Received: 14 October 2022 | Revised: 24 October 2023 | Accepted: 12 December 2023

DOI: 10.1111/jocn.16986

META-ANALYSIS

Journal of Clinical Nursing WILEY

Effects of virtual reality-based cognitive interventions on cognitive function and activity of daily living among stroke patients: Systematic review and meta-analysis

Lin Rose Sin Yi PhD, RN, Post Doctoral Research Associate[1] | Su Jing Jing PhD, RN, Research Assistant Professor[2] | Abu-Odah Hammoda PhD, RN, Research Fellow[2] | Bayuo Jonathan PhD, RN, Research Assistant Professor[2] | Batalik Ladislav PhD, PT, Assistant Professor[3,4] | Qin Jing PhD, Professor[2]

[1]School of Nursing, Elaine C. Hubbard Center for Nursing Research on Aging, University of Rochester, Rochester, New York, USA

[2]School of Nursing, The Hong Kong Polytechnic University, Hung Hom, Hong Kong

[3]Department of Rehabilitation, University Hospital Brno, Brno, Czech Republic

[4]Department of Physiotherapy and Rehabilitation, Faculty of Medicine, Masaryk University, Brno, Czech Republic

Correspondence
Su Jing Jing, A103, Hong Kong Polytechnic University, 11 Yuk Choi Rd, Hung Hom, Hong Kong.
Email: jing-jing.su@polyu.edu.hk

Abstract

Aims: To examine the effects of virtual reality-based cognitive interventions on cognitive function and activities of daily living among stroke patients, and to identify the optimal design for such intervention.

Design: Systematic review and meta-analysis.

Data Sources: Medline, EMBASE, Cochrane, CINANL, JBI-EBP and Web of Science from inception to October 2023.

Methods: Methodological quality was assessed by Risk of Bias Tool. Meta-analyses were assessed by Review Manager 5.4. Subgroup analyses were conducted to explore the influence of study design. Grading of Recommendations Assessment, Development and Evaluation approach was adopted to assess the certainty of evidence.

Results: Twenty-five randomized controlled trials (1178 participants) were included. Virtual reality-based cognitive interventions demonstrated moderate-to-large effects in improving global cognitive function (SMD = 0.43; 95% CI [0.01, 0.85]), executive function (SMD = 0.84; 95% CI [0.25, 1.43]) and memory (SMD = 0.65; 95% CI [0.15, 1.16]) compared to control treatments. No significant effects were found on language, visuospatial ability and activities of daily living. Subgroup analyses indicated one-on-one coaching, individualized design and dynamic difficulty adjustment, and interventions lasting ≥ 6 weeks had particularly enhanced effects, especially for executive function.

Conclusions: Virtual reality-based cognitive interventions improve global cognitive function, executive function and memory among stroke patients.

Implications for the Patient Care: This review underscores the broad cognitive advantages offered by virtual technology, suggesting its potential integration into standard stroke rehabilitation protocols for enhanced cognitive recovery.

Impact: The study identifies key factors in virtual technology interventions that effectively improve cognitive function among stroke patients, offering healthcare providers a framework for leveraging such technology to optimize cognitive outcomes in stroke rehabilitation.

Reporting Method: PRISMA 2020 statement.

PROSPERO Registration Number: CRD42022342668.

KEYWORDS

cognitive intervention, cognitive function, meta-analysis, stroke, systematic review, virtual reality

1 | INTRODUCTION

Stroke is a life-threatening condition characterized by the disruption of blood circulation to the brain, leading to oxygen deprivation, brain tissue damage and functional loss (Greenberg et al., 2022). As a major global cause of disability and mortality, stroke affects over 80 million people worldwide (Lindsay et al., 2019). Beyond the well-documented motor impairments, cognitive deficits and memory loss are common consequences (Mane et al., 2019). A meta-analysis of 23 studies revealed that about 40% of stroke survivors experiencing cognitive impairment in the first year post-stroke (Sexton et al., 2019). Cognitive deficits post-stroke is influenced by several factors such as stroke location, severity, age and time of onset. The most frequently impacted functions include executive, attentional and memory skills (Torrisi et al., 2019). Importantly, these cognitive challenges can hinder the effectiveness of other rehabilitation efforts, such as motor function recovery, which is essential for regaining daily independence (Lingo VanGilder et al., 2020; Torrisi et al., 2019). Prior research indicates that stroke patients with cognitive impairments place a greater burden on caregivers (Viscogliosi et al., 2019), and are more likely to face earlier institutionalization, increased mortality rates and elevated healthcare costs (Jeffares et al., 2022). Given these implications, early and comprehensive cognitive rehabilitation is imperative, particularly when the central nervous system exhibits heightened neuroplasticity post-stroke. This strategy has the potential to mitigate, or even reverse, cognitive decline (Levin, 2020).

Cognitive rehabilitation is centred around the restoration of cognitive function and the development of new skills to compensate for cognitive impairments, ultimately enhancing independence in various roles (Mingming et al., 2022). Recent studies have delved into the effectiveness of various interventions aimed at improving cognitive function in stroke survivors. One systematic review and meta-analysis found that stroke patients who underwent cognitive rehabilitation exhibited less memory loss immediately after the intervention compared to control groups (das Nair et al., 2016). Additionally, another meta-analysis suggested significant improvements in cognitive performance and measures of attention/processing speed among stroke patients who received physical activity training (Oberlin et al., 2017). It is important to note that therapy outcomes are dose-dependent. Therefore, intensive, high-repetition and task-specific therapies have been recommended to maximize clinically meaningful gains (McDonald et al., 2019). However, implementing these techniques can be challenging. They are often tedious, resource-intensive, costly and primarily focused on motor skills, which can lead to a lack of participant interest and poor treatment adherence (Juckett et al., 2020; Longley et al., 2019), compromising the potential benefits of such interventions. Given the limitations of conventional rehabilitation, virtual reality (VR) has emerged as a novel technology in the past decade to improve cognitive function in stroke patients.

Virtual reality is a computer-based technology that allows stroke patients to engage with multiple sensory modalities, facilitating simulated practice of functional tasks at a higher intensity compared to traditional models. Furthermore, VR technology immerses stroke patients in environments resembling real-world scenarios, engaging them both motorically and cognitively to restore neuroplasticity (Levin, 2020). In recent years, a growing number of randomized controlled trials (RCTs) have adopted VR interventions for stroke rehabilitation in post-stroke patients. VR interventions align with a key principle of neurological rehabilitation by offering repetitive, intensive, challenging and task-oriented training involving various cognitive abilities (Takeuchi & Izumi, 2013). VR provides a highly adaptable environment that can cater to the diverse needs, disabilities and goals of patients, offering variations in intensity, difficulty levels and a range of task choices. Moreover, participants are immersed in expansive environments representing real-life scenarios, providing safe, accessible and engaging methods to more effectively improve activity of daily living (ADL) (Wender et al., 2022). These characteristics collectively make VR-based interventions an ideal approach to enhance cognitive function and regain independence in everyday life.

What does this paper contribute to the wider global community?

- Cognitive impairment affects up to 40% of stroke patients, increasing the risk of dementia and reducing daily independence. Virtual reality-based cognitive interventions have been found to significantly enhance global cognitive function, executive function and memory in these patients. Promisingly, one-on-one coaching, personalized design and longer intervention durations show potential for maximizing cognitive benefits. Integrating virtual technology into standard stroke rehabilitation is recommended as a cost-effective means to improve post-stroke cognitive impairment.

Although review studies investigated the effects of VR intervention on global cognitive outcomes, its effectiveness on cognitive outcomes and ADL remains largely unknown. Zhang et al. (2021) extensively evaluated the effects of 87 RCTs ($n=3540$), while Gao et al. (2021) ($n=209$) assessed the effects of six RCTs on global cognitive function but they did not delve into the effects on more specific cognitive domains. Wiley et al. (2020) summarized findings from eight studies ($n=124$) that explored global and specific cognitive domains, yet their focus on VR interventions tailored for cognitive improvement was somewhat limited, potentially leaving the true cognitive benefits of VR intervention inconclusive. In addition, these previous studies have lacked subgroup analyses, making it unclear which implementation strategies are the most effective. Understanding the most effective training approaches is crucial for guiding the future development of VR-based interventions to achieve optimal cognitive benefits for stroke patients. Therefore, this systematic review and meta-analysis served to fill such a research gap by (i) examining the effects of VR-based cognitive intervention on cognitive function and ADL among patients with stroke and (ii) identifying the optimal study design components.

2 | METHODS

This systematic review and meta-analysis were conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 checklist (Page et al., 2021) (Appendix S1), and have been registered in the PROSPERO International Prospective Register of Systematic Reviews (CRD42022342668).

2.1 | Search strategy

Six electronic databases, including Medline, PubMed, EMBASE, Cochrane Database of Systematic Reviews, CINAHL Plus and JBI EBP, were searched from the inception to 20 October 2023, using the following keywords: 'activities of daily living', 'cognitive function', 'virtual reality' and 'stroke'. Appendix S2 outlines the details of the search strategies in PubMed. In addition, reference lists of the included studies, published systematic reviews and meta-analyses were searched to reduce publication bias.

2.2 | Eligibility criteria

The inclusion criteria were established by using the PICOS acronym, including (i) P (population): stroke patients; (ii) I (intervention): VR-based intervention primarily aimed at improving cognitive function; (iii) C (control): any types of control treatment including active control or usual care; (iv) O (outcome): at least one cognitive domain such as attention, memory, executive function or language; (iv) S (study design): RCTs. This review included studies published in English and peer-reviewed journal. Exclusion criteria were as follows: (i) studies focusing on motor rehabilitation only; (ii) discussion paper, editorial paper and commentary; (iii) pre-experimental studies; and (iv) pilot study with <10 participants per group.

2.3 | Data extraction

The literature search was conducted by two reviewers (RL, JJS) independently in August 2022, and an additional search was conducted in October 2023. Endnote X9.1 was used for literature screening and management. After titles and abstracts were screened, and full texts of potentially relevant studies were retrieved. These texts were then evaluated for eligibility based on the study's adherence to predefined inclusion and exclusion criteria. Any disagreements arising during the literature search were resolved through discussion until a consensus was reached. Data extraction was independently carried out by the same two reviewers, RL and JJS, using a standardized data extraction sheet that had been created in advance. Table 1 provides a summary of the study characteristics, encompassing details such as the first author, publication year, study design, country, participant characteristics (mean age, gender), description of the intervention and control arms. In situations where it was necessary to obtain additional information and data for pooling, the original authors were contacted.

2.4 | Quality assessment

Two reviewers (RL and JJS) independently conducted a methodological quality assessment for each included study using the 'Risk of Bias 2.0' tool (Sterne et al., 2019). The tool categorizes studies as having a low, high or unclear risk of bias (Higgins & Green, 2008). This tool assesses internal validity, including (1) random sequence generation, (2) allocation concealment, (3) selecting reports, (4) blinding of participants and personnel, (5) blinding to outcome assessment and (6) incomplete outcome data (Sterne et al., 2019).

2.5 | Statistical analyses

Pairwise meta-analyses were conducted using the Review Manager 5.4 software (Cochrane Collaboration, 2014). Data pooling occurred when at least three studies reported the same outcome indicator. Effect sizes were calculated using the standardized mean difference (SMD) and 95% confidence intervals (CI), with inputs from participant numbers, mean differences and standard deviations (SDs). The SMD was interpreted following Cohen's guidelines, with values of 0.2, 0.5 and 0.8 indicating small, medium and large effect sizes, respectively. To assess statistical heterogeneity among the studies, I^2 statistics were employed, with I^2 values exceeding 50% suggesting

TABLE 1 Characteristics of the included studies ($n = 25$).

No.	First author, year	Country	N	Number of participants (intervention/control)	Mean age (years)	Gender ratio (female)	Intervention	Control	Dosage
1	Ballester, 2017	USA	35	17/18	63.35	60.0	Individual VR Intervention for Goal-Directed Action and Motor Imagery	Conventional home-based occupational therapy for motor training	45-min/d, 5d/w, 3w
2	De luca, 2018	Italy	35	20/15	50.50	43.10	Supervised 'BTs-Nivana' VR with Optoelectronic Infrared Sensors and Semi-Immersive Features	Conventional physiotherapy combined with standard paper-and-pencil cognitive training	45-min/d, 3d/w, 8w + [CR] 45-min, 6d/w, 8w
3	Johnson, 2020	Australia	60	28/30	60.00	41.60	Individualized VR therapy for upper limb improvement via on-screen exercises	Usual care	45-min/d, 2d/w, 8w
4	Baltaduonienė, 2019	Lithuania	126	42/41/40	72.61	62.00	'SeeMeR Brontes' individual programme for spatial perception, memory and attention, with conventional control treatment	(Group 1) Individualized conventional pencil-and-paper cognition training tasks (Group 2) Program in (Group 1) plus computerized cognitive training	45-min/d, 5d/w, 8w
5	Kim, 2019	USA	30	15/15	57.07	53.33	Individualized VR rehabilitation with 'Smart Gloves' for upper limb sensory stimulation	Physiotherapy focusing on active and passive peripheral joint motion as well as preventative treatment	60-min/d, 3d/w, 8w
6	Kim, 2011	Korea	28	15/13	64.02	60.71	Supervised VR training for upper extremity and cognitive rehabilitation	Computer-assisted cognitive rehabilitation	30-min/d, 5d/w, 4w
7	Lee, 2017	Taiwan	47	26/21	57.74	27.66	Supervised 'Kinext' Xbox VR for balance training: stepping, squatting and standing	Conventional rehabilitation centred on strengthening, endurance and ambulation	90-min, 2d/w, 6w
8	Lin, 2020	Taiwan	145	38/107	66.27	60.00	Supervised 'Kinext' Xbox VR for muscle strength, cognition, coordination and conventional therapy	Conventional stroke rehabilitation incorporating postural training, facilitation techniques, stretching exercises and early rehabilitation	15-min, 2d/w, 5d
9	Narvarro, 2020	USA	44	22/22	52.29	55.82	Group-based computerized multitouch exercises with conventional paper-and-pencil methods	Control treatment, identical to the intervention but in an individualized format	60-min, 3d/w, 7w
10	Rogers, 2019	Australia	21	10/11	64.46	42.86	Supervised 'Element' VR rehabilitation with hand-held objects and conventional control treatment	Conventional occupational and physiotherapy	30–40min, 3d/w, 4w
11	Simsek, 2015	Turkey	42	20/22	58.00	69.05	Supervised Nintendo Wii VR for upper limb and balance training	Conventional occupational therapy and physiotherapy targeting upper extremities, strength, balance and functional training	45–60min, 3d/w, 10w

TABLE 1 (Continued)

No.	First author, year	Country	N	Number of participants (intervention/control)	Mean age (years)	Gender ratio (female)	Intervention	Control	Dosage
12	Park, 2019	Korea	30	15/15	53.00	43.33	Supervised cognitive-motor dual-task and auditory-motor synchronization	Cognitive-motor dual training	30-min/d, 3 d/w, 6 w
13	Maier, 2020	Spain	38	19/19	65.42	39.47	Individual adaptive cognitive training on spatial attention, memory, sustained attention, alertness, spatial awareness	Conventional cognitive rehabilitation utilizing traditional paper-and-pencil tasks	30-min, 5 d/w, 6 w
14	Wilson, 2021	Australia	17	10/7	72.95	29.41	Individualized home-based 'EDNA' training upper arm training with weekly phone contact with goal-based and exploratory movement activities and standard treatment	Conventional rehabilitation featuring the 'GRASP' arm and hand exercise program	30-min, 3–4 d/w, 8 w
15	Kannan, 2019	USA	25	13/12	59.18	44.00	Supervised cognitive-motor exergame training in Wii Fit	Conventional balance training including warm-ups, functional stretching, balance exercises and treadmill walking	30-min, 3 d/w, over 6 w
16	Lee, 2020	Korea	36	18/18	72.65	25.00	Supervised 'RAPAEL' non-immersive VR training for games with constraint on hand movement	Non-immersive VR training for recreational activities	30-min, 3 d/w, 8 w
17	Oh, 2019	Korea	33	18/15	54.78	30.30	One-on-one coaching, 'Joytism' VR with real instrumental devices such as doorknob	Conventional rehabilitation via traditional paper-and-pencil tasks	30-min, 3 d/w, 6 w
18	Fraia, 2016	Portugal	18	9/9	55.50	55.60	Supervised 'Reh@City' VR for personalized activities of daily living (ADL) training	Conventional rehabilitation via traditional paper-and-pencil tasks	20-min, 2 d/w, 4–6 w
19	Fraia, 2018	Portugal	32	20/12	61.53	46.88	Supervised 'Reh@City' VR for personalized activities of daily living (ADL) training	Conventional rehabilitation via traditional paper-and-pencil tasks	20-min, 2 d/w, 4–6 w
20	Gamito, 2014	Portugal	20	10/10	55.00	50.50	Individualized VR cognitive training in daily life activities	Waitlist control	60-min, 2–3 d/w, 4–6 w
21	Manuli, 2020	Italy	90	30/30/30	43.70	44.40	Supervised 'Lokomat' robotic exoskeleton training with treadmill	In-person cognitive rehabilitation focusing on pencil-and-paper attention process training	60-mim, 5 d/w, 8 w
22	Fraia, 2020	Portugal	32	17/19	61.53	50.00	Supervised 'Reh@City' VR for personalized activities of daily living (ADL) training	Conventional rehabilitation employing traditional paper-and-pencil tasks	20-min, 2 d/w, 4–6 w

(Continues)

TABLE 1 (Continued)

No.	First author, year	Country	N	Number of participants (intervention/control)	Mean age (years)	Gender ratio (female)	Intervention	Control	Dosage
23	Dabrowská, 2023	Czech	70	35/35	61.20	48.00	One-on-one supervised VR games for painting and puzzles	Conventional rehabilitation and occupational therapy aimed at improving bimanual activities, motor skills and coordination	30-min, 3 d/w, 4–5 w
24	Liu, 2022	China	30	15/15	74.16	43.33	Supervised VR with skill training, exergames and entertainment	Conventional cognitive training on processing speed, attention, memory, executive functions and problem-solving abilities	15-min, 6 d/w, 6 w
25	Shi, 2023	China	94	49/45	64.70	43.62	Supervised VR training for image pairing, obstacle navigation and cognitive skills	Conventional rehabilitation incorporates tailored treatments to enhance communication and psychological well-being, complemented by functional training such as retelling exercises and memory tasks	Session duration no reported, 6 d/w, 8 w

Note: d, days; m, months; min, minutes; VR, virtual reality intervention; w, weeks.

possible heterogeneity. Subgroup analyses were conducted to investigate the sources of heterogeneity and to examine the impact of various study characteristics on treatment effects. These characteristics included delivery mode (self-directed, one-on-one coaching or group-based format), dosage (either above or below median values for the number of sessions, session duration and treatment duration), mode of delivery (incorporation of dynamic difficulty adjustment), study design (customized for cognitive improvement vs. commercially available VR systems) and intervention design (involving activity of daily living simulation vs. individualized design). In cases where there were an insufficient number of studies for subgroup analysis, sensitivity analyses were performed.

The certainty of evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology (Schünemann et al., 2013), which ranks the evidence as either very low, low, moderate or high. Given the anticipated heterogeneity across diverse study designs, random-effects models were used for all analyses. Publication bias was assessed by visually inspecting funnel plots when at least 10 studies reported the same outcome. For studies lacking adequate data for pooling, narrative analyses were supplied.

3 | RESULTS

3.1 | Study selection

Figure 1 shows the PRISMA flow diagram. The literature search yielded 2523 citations, of which 326 duplicates and 2051 irrelevant records were removed. Full-text articles from 68 studies were screened for eligibility, and 25 studies were included for final review.

3.2 | Methodological quality assessment

Figure 2 presents the quality of the evidence. The primary methodological concerns pertained to the lack of blinding for both personnel and outcome assessors. Most studies either did not blind participants because of experimental constraints or failed to report the blinding status for outcome assessors. Seven studies exhibited unclear attrition bias due to unspecified reasons for attrition. All studies were assessed as having a low risk of bias in terms of selective reporting and other potential biases.

3.3 | Participant characteristics

Table 1 presents the characteristics of the included studies. The included studies were published from 2011 to 2023 in nine regions. The sample consisted of 1178 participants with a mean age of 60.86 (ranging from 43.70 to 72.95). Subject recruitment was conducted from hospitals, community centres and outpatient clinics. Thirteen

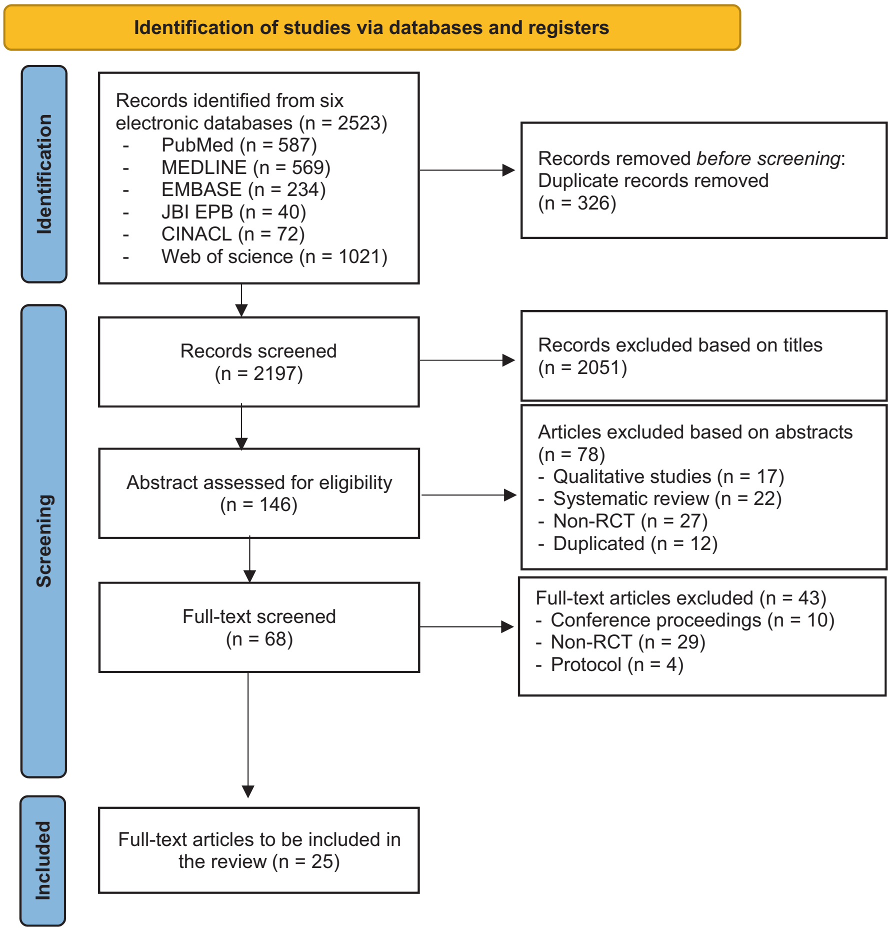

FIGURE 1 PRISMA flow diagram (n = 25). [Colour figure can be viewed at wileyonlinelibrary.com]

studies (Ballester et al., 2017; Faria et al., 2016, 2018, 2020; Johnson et al., 2020; Kannan et al., 2019; Kim et al., 2020; Lee et al., 2017; Liu et al., 2022; Maier et al., 2020; Manuli et al., 2020; Navarro et al., 2020; Park & Lee, 2019) recruited individuals with chronic stroke (≥6 months), seven studies (Dąbrowská et al., 2023; De Luca et al., 2018; Lee et al., 2020; Oh et al., 2019; Rogers et al., 2019; Shi et al., 2023; Şimşek & Çekok, 2016) focused on subacute stroke (2 weeks to 6 months), four studies (Baltaduonienė et al., 2019; Kim et al., 2011; Lin et al., 2020; Wilson et al., 2021) with acute stroke (within 2 weeks) and one study (Gamito et al., 2017) did not provide information for stroke stage. The included studies recruited participants with varying levels of cognitive function. Eleven studies recruited participants without dementia, requiring a Mini-Mental State Assessment (MMSE) score above 19 to 25 (Ballester et al., 2017; Dąbrowská et al., 2023; Kannan et al., 2019; Lee et al., 2019; Navarro et al., 2020; Oh et al., 2019; Park & Yoon, 2015; Shi et al., 2023; Şimşek & Çekok, 2016), and a Montreal Cognitive Assessment score (MoCA) above 24 (Johnson et al., 2020; Liu et al., 2022). Eight studies recruited participants with or without dementia, based on MMSE score ranging from 10 to 16 (Baltaduonienė et al., 2019; De Luca et al., 2018; Faria et al., 2016, 2018; Kim et al., 2011; Maier et al., 2020; Manuli et al., 2020), or a MoCA score above 16 (Lee et al., 2017). Five studies (Faria et al., 2020; Gamito et al., 2017; Lin et al., 2020; Rogers et al., 2019; Wilson et al., 2021) did not report the baseline cognitive level of their participants.

3.4 | Intervention characteristics

Table 1 and Appendix S4 provide an overview of the key elements. Majority of studies utilized non-immersive VR systems (n = 22), where participants were still aware of their physical surroundings while engaging with the virtual content displayed on the screen of computer monitors or tablet. Shi et al. (2023), Lin et al. (2020) and Manuli et al. (2020), however, conducted their studies in a fully immersive environment, which uses headsets or goggles to create a sense of complete immersion and presence in a virtual world. Nine studies incorporated components related to ADL simulation, of which the virtual systems replicated actions and situations encountered in everyday life. Three studies (De Luca et al., 2018; Kim et al., 2020; Lee et al., 2017) trained the participants to perform the ADL-related tasks such as cooking by using real instruments. Gamito et al. (2017) engaged participants in scenarios related everyday activities, such as grocery shopping and findings ways to supermarket. In contrast, three studies (Faria et al., 2016, 2018, 2020) immersed participants in a simulated city environment with streets, shops and buildings, replicating real-world situations. Seven studies adopted an individualized design approach (Faria et al., 2016, 2018, 2020; Johnson et al., 2020; Lee et al., 2020; Manuli et al., 2020; Rogers et al., 2019) adopted an individualized design approach. Tasks were tailored to the specific needs of pats and identified during baseline assessments. The

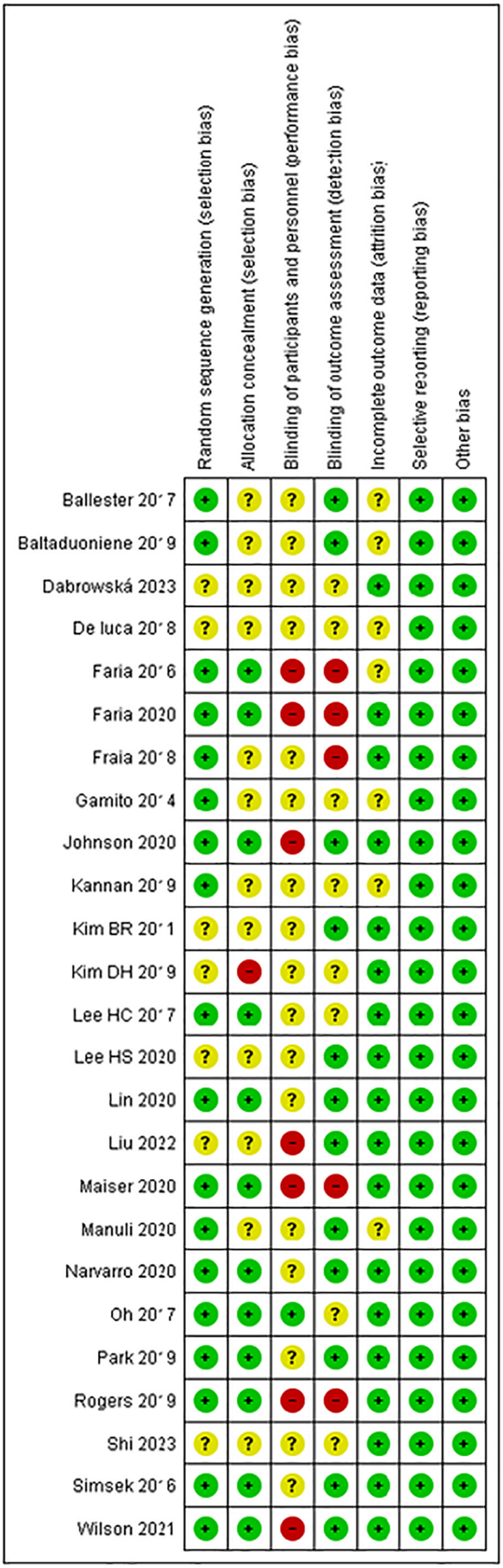

FIGURE 2 Risk of bias tools ($n=25$). [Colour figure can be viewed at wileyonlinelibrary.com]

majority of studies ($n=19$) incorporated dynamic difficulty adjustments. This involved a progression in task difficulties through increasing intensity and complexity, ensuring an adaptive approach to the intervention.

3.5 | Virtual technology interface

Both custom-made and commercially available virtual technology was used; 17 studies adopted custom-made systems tailored for cognitive improvement, typically designed for laboratory use and integrated with virtual technology interfaces. Additionally, four studies utilized off-the-shelf gaming consoles, including Nintendo Wii (Kannan et al., 2019; Navarro et al., 2020; Şimşek & Çekok, 2016) and Xbox games (Lee et al., 2017), originally intended for the general population but increasingly applied in rehabilitation settings.

3.6 | Professional input and group engagement

The VR-based cognitive intervention was delivered by research assistants or healthcare professionals, including nurses, occupational therapists, physiotherapists and psychologists. The majority of these interventions ($n=17$) involves one-on-one coaching, emphasizing the interaction between the interveners and the participants. For instance, in the study of Rogers et al. (2019), interveners provided verbal cues and explanations throughout the training to enhance understanding, safety and engagement in the program. The interveners also continuously monitored participants' progress, adjusting task difficulty according to their individual needs and performance (De Luca et al., 2018; Lin et al., 2020; Park & Yoon, 2015). The study of Navarro et al. (2020) adopted a group-based format by engaging participants to compete with each other during the training. Seven studies (Ballester et al., 2017; Baltaduonienė et al., 2019; Gamito et al., 2017; Johnson et al., 2020; Kim et al., 2020; Maier et al., 2020; Wilson et al., 2021) had participants to complete tasks individually.

3.7 | Dosage

The reviewed studies had an average of 23 sessions per week (ranging from 10 to 72), each lasting 39.5 min (ranging from 15 to 90), over a period of 6.1 weeks (ranging from 3 to 10).

3.8 | Control group condition

The majority of studies adopted active control, including conventional paper-and-pencil cognitive training ($n=6$) (Faria et al., 2016, 2018, 2020; Maier et al., 2020; Manuli et al., 2020; Oh et al., 2019), occupational/physiotherapy motor training ($n=11$) (Ballester et al., 2017; Dąbrowská et al., 2023; De Luca et al., 2018; Kannan et al., 2019; Kim et al., 2020; Lee et al., 2017; Lin et al., 2020; Park & Lee, 2019; Rogers

TABLE 2 Pairwise, subgroup and sensitivity analyses of included studies.

	Global cognitive function	Executive function	Working memory	Attention	Language	Visuospatial function	Activity of daily living
No. of subjects	566	268	238	319	71	202	84
No. of studies	12	8	6	9	3	3	3
Standard mean difference	**0.43 (0.01, 0.85)**	**0.84 (0.25, 1.43)**	**0.65 (0.15, 1.16)**	−0.18 (−0.48, 0.11)	0.81 (−0.05, 1.67)	0.37 (−0.06, 0.81)	0.08 (−0.20, 0.37)
Heterogeneity	82	80	65	40	65	0	0
Chi-square	0.50	0.57	14.30	0.08	5.67	0.03	0.22
Subgroup analysis							
Study design							
VR custom-made for cognition	**0.53 (0.05–1.02)**	**0.87 (0.17, 1.58)**	**0.65 [0.00, 1.29]**	**-0.32 [−0.56, −0.08]**			
VR-based gamification	Excluded LeeHC/Simsek	Excluded Narvarro	Excluded Narvarro	Excluded Narvarro			
Mode of delivery							
One-on-one coaching	**0.57 (0.02–1.12)**	**0.95 (0.18, 1.71)**	0.48 (−0.11, 1.07)	**−0.35 (−0.63, −0.08)**			
Self-directed VR	0.08 (−0.44–0.59)	0.73 (−0.23, 1.69)	Excluded Maiser and Narvarro	0.07 (−0.53, 0.67)			
Intervention design							
Dynamic difficulty adjustment	All adopted this feature	**0.91 (0.24, 1.59)**	All adopted this feature	−0.14 (−0.51, 0.24)			
Same level repetition	//	Exclude Kim DH	//	Excluded Kim DH/ Lee HS			
Combination of VR and conventional OT	0.25 (−0.51–1.02)	0.98 (−0.02, 1.98)	//	//			
Solely VR	**0.55 (0.12–0.98)**	0.76 (−0.07, 1.59)	0.50 (−0.04, 1.04)	**−0.32 (−0.56, −0.08)**			
Adopted ADL simulation	0.19 (−0.19–0.56)	**0.94 (0.17, 1.71)**	Excluded Faria 2020 and Faria 2016	−0.21 (−0.62, 0.21)			
Without ADL simulation	0.59 (−0.01–1.19)	Excluding Kim DH	0.43 (−0.14, 1.00)	−0.12 (−0.55, 0.31)			
Individualized design	**1.10 (0.43, 1.77)**	**1.72 (0.82, 2.62)**	Excluded Faria 2020 and Faria 2016	−0.32 (−0.70, 0.05)			
General design	−0.08 (−0.35, 0.18)	**0.36 (0.01, 0.72)**	0.43 (−0.14, 1.00)	−0.09 (−0.52, 0.35)			
Session number							
≥ 20 sessions	0.44 (−0.23, 1.11)	**.95 (0.18, 1.71)**	0.43 (−0.14, 1.00)	−0.18 (−0.65, 0.29)			
< 20 sessions	0.44 (−0.14, 1.03)	0.73 (−0.23, 1.69)	Excluded Faria 2016 and Faria 2020	−0.18 (−0.55, 0.19)			
Treatment duration							
≥ 6 weeks	0.46 (−0.22, 1.14)	**1.04 (0.02, 2.07)**	**0.48 (0.08, 0.88)**	−0.19 (−0.80, 0.41)			

(Continues)

TABLE 2 (Continued)

	Global cognitive function	Executive function	Working memory	Attention	Language	Visuospatial function	Activity of daily living
< 6 weeks	0.41 (−0.15, 0.97)	0.70 (−0.03, 1.42)	0.37 (−0.44, 1.17)	−0.16 (−0.48, 0.16)			
Session duration							
≥ 45 min	0.31 (−0.33, 0.96)	0.70 (−0.03, 1.42)	**0.48 (0.08, 0.88)**	−0.16 (−1.00, 0.69)			
< 45 minutes	0.55 (−0.05, 1.14)	**1.04 (0.02, 2.07)**	0.37 (−0.44, 1.17)	−0.19 (−0.48, 0.10)			

Note: This table only presents the results for the studies included for data pooling; // = data pooling was not possible due to the limited number of included studies in the respective outcome; Bold = statistically significant; ADL, activity of daily living; OT, occupational therapy; VR, virtual reality.

et al., 2019; Şimşek & Çekok, 2016; Wilson et al., 2021); a combination of conventional computerized and pencil-and-paper cognitive training ($n=1$) (Baltaduonienė et al., 2019), individual-format intervention ($n=1$) (Navarro et al., 2020), recreational activities (i.e. playing video games [$n=1$]) (Lee et al., 2020), computer-assisted cognitive rehabilitation ($n=3$) (Kim et al., 2011; Liu et al., 2022; Shi et al., 2023), except the study of Johnson et al. (2020) adopted treatment as usual care, and Gamito et al. (2017) adopted waitlist control.

3.9 | Results of meta-analyses

3.9.1 | Global cognitive function

Table 2 and Appendix S5 present the pooling results. Global cognitive function, refers to a comprehensive assessment of individuals cognitive abilities, was assessed by 16 studies ($n=864$) using MoCA, MMSE, Function Independence Measure, Addenbrooke's Cognitive Examination and Timed up and go cognition test. The VR-based cognitive intervention demonstrated a small effect on global cognitive function, although high heterogeneity was detected (SMD = 0.43, 95% CI [0.01, 0.85], $p=.04$; $I^2=82\%$). Subgroup analyses for studies that adopted one-on-one coaching (SMD = 0.57; 95% CI [0.02, 1.12]; $I^2=82\%$), individualized design (SMD = 1.10, 95% CI [0.43, 1.77], $p<.01$; $I^2=79\%$) and interventions custom-made for cognitive function (SMD = 0.53, 95% CI [0.05, 1.02], $p=.03$; $I^2=84\%$) resulted in a greater overall effect compared to those without such features. The study of De Luca et al. (2018), which was not included in the pooled analysis due to insufficient data, demonstrated a positive effect with one-on-one coaching by therapists measured by the MMSE (95% CI [20.1–45.9], $p<.0001$), while Dąbrowská et al. (2023) which adopted a similar approach did not reveal significant treatment effect.

3.9.2 | Executive function

Executive function, including cognitive processes such as planning, set shifting and inhibition (Baggetta & Alexander, 2016), was assessed in nine studies ($n=322$) using digit span test-backward, averaged standardized composite score, Frontal Assessment Battery and subscale of MoCA. VR-based cognitive intervention demonstrated significant large effect on improving executive function with high heterogeneity (SMD = 0.84, 95% CI [0.25, 1.43], $p=.005$; $I^2=80\%$). More substantial effects were observed for those adopted one-on-one coaching (SMD = 0.95, 95% CI [0.18, 1.71], $p=.01$; $I^2=66\%$), dynamic difficulty adjustment (SMD = 0.91, 95% CI [0.24, 1.59], $p<.01$; $I^2=82\%$), ADL simulation (SMD = 0.94; 95% CI [0.17, 1.71], $p=.02$; $I^2=85\%$), individualized design (SMD = 1.72, 95% CI [0.82, 2.62], $p<.01$; $I^2=66\%$) and virtual system custom-made for cognitive improvement (SMD = 0.87, 95% CI [0.17, 1.58], $p=.02$; $I^2=83\%$). For intervention dosage, adopting more than 20 sessions (SMD = 0.95, 95% CI [0.18, 1.71], $p=.01$; $I^2=66\%$), <45 min (SMD = 1.04; 95% CI [0.02, 2.07], $p=.05$;

I^2 = 86%) over 6 weeks (SMD = 1.04; 95% CI [0.02, 2.07], p = .05; I^2 = 86%) reported greater treatment effects. No significant effect was found for the study of Faria et al. (2018) and Liu et al. (2022) that were excluded from pooling.

3.9.3 | Working memory

Working memory was assessed in nine studies (n = 268) using the memory subscale of Addenbrooke's Cognitive Examination, memory subscale of MoCA, digit span test-forward, Colour trail test-A and the averaged standardized composite score. A moderate effect was reported with high heterogeneity (SMD = 0.65, 95% CI [0.15, 1.16], p = .01; I^2 = 65%). Significant effects with similar magnitude were demonstrated by studies adopting virtual system custom-designed for cognitive improvement (SMD = 0.65; 95% CI [0.00, 1.29], p = .05; I^2 = 72%), those with treatment more than 6 weeks (SMD = 0.48, 95% CI [0.08, 0.88], p = .02; I^2 = 0%) and sessions more than 45 min (SMD = 0.48; 95% CI [0.08, 0.88], p = .02; I^2 = 0%). Subgroup analyses also showed that adopting one-on-one coaching, ADL simulation and individualized design did not show significant differences. Data pooling was not conducted for three studies; Faria et al. (2018) and Gamito et al. (2017) demonstrated significant effects, yet not for Liu et al. (2022).

3.9.4 | Attention

Attention was assessed by 12 studies (n = 406) using trail making test-A, continuous performance test, averaged standardized composite score and d2TA, and found with non-significant treatment effect (SMD = −0.18, 95% CI [−0.48, 0.11], p = .22; I^2 = 40%). Subgroup analysis demonstrated those adopting one-to-one coaching (SMD = −0.35, 95% CI [−0.63, −0.08], p = .01; I^2 = 0%) and those custom-made for cognitive improvement (SMD = −0.32, 95% CI [−0.56, −0.08], p < .01; I^2 = 0%) had significant greater positive effects on attention. Excluding studies that adopted a combination of VR intervention and conventional occupational therapy, the treatment effects remained significant with heterogeneity resolved (SMD = −0.32, 95% CI [−0.56, −0.08], p < .01; I^2 = 0%). Incorporating ADL simulation, individualized design and various treatment duration did not show a significant difference. The study of Faria et al. (2018) was not pooled due to inadequate data. Its results echoed the pooling data to report the significant treatment effect of a one-on-one format with the ADL elements on attention (p = .002), while De Luca et al. (2018) did not report its result on attention.

3.9.5 | Language

Language was assessed in four studies (n = 95) using the language subscale of Addenbrooke's Cognitive Examination, MoCA subscale and the Neurobehavioral Functioning Inventory—communication subscale. No significant effect was reported with low heterogeneity (SMD = 0.81; 95% CI [−0.05, 1.67], p = .06; I^2 = 65%, p = .06). Subgroup analysis was not conducted due to the limited number of included studies. The study of Faria et al. (2018) which was not included in data pooling due to inadequate data demonstrated significant improvement in language in the control group but not in the intervention group.

3.9.6 | Visuospatial function

Visuospatial function was assessed in five studies (n = 128) using the visuospatial subscale of Addenbrooke's Cognitive Examination, Star Letter Cancellation, Rey Complex Figure Test, Visual Span Test and Spatial Awareness test. No significant effect was reported with low heterogeneity (SMD = 0.37; 95% CI [−0.06, 0.81], p = .09; I^2 = 0%). Subgroup analysis was not conducted due to the limited number of included studies. For studies not included in pooling, both Gamito et al. (2017) and Faria et al. (2018) which adopted non-immersive virtual technology indicated non-significant treatment effects on visuospatial function.

3.9.7 | ADL

ADL was assessed in four studies (n = 414) without adopting ADL simulation using the Korean version of the Modified Barthel Index, and Barthel Index. No significant effect was reported when compared to the control group without heterogeneity (SMD = 0.08; 95% CI [−0.20, 0.37]; p = .57; I^2 = 0%). Subgroup analysis was not conducted due to the limited number of included studies. Faria et al. (2018), Dąbrowská et al. (2023), Liu et al. (2022) and Shi et al. (2023) were excluded from the pooling due to missing SD; its result indicated the non-significant treatment effect on the ADL.

3.9.8 | Rating of the body of evidence

Appendix S3 summarizes the quality of evidence. Across outcomes, the quality ranged from very low for language to high for attention, visuospatial function and ADL. Global cognitive function was rated as low, while executive function and working memory received a moderate rating.

3.9.9 | Publication bias

Visual inspection of contour-enhanced funnel plots was conducted for global cognitive function, which included more than 10 studies in data pooling (Appendix S6). The result showed a rather asymmetrical shape, except for Rogers et al. (2019) deviated from the symmetry, indicating a possible publication bias in this outcome.

4 | DISCUSSION

To our knowledge, this review is the first to assess the impact of VR-based cognitive intervention on cognitive function and ADL in stroke patients. Our findings suggest that VR-based cognitive intervention led to significant improvements in global cognitive function, executive function and memory compared to control treatments. However, it did not yield significant effects on attention, visuospatial ability, language or ADL. Subgroup analyses revealed that incorporating ADL simulation, one-on-one coaching, dynamic difficulty adjustment and individualized design can enhance cognitive benefits, particularly in the realm of executive function.

This review demonstrated significant moderate effects of VR-based cognitive intervention in improving global cognitive function among stroke patients. Such positive results were not reported in previous meta-analyses conducted by Zhang et al. (2021), Wiley et al. (2020) and Gao et al. (2021). This disparity may be attributed to the fact that our review primarily focused on VR-based cognitive intervention embedded with cognition and motor training. Beyond mobility training, VR-based cognitive intervention required participants to comprehend tasks and respond accordingly within an artificial environment offering multisensory feedback (Cooper et al., 2018). Engaging in visual, auditory and/or tactile stimulation demands coordination across various cognitive domains, such as decision-making, attention and memory (Brugada-Ramentol et al., 2022). These cognitive functions are closely tied to the reconstruction and reorganization of new synapses to repair brain lesions after neurological injuries (Johansson, 2012). Furthermore, subgroup analyses suggested that dynamic difficulty adjustment generated a higher magnitude of treatment effect. Qualitative analysis indicated that difficulty adjustment proved highly useful in enhancing engagement by boosting participants' confidence and feelings of joy (Pallesen et al., 2018). Guided by motivational feedback across different levels, participants can quantify their progress and evaluate their rehabilitation journey towards greater health benefits.

Our review, in line with a previous review examining 23 RCTs on general VR therapies for stroke patients (SMD = 0.88) (Zhang et al., 2021), also found a large positive effect of VR-based cognitive intervention. The most pronounced impact was observed in executive function (SMD = 0.84). Notably, when the VR interventions incorporated elements such as one-on-one coaching, individualized design, dynamic difficulty adjustment and ADL simulation, the treatment effect on executive function was even more significant (SMD = 0.91–1.72). Executive function encompasses a range of advanced cognitive skills essential for planning, monitoring and executing complex, goal-oriented tasks (Hofmann et al., 2012). Unlike traditional cognitive rehabilitation, which often involves repetitive, step-by-step tasks, VR environments challenge participants to process information from various sources and perform multiple cognitive functions within simulations of real-life situations (Johansson, 2012). The ADL-based scenarios used in the studies we analysed, such as meal preparation, ATM use and grocery shopping (Faria et al., 2016, 2018, 2020), required coordination across high-level cognitive domains, including working memory, processing and decision-making (Nguyen et al., 2019). Navigating multiple cognitive processes simultaneously are known to enhance activity-dependent plasticity (Kleim & Jones, 2008), leading to more rapid and comprehensive functional recovery. Additionally, VR-based interventions offer a personalized and interactive context, where participants engage in functional tasks tailored to their abilities, receive real-time feedback and adapt to impaired functional tasks more effectively. These features contribute to improved executive function.

In concordance with the review of Zhang et al. (2021), both meta- and narrative analysis of this review consistently highlighted the significant effects on improving working memory. Indeed, working memory has been regarded as one of the core mental skills required in executive function (Nguyen et al., 2019); therefore, the exceptional improvement in executive function may have explained the positive effects of working memory. The ADL-related scenarios adopted in the pooled studies included memory-related parameters, requiring the participants to memorize numbers, recipes and lists of items. Being repetitively engaged in the process of encoding, retrieval and recognition of cues has a direct effect on the improvement of working memory. Subgroup analysis also provided insight into the more effective dosage; consistent with the result in executive function, a longer treatment duration (≥6 weeks) contributed to a more beneficial cognitive improvement among stroke patients. Such findings also aligned with the intervention guideline of stroke rehabilitation that increased time spent in training can provide more beneficial changes in cognitive function (Clark et al., 2017).

Improvement in attention is crucial for both functional performance and active participation in rehabilitation programme (Loetscher et al., 2019). Qualitative studies on the user experience of virtual technology underscores its benefits: its immersive and rewarding features lead to longer time engagement in training compared to conventional rehabilitation (Gustavsson et al., 2021). However, our meta-analysis did not find a significant improvement in attention, which echoed the results of Wiley et al. (2020). The data indicated that one-on-one coaching was the only method that significantly improved attention. This suggests that stroke patients' attention deficits may hinder the effectiveness of VR training. When supervised, these patients received targeted instruction, explanation and encouragement, factors that can sustain their engagement (Gustavsson et al., 2021). In addition, real-time feedback helped participants correct errors, thereby enhancing their performance and overall motivation (Pallesen et al., 2018).

No significant improvements were observed in language and visuospatial ability, possibly due to the lack of training in verbal conversation and social communication during the intervention. Moreover, majority of pooled studies adopted a non-immersive VR interface. This design feature, which allows participants to remain aware of the real-world environment, may limit the effectiveness of VR in enhancing visuospatial skills compared to a fully immersive experience.

This review showed no significant effect on the ADL, possibly because only three studies allowed data pooling in this outcome. Future VR-based interventional studies should include ADL metrics, as robust evidence supports a positive correlation between cognitive gains, especially executive function and attention, and ADL performances (Lee et al., 2019, 2021; Mograbi et al., 2014). In addition, none of the pooled studies that measured ADL included ADL simulation, which is a feature recommended for future studies. VR technology allows the replication of real-world scenarios, generating a safe environment to practice functional movement necessary for daily life (Weber et al., 2019). Such practice no only helps participants regain lost skills, but also boost their motivation, enthusiasm and self-efficacy to re-engage in real-world ADL (Long et al., 2020). Stroke rehabilitation is a long-term process for both physical and psychological adaptation; it takes time for the participants not only to gain familiarity with the changed body but also to accept the subsequent daily impacts and practical help (Dworzynski et al., 2015). Prolonged rehabilitation is expected, especially when cognitive impairments further compromise their learning capacities (Lam et al., 2016). More studies with longer intervention duration incorporating ADL components are needed to generalize improvement to everyday functioning.

4.1 | Limitations

Some limitations need to be acknowledged. First, several of the included studies exhibited methodological weaknesses, such as unclear randomization sequences, allocation concealment and a lack of blinding of participants. Second, heterogeneity persisted despite subgroup analysis, and some outcomes had low to moderate evidence. These factors can impact data interpretation and hinder a comprehensive understanding of results. Third, subgroup analysis based on stroke stages, types of VR technology and types of control treatments was hindered by limited studies. Future research should consider conducting subgroup analyses when more data becomes available. Lastly, the restriction to solely English articles may have limited the ability to identify trends in research across different regions and cultures.

4.2 | Implications for research

The findings of this meta-analysis revealed the beneficial effects of VR-based cognitive intervention on global cognitive function and the more specific domains, including executive function and memory. However, most of the included studies were pilot testing, and some methodological weaknesses such as lack of blinding to participants or outcome assessors, the unclear process of random sequence generation, and missing data, were identified. Therefore, more large-scale, and more rigorously designed studies are warranted to confirm the beneficial effects of VR-based cognitive intervention as identified in this review. In addition, only a few studies followed the participants after the intervention; more research is needed to explore the optimal intensity and design to achieve sustainable effects.

4.3 | Relevance to clinical practice

This review emphasizes the potential of individualized design, bolstered by one-on-one coaching and dynamic difficulty adjustments, as effective methods for optimizing the benefit of VR technology in stroke rehabilitation. Disease management in stroke is inherently complex due to the diverse range of disabilities and impairments present in this population (Stinear et al., 2020). Thus, a nuanced and comprehensive assessment is crucial for tailoring rehabilitation to each client's specific needs, abilities, and learning styles, thereby maximizing recovery outcomes. The importance of holistic care in this context cannot be overstated; it is a core nursing value focused on complete patient care (Van Rooyen & Jordan, 2013). Nurses are uniquely positioned to conduct these comprehensive assessments and oversee tailored interventions. However, to ensure the successful deployment of nurse-led virtual technology interventions, adequate training for nurses is imperative, especially given the frequency of technical challenges reported in the literature (Garrett et al., 2018). Policymakers must also prioritize resource allocation to facilitate the integration of virtual technology into routine stroke rehabilitation programs. This is particularly vital, given that traditional stroke rehabilitation methods are labour- and resource-intensive. Lastly, advances in technology have made virtual technology increasingly affordable and accessible. As a result, there is potential for its application to extend from clinical settings to home-based rehabilitation. This expansion would offer patients greater flexibility, overcoming constraints related to time and location, and thereby promoting more effective recovery.

5 | CONCLUSION

Virtual technology offers an engaging and portable approach resembling real-life scenarios, making it suitable for clinical neurorehabilitation. This review demonstrates the positive impact of VR-based cognitive interventions on global cognitive function, executive function and memory. However, they didn't significantly improve attention, visuospatial ability, language or ADL. Besides virtual technology, optimizing treatment effects on cognitive function, especially executive function, involves key elements such as one-on-one coaching, dynamic difficulty adjustment, individualized design and ADL simulation. Future research should strongly consider these elements to maximize VR-based cognitive intervention benefits.

AUTHOR CONTRIBUTIONS

Lin Rose Sin Yi: study conception, design, data analysis, interpretation and drafting manuscript; Su Jing Jing: study conception, design, interpretation and drafting manuscript; Abu-Odah Hammoda, Bayuo Jonathan, Batalik Ladislav and Qin Jing: reviewing and editing. All authors: critical revision of the article.

ACKNOWLEDGEMENTS

We thank the authors of the primary studies for providing their data.

FUNDING INFORMATION

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

CONFLICT OF INTEREST STATEMENT

No conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

All data generated or analysed during the current study are included in this published article.

ORCID

Lin Rose Sin Yi https://orcid.org/0000-0002-7670-1247
Su Jing Jing https://orcid.org/0000-0002-8242-811X
Batalik Ladislav https://orcid.org/0000-0003-2147-1541

REFERENCES

Baggetta, P., & Alexander, P. A. (2016). Conceptualization and operationalization of executive function. *Mind, Brain, and Education*, *10*(1), 10–33.

Ballester, B. R., Nirme, J., Camacho, I., Duarte, E., Rodríguez, S., Cuxart, A., Duff, A., & Verschure, P. F. (2017). Domiciliary VR-based therapy for functional recovery and cortical reorganization: Randomized controlled trial in participants at the chronic stage post stroke. *JMIR Serious Games*, *5*(3), e6773.

Baltaduonienė, D., Kubilius, R., Berškienė, K., Vitkus, L., & Petruševičienė, D. (2019). Change of cognitive functions after stroke with rehabilitation systems. *Translational Neuroscience*, *10*(1), 118–124.

Brugada-Ramentol, V., Bozorgzadeh, A., & Jalali, H. (2022). Enhance VR: A multisensory approach to cognitive training and monitoring. *Frontiers in Digital Health*, *98*, 916052.

Clark, B., Whitall, J., Kwakkel, G., Mehrholz, J., Ewings, S., & Burridge, J. (2017). Time spent in rehabilitation and effect on measures of activity after stroke. *The Cochrane Database of Systematic Reviews*, *2017*(3), CD012612.

Cochrane Collaboration. (2014). Review manager (RevMan)[computer program]. *Vol Version*.

Cooper, N., Milella, F., Pinto, C., Cant, I., White, M., & Meyer, G. (2018). The effects of substitute multisensory feedback on task performance and the sense of presence in a virtual reality environment. *PLoS One*, *13*(2), e0191846.

Dąbrowská, M., Pastucha, D., Janura, M., Tomášková, H., Honzíková, L., Baníková, Š., Filip, M., & Fiedorová, I. (2023). Effect of virtual reality therapy on quality of life and self-sufficiency in post-stroke patients. *Medicina*, *59*(9), 1669.

das Nair, R., Cogger, H., Worthington, E., & Lincoln, N. B. (2016). Cognitive rehabilitation for memory deficits after stroke. *Cochrane Database of Systematic Reviews*, *9*, CD002293.

De Luca, R., Russo, M., Naro, A., Tomasello, P., Leonardi, S., Santamaria, F., Desireè, L., Bramanti, A., Silvestri, G., & Bramanti, P. (2018). Effects of virtual reality-based training with BTs-nirvana on functional recovery in stroke patients: Preliminary considerations. *International Journal of Neuroscience*, *128*(9), 791–796.

Dworzynski, K., Ritchie, G., & Playford, E. D. (2015). Stroke rehabilitation: Long-term rehabilitation after stroke. *Clinical Medicine*, *15*(5), 461–464.

Faria, A. L., Andrade, A., Soares, L., & I Badia, S. B. (2016). Benefits of virtual reality based cognitive rehabilitation through simulated activities of daily living: A randomized controlled trial with stroke patients. *Journal of Neuroengineering and Rehabilitation*, *13*(1), 96. https://doi.org/10.1186/s12984-016-0204-z

Faria, A. L., Cameirão, M. S., Couras, J. F., Aguiar, J. R. O., Costa, G. M., & Bermúdez, I. B. S. (2018). Combined cognitive-motor rehabilitation in virtual reality improves motor outcomes in chronic stroke – a pilot study. *Frontiers in Psychology*, *9*, 854. https://doi.org/10.3389/fpsyg.2018.00854

Faria, A. L., Pinho, M. S., & Bermúdez I Badia, S. (2020). A comparison of two personalization and adaptive cognitive rehabilitation approaches: A randomized controlled trial with chronic stroke patients. *Journal of Neuroengineering and Rehabilitation*, *17*(1), 1–15.

Gamito, P., Oliveira, J., Coelho, C., Morais, D., Lopes, P., Pacheco, J., Brito, R., Soares, F., Santos, N., & Barata, A. F. (2017). Cognitive training on stroke patients via virtual reality-based serious games. *Disability and Rehabilitation*, *39*(4), 385–388. https://doi.org/10.3109/09638288.2014.934925

Gao, Y., Ma, L., Lin, C., Zhu, S., Yao, L., Fan, H., Gong, J., Yan, X., & Wang, T. (2021). Effects of virtual reality-based intervention on cognition, motor function, mood, and activities of daily living in patients with chronic stroke: A systematic review and meta-analysis of randomized controlled trials. *Frontiers in Aging Neuroscience*, *13*, 766525.

Garrett, B., Taverner, T., Gromala, D., Tao, G., Cordingley, E., & Sun, C. (2018). Virtual reality clinical research: Promises and challenges. *JMIR Serious Games*, *6*(4), e10839.

Greenberg, S. M., Ziai, W. C., Cordonnier, C., Dowlatshahi, D., Francis, B., Goldstein, J. N., Hemphill, J. C., III, Johnson, R., Keigher, K. M., & Mack, W. J. (2022). 2022 guideline for the management of patients with spontaneous intracerebral hemorrhage: A guideline from the American Heart Association/American Stroke Association. *Stroke*, *53*, e282–e361. https://doi.org/10.1161/STR.0000000000000407

Gustavsson, M., Kjörk, E. K., Erhardsson, M., & Alt Murphy, M. (2021). Virtual reality gaming in rehabilitation after stroke–user experiences and perceptions. *Disability and Rehabilitation*, *44*, 1–7.

Higgins, J. P. T., & Green, S. (2008). *Cochrane handbook for systematic reviews of interventions: Cochrane book series*. John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470712184

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, *16*(3), 174–180.

Jeffares, I., Rohde, D., Doyle, F., Horgan, F., & Hickey, A. (2022). The impact of stroke, cognitive function and post-stroke cognitive impairment (PSCI) on healthcare utilisation in Ireland: A cross-sectional nationally representative study. *BMC Health Services Research*, *22*(1), 1–13.

Johansson, B. B. (2012). Multisensory stimulation in stroke rehabilitation. *Frontiers in Human Neuroscience*, *6*, 60.

Johnson, L., Bird, M.-L., Muthalib, M., & Teo, W.-P. (2020). An innovative stroke interactive virtual therapy (STRIVE) online platform for community-dwelling stroke survivors: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, *101*(7), 1131–1137.

Juckett, L. A., Wengerd, L. R., Faieta, J., & Griffin, C. E. (2020). Evidence-based practice implementation in stroke rehabilitation: A scoping review of barriers and facilitators. *The American Journal of Occupational Therapy*, *74*(1), 7401205050p1–7401205050p14.

Kannan, L., Vora, J., Bhatt, T., & Hughes, S. L. (2019). Cognitive-motor exergaming for reducing fall risk in people with chronic stroke: A randomized controlled trial. *NeuroRehabilitation*, *44*(4), 493–510.

Kim, B. R., Chun, M. H., Kim, L. S., & Park, J. Y. (2011). Effect of virtual reality on cognition in stroke patients. *Annals of Rehabilitation Medicine*, *35*(4), 450–459. https://doi.org/10.5535/arm.2011.35.4.450

Kim, D. H., Kim, K.-H., & Lee, S.-M. (2020). The effects of virtual reality training with upper limb sensory exercise stimulation on the AROM of upper limb joints, function, and concentration in chronic stroke patients. *Physikalische Medizin, Rehabilitationsmedizin, Kurortmedizin*, *30*(2), 86–94.

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage.

Lam, J., Globas, C., Hosp, J., Karnath, H.-O., Wächter, T., & Luft, A. (2016). Impaired implicit learning and feedback processing after stroke. *Neuroscience*, *314*, 116–124.

Lee, H.-C., Huang, C.-L., Ho, S.-H., & Sung, W.-H. (2017). The effect of a virtual reality game intervention on balance for patients with stroke: A randomized controlled trial. *Games for Health Journal*, *6*(5), 303–311.

Lee, H.-S., Lim, J.-H., Jeon, B.-H., & Song, C.-S. (2020). Non-immersive virtual reality rehabilitation applied to a task-oriented approach for stroke patients: A randomized controlled trial. *Restorative Neurology and Neuroscience*, *38*(2), 165–172.

Lee, H. S., Park, Y. J., & Park, S. W. (2019). The effects of virtual reality training on function in chronic stroke patients: A systematic review and meta-analysis. *BioMed Research International*, *2019*, 7595639.

Lee, P.-H., Yeh, T.-T., Yen, H.-Y., Hsu, W.-L., Chiu, V. J.-Y., & Lee, S.-C. (2021). Impacts of stroke and cognitive impairment on activities of daily living in the Taiwan longitudinal study on aging. *Scientific Reports*, *11*(1), 1–9.

Levin, M. F. (2020). What is the potential of virtual reality for post-stroke sensorimotor rehabilitation? *Expert Review of Neurotherapeutics*, *20*(3), 195–197.

Lin, R. C., Chiang, S. L., Heitkemper, M. M., Weng, S. M., Lin, C. F., Yang, F. C., & Lin, C. H. (2020). Effectiveness of early rehabilitation combined with virtual reality training on muscle strength, mood state, and functional status in patients with acute stroke: A randomized controlled trial. *Worldviews on Evidence-Based Nursing*, *17*(2), 158–167.

Lindsay, M. P., Norrving, B., Sacco, R. L., Brainin, M., Hacke, W., Martins, S., Pandian, J., & Feigin, V. (2019). *World Stroke Organization (WSO): Global stroke fact sheet 2019*. SAGE Publications Sage UK.

Lingo VanGilder, J., Hooyman, A., Peterson, D. S., & Schaefer, S. Y. (2020). Post-stroke cognitive impairments and responsiveness to motor rehabilitation: A review. *Current Physical Medicine and Rehabilitation Reports*, *8*(4), 461–468.

Liu, Z., He, Z., Yuan, J., Lin, H., Fu, C., Zhang, Y., Wang, N., Li, G., Bu, J., & Chen, M. (2022). Application of immersive virtual-reality-based puzzle games in elderly patients with post-stroke cognitive impairment: A pilot study. *Brain Sciences*, *13*(1), 79.

Loetscher, T., Potter, K. J., Wong, D., & das Nair, R. (2019). Cognitive rehabilitation for attention deficits following stroke. *Cochrane Database of Systematic Reviews*, *2019*(11), CD002842.

Long, Y., Ouyang, R.-g., & Zhang, J.-q. (2020). Effects of virtual reality training on occupational performance and self-efficacy of patients with stroke: A randomized controlled trial. *Journal of Neuroengineering and Rehabilitation*, *17*(1), 1–9.

Longley, V., Peters, S., Swarbrick, C., Rhodes, S., & Bowen, A. (2019). Does pre-existing cognitive impairment impact on amount of stroke rehabilitation received? An observational cohort study. *Clinical Rehabilitation*, *33*(9), 1492–1502.

Maier, M., Ballester, B. R., Leiva Bañuelos, N., Duarte Oller, E., & Verschure, P. (2020). Adaptive conjunctive cognitive training (ACCT) in virtual reality for chronic stroke patients: A randomized controlled pilot trial. *Journal of Neuroengineering and Rehabilitation*, *17*(1), 42. https://doi.org/10.1186/s12984-020-0652-3

Mane, R., Chew, E., Phua, K. S., Ang, K. K., Robinson, N., Vinod, A., & Guan, C. (2019). Prognostic and monitory EEG-biomarkers for BCI upper-limb stroke rehabilitation. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *27*(8), 1654–1664.

Manuli, A., Maggio, M. G., Latella, D., Cannavò, A., Balletta, T., De Luca, R., Naro, A., & Calabrò, R. S. (2020). Can robotic gait rehabilitation plus virtual reality affect cognitive and behavioural outcomes in patients with chronic stroke? A randomized controlled trial involving three different protocols. *Journal of Stroke and Cerebrovascular Diseases*, *29*(8), 104994.

McDonald, M. W., Black, S. E., Copland, D. A., Corbett, D., Dijkhuizen, R. M., Farr, T. D., Jeffers, M. S., Kalaria, R. N., Karayanidis, F., & Leff, A. P. (2019). Cognition in stroke rehabilitation and recovery research: Consensus-based core recommendations from the second stroke recovery and rehabilitation roundtable. *International Journal of Stroke*, *14*(8), 774–782.

Mingming, Y., Bolun, Z., Zhijian, L., Yingli, W., & Lanshu, Z. (2022). Effectiveness of computer-based training on post-stroke cognitive rehabilitation: A systematic review and meta-analysis. *Neuropsychological Rehabilitation*, *32*(3), 481–497.

Mograbi, D. C., de Assis Faria, C., Fichman, H. C., Paradela, E. M. P., & Lourenço, R. A. (2014). Relationship between activities of daily living and cognitive ability in a sample of older adults with heterogeneous educational level. *Annals of Indian Academy of Neurology*, *17*(1), 71–76.

Navarro, M. D., Llorens, R., Borrego, A., Alcañiz, M., Noé, E., & Ferri, J. (2020). Competition enhances the effectiveness and motivation of attention rehabilitation after stroke. A randomized controlled trial. *Frontiers in Human Neuroscience*, *14*, 575403. https://doi.org/10.3389/fnhum.2020.575403

Nguyen, L., Murphy, K., & Andrews, G. (2019). Cognitive and neural plasticity in old age: A systematic review of evidence from executive functions cognitive training. *Ageing Research Reviews*, *53*, 100912.

Oberlin, L. E., Waiwood, A. M., Cumming, T. B., Marsland, A. L., Bernhardt, J., & Erickson, K. I. (2017). Effects of physical activity on poststroke cognitive function: A meta-analysis of randomized controlled trials. *Stroke*, *48*(11), 3093–3100.

Oh, Y.-B., Kim, G.-W., Han, K.-S., Won, Y. H., Park, S.-H., Seo, J.-H., & Ko, M.-H. (2019). Efficacy of virtual reality combined with real instrument training for patients with stroke: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, *100*(8), 1400–1408.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., & Brennan, S. E. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *International Journal of Surgery*, *88*, 105906.

Pallesen, H., Andersen, M. B., Hansen, G. M., Lundquist, C. B., & Brunner, I. (2018). Patients' and health professionals' experiences of using virtual reality technology for upper limb training after stroke: A qualitative substudy. *Rehabilitation Research and Practice*, *2018*, 4318678.

Park, I. S., & Yoon, J. G. (2015). The effect of computer-assisted cognitive rehabilitation and repetitive transcranial magnetic stimulation on cognitive function for stroke patients. *Journal of Physical Therapy Science*, *27*(3), 773–776. https://doi.org/10.1589/jpts.27.773

Park, M.-O., & Lee, S.-H. (2019). Effect of a dual-task program with different cognitive tasks applied to stroke patients: A pilot randomized controlled trial. *NeuroRehabilitation*, *44*(2), 239–249.

Rogers, J. M., Duckworth, J., Middleton, S., Steenbergen, B., & Wilson, P. H. (2019). Elements virtual rehabilitation improves motor, cognitive, and functional outcomes in adult stroke: Evidence from a randomized controlled pilot study. *Journal of Neuroengineering and Rehabilitation*, *16*(1), 1–13.

Schünemann, H., Brożek, J., Guyatt, G., & Oxman, A. (2013). *The GRADE handbook*. Cochrane Collaboration.

Sexton, E., McLoughlin, A., Williams, D. J., Merriman, N. A., Donnelly, N., Rohde, D., Hickey, A., Wren, M.-A., & Bennett, K. (2019). Systematic review and meta-analysis of the prevalence of cognitive impairment no dementia in the first year post-stroke. *European Stroke Journal*, *4*(2), 160–171.

Shi, J., Ma, S., Hu, J., Hu, Z., Xia, J., & Xu, H. (2023). The effects of computer-aided cognitive rehabilitation combined with virtual reality technology on event-related potential P300 and cognitive function of patients with cognitive impairment after stroke. *European Review for Medical and Pharmacological Sciences*, *27*, 8993–9000.

Şimşek, T. T., & Çekok, K. (2016). The effects of Nintendo WiiTM-based balance and upper extremity training on activities of daily living and quality of life in patients with sub-acute stroke: A randomized controlled study. *International Journal of Neuroscience*, *126*(12), 1061–1070.

Sterne, J. A., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., Cates, C. J., Cheng, H.-Y., Corbett, M. S., & Eldridge, S. M. (2019). RoB 2: A revised tool for assessing risk of bias in randomised trials. *BMJ*, *366*, l4898.

Stinear, C. M., Lang, C. E., Zeiler, S., & Byblow, W. D. (2020). Advances and challenges in stroke rehabilitation. *The Lancet Neurology*, *19*(4), 348–360.

Takeuchi, N., & Izumi, S.-I. (2013). Rehabilitation with poststroke motor recovery: A review with a focus on neural plasticity. *Stroke Research and Treatment*, *2013*, 1–13.

Torrisi, M., Maresca, G., De Cola, M. C., Cannavò, A., Sciarrone, F., Silvestri, G., Bramanti, A., De Luca, R., & Calabrò, R. S. (2019). Using telerehabilitation to improve cognitive function in post-stroke survivors: Is this the time for the continuity of care? *International Journal of Rehabilitation Research*, *42*(4), 344–351.

Van Rooyen, D., & Jordan, P. J. (2013). *Foundations of nursing practice: Fundamentals of holistic care*. Elsevier Health Sciences.

Viscogliosi, C., Desrosiers, J., & Belleville, S. (2019). Optimizing participation of older adults with cognitive deficits post-stroke: Types of help and caregiver burden. *Canadian Journal on Aging/La Revue Canadienne Du Vieillissement*, *38*(2), 222–235.

Weber, L. M., Nilsen, D. M., Gillen, G., Yoon, J., & Stein, J. (2019). Immersive virtual reality mirror therapy for upper limb recovery following stroke: A pilot study. *American Journal of Physical Medicine & Rehabilitation*, *98*(9), 783–788.

Wender, C. L., DeLuca, J., & Sandroff, B. M. (2022). Developing the rationale for including virtual reality in cognitive rehabilitation and exercise training approaches for managing cognitive dysfunction in MS. *NeuroSci*, *3*(2), 200–213.

Wiley, E., Khattab, S., & Tang, A. (2020). Examining the effect of virtual reality therapy on cognition post-stroke: A systematic review and meta-analysis. *Disability and Rehabilitation. Assistive Technology*, *17*, 1–11. https://doi.org/10.1080/17483107.2020.1755376

Wilson, P. H., Rogers, J. M., Vogel, K., Steenbergen, B., McGuckian, T. B., & Duckworth, J. (2021). Home-based (virtual) rehabilitation improves motor and cognitive function for stroke patients: A randomized controlled trial of the elements (EDNA-22) system. *Journal of Neuroengineering and Rehabilitation*, *18*(1), 1–12.

Zhang, Q., Fu, Y., Lu, Y., Zhang, Y., Huang, Q., Yang, Y., Zhang, K., & Li, M. (2021). Impact of virtual reality-based therapies on cognition and mental health of stroke patients: Systematic review and meta-analysis. *Journal of Medical Internet Research*, *23*(11), e31007.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Rose Sin Yi, L., Jing Jing, S., Hammoda, A.-O., Jonathan, B., Ladislav, B., & Jing, Q. (2024). Effects of virtual reality-based cognitive interventions on cognitive function and activity of daily living among stroke patients: Systematic review and meta-analysis. *Journal of Clinical Nursing*, *33*, 1169–1184. https://doi.org/10.1111/jocn.16986