The Effectiveness of Computerized Cognitive Training in Patients with Post-Stroke Cognitive Impairment: A Systematic Review and Meta-analysis

Min Gao, Lu Huang, Jiang Yi, Tianqi Zhang, Guangyao Zhu, Qi Zhang, Jiaxiao Tian, Rongxuan Zhao, Xiaoqin Duan, Zhongliang Liu

Submitted to: Journal of Medical Internet Research
on: February 27, 2025

Table of Contents

Original Manuscript **5**
Supplementary Files **30**
Figures **31**
Figure 1 ..... **32**
Figure 2 ..... **33**
Figure 3 ..... **34**
Figure 4 ..... **35**
Figure 5 ..... **36**
Figure 6 ..... **37**
Figure 7 ..... **38**
Figure 8 ..... **39**
Multimedia Appendixes **40**
Multimedia Appendix 1 ..... **41**
Multimedia Appendix 2 ..... **41**
Multimedia Appendix 3 ..... **41**
Multimedia Appendix 4 ..... **41**
Multimedia Appendix 5 ..... **41**
Multimedia Appendix 6 ..... **41**
Multimedia Appendix 7 ..... **41**

The Effectiveness of Computerized Cognitive Training in Patients with Post-Stroke Cognitive Impairment: A Systematic Review and Meta-analysis

Min Gao[1] MD; Lu Huang[1] MD; Jiang Yi[2] MD; Tianqi Zhang[2] BS; Guangyao Zhu[2] BS; Qi Zhang[2] MD; Jiaxiao Tian[3] MD; Rongxuan Zhao[1] BS; Xiaoqin Duan[2*] PhD; Zhongliang Liu[2*] PhD

[1] School of Nursing Jilin University Changchun, Jilin Province CN
[2] Department of Rehabilitation Medicine The Second Hospital of Jilin University Changchun, Jilin Province CN
[3] School of Automotive Engineering Jilin University Changchun CN
[*]these authors contributed equally

Corresponding Author:
Xiaoqin Duan PhD

Department of Rehabilitation Medicine
The Second Hospital of Jilin University
No. 4026 Yatai Street? Nanguan District
Changchun, Jilin Province
CN

Abstract

Background: Stroke often triggers post-stroke cognitive impairment (PSCI) within six months, impairing memory, attention, and executive function while exacerbating physical disabilities and mortality. Computerized cognitive training (CCT) is a promising treatment approach. Compared to traditional methods, CCT provides cost-effective, easily accessible, personalized and repetitive rehabilitation training. Therefore, we performed a systematic review of the efficacy of CCT to improve cognitive function in patients with PSCI and supplemented the findings with a meta-analysis.

Objective: To evaluate the efficacy of CCT in comparison to usual care or routine rehabilitation for patients with PSCI, with the aim of providing clinicians and therapists with more effective and convenient therapeutic options.

Methods: The systematic search was conducted across multiple databases, including PubMed, Web of Science, Embase, Cochrane Library, and Scopus, covering publications from 2010 to June 2024, with a focus on English-language articles. The primary outcome measured was cognitive function, assessed through standardized cognitive function scales, while secondary outcomes included daily living activities and motor function of the patients. The risk of bias was evaluated using the Cochrane Risk of Bias tool, and the quality of evidence was determined according to the GRADE framework.

Results: A total of nineteen trials were included in the meta-analysis (n = 880 participants). The findings provided moderate to high-quality evidence indicating that CCT significantly enhances general cognitive function (15 trials, standardized mean difference [SMD]= 0.46, 95% CI = 0.21 to 0.71; P <.001, I2 = 60%), attention (11 trials, SMD = -0.41, 95% CI = -0.62 to -0.20; P <.001, I2 = 15%), executive function (6 trials, SMD = 0.39, 95% CI = 0.12 to 0.67; P =.005, I2 = 0%), and quality of life of PSCI patients (9 trials, SMD = 0.34, 95% CI = 0.15 to 0.53; P <.001, I2 = 6%). However, low to very low quality evidence indicated that CCT has limited improvement in memory, language function, and motor function in PSCI patients.

Conclusions: CCT can significantly enhance general cognitive function, attention, executive function, and quality of life in PSCI patients. Clinical Trial: PROSPERO, CRD42024573594.

(JMIR Preprints 27/02/2025:73140)
DOI: https://doi.org/10.2196/preprints.73140

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?
✓ **Please make my preprint PDF available to anyone at any time (recommended).**

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
Only make the preprint title and abstract visible.
No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**
Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v
Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http
No. Please do not make my accepted manuscript PDF available to anyone.

Original Manuscript

Authors' information/metadata
Heading/heading styles
Type of Paper
Length of paper
Title
Keywords
Trial registration
Introduction
Methods
Results
Discussion
Other components
- Figures
- Tables
  - Footnotes
- Textboxes
- Multimedia Appendices
  - CONSORT-EHEALTH

Acknowledgements (previously Authors' Contributions)
Conflicts of Interest
Abbreviations
URLs
Field codes/citation formatting
References:
- Formatting
- Published works
- Journal
- Book
- Web
- Conference proceedings
- Website URLs

Original Paper

Enter information for authors (including designations, affiliations, correspondence, contributions) in the online metadata form. Do not use periods after initials, and include degree designations and affiliations for all authors. Trial registration numbers are also filled in on the metadata forms online.

The Effectiveness of Computerized Cognitive Training in Patients with Post-Stroke Cognitive Impairment: A Systematic Review and Meta-analysis

Min Gao[1*]; Lu Huang[1*]; Jiang Yi[2]; Tianqi Zhang[2]; Guangyao Zhu[2]; Qi Zhang[2]; Jiaxiao Tian[3]; Rongxuan Zhao[1]; Xiaoqin Duan[2*]; Zhongliang Liu[2*].

[1] School of Nursing, Jilin University, Changchun, China
[2] Department of Rehabilitation Medicine, The Second Hospital of Jilin University, Changchun, China
[3] School of automotive Engineering, Jilin University, Changchun, China
[*]these authors contributed equally

Corresponding Author:
Xiaoqin Duan, PhD
Department of Rehabilitation Medicine, The Second Hospital of Jilin University
No. 4026, Yatai Street, Nanguan District
Changchun , Jilin Province, China. 130041
Phone: +86 15204309769
Email: 15204309769@163.com

Abstract

Background: Stroke often triggers post-stroke cognitive impairment (PSCI) within six months, impairing memory, attention, and executive function while exacerbating physical disabilities and mortality. Computerized cognitive training (CCT) is a promising treatment approach. Compared to traditional methods, CCT provides cost-effective, easily accessible, personalized and repetitive rehabilitation training. Therefore, we performed a systematic review of the efficacy of CCT to improve cognitive function in patients with PSCI and supplemented the findings with a meta-analysis.

Objective: To evaluate the efficacy of CCT in comparison to usual care or routine rehabilitation for patients with PSCI, with the aim of providing clinicians and therapists with more effective and convenient therapeutic options.

Methods: The systematic search was conducted across multiple databases, including PubMed, Web of Science, Embase, Cochrane Library, and Scopus, covering publications from 2010 to June 2024, with a focus on English-language articles. The primary outcome measured was cognitive function, assessed through standardized cognitive function scales, while secondary outcomes included daily living activities and motor function of the patients. The risk of bias was evaluated using the Cochrane Risk of Bias tool, and the quality of evidence was determined according to the GRADE framework.

Results: A total of nineteen trials were included in the meta-analysis (n = 880 participants). The findings provided moderate to high-quality evidence indicating that CCT significantly enhances general cognitive function (15 trials, standardized mean difference [SMD]= 0.46, 95% CI = 0.21 to 0.71; P <.001, I^2 = 60%), attention (11 trials, SMD = -0.41, 95% CI = -0.62 to -0.20; P <.001, I^2 = 15%), executive function (6 trials, SMD = 0.39, 95% CI = 0.12 to 0.67; P =.005, I^2 = 0%), and quality of life of PSCI patients (9 trials, SMD = 0.34, 95% CI = 0.15 to 0.53; P <.001, I^2 = 6%). However, low to very low quality evidence indicated that CCT has limited improvement in memory, language function, and motor function in PSCI patients.

Conclusions: CCT can significantly enhance general cognitive function, attention, executive function, and quality of life in PSCI patients.

Systematic Review Registration: PROSPERO, CRD42024573594.

Keywords: Computerization; Cognitive training; Post-stroke cognitive impairment; Cognitive function; Meta-analysis.

Introduction

Background

Stroke has emerged as the second leading cause of mortality and disability globally. [1,2]. Post-stroke cognitive impairment (PSCI) refers to a series of syndromes that meet the diagnostic criteria for cognitive impairment within 6 months following the clinical event of stroke[3,4]. The prevalence of cognitive deficits among stroke survivors ranges from 17.6% to 83%, with considerable variability across studies conducted in different countries. This variability is attributed to differences in stroke type, timing of assessments, study settings, population characteristics, and variations in cognitive tests and cutoff points[4,5]. PSCI is the most prevalent complication associated with stroke, leading to impairments in attention, executive function, memory, language, and visuospatial abilities. Additionally, it exacerbates motor disorders, increases disability and mortality rates, hinders rehabilitation progress, and severely impacts daily living abilities of patients[6]. If not effectively managed, PSCI can result in abnormal mental behaviors and may even progress to rapidly advancing dementia. Consequently, PSCI poses significant challenges to both families and society at large.

The clinical management of PSCI primarily encompasses the intervention and prevention of established risk factors, pharmacological treatment, and cognitive training [4,7–10]. Notably, evidence-based management of risk factors for PSCI, alongside interdisciplinary research efforts focused on primary prevention, is critically needed [7,11]. The pharmacological agents recommended for treatment are primarily those used for cognitive impairments associated with Alzheimer's disease; however, their efficacy and safety in the context of PSCI remain unverified[12,13]. Traditional cognitive training has been proven to be effective in most studies. Nonetheless, challenges persist, including the time-consuming and labor-intensive nature of these interventions, as well as suboptimal patient compliance among individuals with cognitive impairments[7].

In recent years, the rapid development of computer technology has facilitated the direct delivery of stimuli to patients' visual, auditory, and tactile channels through multimedia, thereby enhancing their ability to gather and organize information, make decisions, and improve cognitive functions. Computerized cognitive training (CCT) leverages multimedia and informatics resources to optimize impaired cognitive functions, ultimately enhancing the quality of life for stroke patients[14]. The underlying principles of CCT are grounded in cognitive psychology and neuroscience research, focusing on the activation of brain plasticity through repetitive exercises and feedback mechanisms. Compared to traditional rehabilitation methods, CCT offers distinct advantages, including interactivity, standardization, individualization, repeatability, and efficiency [15,16]. Furthermore, the low implementation cost, high availability, and accessibility of CCT have contributed to its increasing adoption both domestically and internationally. In current literature, CCT is frequently utilized for patients with mild cognitive impairment, dementia, and Parkinson's disease, demonstrating varying levels of enhancement across different cognitive domains[17–20].A meta-analysis conducted by Rodrigo et al. revealed that CCT significantly improved visual and verbal working memory in individuals with acquired brain injury, although it did not enhance attention or executive function[21]. Another meta-analysis indicates that higher intensity CCT, including remote unsupervised training, is advantageous for general cognitive function in patients with Parkinson's disease[20]. Research by Nicole et al. found CCT to be effective in enhancing general cognition, memory, and attention in elderly patients with mild cognitive impairment, as well as in improving psychosocial functioning, including alleviation of depressive symptoms, albeit with limited impact on executive function. Additionally, there is insufficient evidence to support the efficacy of CCT in enhancing cognitive function in patients with dementia[17]. Although more and more studies have investigated the beneficial impact of CCT on cognitive function, there is still a lack of high-quality evidence on cognitive function and different cognitive domains in PSCI patients.

Aims of This Review

The objective of this review is to systematically evaluate existing clinical studies and conduct a meta-analysis to compare the effectiveness of CCT with alternative interventions, such as usual care and routine rehabilitation training, for patients experiencing post-stroke cognitive impairment. At the same time, we hope to provide new ideas and new methods for clinicians and therapists.

Methods

Study Registration

This review was conducted and reported based on the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA).[22] And the systematic review with meta-analysis had been registered in the PROSPERO database (CRD42024573594).

Search Strategy

We searched PubMed, Web of Science, Embase, Cochrane Library, and Scopus databases from 2010 to 2024. The complete search strategies, developed with the assistance of the research librarian, is presented in the *Multimedia Appendix 1*. All publications in English were searched. Informed by preliminary scoping of the literature, our keywords and MeSH (Medical Subject Headings) terms related to “stroke”, “Cognitive Dysfunction”, “training”, “compute*” and “randomized controlled trial”. In addition, keywords and subject words are combined using Boolean operators. Reference lists of selected articles were independently screened to detect additional studies not included in the original search.

Selection Criteria

Screen titles, abstracts and methods using inclusivity/exclusivity criteria as PICOS.

The inclusion criteria for this study were as follows: (1) the study must be a published randomized controlled trial (RCT); (2) the study population must be PSCI, defined as cognitive dysfunction resulting from a stroke; (3) the intervention group must have received CCT; (4) the control group must have received interventions other than CCT, such as conventional treatment, traditional paper-and-pencil-based cognitive training, and/or health education; and (5) the study must report at least one cognitive assessment (general cognitive function, attention, memory, executive function, language and other cognitive domains) was included, and other indicators could or could not include quality of life and limb motor function.

The exclusion criteria for this study were as follows: (1) patients whose baseline conditions differed significantly within the study; (2) studies that did not report original outcome metrics or where relevant outcome metrics could not be obtained despite contacting the authors; (3) articles in which the study population included patients with other cognitive disorders, such as Alzheimer's disease;

(4) studies where the intervention group received additional interventions alongside CCT, such as CCT combined with medication or acupuncture, compared to the control group treatment; (5) animal experimental studies, case reports, or protocols; (6) articles that were either repeatedly published or retracted; (7) studies for which only abstracts were available and the full text could not be retrieved; (8) publications not in English.

Data Extraction

The literature retrieved was screened by 2 researchers in accordance with the inclusion and exclusion criteria. Baseline characteristics and outcome indicators were extracted using standardized forms. In cases of differing opinions, resolution was achieved through discussion or consultation with a third researcher. The descriptive data extracted from each trial included baseline characteristics (such as authors, year of publication, and country), participant characteristics (including intervention population and sample size), intervention characteristics (such as setting, frequency, duration, and any additional components like computer systems), and outcome indicators. For outcome indicators, the mean and standard deviation (SD) were collected for each group. If studies did not report the relevant data, the corresponding authors were contacted to obtain any missing data.

Data Analysis and Synthesis

The primary outcome measure was the assessment of cognitive function, while the secondary outcome measures included evaluations of patients' activities of daily living and motor function. In instances where multiple scales were employed to assess the same outcome measure, we prioritized those indicators with higher reliability or sensitivity. Detailed prioritization criteria are provided in *Multimedia Appendix 2*. For certain scales, lower scores indicated better functioning, e.g., Trail Making Test-A (TMT-A) and Shulte's table; thus, we applied a negative effect size to this indicator to denote improved functioning in the trial group compared to the control group. Statistical heterogeneity tests and comprehensive data analyses were conducted using Review Manager version 5.3, following the Cochrane guidelines. Standardized mean differences (SMDs) and 95% confidence intervals (CIs) were calculated for continuous data due to the use of different scales across the included trials for the same outcome. Given the substantial heterogeneity in the intervention characteristics of the studies, a random-effects model was employed to derive pooled estimates for all outcome measures. Differences were deemed statistically significant when $P<.05$.

Risk-of-Bias Assessment

We evaluated the risk of bias in trials utilizing the Cochrane Risk of Bias tool (*RoB 2, version 2*) as outlined in the Cochrane Handbook, focusing on the following domains: the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting of outcomes[23]. Each domain was classified as having a high, low, or unclear risk of bias. An overall risk of bias assessment was subsequently determined based on the individual domain assessments, typically reflecting the highest level of bias identified in any domain. In instances of disagreement or discrepancy during the quality assessment process, a third researcher was tasked with verification and resolution.

Certainty Assessment

To evaluate the quality of evidence, we employed the Grading of Recommendations, Assessment, Development, and Evaluations (GRADEpro GDT) methodology[24]. Two independent assessors utilized the GRADEpro GDT software (*gradepro.org*) to appraise the quality of evidence, categorizing it as very low, low, moderate, or high. Footnotes were provided to elucidate the rationale for any downgrading of evidence, which included considerations of risk of bias, inconsistency, indirectness, imprecision, and publication bias.

Additional Analyses

To further investigate the robustness of the results and identify potential sources of heterogeneity, we performed several additional post hoc analyses. A sensitivity analysis was conducted to evaluate the stability of the meta-analysis outcomes by sequentially excluding individual studies to assess their influence on the overall results. For meta-analyses comprising a sufficient number of studies ($n \geq 10$), we intended to evaluate publication bias through the use of funnel plots and Begg tests[25]. $P<.05$ was considered statistically significant.

Results

Search Outcomes

The search results are presented in Figure 1. An initial retrieval yielded 22,114 studies from five electronic databases. Of these, 9,643 studies were excluded due to duplication. A meticulous screening of the titles and abstracts of the remaining 12,471 studies resulted in the exclusion of 12,377 studies that did not satisfy the research criteria. Consequently, 94 studies underwent a comprehensive review. Ultimately, 19 randomized controlled trials (RCTs) were included in the meta-analysis.

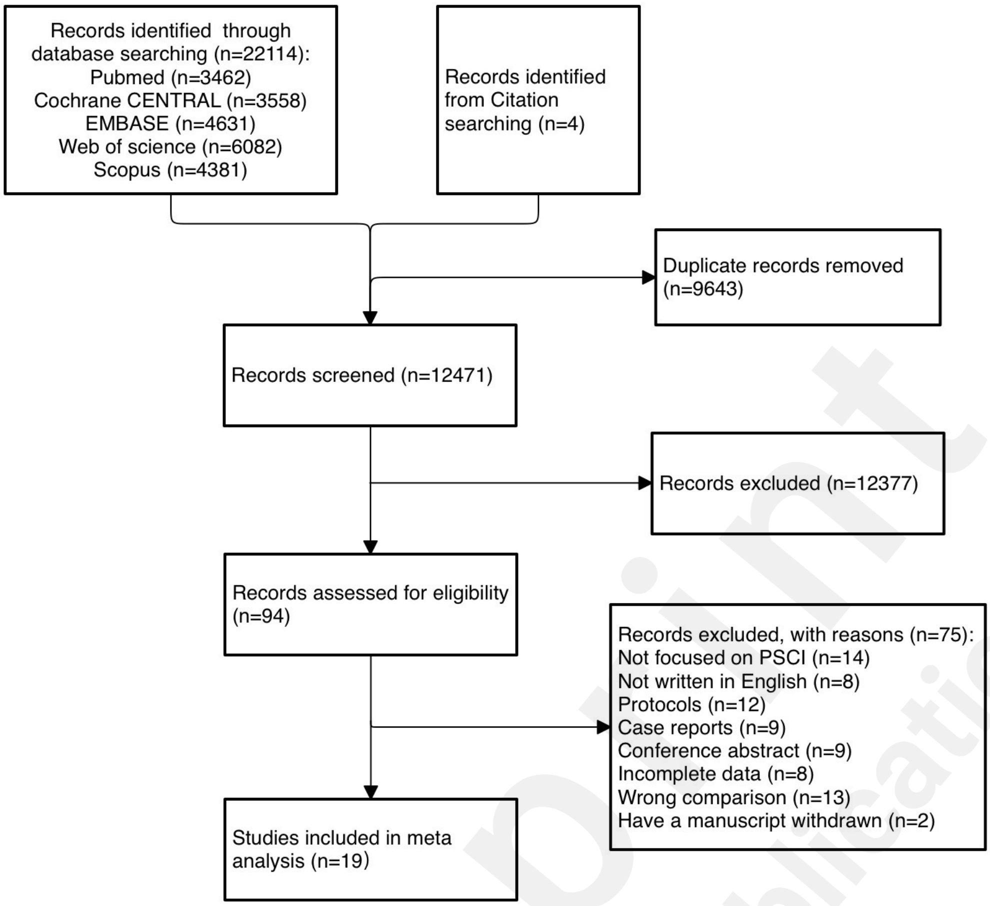


Figure 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flow diagram.

Characteristics of Included Studies

This review incorporated a total of 19 randomized controlled trials (RCTs) encompassing 880 participants. The participants' ages ranged from 27 to 84 years. The duration and frequency of the interventions varied significantly, with seven trials having an intervention frequency of 5 times per week for approximately 8 weeks, and each training session lasting 30-60 minutes [26–32]. Regarding the software employed in CCT, 3 studies used *Rehacom* [28,33,34], 2 studies used *Reh@City* [35,36], 2 studies used *Lumosity* software [29,37], 2 studies used the *Forbrain* System [27,31]. The remaining 5 studies utilized various software, including *NeuroActive®* [38], *Erica* software [39], *Netblue Co., Ltd, Korea* [30], the *Rehabilitation Gaming System* (*RGS*) [26], and the *Kinect* System[32]. 5 studies either did not specify the software used or employed individually customized computer-assisted training programs [40–44]. Participants in the control groups primarily received conventional drug therapy alongside rehabilitation training, such as occupational therapy or traditional paper-and-pencil cognitive training. Further details on the specific characteristics of the included studies are provided in *Multimedia Appendix 3*.

Risk of Bias Assessment

Multimedia Appendix 4 presents the risk of bias assessment for each study included in the analysis. Among the 19 studies, 3 trials exhibited some risk of bias [33,39,40], 8 trials were assessed as having a low risk of bias [26,27,31,32,34,38,43,44], and 8 trials were assessed as having a high risk of bias [28–30,35–37,41,42]. The reasons for the identified risk of bias included the lack of assessor blinding in five trials [28,30,35,36,41], the presence of randomization bias in one trial [42], and the absence of available protocols or complete outcome data reporting in two trials [29,37].

Intervention Effect

The GRADEpro GDT evidence level for the meta-analysis results indicated that the quality of evidence for attention and quality of life was high, the quality of evidence for executive function was medium, and the quality of evidence for other outcomes was low or very low. The primary factors contributing to the reduction in evidence quality were the risk of bias and inconsistency. A comprehensive GRADEpro GDT summary of the results is available in *Multimedia Appendix 5*.

Meta-analysis results

Primary Outcome: General Cognitive

Based on moderate-quality evidence, a meta-analysis of 15 trials indicated that general cognitive function scores were superior in the CCT group compared to the control group (SMD = 0.46, 95%CI = 0.21 to 0.71, P <.001, I^2 = 60%) (Figure 2). After excluding one study by Park JH et al. [30], the heterogeneity was reduced (I^2 = 32%), while the pooled SMD remained largely unchanged (SMD = 0.36, 95%CI = 0.17 to 0.55; P <.001) (*Multimedia Appendix 6*). Overall, these findings suggest that CCT can enhance the general cognitive function in patients with PSCI.

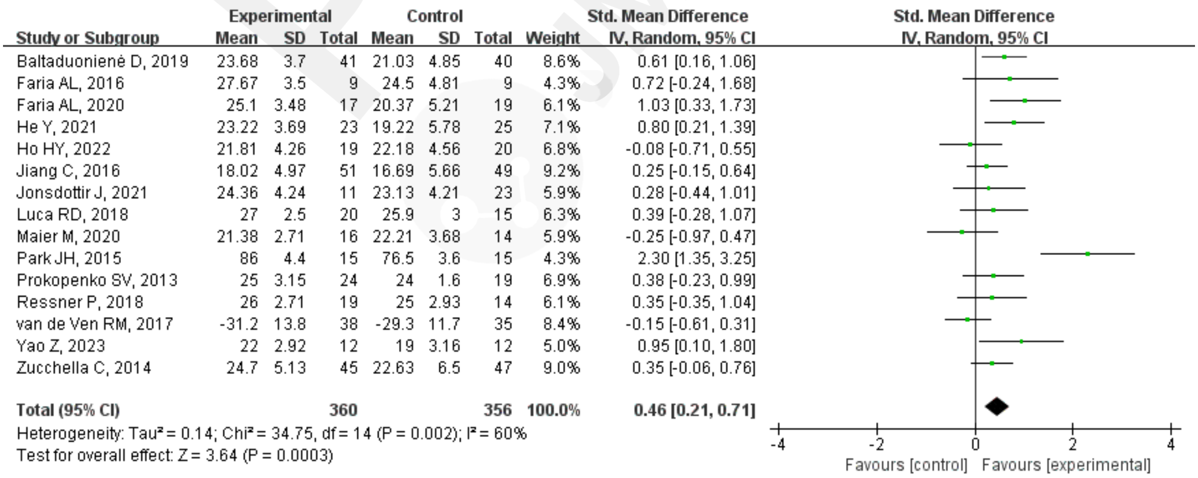


Figure 2 Forest plots of general cognitive outcomes. Abbreviations: CI, confidence interval; SD, standard deviation.

Primary Outcome: Attention

Based on high-quality evidence, a meta-analysis of 11 studies showed that the attention function of PSCI patients in the CCT group was significantly improved, and the difference between the groups was statistically significant (SMD = -0.41, 95%CI = -0.62 to -0.20, *P* <.001, I^2 = 15%) (Figure 3). Thus, CCT can significantly improve the attention function of PSCI patients.

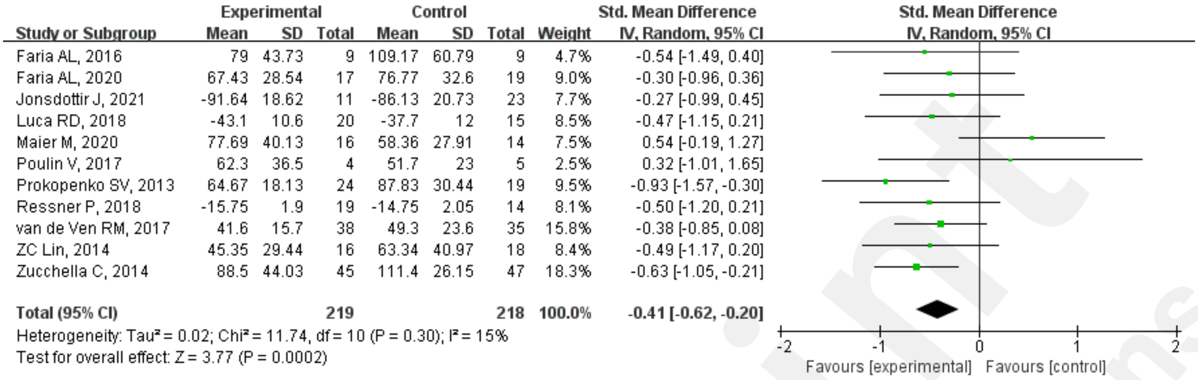


Figure 3 Forest plots of attention. Abbreviations: CI, confidence interval; SD, standard deviation.

Primary Outcome: Memory

Based on very low-quality evidence, a meta-analysis of 11 studies showed no statistical difference in memory function between groups (SMD= -0.11, 95%CI = -0.59 to 0.37, *P* =.67, I^2 = 82%) (Figure 4). After excluding one study by Withiel TD et al.[29], the heterogeneity was reduced (I^2 = 15%), and the pooled SMD changed significantly but were still not statistically significant (SMD=0.16, 95%CI=-0.06 to 0.38; *P* =.15) (*Supplementary File 6*). The improvement of memory function in patients with PSCI is limited by CCT.

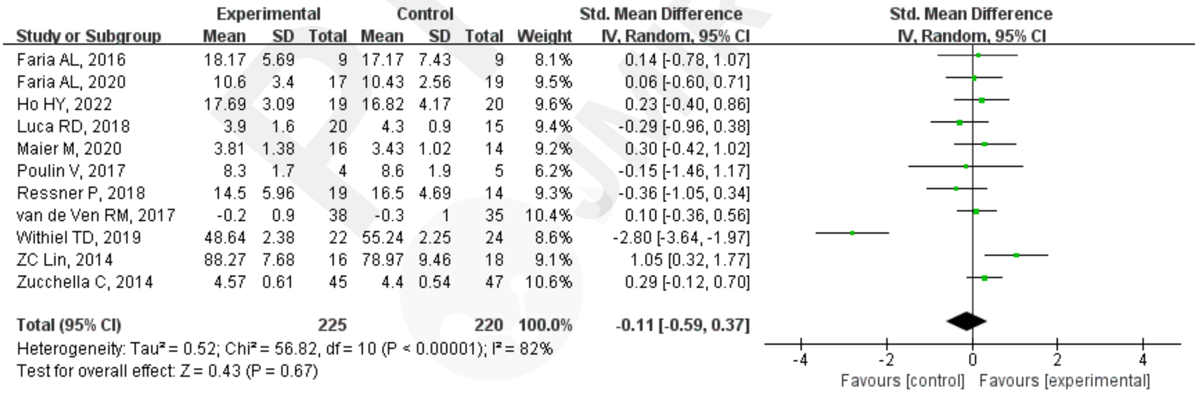


Figure 4 Forest plots of memory. Abbreviations: CI, confidence interval; SD, standard deviation.

Primary Outcome: Executive Function

Based on moderate quality evidence, a meta-analysis of 6 studies showed that executive function was significantly improved in patients with PSCI in the CCT group, and the difference between the groups was statistically significant (SMD = 0.39, 95%CI = 0.12 to 0.67, *P* =.005, I^2 = 0%) (Figure 5). The results indicate that CCT can significantly improve the executive function of patients with PSCI.

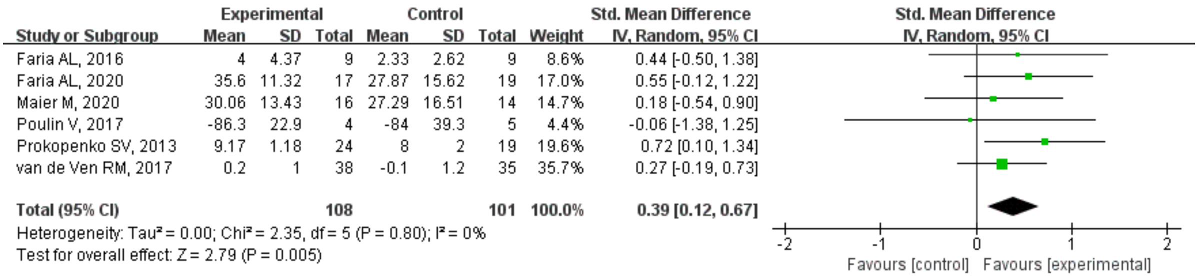


Figure 5 Forest plots of executive functions. Abbreviations: CI, confidence interval; SD, standard deviation.

Primary Outcome: Language

Based on low-quality evidence, a meta-analysis of 5 studies showed no statistical difference in language function between groups (SMD = 0.21, 95%CI = -0.06 to 0.48, P =.12, I^2 = 0%) (Figure 6), indicating limited improvement of language function in PSCI patients with CCT.

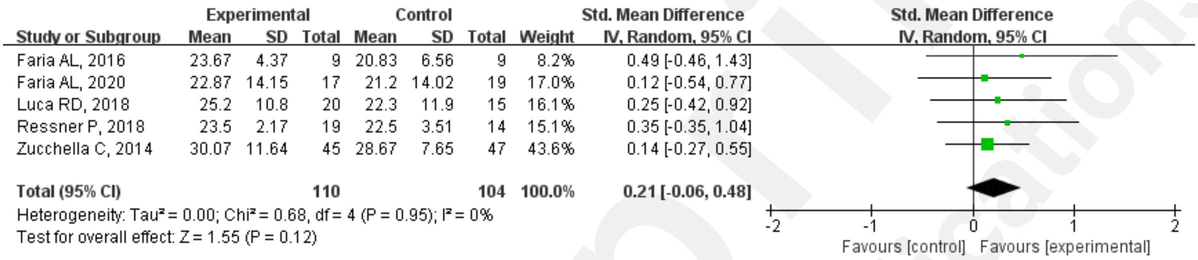


Figure 6 Forest plots of language. Abbreviations: CI, confidence interval; SD, standard deviation.

Secondary Outcome: Quality of Life

Based on high-quality evidence, the meta-analysis of 9 studies showed that the quality of life of PSCI patients in the CCT group was significantly improved, and the difference between the groups was statistically significant (SMD = 0.34, 95%CI= 0.15 to 0.53, P <.001, I^2 = 6%) (Figure 7), indicating that CCT significantly improved quality of life in PSCI patients.

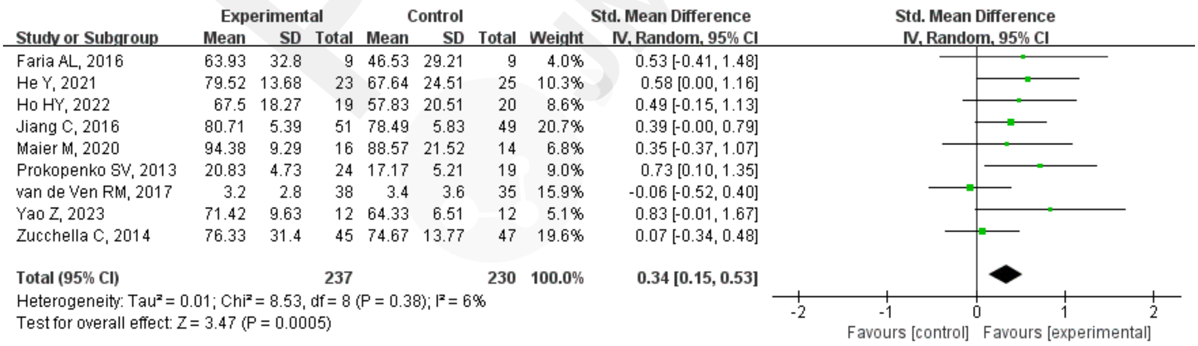


Figure 7 Forest plots of quality of life. Abbreviations: CI, confidence interval; SD, standard deviation.

Secondary Outcome: Motor Function

Based on low-quality evidence, a meta-analysis of 3 trials showed no statistical difference in motor function between CCT and control groups (SMD = 0.11, 95%CI = -0.58 to 0.79, P =.76, I^2 = 65%)

(Figure 8).

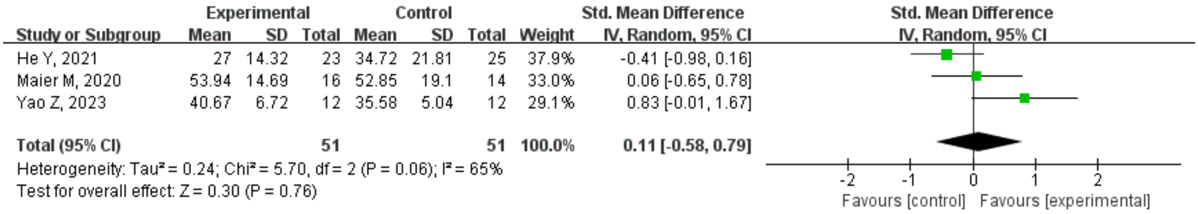


Figure 8 Forest plots of motor function. Abbreviations: CI, confidence interval; SD, standard deviation.

Additional Analyses

Publication bias was evaluated for general cognitive function, attention, and memory across more than 10 included studies, as detailed in *Multimedia Appendix 7*. A visual inspection of the funnel plots indicated no significant asymmetry. Furthermore, Begg's test results demonstrated the absence of publication bias for general cognitive function (*P* =.092), attention (*P* =.21), and memory (*P* =.36), with all *P* >.05.

Discussion

This review synthesizes the evidence concerning the impact of CCT on general cognitive function, specific cognitive domains, daily activities and motor function in individuals with PSCI. Despite variations in the CCT systems employed, based on moderate to high levels of evidence, the findings indicate that CCT is generally effective in enhancing general cognitive function, particularly in the domains of attention and executive function, as well as in improving the quality of life for patients with PSCI.

Mechanisms by which CCT improves cognitive function

Studies have shown that CCT can significantly enhance the recovery of cognitive function in PSCI through the combined influence of neuroplasticity, neurofeedback, task design, and other aspects. Vermeir et al. [45] demonstrated that CCT facilitates the reorganization of brain function by incorporating challenging cognitive tasks that activate adjacent or contralateral brain regions relative to the stroke-affected area. Concurrently, CCT systems typically provide immediate feedback, enabling patients to assess their task performance in real-time and adjust their strategies accordingly. Yuan et al. [46] highlighted the critical role of positive feedback and reward mechanisms in bolstering patient engagement and motivation for training. Moreover, CCT tasks frequently involve the stimulation of multiple sensory modalities, including visual, auditory, and tactile inputs. This cross-modal training approach engages multiple brain regions concurrently, thereby enhancing the cognitive function of patients.

Principal Results

In this review, we found that there was a large heterogeneity in the meta-analysis of general cognitive function (I^2 = 73%). Upon excluding the study by Park JH et al., the heterogeneity reduced moderately (I^2 = 32%), although the effect size was reduced to 0.36. This reduction in effect size may be attributed to the more pronounced improvement in general cognitive function observed in the Park JH et al. study compared to others. This discrepancy could be due to variations in the scales used to measure functional outcomes. Specifically, the study by Park JH et al. [30] used the Loewenstein Occupational Therapy Cognitive Assessment (LOTCA) scale to assess patients' general cognitive function. Unlike the Montreal Cognitive Assessment (MoCA) and the Mini-Mental State Examination (MMSE), the LOTCA scale evaluates not only cognitive function but also perceptual and daily functional abilities, involving more complex cognitive domains, particularly visuospatial cognition. The extended evaluation time required by the LOTCA scale allows for a more comprehensive analysis, potentially offering a better reflection of functional improvements in patients with PSCI [47,48].

CCT improves the function of multiple cognitive domains in patients with PSCI by employing targeted cognitive tasks designed to stimulate neuroplasticity. The mechanisms underlying improvements is intricately linked to the physiological processes of the brain, including neural remodeling, functional compensation, and cognitive stimulation. Consistent with previous research [49–51], our review found significant benefits of CCT in improving attention and executive function in PSCI patients. The regulation of attention and executive functions primarily relies on the prefrontal cortex, parietal lobe, and other associated brain regions. CCT enhances the brain's executive function network, particularly the prefrontal cortex, by gradually increasing task complexity and facilitating task-switching training through repeated attention training and visual attention exercises. This approach incorporates decision-making, planning, and organizing tasks, thereby improving sustained attention and concentration [52–54].

A meta-analysis conducted by Kazinczi et al. [55] demonstrated that CCT exerts a significant impact on memory function in stroke patients, as assessed by the Digit Span Backward Test (DSTB). Conversely, our findings indicate that CCT has a limited effect on improving memory and language functions in patients with PSCI. This may be due to the fact that DSTB is a widely utilized measure of working memory, requiring participants to recall a sequence of digits in reverse order. This task necessitates the retention and manipulation of information, engaging both central executive (CE) functions and short-term memory capacity. Our study extends beyond the digit span test by incorporating assessments such as the Addenbrooke's Cognitive Examination (ACE) memory subscale and Goal Attainment Scaling (GAS), which evaluate memory function through various high-level cognitive behaviors, including directed attention and complex decision-making. The observed discrepancies in findings may be attributable to differences in neural mechanisms and functional brain networks. Notably, upon excluding the study by Withiel TD et al., heterogeneity was reduced (I^2=15%), and the effect size showed a notable change (SMD=0.16), indicating an improvement in memory function, although this change was not statistically significant. The GAS used in this study is primarily employed for goal setting and outcome evaluation in rehabilitation interventions, demonstrating robust reliability and validity. Nevertheless, its subjective and individualized nature limits its direct validity in assessing specific cognitive domains, such as memory or attention, which accounts for its infrequent application in detailed cognitive function assessments. Similar to our results, previous studies have indicated that CCT may facilitate improvements in working memory and short-term information retention, yet it appears to be less effective in enhancing long-term and contextual memory[56–58].

In addition, our results showed that CCT could enhance the quality of life in patients with PSCI. Cognitive impairment after stroke can substantially diminish patients' quality of life, affecting their self-care capabilities, emotional well-being, and social interactions [12] . By improving cognitive function and emotional state, CCT can indirectly contribute to an improved quality of life. The immediate feedback and reward mechanisms inherent in CCT training facilitate patients' perception of progress and achievement, thereby boosting self-confidence and fostering positive emotions, which are essential for improving overall quality of life [50,54,59].

In clinical practice, cognitive impairment and motor dysfunction frequently coexist in patients who have experienced a stroke. Research indicates a correlation between motor functions, such as grip strength disorders, gait, and balance, and general cognitive impairment, including executive dysfunction and memory impairment [60–64] . This review suggests that while CCT may not directly enhance motor function, cognitive abilities are crucial for limb and motor rehabilitation. Cognitive impairments, such as memory deficits or executive dysfunction, can influence the progression of motor rehabilitation [12,60,65,66] . Consequently, these factors should be considered when developing targeted interventions for the stroke population. Other studies have shown that aerobic exercise can enhance the activation of the left dorsolateral prefrontal cortex, thereby improving executive function [67–69] . Thus, integrating aerobic exercise with CCT in clinical practice may yield beneficial therapeutic effects on the recovery of both motor and cognitive functions in patients with PSCI.

Limitations

Our systematic review and meta-analysis are subject to several limitations. Firstly, there is variability in the diagnostic criteria for cognitive impairment among the studies included in this review, which may introduce a certain degree of heterogeneity. Secondly, there is considerable variation in the frequency and intensity of CCT interventions, including differences in the duration of each training session and the overall intervention period, potentially affecting the reliability of the results. Thirdly, the limited number of available trials precluded the possibility of conducting subgroup analyses based on different interventions, CCT systems, or levels of PSCI severity. Lastly, there is a scarcity of studies with long-term follow-up outcomes, with only three trials providing follow-up data extending from one to four months.

Future research

Based on the results of the meta-analysis, we propose that future research should establish standardized assessment criteria for each cognitive domain and identify the most effective rating scales to enhance comparability across studies and facilitate the integration of findings. It is advisable to strengthen multi-center collaboration, increase sample sizes, and conduct long-term follow-up studies to assess the enduring effects of CCT and its applicability at various stages. Given the substantial variability in intervention duration and CCT systems among the included trials, minor discrepancies in results may be anticipated. It has been suggested that such research should be expanded to evaluate effectiveness in real-world applications, with a focus on implementation strategies, collaboration with healthcare systems, and treatment settings that optimize healthcare expenditures and maximize patient benefits [14,20,70].Future studies should consider conducting subgroup analyses based on varying frequencies and intensities of interventions, the type of CCT system used, and the severity of PSCI, contingent upon a sufficient number of experiments. Concurrently, there should be an increased focus on developing personalized treatment and intervention strategies. These strategies should be integrated with other rehabilitation measures and tailored precisely to meet the specific needs of individual patients to optimize intervention outcomes. Additionally, the inherent complexity of CCT may present challenges for rehabilitation medical personnel and hinder the use of patients.. To address these issues and facilitate the sustainable use of computerized rehabilitation, Nahas et al. have suggested the development of standardized guidelines for medical staff, along with the implementation of CCT acceptability and acceptance models to enhance patient engagement [71] . Furthermore, larger, adequately powered trials are necessary to determine which specific CCT regimens are most effective in improving cognitive function, specific cognitive domains, and daily functioning in patients with PSCI over the long term.

Conclusions

In summary, based on moderate to high level of evidence, we conclude that CCT is effective in improving general cognitive function, as well as attention and executive function, and quality of life in patients with PSCI. Clinicians can devise personalized training programs targeting specific cognitive domains when designing CCT interventions, thereby augmenting cognitive engagement and enhancing the quality of life for these patients.

Data Availability

All data generated or analyzed during this study were included in published articles. All data have been published in open access journals.

Acknowledgments

This study was funded by grants from the Jilin Province International Science and Technology Cooperation Project (20230402006GH) and Jilin Provincial Natural Science Foundation project (YDZJ202501ZYTS677). The funding sources played no role in the design, implementation, data analysis, interpretation, or reporting of this study. The content of this publication is solely the responsibility of the authors.

Authors' Contributions

Min Gao: Conceptualization, Methodology, Validation, Writing-Original draft preparation. Lu Huang: Methodology, Data curation, Software, Writing-Original draft preparation. Jiang Yi: Data extraction, Formal analysis. Tianqi Zhang: Visualization, Investigation. Guangyao Zhu: Visualization, Investigation. Qi Zhang: Data curation, Investigation. Jiaxiao Tian: Conceptualization, Investigation. Rongxuan Zhao: Methodology, Validation. Xiaoqin Duan: Writing-Reviewing, Supervision. Zhongliang Liu: Writing-Reviewing, Supervision, Editing.

Conflicts of Interest

None declared.

Abbreviations

CCT: Computerized Cognitive Training

DSTB: Digit Span Backward Test

GAS: Goal Attainment Scaling

GRADEpro GDT: Grading of Recommendations Assessment, Development, and Evaluation

LOTCA: Loewenstein Occupational Therapy Cognitive Assessment

MMSE: Mini-Mental State Examination

MoCA: Montreal Cognitive Assessment

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PSCI: Post-Stroke Cognitive Impairment

RCT: randomized controlled trial

Rob 2: Cochrane Risk of Bias 2

SD: standard deviation

SMD: standardized mean difference

TMT-A: Trail Making Test-A

95%CI: 95% confidence intervals

Multimedia Appendix 1

Example search strategy.

Multimedia Appendix 2

Outcome indicators.

Multimedia Appendix 3

Characteristics of Included Studies.

Multimedia Appendix 4

Risk of bias.

Multimedia Appendix 5

The GRADE Summary of Findings for the Outcomes.

Multimedia Appendix 6

Sensitivity analysis results.

Multimedia Appendix 7

Funnel plot of publication bias.

References

1. Krishnamurthi RV, Ikeda T, Feigin VL. Global, Regional and Country-Specific Burden of Ischaemic Stroke, Intracerebral Haemorrhage and Subarachnoid Haemorrhage: A Systematic Analysis of the Global Burden of Disease Study 2017. Neuroepidemiology 2020 Feb 20;54(2):171–179. doi: 10.1159/000506396

2. Feigin VL, Brainin M, Norrving B, Martins S, Sacco RL, Hacke W, Fisher M, Pandian J, Lindsay P. World stroke organization (WSO): Global stroke fact sheet 2022. Int J Stroke 2022 Jan;17(1):18–29. PMID:34986727

3. Mijajlović MD, Pavlović A, Brainin M, Heiss W-D, Quinn TJ, Ihle-Hansen HB, Hermann DM,

Assayag EB, Richard E, Thiel A, Kliper E, Shin Y-I, Kim Y-H, Choi S, Jung S, Lee Y-B, Sinanović O, Levine DA, Schlesinger I, Mead G, Milošević V, Leys D, Hagberg G, Ursin MH, Teuschl Y, Prokopenko S, Mozheyko E, Bezdenezhnykh A, Matz K, Aleksić V, Muresanu D, Korczyn AD, Bornstein NM. Post-stroke dementia – a comprehensive review. BMC Medicine 2017 Jan 18;15(1):11. doi: 10.1186/s12916-017-0779-7

4. Rost NS, Brodtmann A, Pase MP, Van Veluw SJ, Biffi A, Duering M, Hinman JD, Dichgans M. Post-Stroke Cognitive Impairment and Dementia. Circulation Research American Heart Association; 2022 Apr 15;130(8):1252–1271. doi: 10.1161/CIRCRESAHA.122.319951

5. Huang Y-Y, Chen S-D, Leng X-Y, Kuo K, Wang Z-T, Cui M, Tan L, Wang K, Dong Q, Yu J-T. Post-Stroke Cognitive Impairment: Epidemiology, Risk Factors, and Management. J Alzheimers Dis 2022;86(3):983–999. PMID:35147548

6. Pollock A, George BS, Fenton M, Firkins L. Top ten research priorities relating to life after stroke. The Lancet Neurology Elsevier; 2012 Mar 1;11(3):209. PMID:22341029

7. Quinn TJ, Richard E, Teuschl Y, Gattringer T, Hafdi M, O'Brien JT, Merriman N, Gillebert C, Huygelier H, Verdelho A, Schmidt R, Ghaziani E, Forchammer H, Pendlebury ST, Bruffaerts R, Mijajlovic M, Drozdowska BA, Ball E, Markus HS. European stroke organisation and european academy of neurology joint guidelines on post-stroke cognitive impairment. Eur J Neurol 2021 Dec;28(12):3883–3920. PMID:34476868

8. Narasimhalu K, Effendy S, Sim CH, Lee JM, Chen I, Hia SB, Xue HL, Corrales MP, Chang HM, Wong MC, Chen CP, Tan EK. A randomized controlled trial of rivastigmine in patients with cognitive impairment no dementia because of cerebrovascular disease. Acta Neurol Scand 2010 Apr;121(4):217–224. PMID:19951274

9. Battle CE, Abdul-Rahim AH, Shenkin SD, Hewitt J, Quinn TJ. Cholinesterase inhibitors for vascular dementia and other vascular cognitive impairments: A network meta-analysis. Cochrane Database Syst Rev 2021 Feb 22;2(2):CD013306. PMID:33704781

10. Lanctôt KL, Lindsay MP, Smith EE, Sahlas DJ, Foley N, Gubitz G, Austin M, Ball K, Bhogal S, Blake T, Herrmann N, Hogan D, Khan A, Longman S, King A, Leonard C, Shoniker T, Taylor T, Teed M, de Jong A, Mountain A, Casaubon LK, Dowlatshahi D, Swartz RH, Management of Mood, Cognition and Fatigue Following Stroke Best Practice Writing Group, the Heart & Stroke Canadian Stroke Best Practices and Quality Advisory Committee; in collaboration with the Canadian Stroke Consortium. Canadian stroke best practice recommendations: Mood, cognition and fatigue following stroke, 6th edition update 2019. Int J Stroke 2020 Aug;15(6):668–688. PMID:31221036

11. Kernan WN, Viera AJ, Billinger SA, Bravata DM, Stark SL, Kasner SE, Kuritzky L, Towfighi A, American Heart Association Stroke Council; Council on Arteriosclerosis, Thrombosis and Vascular Biology; Council on Cardiovascular Radiology and Intervention; and Council on Peripheral Vascular Disease. Primary Care of Adult Patients After Stroke: A Scientific Statement From the American Heart Association/American Stroke Association. Stroke 2021 Aug;52(9):e558–e571. PMID:34261351

12. Sikkes SAM, Tang Y, Jutten RJ, Wesselman LMP, Turkstra LS, Brodaty H, Clare L, Cassidy-Eagle E, Cox KL, Chételat G, Dautricourt S, Dhana K, Dodge H, Dröes R-M, Hampstead BM,

Holland T, Lampit A, Laver K, Lutz A, Lautenschlager NT, McCurry SM, Meiland FJM, Morris MC, Mueller KD, Peters R, Ridel G, Spector A, van der Steen JT, Tamplin J, Thompson Z, Bahar-Fuchs A. Toward a theory-based specification of non-pharmacological treatments in aging and dementia: Focused reviews and methodological recommendations. Alzheimers Dement 2021 Feb;17(2):255–270. PMID:33215876

13. Reuben DB, Kremen S, Maust DT. Dementia prevention and treatment: A narrative review. JAMA Intern Med 2024 May 1;184(5):563–572. PMID:38436963

14. Gates NJ, Vernooij RW, Di Nisio M, Karim S, March E, Martínez G, Rutjes AW. Computerised cognitive training for preventing dementia in people with mild cognitive impairment. Cochrane Database Syst Rev 2019 Mar 13;2019(3):CD012279. PMID:30864747

15. Dresler M, Sandberg A, Ohla K, Bublitz C, Trenado C, Mroczko-Wąsowicz A, Kühn S, Repantis D. Non-pharmacological cognitive enhancement. Neuropharmacology 2013 Jan;64:529–543. PMID:22828638

16. Tortora C, Di Crosta A, La Malva P, Prete G, Ceccato I, Mammarella N, Di Domenico A, Palumbo R. Virtual reality and cognitive rehabilitation for older adults with mild cognitive impairment: A systematic review. Ageing Res Rev 2024 Jan;93:102146. PMID:38036103

17. Hill NTM, Mowszowski L, Naismith SL, Chadwick VL, Valenzuela M, Lampit A. Computerized cognitive training in older adults with mild cognitive impairment or dementia: A systematic review and meta-analysis. Am J Psychiatry 2017 Apr 1;174(4):329–340. PMID:27838936

18. Li B-Y, He N-Y, Qiao Y, Xu H-M, Lu Y-Z, Cui P-J, Ling H-W, Yan F-H, Tang H-D, Chen S-D. Computerized cognitive training for Chinese mild cognitive impairment patients: A neuropsychological and fMRI study. Neuroimage Clin 2019;22:101691. PMID:30708349

19. Savulich G, Piercy T, Fox C, Suckling J, Rowe JB, O'Brien JT, Sahakian BJ. Cognitive training using a novel memory game on an iPad in patients with amnestic mild cognitive impairment (aMCI). Int J Neuropsychopharmacol 2017 Aug 1;20(8):624–633. PMID:28898959

20. Gavelin HM, Domellöf ME, Leung I, Neely AS, Launder NH, Nategh L, Finke C, Lampit A. Computerized cognitive training in parkinson's disease: A systematic review and meta-analysis. Ageing Res Rev 2022 Sep;80:101671. PMID:35714854

21. Fernández López R, Antolí A. Computer-based cognitive interventions in acquired brain injury: A systematic review and meta-analysis of randomized controlled trials. PLoS One 2020 Jul 9;15(7):e0235510. PMID:32645046

22. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ 2021 Mar 29;372:n71. PMID:33782057

23. Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, Cates CJ, Cheng H-Y,

Corbett MS, Eldridge SM, Emberson JR, Hernán MA, Hopewell S, Hróbjartsson A, Junqueira DR, Jüni P, Kirkham JJ, Lasserson T, Li T, McAleenan A, Reeves BC, Shepperd S, Shrier I, Stewart LA, Tilling K, White IR, Whiting PF, Higgins JPT. RoB 2: A revised tool for assessing risk of bias in randomised trials. BMJ 2019 Aug 28;366:l4898. PMID:31462531

24. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, Schünemann HJ. GRADE: An emerging consensus on rating quality of evidence and strength of recommendations. BMJ 2008 Apr 26;336(7650):924–926. PMID:18436948

25. GRADE handbook. Available from: https://gdt.gradepro.org/app/handbook/handbook.html [accessed Jan 4, 2025]

26. Maier M, Ballester BR, Leiva Bañuelos N, Duarte Oller E, Verschure PFMJ. 2 Adaptive conjunctive cognitive training (ACCT) in virtual reality for chronic stroke patients: a randomized controlled pilot trial. J Neuroeng Rehabil 2020 Mar 6;17:42. PMID:32143674

27. Ven RM van de, Buitenweg JIV, Schmand B, Veltman DJ, Aaronson JA, Nijboer TCW, Kruiper-Doesborgh SJC, Bennekom CAM van, Rasquin SMC, Ridderinkhof KR, Murre JMJ. 6 Brain training improves recovery after stroke but waiting list improves equally: A multicenter randomized controlled trial of a computer-based cognitive flexibility training. PLOS ONE Public Library of Science; 2017 Mar 3;12(3):e0172993. doi: 10.1371/journal.pone.0172993

28. Baltaduonienė D, Kubilius R, Berškienė K, Vitkus L, Petruševičienė D. 7 Change of Cognitive Functions after Stroke with Rehabilitation Systems. Transl Neurosci De Gruyter; 2019;10:118. PMID:31149357

29. Withiel TD, Wong D, Ponsford JL, Cadilhac DA, New P, Mihaljcic T, Stolwyk RJ. 10 Comparing memory group training and computerized cognitive training for improving memory function following stroke: A phase II randomized controlled trial. J Rehabil Med 2019 Apr 26;51(5):343–351. doi: 10.2340/16501977-2540

30. Park J-H, Park J-H. 18 The effects of a Korean computer-based cognitive rehabilitation program on cognitive function and visual perception ability of patients with acute stroke. Journal of Physical Therapy Science Society of Physical Therapy Science; 2015 Aug;27(8):2577. PMID:26356152

31. Rm van de V, Jmj M, Jiv B, Dj V, Ja A, Tcw N, Sjc K-D, Cam van B, Kr R, B S. 19 The influence of computer-based cognitive flexibility training on subjective cognitive well-being after stroke: A multi-center randomized controlled trial. PloS one PLoS One; 2017 Nov 16;12(11). PMID:29145410

32. Jonsdottir J, Baglio F, Gindri P, Isernia S, Castiglioni C, Gramigna C, Palumbo G, Pagliari C, Di Tella S, Perini G, Bowman T, Salza M, Molteni F. 20 Virtual Reality for Motor and Cognitive Rehabilitation From Clinic to Home: A Pilot Feasibility and Efficacy Study for Persons With Chronic Stroke. Front Neurol 2021 Apr 7;12:601131. PMID:33897579

33. Lin Z, Tao J, Gao Y, Yin D, Chen A, Chen L. 3 Analysis of central mechanism of cognitive training on cognitive impairment after stroke: Resting-state functional magnetic resonance imaging study. J Int Med Res SAGE Publications Ltd; 2014 Jun 1;42(3):659–668.

doi: 10.1177/0300060513505809

34. Jiang C, Yang S, Tao J, Huang J, Li Y, Ye H, Chen S, Hong W, Chen L. 8 Clinical Efficacy of Acupuncture Treatment in Combination With RehaCom Cognitive Training for Improving Cognitive Function in Stroke: A 2 × 2 Factorial Design Randomized Controlled Trial. J Am Med Dir Assoc 2016 Dec 1;17(12):1114–1122. doi: 10.1016/j.jamda.2016.07.021

35. Faria AL, Pinho MS, Badia SB i. 1 A comparison of two personalization and adaptive cognitive rehabilitation approaches: a randomized controlled trial with chronic stroke patients. Journal of NeuroEngineering and Rehabilitation BMC; 2020;17. PMID:32546251

36. Faria AL, Andrade A, Soares L, i Badia SB. 5 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 2016 Nov 2;13(1):96. doi: 10.1186/s12984-016-0204-z

37. Ho H-Y, Chen M-D, Tsai C-C, Chen H-M. 15 Effects of computerized cognitive training on cognitive function, activity, and participation in individuals with stroke: A randomized controlled trial. NeuroRehabilitation IOS Press; 2022 Jan 1;51(1):79–89. doi: 10.3233/NRE-210271

38. Poulin V, Korner-Bitensky N, Bherer L, Lussier M, Dawson DR. 11 Comparison of two cognitive interventions for adults experiencing executive dysfunction post-stroke: a pilot study. Disabil Rehabil Taylor & Francis; 2017 Jan 2;39(1):1–13. PMID:26750772

39. De Luca R, Leonardi S, Spadaro L, Russo M, Aragona B, Torrisi M, Maggio MG, Bramanti A, Naro A, De Cola MC, Calabrò RS. 16 Improving Cognitive Function in Patients with Stroke: Can Computerized Training Be the Future? Journal of Stroke and Cerebrovascular Diseases 2018 Apr 1;27(4):1055–1060. doi: 10.1016/j.jstrokecerebrovasdis.2017.11.008

40. Zucchella C, Capone A, Codella V, Vecchione C, Buccino G, Sandrini G, Pierelli F, Bartolo M. 4 Assessing and restoring cognitive functions early after stroke. Functional Neurology CIC Edizioni Internazionali; 2014 Dec;29(4):255. PMID:25764255

41. Prokopenko SV, Mozheyko EY, Petrova MM, Koryagina TD, Kaskaeva DS, Chernykh TV, Shvetzova IN, Bezdenezhnih AF. 13 Correction of post-stroke cognitive impairments using computer programs. J Neurol Sci 2013 Feb 15;325(1):148–153. doi: 10.1016/j.jns.2012.12.024

42. Ressner P, Krulová P, Beránková D, Nilius P, Bártová P, Zapletalová J, Srovnalová Zakopčanová H, Novobilský R, Martinková J, Školoudík D, Bar M. 14 Effect of a combined approach to cognitive rehabilitation in post-stroke patients. Cesk Slov Neurol N 2018 May 31;81/114(3):314–319. doi: 10.14735/amcsnn2018314

43. Yao Z, Zhang T, Chen F, Shi W, Zheng J, Zhang Z, Chen Z. 9 Cognitive Function and Upper Limb Rehabilitation Training Post-Stroke Using a Digital Occupational Training System. J Vis Exp United States: MYJoVE Corporation; 2023 Dec 29;(202). doi: 10.3791/65994

44. Youze H, Ting Y, Yaqi B, Tianshen X, Tiecheng W, Jingsong W. 12 Computer aided self-regulation learning and cognitive training improve generalization ability of patients with

poststroke cognitive impairment. Sci Rep-uk 2021 Dec 17;11(1):24200. PMID:34921201

45. Vermeir JF, White MJ, Johnson D, Crombez G, Ryckeghem DMLV. The effects of gamification on computerized cognitive training: Systematic review and meta-analysis. JMIR Serious Games 2020 Aug 10;8(3):e18644. doi: 10.2196/18644

46. Yuan Z, Peng Y, Wang L, Song S, Chen S, Yang L, Liu H, Wang H, Shi G, Han C, Cammon JA, Zhang Y, Qiao J, Wang G. Effect of BCI-controlled pedaling training system with multiple modalities of feedback on motor and cognitive function rehabilitation of early subacute stroke patients. IEEE Trans Neural Syst Rehabil Eng 2021;29:2569–2577. PMID:34871175

47. Almomani F, Avi-Itzhak T, Demeter N, Josman N, Al-momani MO. Construct validity and internal consistency reliability of the loewenstein occupational therapy cognitive assessment (LOTCA). BMC Psychiatry 2018 Jun 11;18:184. PMID:29890961

48. Wang S-Y, Gong Z-K, Sen J, Han L, Zhang M, Chen W. The usefulness of the loewenstein occupational therapy cognition assessment in evaluating cognitive function in patients with stroke. Eur Rev Med Pharmacol Sci 2014;18(23):3665–3672. PMID:25535138

49. Zhou Y, Feng H, Li G, Xu C, Wu Y, Li H. Efficacy of computerized cognitive training on improving cognitive functions of stroke patients: A systematic review and meta-analysis of randomized controlled trials. Int J Nurs Pract 2022 Jun;28(3):e12966. PMID:34036682

50. Zhou L, Huang X, Wang J, Wang F, Liu J, Liu N. The influence of eight cognitive training regimes upon cognitive screening tool performance in post-stroke survivors: A network meta-analysis. Front Aging Neurosci 2024;16:1374546. PMID:39100748

51. Niemeijer M, Sværke KW, Christensen HK. The effects of computer based cognitive rehabilitation in stroke patients with working memory impairment: A systematic review. J Stroke Cerebrovasc Dis 2020 Dec;29(12):105265. PMID:32992171

52. Bogdanova Y, Yee MK, Ho VT, Cicerone KD. Computerized cognitive rehabilitation of attention and executive function in acquired brain injury: A systematic review. J Head Trauma Rehabil 2016;31(6):419–433. PMID:26709580

53. Specht J, Stegmann B, Gross H, Krakow K. Cognitive training with head-mounted display virtual reality in neurorehabilitation: Pilot randomized controlled trial. JMIR Serious Games 2023 Jul 21;11:e45816. PMID:37477957

54. Oliveira J, Gamito P, Lopes B, Silva AR, Galhordas J, Pereira E, Ramos E, Silva AP, Jorge Á, Fantasia A. Computerized cognitive training using virtual reality on everyday life activities for patients recovering from stroke. Disabil Rehabil Assist Technol 2022 Apr;17(3):298–303. PMID:32255695

55. Kazinczi C, Kocsis K, Boross K, Racsmány M, Klivényi P, Vécsei L, Must A. The effect of computerized cognitive training and transcranial direct current stimulation on working memory among post-stroke individuals: A systematic review with meta-analysis and meta-regression. BMC Neurol 2024 Sep 4;24:314. PMID:39232643

56. Wu J, He Y, Liang S, Liu Z, Huang J, Liu W, Tao J, Chen L, Chan CCH, Lee TMC. Effects of computerized cognitive training on structure–function coupling and topology of multiple

brain networks in people with mild cognitive impairment: A randomized controlled trial. Alzheimers Res Ther 2023 Sep 23;15(1):158. PMID:37742005

57. Ho H-Y, Chen M-D, Tsai C-C, Chen H-M. Effects of computerized cognitive training on cognitive function, activity, and participation in individuals with stroke: A randomized controlled trial. NeuroRehabilitation 2022;51(1):79–89. PMID:35311716

58. Majid MJ, Lincoln NB, Weyman N. Cognitive rehabilitation for memory deficits following stroke. Cochrane Database Syst Rev 2000;(3):CD002293. PMID:10908546

59. Han K, Liu G, Liu N, Li J, Li J, Cui L, Cheng M, Long J, Liao X, Tang Z, Liu Y, Liu J, Chen J, Lu H, Zhang H. Effects of mobile intelligent cognitive training for patients with post-stroke cognitive impairment: A 12-week, multicenter, randomized controlled study. J Alzheimers Dis 2024;100(3):999–1015. PMID:38968051

60. Einstad MS, Saltvedt I, Lydersen S, Ursin MH, Munthe-Kaas R, Ihle-Hansen H, Knapskog A-B, Askim T, Beyer MK, Næss H, Seljeseth YM, Ellekjær H, Thingstad P. Associations between post-stroke motor and cognitive function: A cross-sectional study. BMC Geriatrics 2021 Feb 5;21:103. PMID:33546620

61. Auriat AM, Ferris JK, Peters S, Ramirez J, Black SE, Jacova C, Boyd LA. The impact of covert lacunar infarcts and white matter hyperintensities on cognitive and motor outcomes after stroke. Journal of Stroke and Cerebrovascular Diseases 2019 Feb 1;28(2):381–388. doi: 10.1016/j.jstrokecerebrovasdis.2018.10.009

62. Callisaya ML, Beare R, Phan T, Blizzard L, Thrift AG, Chen J, Srikanth VK. Progression of white matter hyperintensities of presumed vascular origin increases the risk of falls in older people. The Journals of Gerontology: Series A 2015 Mar 1;70(3):360–366. doi: 10.1093/gerona/glu148

63. Molad J, Kliper E, Korczyn AD, Ben Assayag E, Ben Bashat D, Shenhar-Tsarfaty S, Aizenstein O, Shopin L, Bornstein NM, Auriel E. Only white matter hyperintensities predicts post-stroke cognitive performances among cerebral small vessel disease markers: Results from the TABASCO study. J Alzheimers Dis 2017;56(4):1293–1299. PMID:28157096

64. Keleman A, Wisch JK, Bollinger RM, Grant EA, Benzinger TL, Morris JC, Ances BM, Stark SL. Falls associate with neurodegenerative changes in ATN framework of alzheimer’s disease. Journal of Alzheimer’s disease : JAD 2020;77(2):745. PMID:32741815

65. VanGilder JL, Hooyman A, Peterson DS, Schaefer SY. Post-stroke cognitive impairments and responsiveness to motor rehabilitation: A review. Current physical medicine and rehabilitation reports 2020 Sep 10;8(4):461. PMID:33767922

66. Georgakis MK, Duering M, Wardlaw JM, Dichgans M. WMH and long-term outcomes in ischemic stroke: A systematic review and meta-analysis. Neurology 2019 Mar 19;92(12):e1298–e1308. PMID:30770431

67. Swatridge K, Regan K, Staines WR, Roy E, Middleton LE. The acute effects of aerobic exercise on cognitive control among people with chronic stroke. Journal of Stroke and Cerebrovascular Diseases 2017 Dec 1;26(12):2742–2748. doi:

10.1016/j.jstrokecerebrovasdis.2017.06.050

68. Montero-Odasso M, Zou G, Speechley M, Almeida QJ, Liu-Ambrose T, Middleton LE, Camicioli R, Bray NW, Li KZH, Fraser S, Pieruccini-Faria F, Berryman N, Lussier M, Shoemaker JK, Son S, Bherer L, Canadian Gait and Cognition Network. Effects of exercise alone or combined with cognitive training and vitamin D supplementation to improve cognition in adults with mild cognitive impairment: A randomized clinical trial. JAMA Netw Open 2023 Jul 3;6(7):e2324465. PMID:37471089

69. Yanagisawa H, Dan I, Tsuzuki D, Kato M, Okamoto M, Kyutoku Y, Soya H. Acute moderate exercise elicits increased dorsolateral prefrontal activation and improves cognitive performance with stroop test. NeuroImage 2010 May 1;50(4):1702–1710. doi: 10.1016/j.neuroimage.2009.12.023

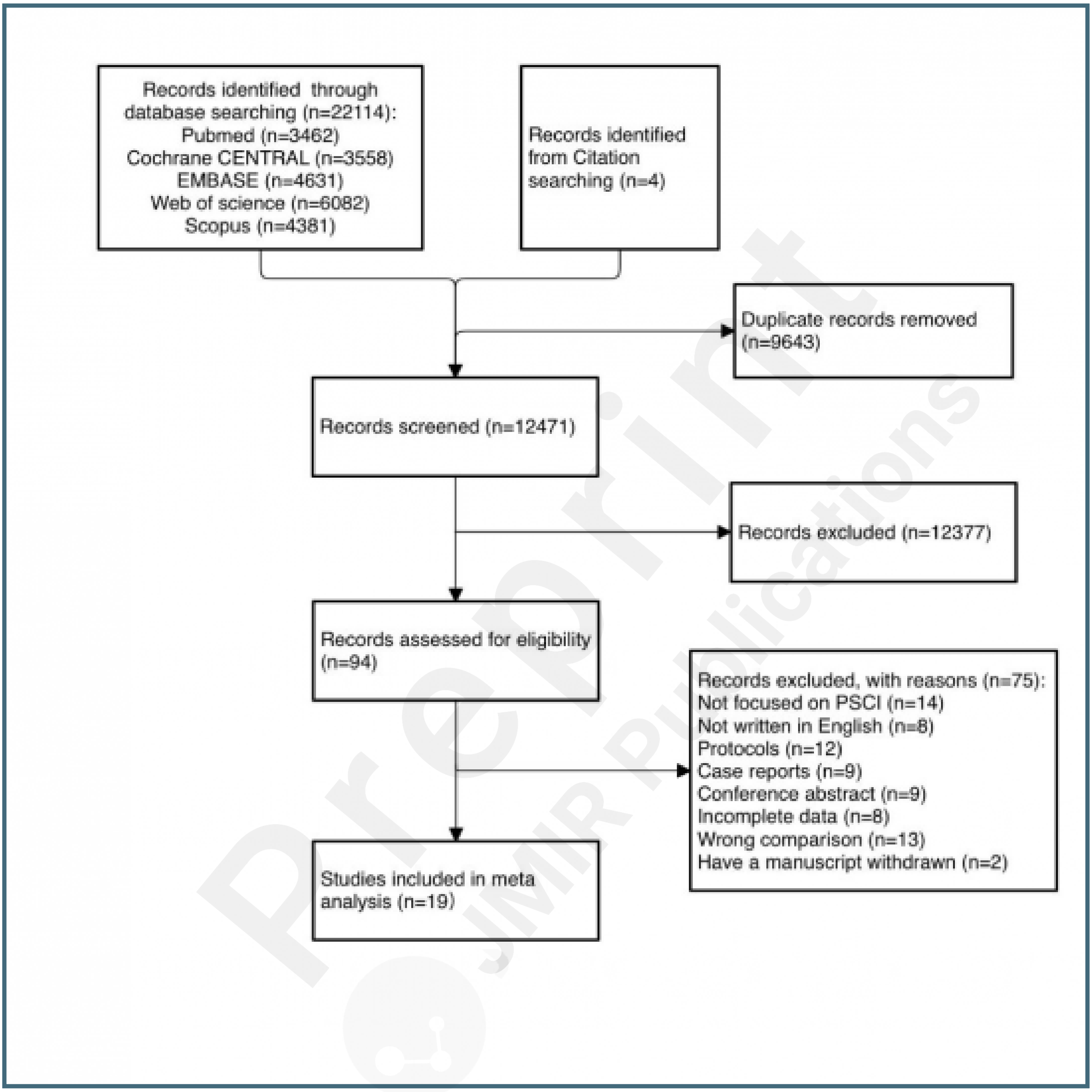
70. Harvey PD, McGurk SR, Mahncke H, Wykes T. Controversies in Computerized Cognitive Training. Biological Psychiatry: Cognitive Neuroscience and Neuroimaging 2018 Nov 1;3(11):907–915. doi: 10.1016/j.bpsc.2018.06.008

71. Nahas C, Gandit M, Quillion-Dupré L, Monfort E. How to engage patients in computerized cognitive training: A cognitive rehabilitation expert’s perspective. Disabil Rehabil Assist Technol 2024 Aug;19(6):2306–2318. PMID:37994038

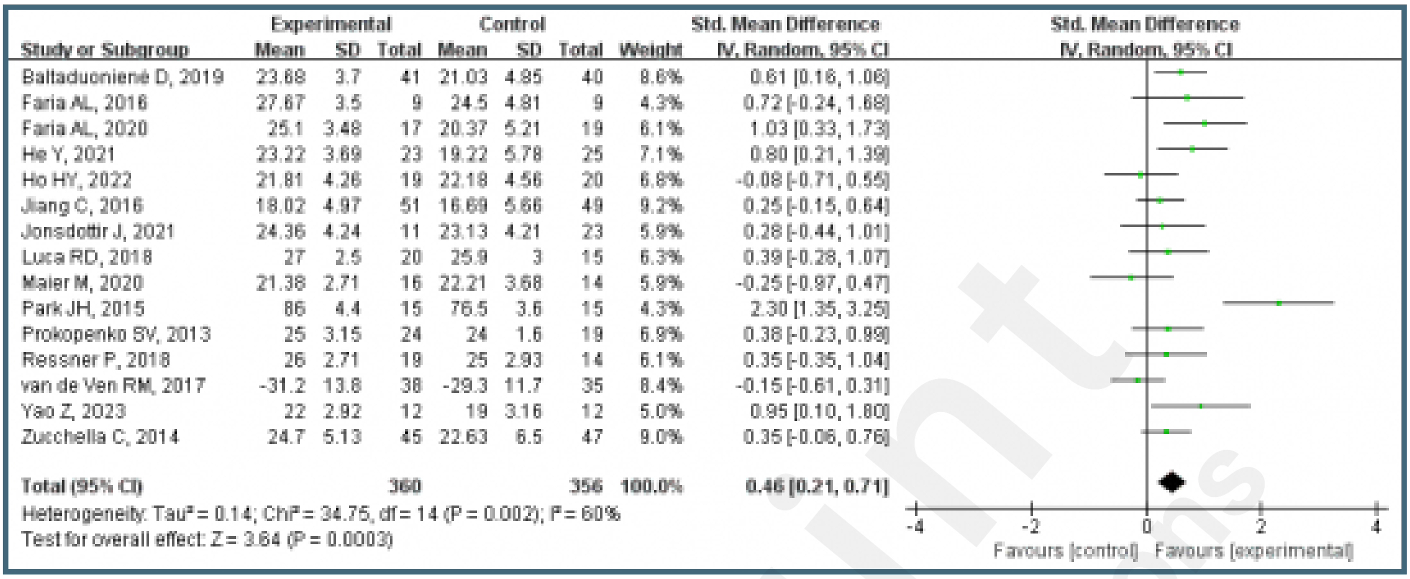
Supplementary Files

Figures

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flow diagram.



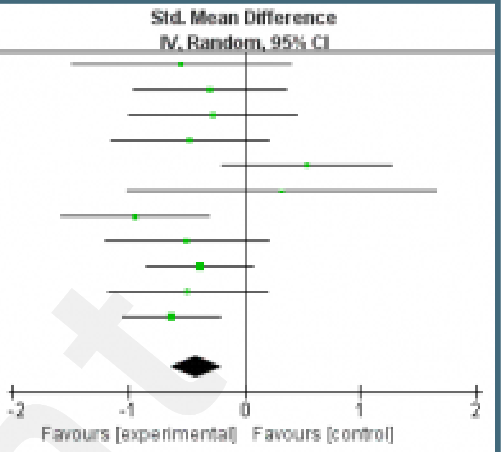
Forest plots of general cognitive outcomes. Abbreviations: CI, confidence interval; SD, standard deviation.



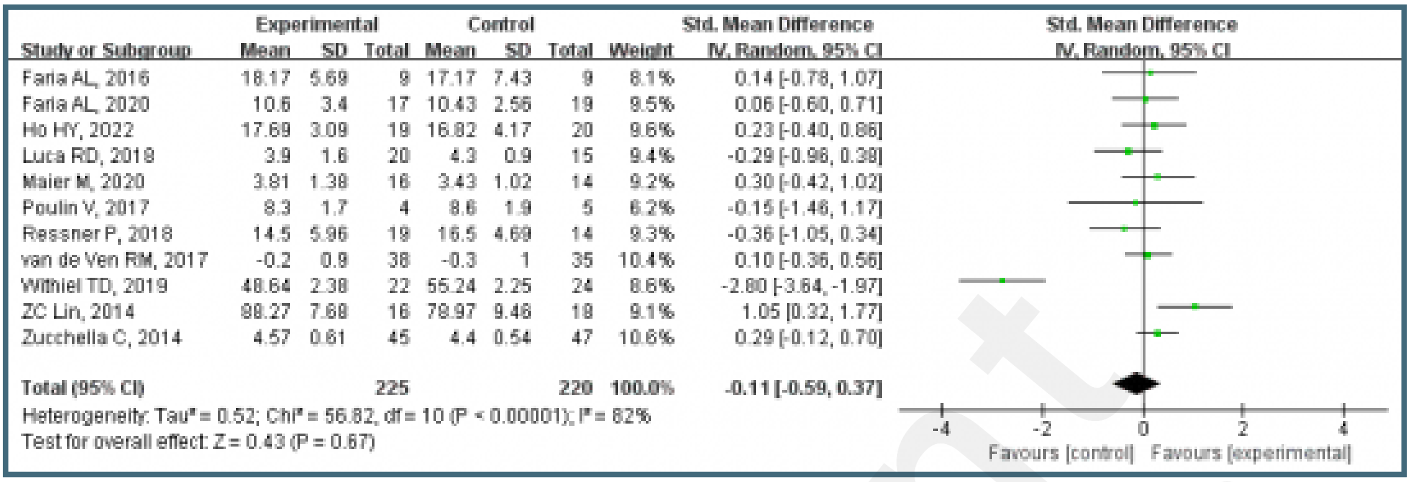
Forest plots of attention. Abbreviations: CI, confidence interval; SD, standard deviation.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Faria AL, 2016	79	43.73	9	109.17	60.79	9	4.7%	-0.54 [-1.49, 0.40]
Faria AL, 2020	67.43	28.54	17	76.77	32.6	19	9.0%	-0.30 [-0.96, 0.36]
Jonsdottir J, 2021	-91.64	18.62	11	-86.13	20.73	23	7.7%	-0.27 [-0.99, 0.45]
Luca RD, 2018	-43.1	10.6	20	-37.7	12	15	8.5%	-0.47 [-1.15, 0.21]
Maier M, 2020	77.69	40.13	16	58.36	27.91	14	7.5%	0.54 [-0.19, 1.27]
Poulin V, 2017	62.3	36.5	4	51.7	23	5	2.5%	0.32 [-1.01, 1.65]
Prokopenko SV, 2013	64.67	18.13	24	87.83	30.44	19	9.5%	-0.93 [-1.57, -0.30]
Ressner P, 2018	-15.75	1.9	19	-14.75	2.05	14	8.1%	-0.50 [-1.20, 0.21]
van de Ven RM, 2017	41.6	15.7	38	49.3	23.6	35	15.8%	-0.38 [-0.85, 0.08]
ZC Lin, 2014	45.35	29.44	16	63.34	40.97	18	8.4%	-0.49 [-1.17, 0.20]
Zucchella C, 2014	88.5	44.03	45	111.4	28.15	47	18.3%	-0.63 [-1.05, -0.21]
Total (95% CI)			**219**			**218**	**100.0%**	**-0.41 [-0.62, -0.20]**

Heterogeneity: Tau² = 0.02; Chi² = 11.74, df = 10 (P = 0.30); I² = 15%
Test for overall effect: Z = 3.77 (P = 0.0002)



Forest plots of memory. Abbreviations: CI, confidence interval; SD, standard deviation.

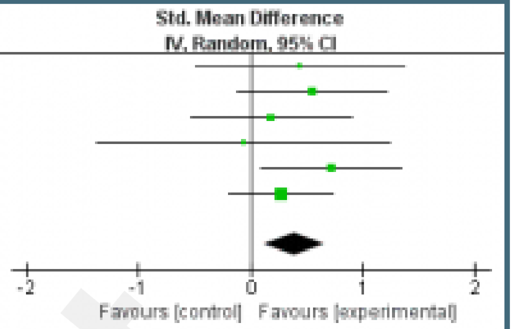


Forest plots of executive functions. Abbreviations: CI, confidence interval; SD, standard deviation.

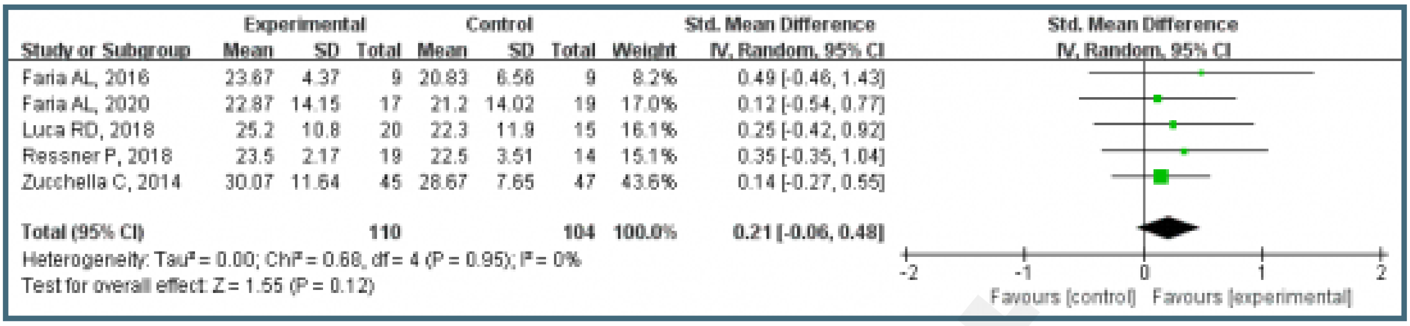
	Experimental			Control				Std. Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Faria AL, 2016	4	4.37	9	2.33	2.62	9	8.6%	0.44 [-0.50, 1.38]
Faria AL, 2020	35.6	11.32	17	27.87	15.62	19	17.0%	0.55 [-0.12, 1.22]
Maier M, 2020	30.06	13.43	16	27.29	16.51	14	14.7%	0.18 [-0.54, 0.90]
Poulin V, 2017	-86.3	22.9	4	-84	39.3	5	4.4%	-0.06 [-1.38, 1.25]
Prokopenko SV, 2013	9.17	1.18	24	8	2	19	19.6%	0.72 [0.10, 1.34]
van de Ven RM, 2017	0.2	1	38	-0.1	1.2	35	35.7%	0.27 [-0.19, 0.73]
Total (95% CI)			**108**			**101**	**100.0%**	**0.39 [0.12, 0.67]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 2.35$, df = 5 (P = 0.80); $I^2 = 0\%$

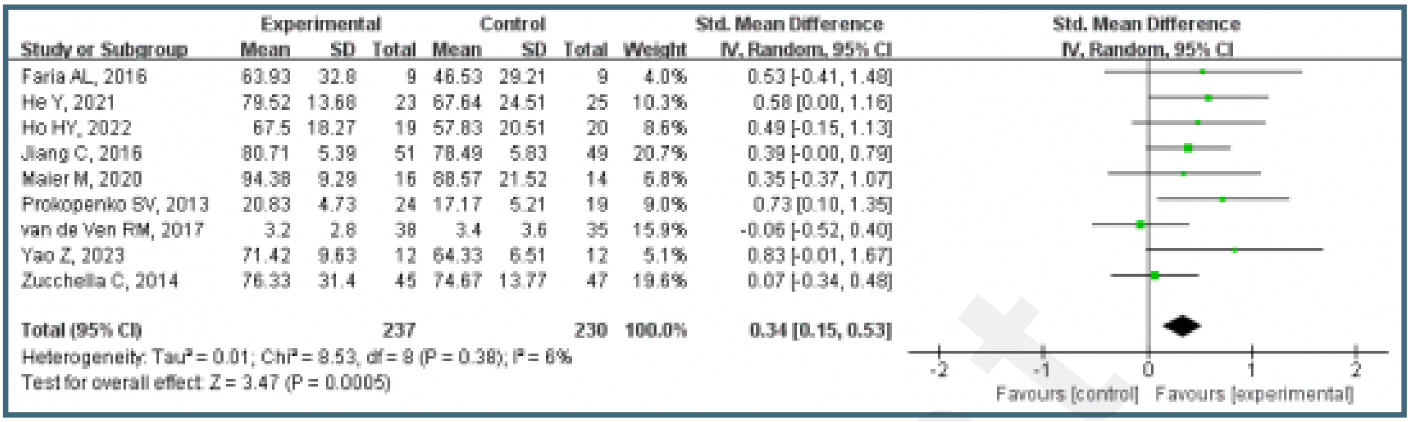
Test for overall effect: Z = 2.79 (P = 0.005)



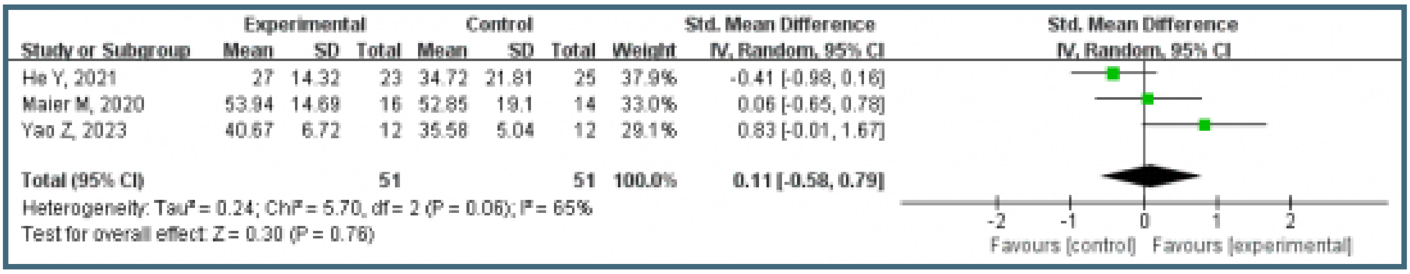
Forest plots of language. Abbreviations: CI, confidence interval; SD, standard deviation.



Forest plots of quality of life. Abbreviations: CI, confidence interval; SD, standard deviation.



Forest plots of motor function. Abbreviations: CI, confidence interval; SD, standard deviation.



Multimedia Appendixes

Example search strategy.
URL: http://asset.jmir.pub/assets/b235ee4696ac77e00228d08fefbb1bf5.docx

Outcome indicators.
URL: http://asset.jmir.pub/assets/9be95cf940ad35f1634c77afb6772de2.docx

Characteristics of Included Studies.
URL: http://asset.jmir.pub/assets/0e67c99dc5ad86a8a9e7d773d06d20ec.docx

Risk of bias.
URL: http://asset.jmir.pub/assets/a2fb667351dac413c98b880d118b4453.docx

The GRADE Summary of Findings for the Outcomes.
URL: http://asset.jmir.pub/assets/5902ed1294aaa276fc56ab2a0deead04.docx

Sensitivity analysis results.
URL: http://asset.jmir.pub/assets/85ac82c524f0d1559781394a2ec28d18.docx

Funnel plot of publication bias.
URL: http://asset.jmir.pub/assets/b01cefc2611a413ae84298b832044ba4.docx