years. Despite the inclusion of some higher-quality studies, the new RCTs mostly mirror those included in the previous review. Researchers in this field should not continue to conduct small studies involving similar populations and interventions which are not furthering research in this field. However, it is important that researchers and manufacturers designing new virtual reality programmes for rehabilitation purposes should include the use of pilot studies assessing usability and validity as part of the development process. This is an important part of the development process and should be conducted with the intended users of the programme.

Our review included only RCTs, resulting in the exclusion of observational studies that showed improvements in real-world tasks based on virtual reality training. It is evident that the sophistication of virtual environments is still developing, and it is challenging to design a controlled trial comparing virtual reality to real-world correlates. This is in part because virtual reality systems allow us to train in ways that are not possible in the real world. Future research needs to carefully examine what we control for when comparing real-world with virtual reality-based interventions

and overcome, when possible, the challenge of making groups equivalent.

Ideally, studies should use common outcome measures. However, this is likely to be difficult due to the range of virtual reality interventions. Studies should measure whether effects are long-lasting with outcome assessment more than three months after the end of the intervention. Researchers should also examine the impact of virtual reality on the person's motivation to participate in rehabilitation, engagement in therapy, and level of enjoyment.

Many of the studies included in this review did not report the number of participants screened against eligibility criteria. Future research trials should report these data as they provide useful information regarding the proportion of stroke survivors for whom virtual reality intervention may be appropriate. Furthermore, people with visual and communication impairments have been excluded from many of these studies, and it is important to understand how virtual reality applications can be more inclusive for people with these impairments.

The majority of studies to date have evaluated interventions that were designed to address motor impairments. There are fewer studies that include cognitive rehabilitation or studies that aim to make improvements at the levels of activity or participation. There is also currently insufficient evidence from RCTs to tell whether activity training in a virtual environment translates to activity performance in the real world.

Equity-related implications for research

Study populations tended to be relatively young, and older people appeared to be underrepresented in the included studies.

SUPPLEMENTARY MATERIALS

Supplementary materials are available with the online version of this article: [10.1002/14651858.CD008349.pub4](https://doi.org/10.1002/14651858.CD008349.pub4).

Supplementary material 1 Search strategies

Supplementary material 2 Characteristics of included studies

Supplementary material 3 Characteristics of excluded studies

Supplementary material 4 Analyses

Supplementary material 5 Data package

Supplementary material 6 Cochrane 'Risk of bias' table

Supplementary material 7 Differences between the protocol and this version of the review

Supplementary material 8 Search strategies adopted in previous versions of this review

ADDITIONAL INFORMATION

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Editorial and peer-reviewer contributions

Cochrane Stroke supported the authors in the development of this review update.

The following people conducted the editorial process for this article:

- Sign-off Editor (final editorial decision): Derick T Wade, Professor in Neurological Rehabilitation, Centre for Movement, Occupation and Rehabilitation Sciences (MORES), Oxford Brookes University, Headington Campus, Oxford;
- Managing Editor (selected peer reviewers, provided editorial guidance to authors, edited the article): Luisa Fernandez Mauleffinch, Cochrane Central Editorial Service;
- Editorial Assistant (conducted editorial policy checks, collated peer-reviewer comments, and supported the editorial team): Jacob Hester, Cochrane Central Editorial Service;
- Copy Editor (copy editing and production): Lisa Winer, Cochrane Central Production Service;
- Peer reviewers (provided comments and recommended an editorial decision): Philippe Archambault, School of Physical and Occupational Therapy, McGill University; Centre for Interdisciplinary Research in Rehabilitation, Montreal, Canada (clinical/content review); Nawoda Hewage, Department of Biochemistry, Faculty of Medical Sciences, University of Sri Jayewardenepura, Gangodawila, Nugegoda, Sri Lanka (consumer review); Nuala Livingstone, Cochrane Evidence Production and Methods Directorate (methods review); and Jo Platt, Central Editorial Information Specialist (search review). One additional peer reviewer provided clinical/content peer review but chose not to be publicly acknowledged.

Contributions of authors

Kate Laver is the guarantor of the review. She was involved in conceiving, designing, and co-ordinating the review; designing the search strategies; undertaking the searches; screening the search

results; organising retrieval of papers; screening retrieved papers against the inclusion criteria; appraising the quality of the papers; extracting data from the papers; writing to study authors for additional information; managing and entering data into Review Manager 5 and RevMan Web; analysing and interpreting the data; and writing the review.

Belinda Lange was involved in screening the search results; organising retrieval of papers; screening retrieved papers against the inclusion criteria; analysing and interpreting the data; and writing the review.

Stacey George was involved in conceiving and designing the review; extracting data; analysing and interpreting the data; and writing the review.

Judith Deutsch was involved in designing the review; screening retrieved papers against inclusion criteria; extracting data; appraising the quality of papers; analysing and interpreting the data; and writing the review. Regarding the two studies of which Judith Deutsch is an author, she did not make study eligibility decisions about, extract data from, or perform risk of bias or GRADE assessments for these studies.

Gustavo Saposnik was involved in extracting data; appraising the quality of papers; analysing and interpreting the data; and writing the review. Regarding the two studies of which Gustavo Saposnik is an author, he did not make study eligibility decisions about, extract data from, or perform risk of bias or GRADE assessments for these studies.

Madison Chapman was involved in screening the search results; organising retrieval of papers; screening retrieved papers against the inclusion criteria; analysing and interpreting the data; and preparing parts of the review.

Maria Crotty was involved in conceiving and designing the review; extracting data; appraising the quality of papers; analysing and interpreting the data; and writing the review.

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Declarations of interest

Kate Laver: none known.

Belinda Lange conducts research on virtual reality for stroke rehabilitation, with a previous Researcher Exchange and Development within Industry (REDI) Fellowship with Penumbra Inc funded by MTP Connect. She also provides consulting to UbiquityVX to support the development and evaluation of rehabilitation tools. Belinda Lange is a non-executive director for the Australian Institute of Digital Health (volunteer position), Australian Physiotherapy Council (annual sitting fee), and Gymnastics South Australia (volunteer position).

Stacey George: none known.

Judith Deutsch is the first and third author of two studies included in the review. She did not make study eligibility decisions about, extract data from, or perform risk of bias or GRADE assessments for these studies. This work was affiliated with UMDNJ (now Rutgers) Rivers Lab and Spaulding. Judith Deutsch is also a named inventor on patents related to virtual reality for rehabilitation (patent

numbers US12/883,814 and US15/757,077). None of that work is included in this systematic review.

Gustavo Saposnik is the first author of two of the studies included in the review. He did not make study eligibility decisions about, extract data from, or perform risk of bias or GRADE assessments for these studies. He has received an operating grant from Hoffman-La Roche Limited (ongoing), is a faculty member of the University of Toronto (ongoing), and was the editor-in-chief of the World Stroke Academy for the World Stroke Organization (ended May 2024).

Madison Chapman: none known.

Maria Crotty has previously received funding from Amgen to introduce a fracture liaison service to a hospital orthopaedic unit (ended 2020) and consulted on the Royal Commission into Aged Care Quality and Safety regarding new innovations in aged care (ended 2020). She has also worked as a rehabilitation physician within the Southern Adelaide Local Health Network.

What's new

Date	Event	Description
20 June 2025	New search has been performed	New search performed on 27 September 2023.
20 June 2025	New citation required and conclusions have changed	Change in definition of virtual reality intervention with removal of the phrase ("and become immersed in") due to more contemporary awareness of the relationship of immersion within virtual reality intervention. This has not impacted the inclusion of studies from previous versions of the review. Review updated with 119 new studies (n = 4740 participants) with updated meta-analysis and new meta-analyses (cognitive function, quality of life and participation restriction). New findings relevant to clinical practice. In the previous version of the review (in Analysis 1.1), we found that virtual reality was not more beneficial than conventional therapy for upper limb function and activity. In this update, Analysis 1.1 contains 46 new studies, and we found that virtual reality may be slightly more beneficial than alternative therapy for upper limb function. Additional author added: Madison Chapman.

History

Protocol first published: Issue 2, 2010

Review first published: Issue 9, 2011

Date	Event	Description
19 January 2018	Amended	Two copy-editing errors corrected.

Virtual reality for stroke rehabilitation (Review)

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Registration and protocol

Protocol (2010) <https://doi.org/10.1002/14651858.CD008349>

Original review (2011) <https://doi.org/10.1002/14651858.CD008349.pub2>

Review update (2015) <https://doi.org/10.1002/14651858.CD008349.pub3>

Review update (2017) <https://doi.org/10.1002/14651858.CD008349.pub4>

Data, code and other materials

No additional data or materials.

Date	Event	Description
31 July 2017	New citation required and conclusions have changed	The conclusions of the review have changed.
31 July 2017	New search has been performed	We updated the searches to April 2017. We have added 35 new studies bringing the total number of included studies to 72, involving a total of 2470 participants. We have revised the review throughout. We re-ran the searches in April 2017 and have added new studies to the 'studies awaiting classification' list.
27 August 2014	New citation required but conclusions have not changed	The conclusions of the review have not changed.
27 August 2014	New search has been performed	We updated the searches to November 2013. We have added 18 new studies, bringing the total number of included studies to 37, involving a total of 1019 participants. We have revised the review throughout.

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ADDITIONAL TABLES

Table 1. Characteristics of studies focused on upper limb training

	Recruitment post-stroke	Comparison intervention	Amount of therapy provided	Virtual reality equipment
Adams 2023	> 6 months	Usual care	24 hours	Custom
Adie 2017	< 6 months	Alternative	21 hours or more	Nintendo Wii
Allegue 2023	> 6 months	Alternative	20 hours	Jintronix
Afsar 2018	< 3 months	Usual care	10 hours	Microsoft Kinect
Ain 2021	NR	Alternative	20 hours	Microsoft Kinect
Alves 2018	>6 months	3 arms: VR, Alternative, Usual Care	12.5 hours	Nintendo Wii
Anwar 2022	Unclear	Alternative	18 hours	Nintendo Wii
Askin 2018	>6 months	Alternative	20 hours	Microsoft Kinect
Assadi 2016	< 3 months	Alternative	12 hours	Nintendo Wii, PS2 EyeToy, PS3 Move
Bai 2022	< 6 months	Usual care	50 hours	Custom
Ballester 2017	>12 months	Alternative	5 hours	Rehabilitation Gaming System
Brunner 2017	< 3 months	Alternative	16 hours	YouGrabber
Byl 2013	> 6 months	Alternative	18 hours	Custom
Chen 2022	< 3 months	Alternative	10 hours	Custom
Cho 2021	< 3 months	Alternative	10 hours	Nintendo Wii
Choi 2014	< 6 months	Alternative	10 hours	Nintendo Wii

Table 1. Characteristics of studies focused on upper limb training (Continued)

Cinakli 2023	> 6 months	Usual care	10 hours	Microsoft Kinect
Coupar 2012	< 3months	3 arms: Low intensity VR, High intensity VR, Usual care	Variable	ArmeoSpring
Crosbie 2008	>6 months	Alternative	6 hours	Custom
da Silva Cameirao 2011	< 3months	3 arms: VR Custom, VR Nintendo Wii, Alternative	12 hours	Rehabilitation Gaming System, Nintendo Wii
Dhanusia 2023	< 3 months	Alternative	48 hours	Unclear
El Kafy 2021	> 6 months	Alternative	36 hours	Armeo
El Kafy 2022	> 6 months	Alternative	36 hours	Armeo
Esquenazi 2021	< 3 months	Alternative	7 hours	Armeo Spring
Fan 2014	>6 months	Alternative	9 hours	Nintendo Wii
Galvao 2015	NR	Alternative	11-20 hours	Nintendo Wii
Gueye 2021	< 3 months	Alternative	9 hours	Armeo Spring
Guo 2023	< 3 months	Alternative	15 hours	Custom
Hegazy 2022	< 6 months	Alternative	4 hours	Custom
Hernandez 2022	> 6 months	Alternative	7 hours	Jintronix
Housman 2009	>6 months	Alternative	24 hours	Custom
Huang 2022	> 3 months	Alternative	16 hours	Commercial: HTC Vive
Hung 2019	>6 months	Alternative	12 hours	Microsoft Kinect
Johnson 2020	< 3 months	Usual care	12 hours	Jintronix
Kaur 2020	< 6 months	Alternative	15 hours	Microsoft Kinect
Kim 2012a	>6 months	Usual care	5 hours	Nintendo Wii
Kim 2018a	>6 months	Alternative	62 hours	Microsoft Kinect
Kim 2018b	>6 months	Alternative	30 hours	Nintendo Wii
Kiper 2011	< 12 months	Alternative	20 hours	Custom: Reinforced Feed- back Virtual Environment
Kiper 2018	>6 months	Alternative	40 hours	Custom: Reinforced Feed- back Virtual Environment

Table 1. Characteristics of studies focused on upper limb training (Continued)

Klamroth-Marganska 2014	>6months	Alternative	18 hours	Custom
Kong 2014	< 3months	3 arms: VR, Alternative, Usual care	6-12 hours	Nintendo Wii
Kong 2016	< 3 months	3 arms: VR, Alternative, Usual care	12 hours	Nintendo Wii
Kottink 2014	< 6 months	Alternative	9 hours	Furball Hunt
Kuo 2023	> 6 months	Alternative	9 hours	Custom
Lee 2015b	>6 months	Alternative	4 hours	Custom
Lee 2016	>6 months	Alternative	9 hours	Custom
Lee 2016a	>12 months	Alternative	12 hours	Custom
Lee 2020	< 6 months	Alternative	12 hours	Custom
Leng 2022	< 6 months	Alternative	7.5 hours	Microsoft Kinect
Levin 2012	> 2 months	Alternative	6 hours	Custom
Lin 2021	>6 months	Alternative	15 hours	Custom
Linder 2015	<6 months	Alternative	40 hours	Custom
Luo 2023	> 6 months	Alternative	2 hours	Custom
Manlapaz 2010	>6 months	NR	6-10 hours	Nintendo Wii
Matsuo 2013	NR	Usual care	5 hours	Nintendo Wii
McNulty 2015	> 2 months	Alternative	20 hours	Nintendo Wii
Mekbib 2021	< 3 months	Alternative	16 hours	Custom
Miclaus 2020	< 6 months	Alternative	10 hours	MIRA
Norouzi-Gheidari 2019	>6 months	Usual care	4 hours	Jintronix
Ogun 2019	>6 months	Alternative	18 hours	Custom
Oh 2019	>6 months	Alternative	9 hours	Custom
Park 2021	< 1 month	Usual care	10 hours	Custom
Piron 2007	< 3months	Alternative	25-35 hours	Custom
Piron 2009	>6 months	Alternative	20 hours	Custom
Piron 2010	>6 months	Alternative	20 hours	Custom

Table 1. Characteristics of studies focused on upper limb training *(Continued)*

Prange 2015	< 3months	Alternative	9 hours	Custom
Rand 2017	>6 months	Alternative	30 hours	Microsoft Kinect and PS2 EyeToy
Reinkensmeyer 2012	> 2 months	Alternative	24 hours	Custom
Rodriguez-Hernandez	< 6 months	Alternative	12 hours	Custom
Saposnik 2010	< 3 months	Alternative	8 hours	Nintendo Wii
Saposnik 2016	< 3 months	Alternative	10 hours	Nintendo Wii
Schuster-Amft 2018	>6 months	Alternative	12 hours	YouGrabber
Shin 2014	<6 months	Usual care	4 hours	Custom
Shin 2015	<12 months	Alternative	20 hours	Custom
Shin 2022	1-3 months	Alternative	10 hours	Custom
Sin 2013	>6 months	Alternative	9 hours	Microsoft Kinect
Standen 2017	>3 months	Usual care	52 hours	Custom
Stockley 2017	>6 months	Alternative	9 hours	YouGrabber
Subramanian 2013	>6 months	Alternative	9 hours	Custom
Térémetz 2022	>6 months	Alternative	36 hours	Nintendo Wii
Thielbar 2014	>6 months	Alternative	18 hours	Custom
Tramontano 2020	< 6 months	Alternative	8 hours	Custom
Turkbey 2017	>6 months	Alternative	20 hours	Microsoft Kinect
Velmurugan 2023	3-9 months	Alternative	22 hours	Nintendo Wii
Wang 2017	< 3 months	Alternative	30 hours	Custom
Xiao 2022	6 months	Usual care	20 hours	Microsoft Kinect
Xie 2021	>6 months	Alternative	15 hours	Custom
Yavuzer 2008	< 12 months	Alternative	10 hours	Playstation EyeToy
Yin 2014	<3 months	alternative	15-17 hours	Custom
Zucconi 2012	>6 months	3 arms: VR with feedback, VR without feedback, usual care	20 hours	Custom (Reinforced Feedback Virtual Environment)

VR: virtual reality

Table 2. Studies reporting adverse events

Study	Adverse events reported
Allegue 2023	Four participants in the experimental group reported fatigue of the affected upper extremity; one participant in the experimental group reported an increase in pain in the less-affected upper extremity during the third month, although it did not seem to affect their adherence to the intervention.
Bower 2015	Several participants receiving the intervention had symptoms of pain, and one participant reported dizziness; however, these were not thought to be related to the intervention.
Crosbie 2008	Two people in the virtual reality group reported side effects of transient dizziness and headache.
Esquenazi 2021	Adverse effects included fatigue, falls, and pain; however, the number of events were low and were equivalent across groups.
Guo 2023	Twenty-eight adverse events were reported in the control group with an incidence rate of 46.67%, and 22 adverse events were reported in the experimental group with an incidence rate of 36.67% (no significant difference between groups), events judged by investigator to be irrelevant to the test system.
Huang 2022	Most common adverse symptoms were eye strain (46.67%) and sweating (46.67%), eye strain was the most intense (25.58%) followed by blurred vision (12.79%), fatigue (9.3%), sweating (9.3%), and dizziness (9.3%); however, most symptoms were mild, except for eye strain and blurred vision, which were reported to cause moderate discomfort.
Hung 2014	Three participants in the intervention group (out of 15) reported an increase in hypertonicity during treatment.
Kong 2016	Upper limb pain was the most common side effect experienced.
Kuo 2023	Shoulder soreness was most common in both groups, some participants felt shoulder pain, stiffness, or dizziness; however, the symptoms did not carry over to the next session after rest.
Lee 2017a	Occasions of upper limb soreness, hypertonicity, and dizziness; however, these were equivalent across groups
Liu 2023	In the experimental group, two participants reported dizziness without nausea and vomiting; two participants reported dry eyes; and three participants reported eye fatigue.
Turkbey 2017	Occasions of dizziness, fatigue, arm pain, and nausea (n = 4 reports) in people who participated in virtual reality

INDEX TERMS

Medical Subject Headings (MeSH)

Activities of Daily Living; Gait; Postural Balance; Psychomotor Performance; Quality of Life; Randomized Controlled Trials as Topic; Stroke [psychology]; Stroke Rehabilitation [*methods]; Therapy, Computer-Assisted [*methods]; Upper Extremity; User-Computer Interface; *Video Games

MeSH check words

Humans