Research

Rehabilitation that incorporates virtual reality is more effective than standard rehabilitation for improving walking speed, balance and mobility after stroke: a systematic review

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ABSTRACT

Question: In people after stroke, does virtual reality based rehabilitation (VRBR) improve walking speed, balance and mobility more than the same duration of standard rehabilitation? In people after stroke, does adding extra VRBR to standard rehabilitation improve the effects on gait, balance and mobility? **Design:** Systematic review with meta-analysis of randomised trials. **Participants:** Adults with a clinical diagnosis of stroke. **Intervention:** Eligible trials had to include one these comparisons: VRBR replacing some or all of standard rehabilitation or VRBR used as extra rehabilitation time added to a standard rehabilitation regimen. **Outcome measures:** Walking speed, balance, mobility and adverse events. **Results:** In total, 15 trials involving 341 participants were included. When VRBR replaced some or all of the standard rehabilitation, there were statistically significant benefits in walking speed (MD 0.15 m/s, 95% CI 0.10 to 0.19), balance (MD 2.1 points on the Berg Balance Scale, 95% CI 1.8 to 2.5) and mobility (MD 2.3 seconds on the Timed Up and Go test, 95% CI 1.2 to 3.4). When VRBR was added to standard rehabilitation, mobility showed a significant benefit (0.7 seconds on the Timed Up and Go test, 95% CI 0.4 to 1.1), but insufficient evidence was found to comment about walking speed (one trial) and balance (high heterogeneity). **Conclusion:** Substituting some or all of a standard rehabilitation regimen with VRBR elicits greater benefits in walking speed, balance and mobility in people with stroke. Although the benefits are small, the extra cost of applying virtual reality to standard rehabilitation is also small, especially when spread over many patients in a clinic. Adding extra VRBR time to standard rehabilitation also has some benefits; further research is needed to determine if these benefits are clinically worthwhile. **[Corbetta D, Imeri F, Gatti R (2015) Rehabilitation that incorporates virtual reality is more effective than standard rehabilitation for improving walking speed, balance and mobility after stroke: a systematic review. *Journal of Physiotherapy* 61: 117–124]**

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Introduction

Several studies have assessed stroke survivors' opinions about the conditions that facilitate activity and participation in daily life.[1,2] Over 70% of the respondents in these studies rated the ability to 'get out and about' in the community as very important.[1] However, nearly 40% of people who experience a stroke are either unable to walk or limited to walking within their immediate environment.[1] Because of this limited walking ability, they cannot participate in community activities, which leads to a reduced quality of life.[3,4] An objective of rehabilitation after stroke is to return the survivors to social and working activities.

The high repetition of task-oriented exercises[5] has been described as being important for locomotion recovery. In particular, the repetition of tasks connected to locomotion has been shown to be effective in many aspects such as improving walking distance and speed in people exhibiting motor deficits following stroke.[6] Virtual reality based rehabilitation (VRBR) is a relatively

recent approach that may enable simulated practice of functional tasks at a higher dosage than traditional therapies.[7,8] It consists of techniques that allow sensory experimentation through the interaction between humans and informatics technologies.[9] Virtual reality has been defined as the 'use of interactive simulations created with computer hardware and software to present users with opportunities to be engaged in environments that appear and feel similar to real-world objects and events'.[10] The key features of all virtual reality applications are the sense of 'presence in' and 'control over' the simulated environment.[11] The sense of 'presence in' consists of the feeling of being in an environment, even if not physically present in that environment; the sense of 'control over' involves the possibility of interaction with the environment and objects.[12] These two aspects distinguish virtual reality from other forms of visual imaging such as watching videos or television. VRBR attempts to simulate real-world activities, which may provide more involving tasks when compared to standard rehabilitation. The use of virtual reality encourages a higher number of exercise

repetitions.[13,14] It is also described as promoting motor learning through immediate feedback about performed tasks[15] that are related to real-life activities[16,17] such as navigation[18] and road crossing.[19,20]

Previous systematic reviews have reported a moderate advantage obtained from VRBR on body functions of the upper limb[21,22] and lower limb,[23] and on activities (especially those related to the lower limb[22,24,25]) when compared to standard rehabilitation in people with stroke. A Cochrane systematic review[26] published in 2015 concluded that there was insufficient evidence to draw conclusions about the effectiveness of VRBR in improving gait speed in people with stroke. More trials have been published since these earlier reviews conducted their searches, allowing for meta-analyses of more outcomes and more specific comparisons.

A lot of interactive gaming consoles are available and used in rehabilitation units[27,28] but virtual reality programs designed specifically for rehabilitation purposes are still expensive and, thus, not frequently used in clinical contexts. The development of a body of evidence about VRBR for the functional recovery of people after stroke may further assist the clinician in the choice of rehabilitation approach. The aim of this work was to systematically review published studies of the efficacy of VRBR versus standard rehabilitation in subjects presenting motor limitation following stroke. Studies performing VRBR of walking, balance and/or mobility were included in the review, assuming that a post-stroke physiotherapy program that targets deficits in balance may be also effective in restoring independent functional walking.[29] In fact, impaired balance seems to be related to a decreased locomotor function.[30,31] This review therefore sought to answer the following questions:

1. In people after stroke, does VRBR improve walking speed, balance and mobility more than the same duration of standard rehabilitation?
2. In people after stroke, does adding extra VRBR to standard rehabilitation improve the effects on gait, balance and mobility?

Method

Identification and selection of studies

In August 2014, the Cochrane Central Register of Controlled Trials (from 1929), PubMed (from 1950), Embase (from 1980), CINAHL (from 1982) and PEDro (from 1929) databases were electronically searched. A modified sensitivity maximising version of the Cochrane Highly Sensitive Search Strategy[32] was combined with the subject-specific search in order to identify randomised trials that tested VRBR to train stroke survivors who had motor deficits that impaired locomotion and balance. Four key terms – 'stroke', 'virtual reality', 'walking' and 'postural balance' – were used to generate a list of search terms, which were combined into a search strategy adapted to each database (Appendix 1 on the eAddenda).

Reference lists of identified studies and published reviews were manually checked for additional trials. References retrieved by the electronic search were compared for duplicate entries using the 'find duplicates' facility of reference management software[33] and were manually crosschecked. Two review authors (DC and FI) independently selected potentially eligible articles based on the titles and abstracts. Full-text copies of these articles were assessed against the inclusion criteria presented in Box 1. Disagreements were solved by discussion, with a third reviewer (RG) consulted if the disagreement persisted. Eligible studies underwent data extraction by two reviewers (DC and FI) who worked independently and used a piloted, standardised data collection form.

Assessment of characteristics of included studies

Quality

The quality of the included studies was analysed with the Cochrane Collaboration's tool for assessing risk of bias.[34] The

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Box 1. Inclusion criteria

Design
- Randomised or quasi-randomised controlled trial

Population
- Adults (> 18 years old)
- Clinical diagnosis of stroke (ischaemic or haemorrhagic)
- No other pathological conditions affecting lower limbs (eg, musculoskeletal disorders)

Intervention
- VRBR using head mounted devices or conventional workstation (eg, monitor, keyboard)
- Any intensity
- Duration exceeding a single treatment session

Outcomes
- Walking speed
- Balance
- Mobility

Comparisons
- VRBR replacing some or all standard rehabilitation
- VRBR added to standard rehabilitation versus standard rehabilitation alone

VRBR = virtual reality based rehabilitation.

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assessment was achieved by assigning a judgment of 'low risk' of bias when bias was considered unlikely to have seriously altered the results, 'high risk' of bias when the potential for bias seriously weakened confidence in the results, or 'unclear risk' when there was some doubt about the effect of bias on the results. It was applied for seven specific domains: sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective outcome reporting and 'other issues'. Considering the nature of the interventions in the included studies, blinding of the participants and personnel would have been impractical, so only outcome assessor blinding was considered.

Participants

To be eligible, studies had to have examined adults aged over 18 years and with a clinical diagnosis of ischaemic or haemorrhagic stroke, as defined by the World Health Organization.[35] Confirmation of the clinical diagnosis using imaging was not compulsory.

Intervention

Eligible studies evaluated VRBR that replaced, or was in addition to, standard rehabilitation to improve gait, balance and/or mobility in people after stroke. If the total regimen exceeded a single session, any duration of VRBR was acceptable. The VRBR had to meet the definition of Schultheis 2001:

an advanced form of human-computer interface that allows the user to 'interact' with and become 'immersed' in a computer-generated environment in a naturalistic fashion.[36]

The VRBR consisted of either a single type of exercise (eg, walking while watching videos or moving in a virtually reproduced setting) with various aims (eg, increasing walking speed, improving gait and balance) or in a combination of different types of exercises (eg, weight shifting toward the paretic side, proprioceptive neuromuscular facilitation, or muscle strengthening). Trials that compared different types of VRBR without a comparison group were not included.

Outcome measures

The primary outcome was walking speed evaluated with objective measures (eg, the 6-minute walk test, the 10-metre walk test, or instrumental gait analysis devices).[37] The secondary outcomes were: measures of balance, assessed with functional scales such as the Berg Balance Scale,[38] and mobility, evaluated with performance measures such as the Timed Up and Go test.[39] Data were extracted for the end of the intervention period and at

the longest follow-up point reported in each of the included studies. Any statements about adverse events were also noted.

Data analysis

Results from comparable trials were pooled using RevMan software.[40] For the primary outcome (walking speed), data in m/s were directly obtained from each article or they were converted to m/s from the reported test description and results. For example, the velocity for performing the 6-minute walk test was calculated by dividing the distance covered in metres by 360 seconds (total duration of the test), or the gait speed reported as m/min in the study of Jaffe and colleagues[41] was converted to m/s. For secondary outcomes, measures were similar among included studies; therefore, all results were expressed as mean differences on the same scale. Change scores and their standard deviations were used to compute pooled effect estimates. The pooled results from the meta-analyses were therefore expressed as weighted mean differences (MD) with 95% CI, in the original units of the measurement. Four authors of the included studies were contacted through emails for data not reported in their papers.[42–45] Two authors[42,43] replied and provided the unreported data. The remaining unreported measures of variability were estimated through the use of reported variances with an appropriate correction, as suggested in the Cochrane Handbook.[34] In one study[45] with non-parametric distribution of data, mean changes and their relative measures of variability were estimated with the method proposed by Hozo et al.[46] Heterogeneity was assessed by visual inspection of the forest plot and consideration of the I^2 statistic in conjunction with the chi-square test.[34]

Results

Flow of studies through the review

After screening the search results, 15 studies were identified for inclusion in the review.[41–45,47–56] Hand searching did not identify any additional papers. The flow of studies through the review is shown in Figure 1.

Characteristics of included studies

The included studies took place in seven countries: eight trials took place in Korea,[47–49,52–56] two in the USA,[41,44] one in Taiwan,[51] one in Singapore,[43] one in Brazil,[42] one in Spain[50] and one in Italy.[45]

Quality

The individual items achieved by each of the included studies are presented in Table 1. The quality of the trials was good, although in three out of 15, the randomisation procedure
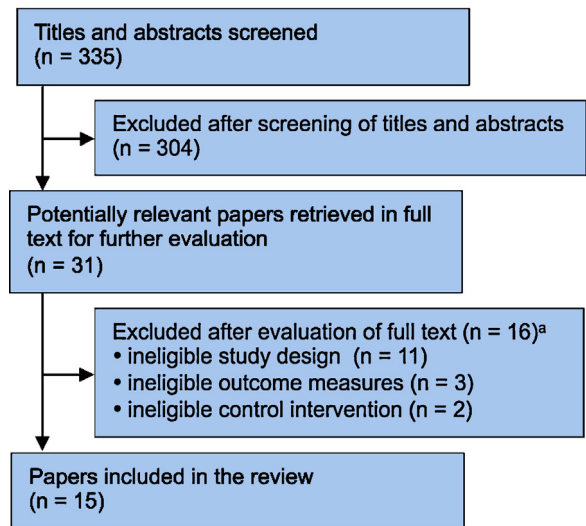

Figure 1. Flow of studies through the review.
[a]Papers may have been ineligible for failing to meet more than one eligibility criterion.

was unclear and half of the trials did not properly report the allocation procedure. The majority of the studies reported that the outcome assessors were blinded. Seven studies reported withdrawals[45,47–51,56] and provided the reasons for these dropouts. All trials were analysed on a per protocol basis. There were no marked differences in quality between the studies that had the same duration of treatment in both the experimental and control groups[41,43–45,47,49–52,54,56] and the studies that added VRBR to standard rehabilitation in order to produce a greater amount of treatment in the experimental group.[42,48,53,55]

Participants

The included studies involved 341 participants: 169 were randomised to receive VRBR and 172 to receive standard rehabilitation. The mean age of the participants in the included studies ranged from 53 to 65 years. About 44% of the participants were female. Table 2 reports the characteristics of the participants in the included studies. The majority of the studies enrolled subjects who had had an episode of ischaemic stroke more than 6 months before enrolment into the study. Where reported, they had preserved ability to walk with or without an assistive device[44,45,47–49,52–54] or the ability to maintain an upright posture.[42,50]

Intervention

In the experimental groups of 11 studies,[41,43–45,47,49–52,54,56] VRBR was integrated into or was used in place of standard rehabilitation, resulting in an equal total treatment time between

Table 1
Methodological quality of included studies.

Study	Random allocation	Concealed allocation	Assessor blinding	Dropouts (%)	Reasons for withdrawals	Selective reporting bias	Type of analysis
Barcala et al (2013)[42]	LR	LR	LR	0	-	LR	P
Cho et al (2012)[48]	LR	Unclear	Unclear	8	Yes	LR	P
Cho et al (2013)[47]	LR	LR	LR	12	Yes	LR	P
Cho et al (2014)[49]	LR	Unclear	LR	6	Yes	LR	P
Jaffe et al (2004)[41]	LR	HR	LR	0	-	Unclear	P
Jung et al (2012)[52]	Unclear	Unclear	LR	0	-	LR	P
Kang et al (2012)[56]	LR	LR	LR	< 1	Yes	LR	P
Kim et al (2009)[53]	LR	Unclear	LR	0	-	LR	P
Lloréns et al (2015)[50]	LR	LR	LR	9	Yes	LR	P
Mirelman et al (2009)[44]	LR	LR	LR	0	-	LR	P
Morone et al (2014)[45]	LR	LR	LR	< 1	Yes	LR	P
Park et al (2013)[54]	Unclear	Unclear	Unclear	0	-	LR	P
Rajaratnam et al (2013)[43]	LR	Unclear	LR	0	-	LR	P
Song et al (2014)[55]	Unclear	Unclear	Unclear	0	-	LR	P
Yang et al (2008)[51]	LR	Unclear	LR	16	Yes	LR	P

HR = high risk of bias, LR = low risk of bias, P = per protocol analysis, Unclear = unclear risk of bias.

Table 2
Summary of the included studies.

Study	Participants	Intervention	Outcome measures
Barcala et al (2013)[42]	n = 20 Age (yr) = 64 (SD 14) Gender = 9 M, 11 F	Exp = Conventional rehabilitation (60 min PT, 2/wk x 5 wk) + balance training on Nintendo WBB (30 min, 2/wk x 5 wk) Con = Conventional rehabilitation (60 min PT, 2/wk x 5 wk)	• Balance = BBS, TUG • Postural stability = COP oscillations • ADL Independence = FIM
Cho et al (2012)[48]	n = 22 Age (yr) = 64 (SD 8) Gender = 14 M, 8 F	Exp = Conventional rehabilitation (30 min PT + 30 min OT, 5/wk x 6 wk) + balance training on Nintendo WBB (30 min, 3/wk x 6 wk) Con = Conventional rehabilitation (30 min PT + 30 min OT, 5/wk x 6 wk)	• Balance = BBS, TUG • Postural stability = PSV

Cho et al (2013)[47]	n = 14
	Age (yr) = 65 (SD 5)
	Gender = 7 M, 7 F
		Exp = Conventional rehabilitation (30 min PT + 30 min OT + 20 min FES,
		  5/wk x 6 wk) and treadmill walking in virtual outdoor environment
		  (30 min, 3/wk x 6 wk)
		Con = Conventional rehabilitation (30 min PT + 30 min OT + 20 min FES,
		  5/wk x 6 wk) and treadmill walking training (30 min, 3/wk x 6 wk)
			• Balance = BBS, TUG
			• Gait kinematics = Spatiotemporal gait
			  parameters (including walking speed)

Cho et al (2014)[49]	n = 30
	Age (yr) = 65 (SD 6)
	Gender = 15 M, 15 F
		Exp = Conventional rehabilitation (30 min PT + 30 min OT + 20 min FES,
		  5/wk x 6 wk) and treadmill walking in a virtual outdoor
		  environment (30 min, 3/wk x 6 wk)
		Con = Conventional rehabilitation (30 min PT + 30 min OT + 20 min FES,
		  5/wk x 6 wk) and treadmill walking training (30 min, 3/wk x 6 wk)
			• Balance = BBS, TUG
			• Postural stability = PSV
			• Gait kinematics = Spatiotemporal gait
			  parameters (including walking speed)

Jaffe et al (2004)[41]	n = 20 Age (yr) = 61 (SD 10) Gender = 12 M, 8 F	Exp = Stepping over virtual objects on treadmill (60 min, 3/wk x 2 wk) Con = Stepping over real foam objects in a hallway (60 min, 3/wk x 2 wk)	• Gait endurance = 6MWT • Gait kinematics = Spatiotemporal gait parameters (including walking speed) • Others = Obstacle clearance test, Balance test • Adverse events
Jung et al (2012)[52]	n = 21 Age (yr) = 62 (SD 7) Gender = 13 M, 8 F	Exp = Treadmill walking in a virtual outdoor environment (30 min, 5/wk x 3 wk) Con = Treadmill walking training (30 min, 5/wk x 3 wk)	• Balance = TUG • Balance self-efficacy = ABC scale

Kang et al (2012)[56]	n = 30
	Age (yr) = 56 (SD 7)
	Gender = 16 M, 14 F
		Exp = Conventional rehabilitation (PT 5/wk x 4 wk) + treadmill walking
		  with optic flow (30 min, 3/wk x 4 wk)
		Con 1 = Conventional rehabilitation (PT 5/wk x 4 wk) + treadmill training
		  (30 min, 3/wk x 4 wk)
		Con 2 = Conventional rehabilitation (PT 5/wk x 4 wk) + stretching added
		  ROM exercises (30 min, 3/wk x 4 wk)
			• Balance = TUG
			• Walking speed = 10MWT
			• Gait endurance = 6MWT
			• Others = FRT

Kim et al (2009)[53]	n = 24
	Age (yr) = 53 (SD 9)
	Gender = 13 M, 11 F
		Exp = Conventional rehabilitation (40 min PT, 4/wk x 4 wk) + VR exercises
		  for balance and stepping skills (30 min, 4/wk x 4 wk)
		Con = Conventional rehabilitation (40 min PT, 4/wk x 4 wk)
			• Balance = BBS
			• Postural stability = PSV
			• Walking speed = 10MWT
			• Gait kinematics = Spatiotemporal gait
			  parameters (including walking speed)
			• Others = MMAS

Lloréns et al (2015)[50]	n = 20 Age (yr) = 57 (SD 11) Gender = 9 M, 11 F	Exp = Conventional rehabilitation (30 min PT, 5/wk x 4 wk) + stepping task in a 3D virtual environment (30 min, 5/wk x 4 wk) Con = Conventional rehabilitation (60 min PT, 5/wk x 4 wk)	• Balance = BBS, Tinetti POMA, BBA • Walking speed = 10MWT

Mirelman et al (2009)[44]	n = 18
	Age (yr) = 61 (SD 9)
	Gender = 15 M, 3 F
		Exp = Robot training for foot movements in a virtual environment
		  (60 min, 3/wk x 4 wk)
		Con = Robot training for foot movements without a virtual environment
		  (60 min, 3/wk x 4 wk)
			• Balance = BBS
			• Gait endurance = 6MWT
			• Gait kinematics = Spatiotemporal gait
			  parameters (including walking speed)
			• Others = FMA (lower extremity)
			Follow-up = 3 mth

Morone et al (2014)[45]	n = 47
	Age (yr) = 60 (SD 10)
	Gender = Unreported
		Exp = Conventional rehabilitation (40 min PT, 2 times/day x 4 wk)
		  + Nintendo WBB (20 min, 3/wk x 4 wk)
		Con = Conventional rehabilitation (40 min PT, 2 times/day x 4 wk)
		  + balance therapy (20 min, 3/wk x 4 wk)
			• Balance = BBS
			• Walking speed = 10MWT
			• ADL Independence = BI
			• Others = FAC

Park et al (2013)[54]	n = 16
	Age (yr) = 48 (SD 8)
	Gender = 11 M, 5 F
		Exp = Conventional rehabilitation (60 min PT, 5/wk x 4 wk) + VR-based
		  postural control exercises (30 min, 3/wk x 4 wk)
		Con = Two administrations of conventional rehabilitation (60 min PT,
		  5/wk x 4 wk) + (30 PT min, 3/wk x 4 wk)
			• Walking speed = 10MWT
			• Gait kinematics = Spatiotemporal gait
			  parameters (including walking speed)
			• Follow-up = 1 mth

Rajaratnam et al (2013)[43]	n = 19
	Age (yr) = 62 (SD 9)
	Gender = 7 M, 12 F
		Exp = Conventional rehabilitation (40 min PT, 15 sessions) + balance
		  training on Nintendo WBB or Microsoft Kinect (20 min, 15 sessions)
		Con = Conventional rehabilitation (60 min PT, 15 sessions)
			• Balance = BBS, TUG
			• Postural stability = COP oscillations
			• ADL Independence = MBI
			  Others = FRT

Song et al (2014)[55]	n = 20 Age (yr) = 63 (SD 14) Gender = 11 M, 9 F	Exp = Conventional rehabilitation (25 min PT, 5/wk x 3 wk) + VR-based balance training (25 min, 3/wk x 3 wk) Con = Conventional rehabilitation (25 min PT, 5/wk x 3 wk)	• Balance = BBS • Others = FI, SI, WDI

Yang et al (2008)[51]	n = 20
	Age (yr) = 58 (SD 11)
	Gender = 10 M, 10 F
		Exp = Treadmill walking in virtual outdoor environment (20 min,
		  3/wk x 3 wk)
		Con = Treadmill training simulating stepping obstacles (20 min,
		  3/wk x 3 wk)
			• Gait kinematics = walking speed
			• Others = ABC, WAQ, CWT
			• Follow-up = 1 mth

10MWT = 10-metre Walk Test, 6MWT = 6-minute Walk Test, ABC = Activities-specific Balance Confidence, ADL = activities of daily living, BBA = Brunel Balance Assessment, BBS = Berg Balance Scale, BI = Barthel Index, Con = control group, COP = centre of pressure, CWT = Community Walk Test, Exp = experimental group, F = female, FES = functional electrical stimulation, FI = Falling Index, FIM = Functional Independence Measure, FMA = Fugl-Meyer Assessment, FRT = Functional Reach Test, M = male, MBI = Barthel Index, MMAS = Modified Motor Assessment Scale, OT = occupational therapy, POMA = Performance-Oriented Mobility Assessment, PSV = Postural Sway Velocity, ROM = range of motion, SI = Stability Index, TUG = Timed Up and Go, WAQ = Walking Ability Questionnaire, FAC = Functional Ambulatory Category, WDI = Weight Distribution Index, PT = physiotherapy, VR = virtual reality, WBB = Wii Balance Board.

the experimental and control groups. Among these studies, the interfaces most frequently used for walking rehabilitation were virtual reality treadmill training systems.[41,47,49,51,52,56] Some consisted of a treadmill and a wide screen that projected a real-world video recording in order to reproduce an immersive virtual outdoor environment;[47,49,51] others used a head-mounted device instead of the monitor.[41,52,56] One study used the head-mounted device without a treadmill.[54] For balance training, one study[43] used Microsoft Xbox 360 Kinect[a], one study[45] used Nintendo Wii Fit[b] and one study[50] used an audio-visual system combined with a motion-tracking system in order to immerse participants in a 3D virtual environment. In the study of Mirelman and colleagues,[44] a robotic virtual reality device was used for training movement of the lower extremity.

In four studies,[42,48,53,55] VRBR was added to standard rehabilitation, resulting in a greater amount of treatment time in the experimental group. Two of these studies[53,55] used the IREX®[c] virtual reality system for rehabilitation of walking and balance. It consisted of a television monitor, a video camera, cyber gloves and virtual objects, scenes and a large screen. The other two studies only trained balance by using the Wii Fit balance program.[42,48]

Frequency of interventions varied from 2[42] to 6[41] days a week and lasted from 2[41] to 6 weeks.[47–49] The duration of each training session ranged from 20 minutes[51] to 1 hour.[41–44,50]

Outcome

Nine studies measured locomotor function: five used the 10-metre walk test,[45,50,53,56] two used the 6-minute walk test[41,44] and two measured gait velocity.[47,51] Balance was assessed using the Berg Balance Scale in nine studies[42,43,45,47–50,53,55] and mobility was assessed using the Timed Up and Go test in seven studies.[42,43,47–49,52,56] Outcomes were assessed immediately after the intervention. Only four studies included follow-up evaluations at 1[51,54] or 3[44,45] months after training.

Does VRBR improve outcomes more than the same duration of standard rehabilitation?

Walking speed

Walking speed was obtained from walking measures reported in seven studies[41,44,47,50,51,54,56] and converted to the same unit of measurement (m/s). These studies reported data on 138 participants, 65 of whom received VRBR. Replacing some or all of the standard rehabilitation with VRBR (for the same total treatment time) significantly improved walking speed, with a mean difference of 0.15 m/s (95% CI 0.10 to 0.19), as presented in Figure 2.
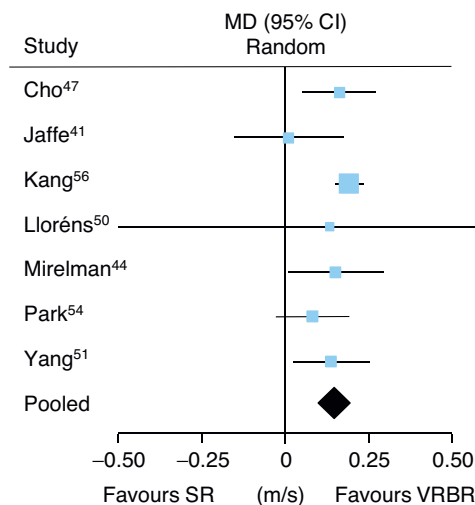

Figure 2. Weighted mean differences (95% CI) of the effect immediately after intervention of substituting some or all of standard rehabilitation (SR) with virtual reality based rehabilitation (VRBR) on walking speed, pooling data from seven trials (n = 138).
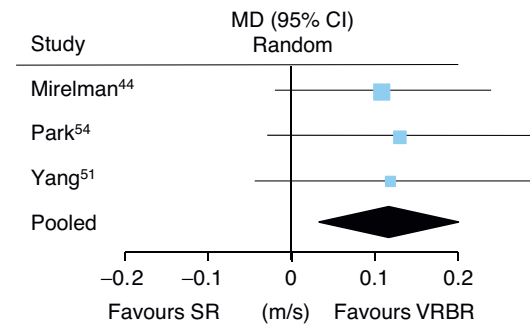

Figure 4. Weighted mean differences (95% CI) of the effect beyond the end of the intervention period of substituting some or all of standard rehabilitation (SR) with virtual reality based rehabilitation (VRBR) on walking speed, pooling data from three trials (n = 54).

See Figure 3 on the eAddenda for a more detailed forest plot. No important statistical heterogeneity was observed (I^2 = 26%).

Three studies measured walking speed beyond the end of the intervention period.[44,51,54] These studies reported data on 54 participants, 28 of whom received VRBR. The effect of the VRBR was well maintained for 1 to 3 months after the end of the intervention period, with a mean difference of 0.12 m/s (95% CI 0.03 to 0.20), as presented in Figure 4. See Figure 5 on the eAddenda for a more detailed forest plot. No statistical heterogeneity was observed (I^2 = 0%).

In addition to the studies that could be meta-analysed, Morone and colleagues[45] measured gait speed over 10 m but only reported percentage improvement. They reported that at the end of the 4-week intervention period gait speed improved by 35% in the experimental group and by 27% in the control group. One month after ceasing the intervention each group improved a further 6%. Although these differences were not statistically significant, they are in the same direction and of a similar magnitude to the meta-analysed studies of this review.

Balance

Balance was assessed with the Berg Balance Scale in five studies.[43,45,47,49,50] These studies reported data on 130 participants, 67 of whom received VRBR. Replacing some or all of the standard rehabilitation with VRBR (for the same total treatment time) significantly improved balance, with a mean difference of 2.1 points on the 0-to-56-point Berg Balance Scale (95% CI 1.8 to 2.5), as presented in Figure 6. See Figure 7 on the eAddenda for a more detailed forest plot. No statistical heterogeneity was observed (I^2 = 0%).

Mobility

Mobility was assessed using the Timed Up and Go test in five studies.[43,47,49,52,56] These studies reported data on 114 participants, 53 of whom received VRBR. Replacing some or all of the standard
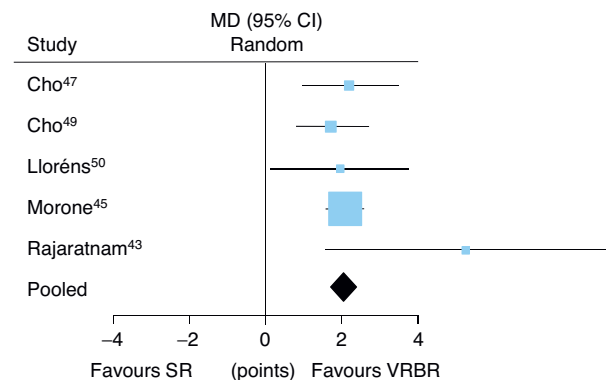

Figure 6. Weighted mean differences (95% CI) of the effect of substituting some or all of standard rehabilitation (SR) with virtual reality based rehabilitation (VRBR) on the Berg Balance Scale score *(0 to 56 points)*, pooling data from five trials (n = 130).
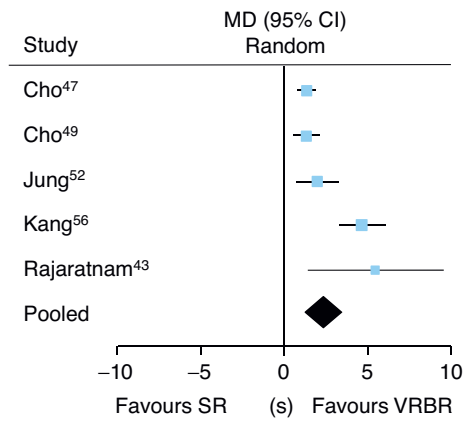
Figure 8. Weighted mean differences (95% CI) of the effect of substituting some or all of standard rehabilitation (SR) with virtual reality based rehabilitation (VRBR) on the Timed Up and Go test, pooling data from five trials (n = 114).

rehabilitation with VRBR (for the same total treatment time) significantly improved mobility, with a mean difference of 2.3 seconds on the Timed Up and Go test (95% CI 1.2 to 3.4), as presented in Figure 8. See Figure 9 on the eAddenda for a more detailed forest plot.

Substantial statistical heterogeneity was observed (I^2 = 84%), which was mainly due to the magnitude of the effect estimated from the studies of Kang et al[56] and Rajaratnam et al.[43] Performing a sensitivity analysis, through the exclusion of these studies from the overall estimation, the level of heterogeneity became acceptable (I^2 = 0%) with a similar estimate of 1.3 (95% CI 1.0 to 1.7). The analysis is presented in Appendix 2 on the eAddenda.

Adverse events

One of the study reports included a statement about adverse events, stating that there were no falls and no undue cardiovascular responses in either group.[41] However, some of the other study reports included statements that implied that adverse events would have been mentioned if they had occurred. For example, Yang et al[51] and Kang et al[56] stated that a staff member stayed close to each participant during the intervention in order to prevent falls.

Does adding extra VRBR to standard rehabilitation improve outcomes?

Walking speed

One study, involving 42 participants, assessed the effect of extra VRBR on walking speed.[53] Although the group that received the extra VRBR increased walking speed by an average of 0.21 m/s more than the standard rehabilitation group, this was not statistically significant (95% CI −0.23 to 0.65). This study did not assess outcomes beyond the intervention period.

Balance

Balance was assessed with the Berg Balance Scale in four studies.[42,48,53,55] These studies reported data on 86 participants, 43 of whom received the extra VRBR. These studies were too heterogeneous to be pooled (I^2 = 97%), as presented in Figure 10. See Figure 11 on the eAddenda for a more detailed forest plot.

Mobility

Mobility was assessed using the Timed Up and Go test in two studies.[42,48] These studies reported data on 42 participants, 21 of whom received the extra VRBR. The group that received the extra VRBR improved their mobility on the Timed Up and Go test significantly more than the standard rehabilitation group, with a mean difference of 0.7 seconds (95% CI 0.4 to 1.1), as presented in Figure 12. See Figure 13 on the eAddenda for a more detailed forest plot. No statistical heterogeneity was observed (I^2 = 0%).
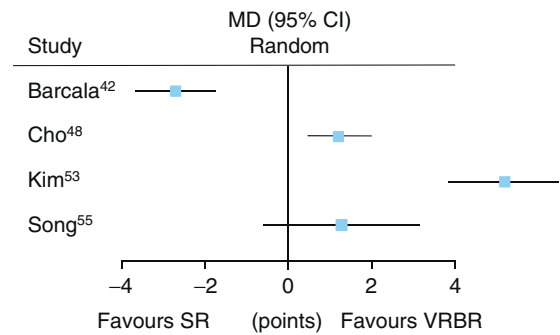

Figure 10. Mean differences (95% CI) of the effect of adding extra virtual reality based rehabilitation (VRBR) to standard rehabilitation (SR) on the Berg Balance Scale score *(0 to 56 points)*, with no pooling due to heterogeneity (n = 86).
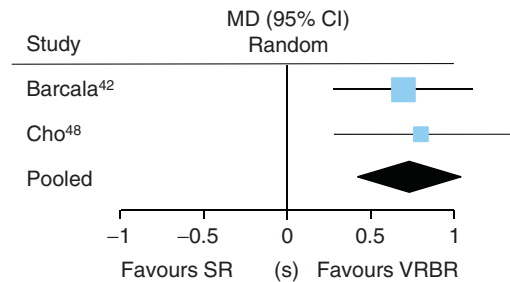

Figure 12. Weighted mean differences (95% CI) of the effect of adding extra virtual reality based rehabilitation (VRBR) to standard rehabilitation (SR) on the Timed Up and Go test, pooling data from two trials (n = 42).

Adverse events

None of the reports of the included studies made an explicit statement about adverse events, but some implied that no adverse events occurred. For example, Cho and colleagues stated that a staff member stayed close to each participant during the rehabilitation in order to prevent falls.[48]

Discussion

The meta-analyses in this systematic review identified some beneficial effects of VRBR on walking speed, balance and mobility outcomes in stroke survivors. These analyses are based on 15 eligible trials with a total of 341 participants, which exceeds the amount of data relating to clinical mobility outcomes that has been reported in past systematic reviews on VRBR after stroke.[21–26,57] Also, this review conducted meta-analyses for clinical mobility outcomes with separate meta-analyses depending on whether the VRBR was substituted for, or in addition to, standard rehabilitation. Only one of the past reviews conducted meta-analyses with this distinction, but it only analysed walking speed, not balance or mobility.[57] Therefore, while the results of this new review are consistent with the general finding of the past reviews (ie, that VRBR appears to be beneficial for people with stroke), some important new insights have been obtained.

The meta-analyses of those trials where the VRBR was substituted for some or all of the standard rehabilitation (to give the same total treatment time) showed significant improvements in walking speed, balance and mobility. These results indicate that, for a given treatment time, VRBR is more beneficial than standard rehabilitation. These findings predict that even greater effects would be seen in the remaining analyses (ie, those where the VRBR was provided as extra treatment time added to a standard rehabilitation regimen). However, this was not clearly observed in these outcomes for several reasons. For walking speed, only one study[53] analysed the effect of additional VRBR. The mean estimate (0.21 m/s) was greater than the effect seen in the earlier meta-analysis (0.15 m/s, Figure 2), but the result was insignificant. The wide confidence interval (95% CI −0.23 to 0.65) means that the potential for a strong benefit in walking speed from additional

VRBR has not yet been excluded; therefore, further research could help to refine this estimate. Although four studies reported data for balance, the studies were too heterogeneous to be pooled. When mobility was analysed, a significant benefit was observed. However, the effect (0.7 seconds on the Timed Up and Go test, Figure 12) was smaller than the effect seen in the earlier meta-analysis (2.3 seconds, Figure 8). This effect may also be too small to be considered clinically worthwhile by many patients; given that the time spent doing the additional VRBR in the included studies was 30 minutes, two to three times per week, for 5 to 6 weeks.

From the analysis of the included studies, it may not be possible to generalise about the efficacy of VRBR in motor recovery of the full range of people after stroke. First of all, most of the studies only recruited participants with mild motor impairment, as was demonstrated by their ability to walk independently and by the high Berg Balance Scale scores. Furthermore, almost all of the studies recruited people who had a stroke more than 6 months before study enrolment, with only three studies[43,45,55] evaluating the VRBR in acute stroke patients.

An open question is whether the changes induced by VRBR are clinically relevant. In previous studies, Flansbjer and colleagues[58,59] reported 95% CIs of the smallest real difference as –0.15 to 0.25m/s for comfortable walking speed, –3.4 to 4.9 points for the Berg Balance Scale and –3.8 to 2.6 seconds for the Timed Up and Go Test for individuals with chronic hemiparesis subsequent to stroke. Even though the smallest real difference is not an instrument to define clinical relevance, the fact that the noted effects were smaller than the smallest real difference limits the ability to conclude that these were real improvements.

The effect of VRBR on walking speed would seem to be maintained from 1 month[51,54] to 3 months[44] of follow-up. The optimal frequency, intensity, time and type of VRBR are still unclear. Finally, no adverse events were reported in the included studies, suggesting that VRBR can be considered a safe treatment for subjects after stroke.

The effects obtained by VRBR could be due to the multisensory (visual and auditory) feedback provided by virtual reality systems and to the influence of motivational aspects on motor performance.[25,60,61] These sensory information allow the central nervous system to better control position and orientation of body segments adapting to the complex external environment.[62] Moreover, You et al[63] suggested that treatment using virtual reality facilitates cortical reorganisation. The VRBR settings were also used to reproduce training activities that closely reproduce real-world tasks, which have been shown to maximise training effects.[64] This represents one of the most important features of exercises proposed in neurorehabilitation; they must be highly repetitive and task oriented in order to facilitate the recovery of functions and activities.[65]

The authors of several of the eligible studies[42,47,49,51,53] included statements that the VRBR was motivating and more involving than standard rehabilitation, although none of them directly assessed the attitude of participants toward VRBR.

Although this meta-analysis suggests that VRBR improves walking speed, balance and mobility in people with stroke more than the same time spent doing standard rehabilitation, further randomised trials with large sample sizes are encouraged. The additional data would help to confirm these results and to improve the precision of the estimates. Further trials that apply the VRBR as extra time added to a standard rehabilitation regimen will help to provide estimates specifically about this use, where the effects on walking speed and balance are unclear. Finally, further trials could also help to determine the optimal frequency, intensity, time and type of VRBR, as well as identifying what may be causing some of the heterogeneity seen in this review.

In conclusion, VRBR appears to produce greater benefits in walking speed, balance and mobility for a given amount of rehabilitation time than standard rehabilitation after stroke. VRBR did not appear to increase the likelihood of adverse events and it has been reported to increase motivation and involvement of people undergoing rehabilitation. Therefore, it appears to be justified to propose VRBR to people who have experienced a stroke in order to promote their recovery of walking speed, balance and mobility.

What is already known on this topic: Problems with walking speed, balance and mobility are common after stroke, but high repetition of task-oriented exercises can improve these sequelae. Virtual reality-based rehabilitation enables simulated practice of functional tasks, with moderate benefits on some upper and lower limb tasks over standard rehabilitation for people with stroke.
What this study adds: Substituting some or all of a standard rehabilitation regimen with virtual reality-based rehabilitation elicits greater benefits in walking speed, balance and mobility in stroke patients.

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