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The use of virtual reality in the rehabilitation of aphasia: a systematic review

Niamh Devane[a] 🔟, Nicholas Behn[a] 🔟, Jane Marshall[a] 🔟, Aparna Ramachandran[b] 🔟, Stephanie Wilson[c] and Katerina Hilari[a] 🔟

[a]Division of Language and Communication Science, School of Health and Psychological Sciences, City University of London, London, UK; [b]Division of Health Services Research and Management, School of Health and Psychological Sciences, City University of London, London, UK; [c]Centre for Human-Computer Design, School of Mathematics, Computer Science and Engineering, City University of London, London, UK

ABSTRACT

Purpose: This systematic review explored how virtual reality (VR) has been used to rehabilitate aphasia.

Materials and methods: Empirical studies were included where VR was used to target language, well-being, or quality of life in adults with acquired language impairment. Degenerative communication disabilities were excluded. Seven health databases were searched in October 2021. Risk of Bias was assessed using published checklists and completeness of intervention reporting evaluated. Narrative synthesis described forms of VR, rationales given, outcome measures, communication functions targeted, characteristics of interventions, and outcomes achieved within the framework of impairment, activity, and participation.

Results: Fourteen studies, involving 229 participants, met the criteria. The studies employed four forms of VR with various rationales given. Interventions used published and novel protocols. Primary outcomes targeted language impairment (12/14), activity (1/14), and well-being (1/14) and achieved positive outcomes in impairment and activity. All studies were exploratory. Risk of bias was high. Findings are discussed in the context of gains achieved by VR in other health contexts and the multi-user gaming literature.

Conclusions: Uses of VR in aphasia rehabilitation described in the literature are limited. Most applications target the remediation of language impairments. Opportunities to address activity, participation, and wider aspects of well-being are rare.

➤ **IMPLICATIONS FOR REHABILITATION**

- Research documenting the use of virtual reality (VR) to rehabilitate aphasia is limited and exploratory, so does not yet offer clear guidance for clinicians.
- Many of the identified studies have used known published protocols (e.g., naming therapy or scripts therapy) delivered through the novel VR format and focus on language impairment outcomes.
- VR offers clinicians a unique opportunity to address communication activity and participation through the use of multi-user virtual worlds, but this has only been explored by only two research teams.

Introduction

Aphasia is a neurological condition that affects a person's ability to use language [1]. The most common cause of aphasia is a stroke. At least a quarter of those who survive a stroke will experience aphasia [2]. It affects 0.1–0.4% of the population worldwide [3] and 35 000 people in the UK [4]. As stroke survival rates improve, more people are living with this lifelong disability [5].

Aphasia has a negative impact on people's lives. People lose their friends [6] with negative emotional effects [7]. Far-reaching consequences have been reported for social inclusion, social connectedness, access to information and services, equal rights, and well-being in family, community, and culture [1]. Social isolation is linked to premature death, and poorer well-being [8–10]. For these reasons, it has been argued that aphasia is a public health concern [11]. There is a need for therapies that address both the aphasia and its impact on people's lives.

Treatments for aphasia can focus on all levels of the International Classification of Functioning and Disability (ICF) framework [12] and go beyond the ICF to focus on well-being and Quality of Life (QOL). The language impairment (the body structure and function domain) has been targeted in treatments for words, sentences, or narratives (for reviews see [13–15]). Communication activity has been targeted in functional approaches [16] as has societal participation [17,18]. Aphasia is known to have a particularly negative impact on well-being, leading to depression [19,20] and reduced QOL [21–23]. Therefore, these constructs should form part of the focus of aphasia rehabilitation. The ICF framework, with the addition of well-being and QOL (hereafter referred to as ICF+) provides a structure for describing a wide range of potential rehabilitation outcomes in this review.

A key priority for people with aphasia is to improve communication in activities [24]. Using communication in a conversational

context has been described as "situated language use" [25] and is key to this aspect of rehabilitation. It places the language functions (naming, syntax, narrative structure) in the context of the environment, the number of people in the conversation, interpersonal history, and the multimodal (facial expression, gesture, tone) nature of conversations [26]. Multiple people and multiple environmental settings can be difficult to recreate in speech and language therapy sessions. There is a need for treatments that address this communication in context.

Virtual reality (VR) is the technology that allows one or many users to experience a three-dimensional space on a computer [27]. Multi-user virtual environments may be uniquely placed to treat communication in context. The potential to create faithful, simulated experiences has been harnessed for learning in a range of contexts. Examples include an island where you interact only in German [28] and recreations of surgical procedures for the training of medics [29]. The simulation allows for practice with minimal risk. The safe practice space that VR offers has been explored in other communication disabilities, notably autism [30]. This review will outline the ways the opportunity for simulated context has been used in aphasia rehabilitation.

The opportunities to interact with multiple users of VR may bestow social and emotional benefits. Indeed, such benefits have been reported in the gaming community where a sense of belonging and warm relationships are cited [31]. Multi-user gaming has been embraced by people with disabilities. Interviews exploring the value of gaming with this group have highlighted why gaming was important to them (see Box 1). In addition to benefits cited by the general gaming community, people with disabilities highlighted the benefits of a space where they can be on an equal footing with other users and practice skills and showed an appreciation for the creativity in design and storytelling [32].

VR can replicate real-world spaces or create novel environments. Some parts of the gaming community have embraced the development of novel creative spaces. There can be dream-like spaces (https://youtu.be/21FaS_bxReo) and worlds where the graphics are inspired by famous artists [33]. Experiences of fun and diversion [32] may have positive implications for mood and well-being. The potential for social and emotional benefits is notable in the context of the negative consequences of aphasia.

In stroke rehabilitation, there is a growing evidence base for the benefits of VR interventions in upper limb rehabilitation [34,35], balance and gait [36], cognitive function, and activities of daily living [37]. There is even some evidence that physical gains following VR rehabilitation may be accompanied by cortical changes [38]. Several reviews have examined the use of VR to improve motor outcomes after stroke using the ICF framework [39–42]. The most recent review identified 34 trials with impairment level outcomes, 17 trials with activity outcomes, and eight trials with a focus on participation [42]. This illustrates that VR is used in physical rehabilitation to address all levels of the ICF, with the most emphasis on impairment.

Synthesis studies of VR in aphasia rehabilitation have been published since 2020 [43–45]. In 2020, Repetto et al. investigated what innovative technologies (smartphones, tablets, and VR) were effective in post-stroke aphasia [45]. This systematic review included three studies that used VR. They were Marshall et al. [46] with EVA Park and Grechuta et al. [47,48] with the Rehabilitation Gaming System (RGS). Outcomes were descriptive with effect sizes reported for one study [46]. The authors concluded that the field was in its infancy.

Picano et al. carried out a review that sought to understand "existing unconventional approaches" [42, p. 2] to aphasia rehabilitation in 2021 [44]. They included eight studies that used VR. The review gave a narrative description of EVA Park [46,49–51], RGS [52,53], the Virtual Reality Rehabilitation System (VRRS) tablet [54], and Giachero et al.'s use of VR for functional communication situations [55]. The authors concluded that VR has the potential to increase treatment dose, maximise sensorimotor stimulation and, overall, improve ecological validity of aphasia treatment [44].

Cao et al. carried out a systematic review and meta-analysis of the effects of VR on post-stroke aphasia in 2021 [43]. They explored whether VR interventions had an effect on communication activity and language function compared to a control condition. The five studies included were EVA Park [46], RGS [48], the VRRS tablet [54], VR for communication situations [55], and a conference paper exploring a virtual reality panoramic helmet [56]. The review found a borderline effect of reducing language severity and no difference between VR and control for communication activity, word finding, or repetition outcomes. The control conditions were both an alternative SLT treatment and no treatment. The conclusions of this review were supported by meta-analyses; however, these were based on limited data (two studies per meta-analysis) and combined studies that employed different treatments (e.g., naming therapy combined with a conversation therapy) and different outcome measures (Communication Activities of Daily Living combined with the Communication Activities Log).

The current review updates and broadens the scope of these previous reviews. Firstly, it places greater emphasis on the rationales for using VR, the therapy goals, how they were measured and how VR was employed to enhance the therapy experience. The quality of reporting is also explored. Secondly, this review is not restricted to post-stroke aphasia. Aphasia can be caused by other brain pathology, e.g., a brain injury, tumour, or surgery. We did not restrict the underlying cause of aphasia. Moreover, given that VR use is an emerging field in this area we broadened the scope of the review to acquired non-progressive language disorders. This review sought to identify the ways in which VR has been used to support language and communication rehabilitation, particularly in reference to the domains of the ICF. Previous reviews highlight that VR has particular value in providing ecological validity, aligning with the activity domain of the ICF [44]. However, the use of VR in rehabilitation is a recent innovation, meaning that applications in aphasia were likely to be limited. The authors were therefore interested in innovations in related disorders that could inform the development of VR for aphasia rehabilitation. Thus, we included cognitive communication

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Box 1. Why gaming is important to players with disabilities [32].

Connecting:	A way of bringing people together both as friends and family but also to build communities.
Diverting:	A distraction from problems and a way to relax and unwind from day-to-day stresses and to enter different worlds.
Beneficial:	Playing games can bring about benefits to players outside of the world, such as developing skills or learning about the world.
Art:	Games are of intrinsic value to players because they are a form of creative expression for both developers and players.
Fun:	Games are to be enjoyed.
A way of life:	Players play games because that's something that they have always done and always want to do.
Universal:	Players felt that games have something for everyone.
Enabling:	For the players with disabilities, games were a way to be on an equal footing with everyone else.

disorder, a related disorder where the communication deficit is due to impaired cognitive functions rather than language [57].

This review aimed to find out how VR has been used in the rehabilitation of acquired communication disorders. Specifically, it explored the following research questions:

i.   What forms of VR were used?
ii. What rationale(s) were given for the use of VR?
iii. What outcome measures were used?
iv. What communication functions were targeted?
v.   What were the characteristics of the interventions?
vi. What outcomes were achieved?

Methods

The reporting of this review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline. The protocol was prospectively registered with PROSPERO (CRD42020196285).

Eligibility criteria

Studies were eligible if VR was used in an intervention study targeting any of the following for people with aphasia or acquired cognitive communication disorder: language, communication activity, participation, well-being, and quality of life. There were no language restrictions and dates were the earliest available within each database.

The population was defined as adults (>18 years) with aphasia and/or cognitive communication disorders following a stroke or traumatic brain injury. Mixed population studies were only included if outcomes were reported separately for people with aphasia or cognitive communication disorder. Studies of motor speech disorders were excluded. Degenerative language disorders, such as dementia, progressive neurological conditions, and primary progressive aphasia were excluded. In degenerative conditions the aims and methods of rehabilitation are different, and it would not be valid to conflate progressive and non-progressive participants.

For this review, we defined virtual reality as a set of images and sounds produced by a computer that seems to represent a real or imagined place or situation that a person can take part [27]. Both immersive (using equipment, such as a head-mounted display) and non-immersive (interacting with an image on a screen) 3D environments were included. 2D applications were excluded. Studies had to report on empirical data with experimental controls and be published in a peer-reviewed journal. Beyond this, there were no constraints on study design, i.e., experimental single case and case series designs were included. New data had to be reported, so review papers were excluded. Box 2 summarises the Population, Intervention, Comparison, and Outcome of interest (PICO) in this systematic review.

Information sources

Seven electronic databases were searched following consultation with the subject librarian: CINAHL, Communication source, MEDLINE, Academic Search Complete, PsycINFO, Embase, and Ovid Emcare. Citation tracking from eligible articles was carried out using Scopus. Searches were run on 30 June–3 July 2020 and repeated on 19, 20, and 21 October 2021.

Search strategy

Search terms were variations on three concepts: acquired language impairments, rehabilitation, and virtual worlds. Search strings varied slightly depending on the MESH terms within each database. Truncation (*) was used to capture variations in terms, e.g., aphasia/aphasic. Box 3 illustrates an example search string. Full searches are available in Appendix 1.

Study selection

Screening on title and abstract used the following hierarchy:

1. Participants were adults with aphasia or acquired cognitive communication disorder following a stroke or other acquired brain injury.
2. Virtual reality was used.
3. Intervention studies to remediate language impairment, communication activity, participation, or quality of life were reported.

Full-text articles were included if:

1. Participants had aphasia or acquired cognitive communication disorder.
2. Intervention targeted language impairment, communication activity, participation, or quality of life.
3. Empirical data was reported with an experimental control, e.g., across time or a comparator group.
4. Immersive or non-immersive virtual reality was used.
5. The publication was peer-reviewed.

Data collection process

Search results were double screened on title and abstract, and full-text articles were double screened independently by the first (ND) and fourth author (AR). A data extraction table was developed in Microsoft Excel to cover study characteristics, participants, intervention, outcomes, and VR aspects. Data were extracted independently by ND and AR and any discrepancies were resolved by

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Box 2. Population, intervention, comparison and outcome (PICO) framework.

P   Adults (>18 years) with aphasia or acquired cognitive
    communication disorder following stroke or traumatic brain injury
I   Therapy delivered by immersive or non-immersive virtual reality
C   Experimental control: multiple baselines or control group of
    alternative treatment, usual care, placebo, or no treatment
O   Changes at any level of the ICF (language function, activity,
    participation) or well-being and quality of life

Box 3. Search string example.
"aphasi*" OR "dysphasi*" OR "cognitive communication"
AND
"rehabilitation" OR "speech therap*" OR "intervent*" OR "treat*" OR
    "train*" OR "program*" OR "language therap*" OR "social support"
    OR "stimulat*" OR "speech patholog*" OR "language patholog*"
AND
"virtual world*" OR "virtual reality" OR "virtual environment" OR "video
    games" OR "computer simulat*" OR "virtual" OR "augmented reality"
    OR "augmented virtuality" OR "mixed reality" OR "virtual reality
    exposure therapy" OR cyberspace OR "immersive environment" OR
    "multi-user virtual environment"

discussion between reviewers. If consensus could not be reached, a third senior researcher (KH) had the deciding vote.

The aim of the intervention was determined by the primary outcome measure used. Outcome measures of selected studies were mapped onto the ICF + categories. For example, a language test as primary outcome measure (e.g., The Western Aphasia Battery–Revised [58]) indicated the use of VR to change language impairment (ICF domain: impairment), whereas a communication test (e.g., The Communication Activities of Daily Living [59]) indicated the use of VR to change activity (ICF: activity). All outcome measures (primary and secondary) and ICF + domains were independently mapped by two authors (ND and KH). These decisions were subsequently checked against the categorisation published by Wallace et al. [60] and found to be in agreement, with the exception that Wallace collapsed activity and participation into one category. Secondary outcome measures were recorded to indicate intervention aims that targeted additional levels of the ICF. Discrepancies were resolved by discussion between reviewers. If consensus could not be reached, a third senior researcher (JM) had the deciding vote.

Data items

Data items described (i) the forms of virtual reality employed, (ii) the theoretical basis given by authors for employing virtual reality, (iii) the primary and secondary outcome measures used, (iv) the ICF domain targeted by these measures, (v) the intervention characteristics, and (vi) the outcomes achieved/changes reported on outcome measures. Additional variables collected were participant number, age, sex, aphasia type, time post-onset, study setting, and country. If data was missing it was indicated as not reported.

Risk of bias

Completeness of the intervention reporting was explored using the TIDieR framework [61]. The framework outlines 12 items that should be reported. A complete TIDieR framework indicates a high quality of reporting that provides enough information for researchers and clinicians to replicate the intervention. Information from each study was extracted to complete the TIDieR framework by the first author (ND) with 35% (5/14 studies) independently extracted by the second author (NB). Discrepancies were resolved by discussion. Each study was given a point if the item was present in the report, to give each study a rating out of 12 for completeness of reporting.

The Physiotherapy Evidence Database (PEDro) scale [62] was used to rate the methodological quality of randomised and non-randomised controlled trials. This is an 11-item checklist that gives a total score out of 10 (item 1 does not contribute to the total score). Quality is considered excellent if a study scores 9–10, good if a study scores 6–8, fair if a study scores 4–6, and poor if a study scores <4.

The Risk of Bias in N-of-1 Trials (RoBiNT) [63] scale was used to assess single-case experimental designs. This 30-item checklist addresses the internal and external validity of studies. The RoBiNT authors subsequently published an algorithm to qualify the methodological rigor of the internal validity [64]. A flow chart is followed to arrive at one of 10 grades from "very low" to "very high." A point to note is that the RoBiNT tool was designed for studies that have dramatic "on-off" effects [65, p. 621] where a decline in performance is hypothesised when treatment is withdrawn. Conversely, in speech and language therapy intervention studies the very aim of treatment is for lasting effects. Participants

are not expected to revert completely to pre-treatment levels when the stimulus (treatment) is removed. Nevertheless, this design is considered "non-withdrawal" and described as an AB + maintenance design in RoBiNT and scores 0 [63]. If a study scores a 0 for design it can only score as "very low" for quality in the algorithm [64, p. 12].

National Heart, Lung and Blood Institute (NIH) Quality Assessment tool for Before After studies with no control group was used to rate before-after studies with the condition rather than group control. This 12-item checklist addresses the internal validity of a study. Quality descriptions followed published guidance [66], based on the number of items in the quality tool that was not present: a score of 0–3 N (N = not present) indicates a low risk of bias, a score of 4–8 N indicates a moderate risk of bias, and a score with 9–11 N indicates a high risk of bias.

Each study was rated for risk of bias independently by two authors (RoBiNT: ND, AR, KH, and JM; PEDro: ND, AR, and NB; NIH Quality Assessment tool: ND and AR). Allocation ensured that authors did not rate their own publications. Disagreements were resolved by discussion.

Summary measures and data synthesis

Descriptive statistics were used to summarise participants. Descriptive information and a narrative synthesis described the focus and detail of interventions, outcome measures used, VR used, and underlying theory. These were tabulated Microsoft Excel. The TIDieR was used to summarise completeness of reporting. Low quality studies are known to provide biased results [67]. Therefore, only studies of adequate quality were included in the synthesis of outcomes. These were studies that scored 4 and above on the PEDro scale, graded as fair-to-very high on the RoBiNT scale, and moderate to low risk of bias on the NIH quality assessment tool. Where data permitted, effect sizes were calculated (d = 0.2, medium is d = 0.5, and large d = 0.8) [68]. A meta-analysis was planned for eligible group-level studies that used the same outcome measures using standardised mean differences (SMD) and a fixed-effect model. However, heterogeneity in the outcome measures was high and a meta-analysis was not feasible.

Results

Study selection

The search of seven databases identified 639 articles with a further 13 identified through citation tracking on Scopus. All 652 records were imported into the evidence synthesis software, EPPI Reviewer [69]. The software removed 232 duplicates. The title and abstract of the remaining 420 articles were screened against the inclusion criteria by ND and AR. 392 were excluded from the review because they did not involve adults with aphasia or acquired cognitive communication disorder (n = 244), did not use virtual reality (n = 68) or they were not intervention studies (n = 78) and two further duplicates were found by reviewers. Full-text articles were retrieved for the remaining 28 records. Two were not available as they were abstracts from conference proceedings. The full text was reviewed of the remaining 26 articles by ND and AR. 12 more were excluded at this stage as they did not meet the inclusion criteria (see Figure 1). Fourteen articles met the criteria and were included in the review.

The review process had a good agreement between raters, with 95% agreement on title and abstract decisions and 89% agreement on full text (25/28). Disagreements were resolved with discussion.
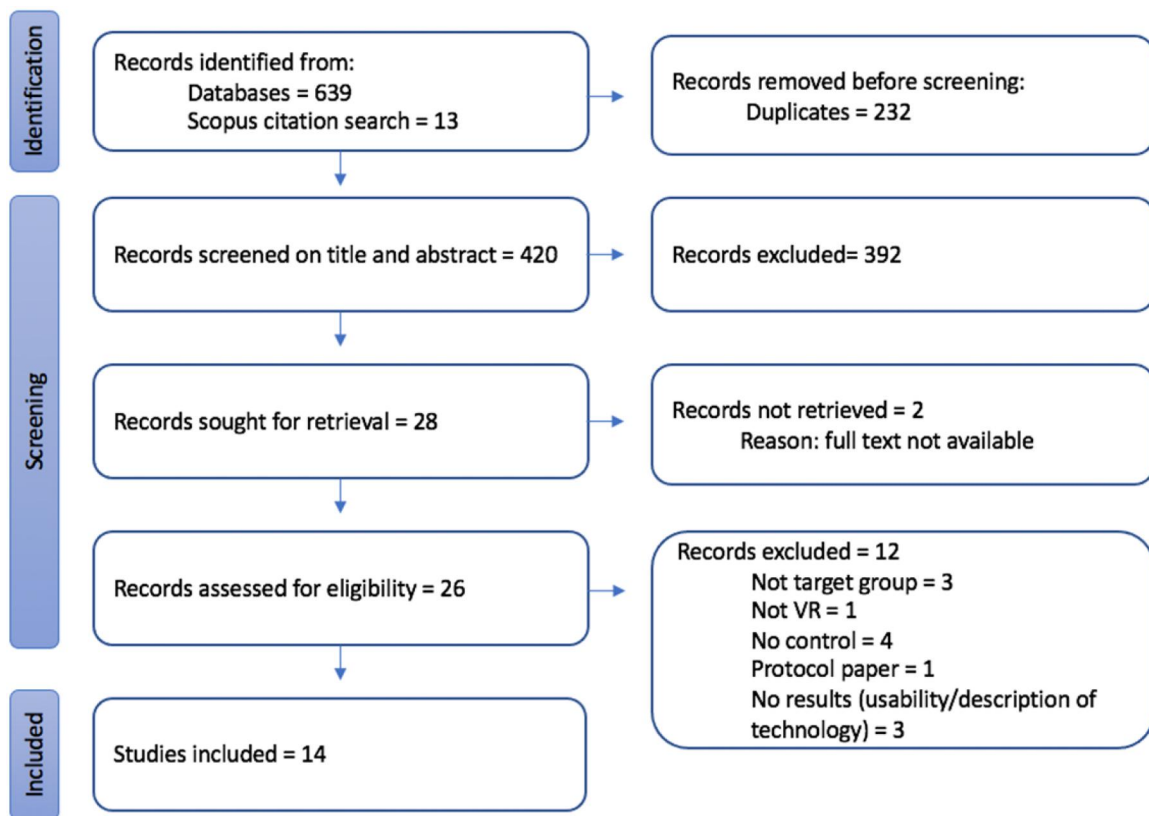
Figure 1. PRISMA flow diagram of study selection process.

Study characteristics

Fourteen articles were included in the review. These articles represent 14 different studies investigating seven different examples of virtual reality in aphasia rehabilitation. They represent the work of seven research teams, working in the UK ($n = 1$) (EVA Park) including a collaboration with Australia, Spain ($n = 1$) [Rehabilitation Gaming Software (RGS)], Italy ($n = 2$) [NeuroVR 2.0 and Virtual Reality Rehabilitation System (VRRS-tablet)], and the USA ($n = 3$) (Sentactics, AphasiaScripts/Web ORLA and the Virtual Human tool-kit [70]). No articles were found on empirical research investigating the use of VR to rehabilitate the language of people with the acquired cognitive-communication disorder.

Seven studies were randomised controlled trials, five were single case studies and two were before-after studies with no control group, where the experimental control was different conditions within the group, e.g., two different cuing methods. All studies were described as exploratory: they described feasibility, pilot, or efficacy studies or reported a sample size too small to be a definitive effectiveness study. Study characteristics are summarised in Table 1.

Participant characteristics

The fourteen studies reported on a total of 229 adults with aphasia, 95 female and 134 males. Almost all were in the chronic stage post-stroke (>6 m), with only one participant reported as <6 months post-stroke. Where mean age was reported (nine studies), all means were younger than 60 years old and ages ranged from 40 to 71 years. Where reported (11 studies), participants were predominantly people with non-fluent aphasia, $n = 119$ vs. $n = 26$ with fluent aphasia. The studies were carried out in three settings:

community, hospital, and research laboratory. Table 1 summarises the studies and study participants.

Risk of bias

The seven randomised control trials were quality assessed using the PEDro scale, see Table 2. Two studies were rated as good quality (6–8/10) [48,73], three studies were rated as fair (4–5/10) [46,51,55] and two were rated poor (<4/10) [54,76].

The five single case studies were rated using the Risk-of-Bias in N-of-1 trials (RoBiNT) tool, see Table 3. These studies received scores ranging from 7 to 18/30 on the RoBiNT 30-item scale, with four studies scoring 15–18/30 and one 7/30. All five studies scored higher on external validity than internal validity. As expected, all five studies were scored as very low quality, when the RoBiNT algorithm was applied, despite the variability in scores. A score for blinding in the intervention was given for one study only where stimuli were computer delivered [75]. None of the studies received points for replication.

The final two studies were assessed for bias using the NIH Quality Assessment tool for Before After studies with no control group, see Table 4. Both studies were judged to have a moderate risk of bias. Neither study reported whether all participants who were eligible were enrolled, gave a rationale for the sample size, blinded assessors, or reported follow-up rate.

Completeness of intervention reporting was assessed using the TIDieR checklist [61], see Table 5. Complete reporting allows for the replication of interventions for research and clinical practice. The 14 studies scored from 6 to 10 on the 12-point scale. The rationale, materials, and procedures, mode of delivery, schedule, and dose (items 2, 3, 4, 6, and 8) were most consistently reported.

Table 1. Study ($n = 14$) and participant ($n = 229$) characteristics.

Study	Design	Country/setting	Participants (sex F/M) Mean age (SD) in years	Time post-onset in months Case series: individual values; group studies: means (SD) or medians (IQR)	Aphasia type
Carragher et al. [71]	Case series	Australia and UK/ community	$n = 3$ (3F) 52, 64, and 68 years	18, 79, 94	Non-fluent = 2 Fluent = 1
Cherney et al. [72]	Before–after study with no control group	USA/not reported	$n = 20$ (6F, 14M) 56.9 (8.4) years	55.1 (6.4–396.4)	Non-fluent = 17 Fluent = 3
Cherney et al. [73]	Randomised control trial	USA/hospital	$n = 32$ (13F, 19M) EG: 58.27 (13.55) CG: 55.19 (11.56)	EG: 39.75 CG: 60.97	Non-fluent = 18 Fluent = 14
Giachero et al. [55]	Randomised control trial	Italy/research lab	$n = 36$ (12F, 24M) 59.75 (11.21)	42.75	Non-fluent = 36 Fluent = 0
Grechuta et al. [47]	Case series	Spain/hospital	$n = 4$ (2F, 2M) 40, 58, 62, and 63 years	5, 7, 31, 46	Non-fluent = 4 Fluent = 0
Grechuta et al. [48]	Randomised control trial	Spain/hospital	$n = 17$ (8F, 9M) 54.6 (9.9)	59.94 (47.83)	Non-fluent = 17 Fluent = 0
Grechuta et al. [53]	Group controlled trial	Spain/hospital	$n = 10$ (5F, 5M) 57.6 (9.9)	69.9 (48.7)	Non-fluent = 10 Fluent = 0
Kalinyak-Fliszar et al. [74]	Case series	USA/research lab	$n = 4$ (1F, 3M) 49, 49, 51, and 51 years	12, 44, 63, 103	Non-fluent = 2 Fluent = 2
Maresca et al. [54]	Randomised control trial	Italy/hospital and community	$n = 30$ (16F, 14M) 51.2 (11.3)	Not reported	Not reported
Marshall et al. [46]	Quasi randomised waitlist controlled	UK/community	$n = 20$ (9F, 11M) 57.8 (11.58)	62.10 (53.56)	Not reported
Marshall et al. [50]	Case series	UK/community	$n = 2$ (2M) 60 and 54 years	36, 60	Non-fluent = 1 Fluent = 1
Marshall et al. [51]	Randomised control trial	UK/community	$n = 34$ (17F, 17M) 53.5, IQR: 48.75–71	46.5 (15–83.75)	Not reported
Snell et al. [75]	Case series	USA/research lab	$n = 5$ (1F, 4M) 49, 55, 56, 62, and 65 years	25, 98, 99, 172, 175	Non-fluent = 0 Fluent = 5
Thompson et al. [76]	Group controlled trial	USA/research lab	$n = 12$ (2F, 10M) 49.5 (10.96)	59.8	Non-fluent = 12 Fluent = 0

M: male; F: female; EG: experimental group; CG: control group; SD: standard deviation; IQR: interquartile range.

Table 2. Randomised controlled trials rated using the PEDro.

PEDro item	Cherney et al. [73]	Giachero et al. [55]	Grechuta et al. [47]	Maresca et al. [54]	Marshall et al. [46]	Marshall et al. [51]	Thompson et al. [76]
1. Eligibility specified*	Y	Y	Y	Y	Y	Y	y
2. Random allocation	1	1	1	1	0	0	1
3. Concealed allocation	0	1	1	0	0	0	0
4. Similar at baseline	1	0	1	0	1	0	0
5. Blind subjects	0	0	0	0	0	0	0
6. Blind treating therapist	1	0	0	0	0	0	1
7. Blind assessor	1	1	1	0	0	1	0
8. Retention > 85%	1	0	1	0	1	1	0
9. Intention to treat analysis	0	0	1	0	1	1	0
10. Between group comparisons	1	1	1	1	1	1	1
11. Point measures and variability measures	1	1	1	1	1	1	1
Total	7/10	5/10	8/10	3/10	5/10	5/10	4/10
Quality	Good	Fair	Good	Poor	Fair	Fair	Poor

Scoring: 1 = reported; 0 = not reported. Quality: 9–10/10 excellent, 6–8/10 good, 4–5/10 fair, ≤4/10 poor.
*Item does not contribute to the score.

Tailoring, modification, and treatment fidelity (items 9–12) were rarely reported.

Forms of VR used

Various forms of VR were used in a range of different ways. The treatment was delivered by the computer program or a therapist, the user was represented in the VR or not, the VR was single user or multi-user, the navigation was user-controlled or not, and finally, the VR environment was of a virtual clinician, a scenario, or a virtual world. These are summarised in Table 6 and described in this section.

In six of the studies reported, the treatment was delivered by the computer program [54,72–76]. These include the programs using a virtual clinician; AphasiaScripts, Web ORLA, Sentactics, the Virtual Human toolkit, as well as the VRRS-tablet which uses virtual scenarios. The Web ORLA/AphasiaScripts and Sentactics VR applications are based on the virtual agent software from the Centre for Spoken Language Research at the University of Colorado [76]. The VR depicts the moving head and shoulders of a clinician. The virtual clinician is pre-programmed to deliver the treatment. Her lips move in a naturalistic way to give visuomotor prompts. Snell et al. [75] used the Virtual Human toolkit software [77]. The VR shows the full body of a virtual clinician avatar standing outside a café. In the five programs using a virtual clinician, the user is not represented in the virtual world. These five programs are for a single user. In the studies, the navigation of the program was controlled by the participant [73,76], a physically

Table 3. Single case designs rated using the RoBiNT.

RoBiNT items	Carragher et al. [71]	Grechuta et al. [47]	Kalinyak-Fliszar et al. [74]	Marshall et al. [50]	Snell et al. [75]
1. Design with control	0	0	0	0	0
2. Randomisation	0	1	1	0	0
3. Sampling of behaviour	1	2	2	0	1
4. Blinding in intervention	0	0	0	0	1
5. Blinding of assessors	2	2	0	2	0
6. Interrater agreement	1	1	2	0	0
7. Treatment adherence	0	2	0	2	0
Internal validity score:	4/14	8/14	5/14	4/14	2/14
8. Baseline characteristics	0	1	2	1	0
9. Setting	2	2	1	2	1
10. Dependent variable	2	2	2	2	1
11. Independent variable	2	2	2	2	1
12. Raw data record	2	2	2	2	1
13. Data analysis	1	1	1	1	1
14. Replication	0	0	0	0	0
15. Generalisation	2	0	1	2	0
External validity score	11/16	10/16	11/16	12/16	5/16
Total	15/30	18/30	16/30	16/30	7/30
Quality	Very low	Very low	Very low	Very low	Very low

Scoring: each item is scored on three-point scale 0–2, where 2 represents the highest quality.

Table 4. NIH quality assessment tool for before after studies with no control group.

NIH quality assessment tool item	Cherney et al. [72]	Grechuta et al. [47]
1. Objective clear	Y	Y
2. Eligibility specified	Y	Y
3. Participants representative	Y	N
4. All eligible enrolled?	N	N
5. Sample size	N	N
6. Intervention	Y	Y
7. Outcome measures	Y	N
8. Blinded assessors	N	N
9. Follow up rate	N	N
10. Statistical analysis	Y	Y
11. Multiple outcome measures	Y	Y
12. Individual level data to determine group effect	N/A	N/A
Total	7/12	5/12
Quality	Moderate	Moderate

Y: yes; N: no or not reported; N/A: not applicable.

Table 5. TIDieR ratings of intervention description in studies (n = 14).

Author	1	2	3	4	5	6	7	8	9	10	11	12	Total
Carragher et al. [71]	1	1	1	1	1	1	1	1	0	0	0	0	8
Cherney et al. [72]	1	1	1	1	0	1	0	1	0	0	0	0	6
Cherney et al. [73]	1	1	0	1	1	1	1	1	0	0	0	0	7
Giachero et al. [55]	1	1	1	1	1	1	1	1	0	0	0	0	8
Grechuta et al. [47]	1	1	1	1	1	1	1	1	0	0	0	0	8
Grechuta et al. [48]	1	1	1	1	1	1	1	1	0	0	0	0	8
Grechuta et al. [53]	1	1	1	1	1	1	1	1	0	0	0	0	8
Kalinyak-Fliszar et al. [74]	1	1	1	1	0	1	0	1	0	0	0	0	6
Maresca et al. [54]	1	1	0	0	0	1	1	1	1	0	0	0	6
Marshall et al. [46]	1	1	0	1	1	1	1	1	1	0	0	0	8
Marshall et al. [50]	1	1	1	1	1	1	1	1	0	0	0	0	8
Marshall et al. [51]	1	1	1	1	1	1	1	1	0	0	1	1	10
Snell et al. [75]	1	1	0	1	0	1	0	1	0	0	0	0	5
Thompson et al. [76]	1	1	1	1	1	1	1	1	0	0	0	0	8

TIDieR items are: (1) brief name, (2) rationale of essential elements of intervention, (3) what—materials, (4) what—procedures, (5) who provided, (6) how, (7) where, (8) when and how much, (9) tailoring, (10) modification, (11) how well—planned, and (12) how well—actual.

present researcher who moved the script forward [72], or selected a pre-programmed response [74,75]. In two studies this was arranged using a "wizard of oz" paradigm where the researcher controlled the virtual clinician from behind a curtain to give the illusion of independent use [74,75].

The VR element of the Virtual Reality Rehabilitation System (VRRS-tablet) intervention was delivered by the computer program [54]. VRRS was single-use and independently navigated by the user. It is not reported if users are represented in the VRRS

3D module. The paper also reports that "the linguistic module with 2D was mainly used" (p4) and the content of the 3D module was not further explained.

The four EVA Park studies used a multi-user virtual world [46,49–51]. Virtual worlds are defined as "shared, simulated spaces which are inhabited and shaped by their inhabitants who are represented as avatars" [78, p. 1099]. Users had EVA Park set up on a laptop in their own homes. Users were represented by personalised avatars. Users viewed the world from a

Table 6. How VR is being used in the included studies.

Study	Treatment summary	Rationale for VR	Software	Environment	Users	Independent	Represented
Carragher et al. [71]	Narrative structure training	Accessibility Cost-effective Stimulating	EVA Park	Virtual world	Multi-user	Yes	Yes
Cherney et al. [72]	Computer delivered script training	Treatment integrity	AphasiaScripts	Virtual clinician head	Single user	No	No
Cherney et al. [73]	Computer delivered oral reading treatment	Intensive Increased dose Compliance	Web ORLA	Virtual clinician head	Single user	Yes	No
Giachero et al. [55]	Conversations in functional environments	Ecological validity Embodied theory	NeuroVR 2.0	Virtual scenarios	3 people in a room with therapist	No	Not reported
Grechuta et al. [47]	Requesting objects with silent visuo-motor cues	Intensive	RGS	The virtual scene represented the actual setting: the table and participants	Pair, sat at a table in the same room	No	Yes
Grechuta et al. [48]	Requesting objects	Socially embedded, intensive	RGS	The virtual scene represented the actual setting: the table and participants	Pair, sat at a table in the same room	No	Yes
Grechuta et al. [53]	Requesting objects with different cues	Not reported	RGS	The virtual scene represented the actual setting: the table and participants	Pair, sat at a table in the same room	No	Yes
Kalinyak-Fliszar et al. [74]	Computer delivered dialogue training	Cost-effective Intensive Home-based Simulations of ADLs	Not reported	Virtual clinician head	Single user	No	No
Maresca et al. [54]	Computer delivered VRRS-Tablet vs. usual linguistic treatment	Promotes functional recovery Motivating Intensive Rich environments	VRRS-Tablet	Virtual scenarios	Single user	Yes	Not reported
Marshall et al. [46]	Conversations in functional environments	Motivating Intensive Generalisation Social networks	EVA Park	Virtual world	Multi-user	Yes	Yes
Marshall et al. [50]	Noun and verb retrieval	Ecological validity Motivating and stimulates conversation	EVA Park	Virtual world	Multi-user	Yes	Yes
Marshall et al. [51]	Social support groups	Ecological validity, motivating and stimulates conversation	EVA Park	Virtual world	Multi-user	Yes	Yes
Snell et al. [75]	Virtual clinician dialogues	Ecological validity	The Virtual Human toolkit	Virtual clinician in a virtual environment	Single user	No	No
Thompson et al. [76]	Computer delivered sentence therapy	Increased dose	Sentactics	Virtual clinician head	Single user	No	No

Multi-user: multiple people can log into and interact within the same virtual space at the same time; Independent: user logs in without a professional to help them; Represented: the user is represented in the virtual space by an avatar; ORLA: Oral Reading for Language in Aphasia; RGS: Rehabilitation Gaming System; VRRS: Virtual Reality Rehabilitation System. ADLs: Activities of Daily Living.

third-person viewpoint just behind their avatar's head. They could see and move around the EVA Park island and see and speak to the avatars of other users. Users could independently navigate and click on objects within the island to interact with them, e.g., they could click on the diving board and the avatar dived into the lake. The island was made up of a town square, two houses, a disco, a lakeside picnic area, and a tiki bar on a smaller island, with all areas linked by green spaces. Interventions were delivered in real-time by a therapist, communication support worker, or group coordinator who was also represented in the world by an avatar.

The Rehabilitation Gaming System (RGS) technology provided a representation of the physical room in which the users sat [47,48,52,53]. Two users were positioned facing each other at the same physical table with two monitors between them. The monitor showed a virtual representation of the user's arms, a virtual table, and a virtual peer across the table. The representation of the arms on the screen corresponded to the movement of the user's arms through the use of Microsoft Kinect technology. Users watched themselves select and pass virtual objects that had been requested. A rehabilitation assistant was present in the room to resolve technical or communication difficulties.

The virtual space in NeuroVR 2.0 [55] represented functional scenarios, such as a station, a hotel, or a supermarket. Three participants with aphasia sat with the SLT in the same room with a large 50" curved screen showing the virtual scene. Participants had tasks within each scenario. For example, they bought a train ticket, checked the platform, and responded to an unexpected

Table 7. Outcome measures used in included studies and ICF + classification.

Study	Primary outcome measure	ICF domain	Secondary outcome measures	ICF domain
Carragher et al. [71]	Content of narratives story grammar, story content, argument structure	Impairment	CADL-2	Activity
Cherney et al. [72]	NORLA-6	Impairment	Script accuracy	Impairment
Cherney et al. [73]	WAB-R LQ	Impairment	–	–
Giachero et al. [55]	AAT	Impairment	CAPPA, VASES, and WHO QOL	Activity, Self Esteem* and Quality of Life*
Grechuta et al. [47]	Correlation between a vocabulary test and the time between the selection and collection of an object	Impairment	Comparing the correlation in early *vs.* late sessions	Impairment
Grechuta et al. [48]	BDAE	Impairment	Communication Activity Log	Activity/Participation
Grechuta et al. [53]	Vocabulary test (VocabT) of trained items	Impairment	Interaction time: Time of successful goal-oriented peer-peer interaction	Activity
Kalinyak-Fliszar et al. [74]	Discourse measure (Nicholas and Brookshire [80])	Impairment	Content of scripts	Impairment
Maresca et al. [54]	Token Test	Impairment	ENPA, ADRS, EQ-5D, PIADS	Impairment, Depression*, HRQOL*, Well-being*
Marshall et al. [46]	CADL-2	Activity	Verbal Fluency, Narrative measures, CCRSA, and Friendship Scale	Impairment, Activity, Confidence*
Marshall et al. [50]	AONB	Impairment	CADL-2, Narrative measures	Activity, Impairment
Marshall et al. [51]	WEMWBS	Well-being*	CADL-2, Social Connectedness Scale, WAB-R, SAQOL-39g	Activity, Participation, Impairment, HRQOL*
Snell et al. [75]	Number and type of gesture	Impairment	Range of movement of gesture	Impairment
Thompson et al. [76]	NAVS	Impairment	Narrative measures	Impairment

CADL-2: Communication Activities of Daily Living-2nd edition; NORLA-6: Naming and Oral Reading for Language in Aphasia 6-Point Scale; WAB-R LQ: Western Aphasia Battery–Revised, Language Quotient; AAT: Aachen Aphasia Test; BDAE: Boston Diagnostic Aphasia Evaluation; AONB: Action and Object Naming Battery: WEMWBS: Warwick-Edinburgh Mental Well-Being Scale; NAVS: Northwestern Assessment of Verbs; CAPPA: Conversation Analysis Profile for People with Aphasia test: VASES: Visual Analogue Self Esteem Scale; WHO QOL: World Health Organisation Quality of Life Scale; ENPA: Esame Neurologico Per l'Afasia; ADRS: Aphasic Depression Rating Scale; EQ5D: Euro-Qol-5D; PIADS: Psychosocial Impact of Assistive Devices Scale; CCRSA: Communication Confidence Rating Scale for Aphasia; SAQOL-39g: Stroke and Aphasia Quality of Life Scale; HRQOL: Health Related Quality of Life.
*Outcome domains beyond the ICF.

request for help from someone who had been mugged. Participants indicated their choice verbally to the SLT, and the SLT controlled and navigated the technology.

What rationale(s) were given for the use of VR

Researchers cited a variety of reasons for employing VR, which are summarised in Table 6 and mapped out for ease of comparison in Table A (Supplementary Material). In Australia, where large, sparsely populated geographical regions make accessibility of services particularly pertinent, the accessibility of a remote online telehealth platform has been highlighted [49]. Cherney et al. [72] argued that a computer-delivered intervention removed human variation and therefore increased treatment integrity. She also argued for more efficiency as human clinicians could potentially "detract from critical treatment time" [73]. Two studies [73,76] additionally argued that computer program-delivered treatments allowed for an increased dose without the additional cost of the therapist's time. Giachero et al. [55] and Marshall et al. [46,50,51] highlighted the ecological validity of setting treatments in simulated real word situations. Settings are considered ecologically valid if they reflect how people behave in a real-world setting. Giachero et al. [55] also cited embodied theory—the idea that semantics and language are multimodal [79] and delivering language therapy in a virtual simulation creates a multimodal learning environment. Grechuta et al. [48] similarly discussed the value of delivering a "socially embedded" protocol by using peer interactions (p.1). Six studies [46–48,54,73,74] cited the opportunity for increased intensity as a rationale for VR treatments.

What outcome measures were used

The 14 studies used 14 different primary outcome measures, see Table 7. Even when studies targeted the same impairment, e.g., object naming, the outcome measures used were different which made the data too heterogeneous for a meta-analysis. For example, Grechuta et al. [47,53] reported a bespoke naming latency measure to demonstrate improved naming while Marshall et al. [50] reported naming correctness, as measured by the Action and Object Naming Battery [81].

Outcome measures used to measure a change in the language impairment were the Aachen Aphasia Test (AAT) [82], the Boston Diagnostic Aphasia Examination (BDAE) [83], the Token Test [84], the Naming and Oral Reading for Language in Aphasia 6-point scale, NORLA-6 [85], content of narratives [80], script accuracy, and therapy specific noun naming and verbal fluency tests [46,53].

Outcome measures used to measure communication activity and participation were the Communication Activities of Daily Living–2nd Edition, (CADL-2) [59], the Conversation Analysis Profile for People with Aphasia [86], and the Psychosocial Impact of Assistive Devices Scale (PIADS) [87], the quantity and quality of information in a dialogue [74], and the Communication Activities Log [88].

In terms of ICF + outcomes, well-being was measured using the Warwick-Edinburgh Mental Well-being Scale (WEMWBS) [89], self-esteem was measured using the Visual Analogue Self Esteem Scale (VASES) [90], confidence was measured using the Communication Confidence Rating Scale for Aphasia (CCRSA) [91], depression was measured using the Aphasic Depression Rating

Table 8. Outcomes of VR interventions in included studies.

Study	Provider	Hours	Frequency	Treatment summary	Comparator	Primary outcome	Post-therapy results	Maintenance
Carragher et al. [71]	SLT	20 h	5 days a week for 5 weeks	*Aim*: To improve participant's story planning, production and content *Content*: Narrative structure training from video retells	Time	Essential story content	Large effect size (Cohen's $d = 2.06$) for producing essential content between mean pre-therapy score 5.33 (SD 1.03), and mean post-therapy score 12.5 (SD 4.8)	Follow up scores were combined with post-therapy scores to give a mean post-therapy score
Cherney et al. [72]	Virtual clinician	1 h	1 session	*Aim*: To improve accuracy and production of scripts *Content*: Single dose of computer script treatment with and without a rest in the training	Rest *vs.* no rest	NORLA-6	Baseline to immediately post-treatment increase in per cent accuracy (10.4%; $p < 0.0001$) and rate (7.8 words/min; $p = 0.004$)	Baseline to 2 weeks post-treatment significant for accuracy (5.0%; $p = 0.006$) and rate (10.9 words/min; $p < 0.0001$)
Cherney et al. [73]	Virtual clinician	53 h	6 days a week for 6 weeks	*Aim*: To improve language performance *Content*: 6 weeks of ORLA (repeated choral and independent reading aloud of sentences with a virtual therapist) or a control game, Bejewelled.	VC *vs.* control game	Western Aphasia Battery–Revised Language Quotient (WAB-R LQ)	There was no significant difference in the gain from pre-treatment to post-treatment for the Web ORLA *vs.* control group.	The difference in the gain from pre-treatment to follow-up for Web ORLA *vs.* Control groups = 2.70 (SD = 1.01); $p = 0.013$; effect size = 1.92
Giachero et al. [55]	SLT	48 h	4 h a week for 6 months	*Aim*: To explore: (1) Does conversational therapy delivered *via* VR environments enhance language recovery? (2) Do therapy benefits generalise to measures of communication efficacy and psychological well-being? (3) Is VR therapy equivalent or more effective than conventional training? *Content*: Conversations in virtual functional environment ($n = 18$) compared to f2f topic-based conversation Tx ($n = 18$)	VR *vs.* face to face	Aachen Aphasia Test (AAT)	No difference between the groups All improved from "moderate" to "mild" on AAT.	None
Grechuta et al. [47]	SLT	27 h	40 min 5 days a week for 8 weeks	*Aim*: To test whether multisensory signals improve naming *Content*: 5 dyads received both silent cueing (lip shape) and acoustic semantic cueing, e.g., engine revving for car.	Silent video cues *vs.* no cue	Interaction time: Time of successful goal-oriented peer-peer interaction	Significant, negative, correlation between interaction time and VocabT scores. Range: $rs = -.88$ ($p < .05$) to $rs = -.98$ ($p < .005$)	None
Grechuta et al. [48]	EG: peer to peer VR CG: SLT	20 h	8 weeks, 5 days a week, 30–40 min sessions	*Aim*: outcomes from RGS training will be comparable to face to face SLT *Content*: The Rehabilitation Gaming System for aphasia provides lexical and syntactic training in a multimodal, goal-oriented manner within a context of dyadic peer-interaction	VR *vs.* face to face	Boston Diagnostic Aphasia Evaluation (BDAE)	No significant differences between the groups.	Gains in BDAE scores for all ppts were maintained at 16 weeks post-baseline
Grechuta et al. [53]	Peer to peer	23 h	5 weekly sessions (30–40 min) for 2 m	*Aim*: Visual priming will facilitate word retrieval *Content*: 50% of stimuli presented with silent videos of correct pronunciation and was compared to stimuli without a visual cue	Silent cueing *vs.* acoustic semantic cueing	Interaction time (time between hearing the cue and naming the object).	Difference between cued and non-cued trials was statistically significant during the early therapy sessions ($N = 15$) both for SVC ($p = .002$) and SAC ($p = .001$). But no differences were found in the late sessions for either SVC ($p = .73$) or SAC ($p = .53$)	Follow up at 16 weeks measured. VocabT scores maintained for all participants but no between condition results reported
Kalinyak-Fliszar et al. [74]	Virtual clinician	2–3 h	4 × 30–40 min session	*Aim*: To develop a dialogue practice tool with a virtual clinician and virtual simulations of activities of daily living. Researchers determined the differences between interactions with a human clinician (HC) and a virtual clinician (VC) *Content*: PWA participate in four dialogues, 2 with HC and 2 with VC	VC *vs.* human clinician	Accuracy and content of dialogues	No difference between conditions for 3 cases, e.g., equally inclined to interact with a HC or a VC. For 1 participant the quality of information conveyed in dialogues suggested a preference for the HC condition.	None
Maresca et al. [54]	Clinician monitored computer system	100 h	2 × 12 weeks 5 days week 50 min	*Aim*: To compare the use of VRRS-Tablet to usual linguistic treatment. *Content*: Two phases: inpatient Tx followed by community services	VRRS tablet *vs.* usual linguistic treatment	Token test	Statistically significant difference between the groups post-treatment. Linear mixed effects analysis results showed that the scores of the Token Test $[X^2(3) = 33.78; p < .001; R^2 = .92]$ were affected by the type of the rehabilitative treatment.	None

Table 8. Continued.

Study	Provider	Hours	Frequency	Treatment summary	Comparator	Primary outcome	Post-therapy results	Maintenance
Marshall et al. [46]	Communication support workers	25 h	1 h 5 days week 5 weeks	*Aim:* To improve functional conversation through situated conversations *Content:* Goal directed 1:1 intervention with a once weekly conversation group.	VR *vs.* no treatment	Communication Activities of Daily Living-2nd edition (CADL-2)	Significant interaction effect, with better functional communication for EG [$F(1, 18) = 5.236, p = .034, \eta_p^2 = .225$]	Gains were maintained at week 13
Marshall et al. [50]	SLT	20 h	1 h 4× week 5 weeks	*Aim:* To improve noun and verb retrieval *Content:* Semantic Feature Analysis or VNeST	Time	Action and Object Naming Battery	Nouns: A significant improvement in the naming of treated words (T2 *vs.* T3, McNemar χ^2 $p < .001$). Naming of the untreated words showed no change. Verbs: A significant increase following therapy (T3), which was maintained at T4. The change was not significant (T2 *vs.* T3, McNemar χ^2 $p = 0.18$; T2 *vs.* T4, McNemar χ^2 $p = 0.18$).	5 weeks. Noun naming well-maintained at T4 (T2 *vs.* T4, McNemar χ^2 $p < .001$).
Marshall et al. [51]	Aphasia group co-ordinators	21 h	14 sessions, once a fortnight for 6 months	*Aim:* To determine if social support groups in a virtual world are feasible *Content:* 14 social support groups delivered in EVA Park.	VR *vs.* no treatment	CADL-2 and Warwick Edinburgh Mental Well-Being Scale (WEMWBS)	No significant difference between the groups (treatment *vs.* waitlist control)	None
Snell et al. [75]	Virtual clinician	≥3 min	3× ≥1 min	*Aim:* To determine whether a virtual clinician that produced gestures facilitated the use of meaningful gestures in individuals with aphasia. *Content:* The VC demonstrates three narratives; (1) without using gestures (pre-gesture), (2) using gesture (gesture), (3) without gesture (post-gesture). The participants spoke after each narrative.	Exposed to gesture *vs.* not exposed	A gesture count and a range of movement measure	The gesture count was not significant between conditions. The range of movement was larger in the gesture condition compared to the pre-gesture condition ($p \leq 0.01$, $Z = -3.56$)	None
Thompson et al. [76]	EG: virtual clinician *vs.* CG: SLT	EG: 13.67 h CG: 14.25 h	1 h session 4× per week	*Aim:* To improve agrammatic sentence deficits *Content:* 14 sentences trained and compared computer delivered (VC) *vs.* SLT delivered	VC *vs.* SLT delivered	NAVS	No significant differences between the two conditions	None

EG: experimental group; CG: control group; SLT: speech and language therapist; NAVS: northwestern assessment of verbs and sentences.
*Snell et al. [75] reports on two studies, (A) a gesture taxonomy study and (B) a gesture production study. We have reported on study B only.
Highlighted (grey) studies are those with a quality rating of fair or above.

Scale (ADRS) [92] and quality of life was measured using the World Health Organisation Quality of Life Scale (WHOQOL) [93] the Euro-Qol-5D (EQ5D) [94], the PIADS [87] and The Stroke and Aphasia Quality Of Life Scale-39 generic stroke version (SAQOL-39g) [95].

The robustness of the measures used was variable. Eight studies used well-validated measures as a primary outcome measure [46–48,50,51,53–55,73,76]. Three studies used measures that required rater reliability checks [49,74,75], with two reporting the interrater reliability agreement [49,74]. In one study, the computer automatically recorded the primary outcome [47] and two studies presented their own specially developed outcome measures as their primary measure [53,72].

What communication functions were targeted

This review explored how VR was used to treat language and communication within the framework of the ICF+, as determined by the primary outcome measure, see Table 7. The majority of studies (n = 11) were primarily influencing the language impairment in aphasia [48–50,52–55,72,73,75,76]. In two studies, the primary outcome was communication activity [46,74], and one aimed to improve well-being [51]. Secondary outcome measures had a broader spread, in that they addressed impairment and activity/participation domains of the ICF as well as well-being, depression, self-esteem, confidence, and QOL.

Characteristics of the interventions

The VR interventions addressed word finding (four studies), sentence structure (one study), narratives (one study), communication activity (four studies), script training (one study), oral reading (one study), comprehension (one study), and social support (one study). A summary of the intervention characteristics is in Table 8.

Some studies took existing protocols into the novel VR environment and some studies created a new protocol for the new environment. Nine studies used published intervention protocols. One naming therapy study [50] used the protocols of Woolf [96] and Edmonds [97]. The RGS papers [47,48,53] used the principles of Intensive Language Action Therapy [98]. The sentence treatment followed the Treatment of Underlying Forms (TUF) protocol [76]. The narrative treatment is described as an adaptation of the Interactive Storytelling Therapy [71]. The script training [72] used the script protocol from the team's previous research [99], and WebORLA used the protocol from Oral Reading for Language in Aphasia [100]. Marshall et al. [51] developed a group social support intervention that drew on elements of several published approaches [101–104].

Two studies developed novel interventions that exploited the potential of simulated real-world environments available in VR technology [46,55]. Giachero et al. created functional scenarios for communication activity practice, e.g., check-in to the hotel, decide how long to stay, and book breakfast. There were additional, unexpected events to navigate, e.g., a forgotten suitcase. Marshall et al. [46] used the EVA Park virtual world to address participant-led communication activity goals, e.g., requesting a haircut in the barbers, ordering dinner in a restaurant, and sharing biographical stories.

Of the remaining three studies, two described exploratory work with a view to developing a novel protocol for dialogue practice tools [74,75], and the final one described an "experimental linguistic treatment" (p. 3) that was delivered using paper and pencil for the control group and via the VRRS-tablet for the experimental group [54].

Total treatment hours (dose) ranged from <1 to 100 h [54] with a mean treatment dose of 19.59 h, and both a median and mode of 20 h. The duration of treatment ranged from one session to six months [51,54,55]. The frequency of the interventions (sessions per week) was mostly once a day, with 4 or 5 sessions per week [46–50,53–55,76] with one study delivering one session every fortnight [51]. Treatments were delivered by qualified SLTs, professionals in aphasia support services (e.g., aphasia group co-ordinators), and computer-delivered. Treatments were delivered in one to one, peer interaction activities and group contexts. The VR interventions were set in hospitals, research laboratories, and community settings, e.g., participant's home.

What outcomes were achieved

Changes demonstrated in the outcome measures for all studies are presented in Table 8. Only studies rated as fair quality or above are included in this section (n = 7) and are highlighted in grey in Table 8 [46,48,51,53,55,72,73].

As reflects the preliminary nature of the research, two trials included feasibility outcomes. They compared VR to a no treatment control and were rated as fair on the PEDro quality measure [46,51]. They demonstrated that virtual worlds showed promise for delivering a communication activity intervention [46] and that online social support groups of up to eight people with aphasia with four additional support staff, each logging in from their own home, were feasible [51].

Five studies employed a measure of language impairment as their primary outcome with all five reporting significant treatment-induced improvement [48,53,55,72,73]. Three studies explored change in communication activity either as a primary or secondary measure, and all three reported positive change [46,53,55]. Two studies [51,55] explored the quality of life as a secondary outcome with one reporting positive change [55]. One study explored change in activity/participation as a secondary measure and reported positive change [48]. One study employed a measure of well-being as their primary outcome measure and reported no significant changes [51].

Four trials compared VR with face-to-face speech and language therapy [48,54,55,76]. Only two of these studies were rated fair or good quality [48,55]. They both demonstrated no difference between the groups on the primary outcome measures. These findings offer preliminary evidence of equivalence between VR and face-to-face therapy.

Discussion

The use of VR in the rehabilitation of aphasia is in the exploratory stages of research. In this review, four forms of VR were seen, none of which were immersive. Rationales for employing VR varied and despite the ecological validity offered by multi-user virtual environments, VR interventions predominantly targeted language impairments and used language impairment measures as the primary outcome. Most interventions used previously published protocols with two technologies making use of the simulated real-world environments available in VR. In terms of outcomes, improvements in language impairment (n = 5 studies) and communication activity (n = 3 studies) were achieved through the use of VR for aphasia rehabilitation. When compared to face-to-face therapy there was a suggestion that VR interventions achieve equivalent outcomes to face to face therapy (n = 2 studies), with

one study reporting added benefits to communication activity/participation.

Four forms of VR have been used in aphasia therapy research to date. They sit on a spectrum that ranges from a constrained, pre-programmed task with a static view to an open virtual space that can be used by multiple people for multiple activities. The computer-programmed virtual clinician, often only the clinician's head, is a static view with computer-delivered tasks [72–76]. The replicated table with objects from RGS widens the lens to the table, the arms, and the peer sitting opposite but the view is still static [47,48,53]. In the virtual scenarios of everyday communication situations, a whole environment is represented, e.g., a train station. The view is moveable and unexpected communication tasks are presented [55]. Finally, EVA Park presents a whole island environment where some elements of the environment are interactive. Participants are represented by a personalised avatar. They moved around the island, chose how they would be represented in the virtual space, and meet multiple other users. Images 1–4 (Supplementary Material) depict examples of the forms of VR used in aphasia rehabilitation.

Recently, a framework for describing situated language has been proposed [26]. It defines language use as (1) interactive, (2) multimodal, and (3) contextual. As the spectrum of VR spaces opens up to encompass multi-users within rich environments, they offer an opportunity for embedding situated language use into aphasia rehabilitation. When VR is selected as the mode of treatment delivery, the possibilities are wide-ranging. VR is not bound by the constraints of geography, physical laws (e.g., in EVA Park you can fly), or physical impairments. There is a potential to develop novel, creative multi-user environments that address the particular issues pertinent to aphasia rehabilitation: how to improve situated language use, mitigate the loss of social networks, and support the renegotiation of identity [105]. This review has demonstrated that this potential is not yet being fully realised. With the exception of EVA Park, where experiences outside of the bounds of reality are possible (e.g., avatars can ride on a turtle underwater), uses of VR in aphasia rehabilitation currently replicate reality or even the constraints of the aphasia clinic room.

Researchers cited a variety of rationales for the use of VR. Some aligned with the rationale for 2D online remote delivery; that it is accessible and provides increased intensity and dose [106,107]. A number of the studies use VR to replicate the clinical context and deliver treatments either remotely and/or independently of therapist input [47,48,53,72,73,76]. Receiving interventions at your home *via* your computer with the option to practice an unlimited amount in your own time has been shown to be acceptable [108,109]. Other rationales were cited that relate to the unique properties of VR, such as the opportunity to situate practice within multimodal simulations of the real world, and these were cited by seven studies. The rationale for the unexpected nature of fantasy elements in EVA Park was that it motivated genuine conversational exchange.

Some rationales were specific to multi-user VR. Gaming research shows users play multi-user games because of (1) warm relationships with others, (2) a sense of accomplishment, (3) a sense of belonging, and (4) fun and enjoyment [31]. These align with speech and language therapy aims to improve social networks and social connectedness (see [51]). Participant views on the multi-user EVA Park interventions similarly included fun, humour, and warm relationships [110,111]. Seven of the studies in this review could be described as multi-user. In one study the interaction with the technology was as a single user but the therapeutic experience was in a group of three [55]. Perhaps

unsurprisingly, the studies with multi-user technology were those that cited socially motivated rationales, e.g., ecological validity, socially embedded, and social networks.

It is interesting to reflect on the rationales that were not cited in the papers. A theme in gaming literature is the *agency* of the user. The degree to which the user can effect change in the virtual space is considered important [112] because the agency is said to support users in feeling like they are really there; a concept called immersion [113]. There is a suggestion that immersion is a potential mechanism of change in VR for health. For example, in virtual reality exposure therapy, it is proposed that the treatment works because the virtual representation is *real enough* to elicit the anxiety [114]. Seven studies in this review reported that the user was represented in the world. In the four EVA Park studies the users have agency of movement in the virtual space. Additionally, users in EVA Park can interact with objects in the virtual space and can effect some limited changes. None of the studies alluded to concepts of immersion or presence in their rationales. Similarly, none referred to the experiences of other disability groups with VR. In summary, only some studies are citing rationales that are unique to VR environments. There is a potential that has not yet been explored.

In relation to outcome measures, all studies but one reported multiple outcome measures. In the study that reported a single score, the WAB LQ [73], the score is calculated from multiple language tasks (reading, writing, speech, comprehension, repetition, and naming). The outcome measures covered all domains of the ICF with language impairment most represented. Additionally, QoL, confidence communicating, well-being, self-esteem, and depression were measured. The wide range of measures used has implications for evaluating the efficacy of these treatments. For meta-synthesis to be carried out, the measurement of outcomes needs to be rationalised. A core outcome set (COS) for aphasia research was agreed upon in 2018 [115]. Eight studies from this review were published after 2018 and yet only one measure from the COS was used in the included studies, the SAQOL-39g [51]. The Scenario Test was recently named as the measure of communication activity in the core outcome set for aphasia [116]. The Scenario Test was not used by any of the studies in this review.

With regards to the communication functions targeted, VR in aphasia rehabilitation has been used predominantly to rehabilitate language impairments (12/14 studies reviewed). This finding is consistent with the physiotherapy literature [42]. Communication activity is cited as a priority for both people with aphasia and clinicians [24,117] and multi-user simulated environments are uniquely placed to target this [44]. This could have driven a rise in the use of VR for communication activity, however, communication activity was the primary outcome in only one study in this review.

The interventions often used familiar therapies delivered in the novel format of VR. This was the goal in some treatments. For example, virtual clinicians freed up therapist time while increasing patient dose. It is interesting that, to date, VR has not taken aphasia therapy in radical new directions. In some cases [46,55], there was an attempt to exploit the virtual environment to promote generalisation of skills or to address multiple levels of the ICF, but this is not possible on all platforms or not attempted in all studies.

The completeness of the intervention description in this review was comparable to an umbrella review of intervention descriptions in aphasia [118]. The umbrella review, 50% of studies scored 8 out of a possible 12 items, and in this review 9/14 (64%) studies scored 8 or more out of the possible 12 items. The location of the

intervention, the fidelity plan, and adherence were the missing items in both reviews. This makes it difficult to replicate therapies, with implications for developing the evidence base and implementing therapies in clinical practice.

Positive language impairment outcomes have been achieved in VR-based interventions. When these outcomes were compared to face-to-face delivery, in two studies of "fair" and "good" quality, they were equivalent. This finding mirrors what is known about non-VR computer-delivered speech and language treatments [96,119] where online and face-to-face delivery were equally effective [96,119].

There was some preliminary evidence that VR-delivered therapy can achieve change in other dimensions of the ICF, with changes seen in communication activity ($n = 3$, fair or moderate quality) and participation ($n = 1$, good quality), and improved quality of life ($n = 1$, fair quality). Changes beyond the language impairment were seen only when interventions were delivered in multi-user virtual environments where there were opportunities to converse with peers with aphasia [48,53] and/or therapists [46,55]. This finding adds to the argument that therapy activities must target areas beyond impairment if we are to see these gains [120].

Feasibility outcomes from the feasibility studies ($n = 2$, fair quality) in this review were positive [46,51]. This review was confined to experimental studies. However, qualitative investigations linked to these studies have explored the acceptability of VR studies to people with aphasia [110,111] and service providers [121] show that VR interventions are acceptable.

Outcome evidence is only indicative but suggests that VR treatments are feasible and can achieve similar gains to those reported from face-to-face therapy. However, the strength of evidence is weak and many issues relating to the potential outcomes of VR therapy remain unexplored.

Limitations

A limited number of studies met the criteria for this review. Despite opening the criteria to include acquired cognitive communication disorder, no articles were found that reported the use of VR to remediate language in this area. This finding was similar to a recent review [122] where authors expanded their search after finding no examples of designing VR for traumatic brain injury. None of the studies included in the review were definitive studies, demonstrating how new this field of research is. The criterion to include only intervention studies may have excluded some of the more creative and novel developments of VR. These are published as user testing or platform development articles. For example, a head-worn display that provides vocabulary cues in context [123]. Qualitative literature about the experience of people with aphasia using VR was also beyond the scope of the review, but this literature points to good acceptability [110,111]. Moreover, only half of the studies were rated as of fair or higher quality with the risk of bias high amongst single case studies.

The participants were younger than is typical for the stroke population. The national average age for a first stroke is 68 years for males and 73 years for females [124]. The relevance of age, e.g., with respect to technology uptake, is not clear-cut [125]. Nevertheless, it would be desirable to test VR treatments with participants who more closely reflect the age of typical stroke survivors. Wider demographic data were not always available and were not extracted from the studies. It would be important to explore such variables, again to ensure that participants reflect the intended user population.

Another problem for this review was the disparate primary outcomes. This meant meta-analysis was not a sensible option. A previous review carried out a meta-analysis of a maximum of two studies [43].

Directions for future research

VR has the potential to create novel, multi-user spaces that engender fun and a feeling of belonging. They can mimic the real world or extend into fantasy. Such spaces may help to address aphasia and its negative social and emotional consequences. There is a need for well-designed empirical studies that explore the impact of multi-user VR interventions on the ICF domains of activity and participation and beyond. Potential variables to be explored are (a) the impact of immersion and presence, to investigate whether this is a mechanism for change in aphasia rehabilitation as it is suggested in the VR exposure therapy literature, (b) the impact of autonomy/agency in using VR and/or creating within VR, e.g., personalising avatars, and (c) the impact of receiving treatments in beautiful, playful spaces. Collaborations between the gaming community, human-computer interaction design, and speech and language therapy may achieve this potential.

There is a need for larger studies and more studies with a low risk of bias to provide definitive evidence. Designs should also explore a wider range of questions, such as whether VR shows equivalence to face-to-face therapy and whether there are added benefits of VR, for example with respect to generalisation and maintenance of change. Additional outcome issues (e.g., cost-effectiveness) could also be explored.

Consistent use of the Core Outcome Set for aphasia rehabilitation [115] will support future meta-analyses in this field.

Conclusion

VR for the rehabilitation of aphasia is being used for predominantly impairment-level interventions with non-definitive evidence of positive outcomes. The rationales for using VR vary across studies, from releasing SLT time to creating ecologically valid environments. There is a need for future studies to strengthen the evidence and explore the particular benefits of VR over other technologies. The opportunity to create novel multi-user spaces for communication activity gains has not been exploited.

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ORCID

Niamh Devane 🔟 http://orcid.org/0000-0001-8448-1478
Nicholas Behn 🔟 http://orcid.org/0000-0001-9356-9957
Jane Marshall 🔟 http://orcid.org/0000-0002-6589-221X
Aparna Ramachandran 🔟 http://orcid.org/0000-0002-5519-010X
Katerina Hilari 🔟 http://orcid.org/0000-0003-2091-4849

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Appendix 1: Searches

Search EBSCOhost CINAHL	Query July 2020–October 2021 Searched on 20 October 2021	Records retrieved
#1	(MH "Aphasia") OR (MH "Anomia") OR (MH "Aphasia, Broca") OR (MH "Aphasia, Transcortical Sensory") OR (MH "Aphasia, Conduction") OR (MH "Aphasia, Wernicke")	367
#2	AB Aphasi* OR AB dysphasi* OR AB cognitive communication	600
#3	**#1 OR #2**	651
#4	(MH "Rehabilitation") OR (MH "Rehabilitation, Speech and Language") OR (MH "Speech Therapy") OR (MH "Research, Speech-Language-Hearing Therapy") OR (MH "Therapy, Computer Assisted") OR (MH "Research, Rehabilitation") OR (MH "Language Therapy") OR (MH "Support, Psychosocial")	9843
#5	AB rehabilitation OR AB speech therap* OR AB interven* OR AB treat* OR AB train* OR AB program OR AB language therap* OR AB social support OR AB stimulat* OR AB speech patholog* OR AB language patholog*	175 770
#6	**#4 OR #5**	180 018
#7	(MH "Virtual Reality") OR (MH "Virtual Reality Exposure Therapy") OR (MH "Augmented Reality")	1380
#8	AB "virtual reality" OR AB "virtual world*" OR AB "virtual environment" OR AB "video game*" OR AB "computer simulat*" OR AB "augmented reality" OR AB "augmented virtuality" OR AB "mixed reality" OR AB "virtual reality exposure therapy" OR AB cyberspace OR AB "immersive environment" OR AB "multi user virtual world"	1300
#9	**#7 OR #8**	2250
#10	**#9 AND #6 and #3**	5

Search EBSCOhost Academic search complete	Query 1 July 2020–31 Oct 2021 Searched on 19 October 2021	Records retrieved
#2	DE "TRANSCORTICAL motor aphasia" OR DE "WERNICKE aphasia" OR DE "ANOMIA" OR DE "JARGON aphasia" OR DE "DIAGNOSIS of aphasia" OR DE "CONDUCTION aphasia" OR DE "APHASIA" OR DE "TRANSCORTICAL sensory aphasia" OR DE "APHASIC persons" OR DE "AGRAMMATISM"	666
#3	AB Aphasi* OR dysphasi* OR cognitive communication	1523
#4	**#2 OR #3**	1611
#7	((DE "REHABILITATION" OR DE "NEUROREHABILITATION" OR DE "NEUROPSYCHOLOGICAL rehabilitation" OR DE "VOCATIONAL rehabilitation" OR DE "STROKE rehabilitation" OR DE "REHABILITATION of aphasic persons") AND (DE "TREATMENT programs" OR DE "SPEECH therapy" OR DE "COMPUTERS in speech therapy")) OR (DE "SOCIAL support")	7036
#8	AB rehabilitation OR speech therap* OR intervent* OR treat* OR train* OR progam OR language therap* OR social support OR stimulat* OR speech patholog* OR language patholog*	586 419
#9	**#7 OR #8**	586 419
#10	((DE "MASSIVELY multiplayer online role-playing games") AND (DE "MIXED reality" OR DE "VIRTUAL reality therapy")) AND (DE "VIRTUAL reality" OR DE "AVATARS (Virtual reality)")) OR (DE "SHARED virtual environments")) OR (DE "CYBERSPACE")	245
#11	AB virtual world OR AB virtual reality OR AB virtual environment OR AB video game OR AB computer simulat* OR AB multi user virtual world OR AB augmented reality OR AB mixed reality OR AB virtual reality exposure therapy OR AB cyberspace OR AB immersive environment	7185
#12	**#10 OR #11**	7277
#13	**#12 AND #9 AND #4**	10

Search EBSCOhost Communication Source	Query 1 July 2020 (Mesh terms under "thesaurus")–October 2021 Search carried out on 21 October 2021	Records retrieved
#1	DE "APHASIA" OR DE "ANOMIA" OR DE "JARGON aphasia" OR DE "CONDUCTION aphasia" OR DE "AGRAMMATISM"	219
#2	AB aphasi* OR AB dysphasi* OR AB "cognitive communication"	278
#3	**#1 OR #2**	301
#4	((DE "VOCATIONAL rehabilitation") OR (DE "SPEECH therapy")) OR (DE "SOCIAL support")	4170
#6	AB rehabilitation OR AB speech therap* OR AB interven* OR AB treat* OR AB train* OR AB program OR AB language therap* OR AB social support OR AB stimulat* OR AB speech patholog*	5006
#7	**#4 OR #6**	5115
#7	(DE "CYBERSPACE") OR (DE "VIRTUAL communities")	199
#8	AB "virtual reality" OR AB "virtual world*" OR AB "augmented reality" OR AB "augmented virtuality" OR AB "video game*" OR AB "computer simulat*" OR AB "mixed reality" OR AB "virtual reality exposure therapy" OR AB "virtual environment" OR AB "immersive environment" OR AB "multi user virtual world" OR AB "cyberspace"	348
#9	#7 OR #8	528
#10	**#3 AND #6 AND #9**	1

Search EBSCOhost Medline complete	Query July 2020–October 2021 Searched on 21 October 2021	Records retrieved
#12	(MH "Aphasia") OR (MH "Aphasia, Broca") OR (MH "Aphasia, Wernicke") OR (MH "Aphasia, Conduction") OR (MH "Anomia")	209
#13	AB aphasi* OR AB dysphasi* OR AB "cognitive communication"	1317
#14	**#12 OR #13**	1350
#15	MH "Rehabilitation") OR (MH "Neurological Rehabilitation") OR (MH "Rehabilitation, Vocational") OR (MH "Stroke Rehabilitation") OR (MH "Rehabilitation Research") OR (MH "Rehabilitation of Speech and Language Disorders") OR (MH "Telerehabilitation") OR (MH "Speech Therapy") OR (MH "Social Support") OR (MH "Language Therapy") OR (MH "Speech-Language Pathology")	4505
#16	AB rehabilitation OR AB "speech therap*" OR AB "language therap*" OR AB "speech patholog*" OR AB "treat*" OR AB "train*" OR AB "interven*" OR AB "program*" OR AB "social support" OR AB stimulat*	6 952 501
#17	**#15 OR #16**	686 577
#18	(MH "Virtual Reality") OR (MH "Virtual Reality Exposure Therapy") OR (MH "Telerehabilitation") OR (MH "Computer Simulation")	189 994
#19	AB "virtual reality" OR AB "virtual world*" OR AB "augmented reality" OR AB "augmented virtuality" OR AB "video game*" OR AB "computer simulat*" OR AB "mixed reality" OR AB "virtual reality exposure therapy" OR AB "virtual environment" OR AB "immersive environment" OR AB "multi user virtual world" OR AB "cyberspace"	4033
#20	MH Augmented Reality	245
#21	#17 OR #18 OR #19	10 413
#22	**#13 AND #16 AND #20**	12

Search EBSCOhost APA PsycINFO	Query Limitations by year only Searched 2020–2021 on 22 October 2021	Records retrieved
#1	(DE "Aphasia" OR DE "Wernicke's Syndrome") OR (DE "Dysphasia")	437
#3	AB aphasi* OR AB dysphasi* OR AB "cognitive communication"	886
#4	**#1 OR #3**	926
#5	((DE "Rehabilitation" OR DE "Vocational Rehabilitation" OR DE "Telerehabilitation" OR DE "Neurorehabilitation") AND (DE "Speech Therapy" OR DE "Language Therapy" OR DE "Speech Language Pathology")) OR (DE "Social Support")	2945
#6	AB rehabilitation OR AB "speech therapy" OR AB "language therapy" OR AB interven* OR AB treat* OR AB train* OR AB program* OR AB "social support" OR AB stimulat* OR AB "speech patholog*"	108 130
#7	**#5 OR #6**	108 673
#8	((DE "Virtual Reality" OR DE "Virtual Reality Exposure Therapy" OR DE "Augmented Reality" OR DE "Avatars") AND (DE "Computer Games" OR DE "Role Playing Games")) OR (DE "Computer Simulation")	343
#9	AB "virtual world*" OR AB "virtual reality" OR AB "virtual environment" OR AB "augmented reality" OR AB "mixed reality" OR AB "augmented virtuality" OR AB "video game*" OR AB "computer simultat*" OR AB "virtual reality exposure therapy" OR AB "multi user virtual world" OR AB "cyberspace" OR AB "immersive environment"	2417
#10	#7 OR #8	2646
#11	**#4 AND #7 AND #10**	4

Search OVID Embase '74–'20	Query Limits: 2020–2021 Searched 22 October 2021	Records retrieved
#2	Exp aphasia	2415
#4	Exp dysphasia	270
#7	Exp traumatic brain injury	8585
#9	(aphasi* or dysphasi* or "cognitive communication").ab.	2358
#10	**2 or 4 or 7 or 9**	12 090
#13	speech rehabilitation/ or stroke rehabilitation/ or "speech and language rehabilitation"/ or psychosocial rehabilitation/ or vocational rehabilitation/ or exp rehabilitation/ or virtual rehabilitation system/ or community based rehabilitation/	12 812
#15	exp speech therapy/	1112
#17	exp language therapy/	211
#19	speech and language'	6147
#23	exp social support/	12 174
#25	(rehabilitation or "speech therapy" or "language therapy" or intervent* or treat* or train* or program* or "social support" or stimulat* or "speech patholog*").ab	1 171 427
#26	**13 or 15 or 17 or1 9 or 23 or 25**	1 179 225
#28	exp virtual reality/ or exp computer simulation/	13 419
#30	exp augmented reality/	854
#32	exp virtual reality exposure therapy/	145
#34	("virtual reality" or "virtual world*" or "multi user virtual world" or "virtual environment" or "augmented reality" or "mixed reality" or "virtual virtuality" or "video game*" or "computer simulation" or "immersive environment" or cyberspace or "virtual reality exposure therapy" or virtual).ab.	19 623
#35	**12 or 13 or 14 or 15**	29 170
#36	**10 and 26 and 36**	65

Search Ovid Emcare ('95-'21)	Query July 2020–Oaphasct 2021 Searched 26 October 2021	Records retrieved
#2	exp aphasia/	655
#4	exp dysphasia/	47
#6	exp traumatic brain injury/	2165
#8	(aphasi* or dysphasi* or "cognitive communication").ab.	793
#9	**2 or 4 or 6 or 8**	3207
#11	speech rehabilitation/ or virtual rehabilitation system/ or "speech and language rehabilitation"/ or psychosocial rehabilitation/ or stroke rehabilitation/ or exp rehabilitation/	6337
#13	exp speech therapy/	385
#15	exp language therapy/ or exp "speech and language"/	93
#17	exp social support/	6544
#19	(rehabilitation or "speech therapy" or "language therapy" or "Speech patholog*" or train* or treat* or program* or interven* or "social support" or stimulat*).ab.	309 024
#20	**11 or 13 or 15 or 17 or 19**	310 969
#22	exp virtual reality/	1542
#24	exp computer simulation	989
#26	exp augmented reality/	274
#28	exp virtual reality exposure therapy/	53
#30	("virtual world*" or "virtual reality" or "virtual environment" or "multi user virtual world" or "augmented reality" or "mixed reality" or "immersive environment" or "computer simulation" or cyberspace or "virtual reality exposure therapy" or "augmented virtuality" or "video game*").ab.	2136
#31	**22 or 24 or 26 or 28 or 30**	3591
#32	**9 and 20 and 31**	22

Total Oct 2021: 119.