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Articles

Working memory training with technological innovation in older adults with mild neurocognitive disorder: a systematic review using ToS (Tree of Science) methodology

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Abstract

Objective: Working memory training has shown both physical and cognitive benefits in aging population. However, these gains are not clear after brain injury and mild cognitive disorder. Thus, the aim of this study is to identify the current state of the scientific literature on technology-mediated working memory training in adults with mild neurocognitive impairment.

Methods: A systematic review was performed, following the PRISMA guidelines in English language in the Scopus, Web of Science and Pubmed databases. We included articles that were experimental studies, from the last 7 years, with older adults, in English language and studies related to working memory training in patients with minor neurocognitive disorder, and excluded those that had a different methodological design, were studies with incomplete information, were subjective and not interpretable and studies in patients with severe neurological diseases and psychiatric diseases.

Results: A total of 745 articles were identified, 675 were eliminated after reading the title, abstract and keywords because they did not fit the specificity of the research topic or the population, and after applying inclusion and exclusion criteria, 1334 articles were eliminated, and 70 were evaluated for eligibility, and of these only 30 met the quality criteria.

Conclusion: Neurological changes in mild neurocognitive impairment reduce the ability to simultaneously maintain and process information to perform complex tasks. The findings of the systematic review support the sensitivity and ecological validity of neuropsychological rehabilitation mediated by virtual reality, computerized training, video games and robotics in working memory training in adults with mild neurocognitive disorder because it represents a protective factor for mental health, allowing brain stimulation and the development of skills that favor social interaction, problem solving and maintenance of cognitive reserve.

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1. Introduction

The aging process entails a series of morphological, physiological, social, and psychological modifications that are a direct consequence of the passage of time. Two significant changes that have occurred in recent decades are a considerable increase in life expectancy and a reduction in birth rates. This has led to a significant aging of the population, and globally, the older adult population is growing rapidly, which subsequently reflects in the prevalence of age-related diseases, such as neuropsychiatric disorders, which are the leading causes of disability in older adults worldwide. The growing study of changes and characteristics within this population segment has allowed us to conclude that aging-related diseases are diverse and result in a deterioration in the quality of life for those affected and their families (Cancino et al., 2016).

Therefore, it is important to note that one of the main effects of this dramatic demographic change is that many older individuals lack access to the basic resources necessary to enjoy a dignified life, and many others face multiple obstacles to fully participate in society. Consequently, healthcare attention generates a high economic cost for accessing services worldwide, with 23% of healthcare expenditure dedicated to the care of individuals over 60 years old, and 7% of that expenditure corresponds to neurological and mental disorders (Prince et al., 2015).

However, one of the main strategies for building an inclusive society for all ages is the global initiative of the Decade of Healthy Aging 2021-2030, declared by the General Assembly of the United Nations (UNGA). This global initiative brings together the efforts of governments, international organizations, professional groups, academia, civil society, media, and the private sector to improve the lives of families, communities, and older individuals.

Even so, according to the estimation from the multinational study Global Burden of Disease, there is international concern because worldwide cases of dementia will triple from the estimated 57 million in 2019 to 153 million in 2050 unless public health education is strengthened and modifiable risk factors are addressed in a timely manner (Nichols et al., 2022). In the case of Colombia, the study estimated 369,422 cases in 2019 and projected 1,375,881 cases for 2050, an increase of 272 percent, the highest in the world, significantly higher than the expected increase (166 percent), and above that of Central Latin America (239 percent) and most countries in the region (Nichols et al., 2022). For that reason, the efforts of researchers and clinicians must focus on identifying risk factors to generate inclusive and effective preventive measures that contribute to improving the quality of life of older adults, their families, and communities.

In the population of Latin America and the Caribbean, estimates for the prevalence of mild neurocognitive disorders ranged from 6.8% to 25.5%, and mild amnestic neurocognitive disorder ranged from 3.1% to 10.5% (Ribeiro, 2022). According to the systematic review conducted by Pais et al. (2020), the global prevalence of mild neurocognitive disorder ranged from 5.1% to 41%, with a median of 19.0%. On the other hand, the incidence of mild neurocognitive disorder ranged from 22 to 76.8 per 1000 person-years, with a median of 53.97 per 1000 person-years, which is alarming and requires intervention from both clinical and research perspectives.

Mild neurocognitive disorder is considered the transitional stage between normal cognitive decline in healthy aging and dementia, affecting 10 to 15% of the population over 65 years old (Anderson, 2019). Thus, 7.1% of individuals aged 60 and above present mild neurocognitive disorder. This cognitive decline increases exponentially, reaching 13% in individuals between 75 and 79 years old and 36.2% in those over 85 years old (González, 2009).

On that account, it is of utmost importance to understand that mild neurocognitive disorder is one of the most common clinical neurological manifestations in the elderly and represents a heterogeneous clinical syndrome that can be associated with different etiologies. In the DSM-5, the proposed diagnostic criteria for mild neurocognitive disorder are as follows: Criterion A demonstrates cognitive decline in one or more cognitive domains compared to a previously higher level of performance, or when there are memory complaints reported by the individuals, which are corroborated by a family member or informant in an objective assessment by a healthcare professional. Additionally, from a neuropsychological perspective, there is a performance decline on tests by one or two standard deviations below the required performance for neuropsychological evaluation (American Psychiatric Association, 2013).

Criterion B states that cognitive deficits do not impair functional independence related to the ability to perform instrumental activities of daily living, which are complex tasks such as managing finances, medication use, running errands, and using public transportation. Criterion C indicates that cognitive deficits do not occur exclusively during delirium, and Criterion D states that cognitive deficits are not primarily due to the presence of other mental disorders (American Psychiatric Association, 2013).

The international working group on mild neurocognitive disorder of Winblad et al. (2004), in an extension of the initial term, identified four subtypes: single-domain amnestic, multiple-domain amnestic, single-domain non-amnestic, and multiple-domain non-amnestic, which are explained as follows. The amnestic subtype involves exclusive impairment of memory, while the multiple-domain amnestic subtype includes impairment of functions beyond memory, such as attention, language, executive functions, gnosis, and praxis. The non-amnestic subtype refers to the impairment of a function other than memory, and the multiple-domain non-amnestic subtype involves impairment of more than one function other than memory (Ocaña et al., 2019).

Furthermore, in older individuals, the component of working memory known as the central executive appears to be most affected, while the functioning of the verbal component of this memory system, known as the phonological loop, seems to be preserved. However, the most common clinical symptom of mild neurocognitive disorder is the loss of episodic memory, with a particularly rapid rate of forgetting and deterioration of delayed recall. Still, deficits in working memory and executive functions are also frequently observed in populations with mild neurocognitive disorder (Huntley & Howard, 2010), especially in the multidomain subtype (Klekociuk & Summers, 2014).

Having said that, working memory is a construct that involves the temporary maintenance and manipulation of recently acquired or retrieved information from long-term memory (Baddeley, 2017). Baddeley's model is one of the most recognized among several models that seek to describe the operating principles of working memory (Osaka et al., 2012). Working memory encompasses interacting subsystems, including two unimodal subsystems (the phonological loop for verbal information and the visuospatial sketchpad for visual and spatial information), a flexible system (the central executive) responsible for controlling and regulating the storage subsystems, and a limited-capacity multimodal system (the episodic buffer) that allows interaction between the components of working memory and communication with long-term memory (Baddeley, 2017).

Working memory is crucial for the selection and attention to relevant information, as well as for filtering out distracting stimuli, functions also known as attentional control. Also, working memory involves processes related to dividing attention across multiple tasks, updating and monitoring verbal and visuospatial information, and inhibiting impulsive responses (Landínez & Montoya, 2021). In the involvement of working memory is involved not only in basic cognitive processes but also in higher order cognitive processes such as executive function, therefore, working memory deficits can lead to a general impairment of cognitive function and have a negative impact on the individual's daily life (Quintero-López et al., 2023). Therefore, among health care alternatives cognitive training interventions have attracted increasing scientific interest as a non-pharmacological intervention and prevention method. In the meta-analysis by Chiu et al., (2017) cognitive intervention in adults was found to be a potential to combat cognitive decline.

Given the above, it is essential to understand that cognitive training has as its premise that brain functioning is modifiable even in old age (López-Higes et al., 2018). Currently, there are different techniques and cognitive training programs. According to Villalba and Tortajada (2014), the first technique is the traditional one, focused on working with paper and pencil exercises. The second type of technique is based on the use of computerized devices, such as brain training games, online programs, or digital media. Finally, there are techniques that seek to create innovative programs mediated by technology, involving several types of functionalities, such as computerization and movement (Villalba and Tortajada, 2014). In this way, healthcare professionals have sought to develop and innovate various cognitive training programs for older adults to improve cognitive function (Villalba and Tortajada, 2014).

Computerized working memory training has significant potential as it allows for the generation of situations related to daily activities such as physical, intellectual, and occupational activities. In these training, working memory acts as a moderator between cognitive tasks and functional abilities, as active storage, information manipulation, and integration of signals are required in daily life, which are central processes in working memory (Landínez & Montoya, 2021). In neuropsychological intervention processes, computer-based technological tools have demonstrated their effectiveness in cognitive training of individuals with neurological disorders and have been shown to help this population to acquire crucial social and personal skills to integrate into the different scenarios of their lives being more autonomous and independent (Mezzalira et al., 2021).

Rehabilitation interventions involving virtual reality technology, computerized training, video games, and robotics have been developed to promote functional independence in patients. Virtual reality encompasses a range of technologies that can artificially generate sensory information in the form of an interactive virtual environment that is perceived as like the real world (Rand et al., 2008). Since virtual environments are interactive and game-like, they promote active exploration, enhance engagement, and provide motivation and enjoyment, enabling longer exercise sessions and better treatment adherence (Holden, 2005). Therapists providing virtual reality-based therapy must make decisions regarding appropriate games that match the individual patient's abilities and treatment goals (Glegg et al., 2014). This decision-making process can be complex and relies on understanding the functioning of the virtual reality system and game requirements.

Virtual reality technology is gaining recognition as a useful tool for cognitive research, assessment, and rehabilitation. Still, while virtual reality-based applications can potentially offer more versatile, comprehensive, and safe function assessments, they can also be more expensive, complex, and challenging to use for older patients. Side effects of head-mounted visual displays include nausea and disorientation, although specific reports in older subjects are lacking (Cherniack, 2011). One application of virtual reality for the treatment of neuropsychological conditions is the Vlad 3D semi-immersive software, where emotions are generated through the manipulation of images, which are recognized with the recording of narrative experiences, and with quantitative and qualitative monitoring (Pappalardo, 2020).

Brain training games have gained popularity over the past decade, with increasingly solid findings and claims that computerized working memory and attention tasks can improve cognition (Morrison & Chein, 2011). Moreover, rehabilitation robotics has provided promising approaches for training and assistance to mitigate cognitive deficits. Yet, there are still multifaceted challenges in this field, including ethical issues, user-centered design, reliability, trust, cost-effectiveness, and personalization of the robot-assisted cognitive training system (Yuan et al., 2021).

Cognitive training utilizes repeated practice of standardized exercises targeting one or more cognitive domains and may aim to improve or maintain optimal cognitive function (Gates et al., 2019). In spite of that, currently available evidence does not allow us to determine whether computerized cognitive training will prevent clinical dementia or improve/maintain cognitive function in those already showing evidence of cognitive decline. The small number of trials, small sample sizes, risk of bias, inconsistency among trials, and highly imprecise results mean that no implications for clinical practice can be derived, despite some large effect sizes observed in individual studies. Direct adverse events are unlikely to occur, although the time and sometimes money involved in computerized cognitive training programs can represent significant burdens (Gates et al., 2019).

Further research is needed and should focus on improving methodological rigor, selecting appropriate outcome measures, and evaluating generalization and persistence of any effects. Long-term follow-up trials are required to determine the potential of this intervention in reducing dementia risk. In view of the above and the lack of consensus regarding technological strategies, the aim of the study is to identify the current state of the scientific literature on working memory training with technological innovation in older adults with mild neurocognitive disorder. The research hypothesis is that cognitive training in working memory mediated by technological innovation helps patients with mild neurocognitive disorder to obtain cognitive improvement in their mental processes and activities of daily living.

2. Methodology

A systematic review was conducted following PRISMA guidelines in the English language using Scopus, PubMed, and Web of Science databases. To identify articles on working memory training with technological innovation in older adults with mild neurocognitive disorder, A bibliometric analysis was conducted between January 2013 and April 2022. The following search equations were used.

Table 1. Search Equations

	Search Equations
1	("Mild neurocognitive disorders" OR "neurocognitive disorders" AND "older adult" "cognitive training" OR "online cognitive training" OR "Brain training games" OR "cognitive games" OR "cognitive rehabilitation" OR "working memory training" NOT “children”)
2	("Mild neurocognitive disorders" AND "cognitive training" OR "online cognitive training" OR "Brain training games" OR "virtual reality" OR "cognitive games" OR "rehabilitation cognitive" OR "memory training" OR "memory" OR "working memory" AND "adults")

2.1 Inclusion Criteria

Articles were included if they met the following criteria: (1) publication date within the last 7 years, (2) full-text articles in English, (3) experimental studies, (4) elderly population, (5) addressing the topic of neuropsychological rehabilitation therapy for patients with mild neurocognitive disorder through working memory training using technological innovation tools.

2.2 Exclusion Criteria

Articles were excluded if they met the following criteria: (1) exploratory research with qualitative methodologies, narrative reviews, and single-case studies; (2) studies with incomplete or uninterpretable subjective information and lack of methodological clarity, (3) patients with severe neurological diseases and psychiatric diseases.

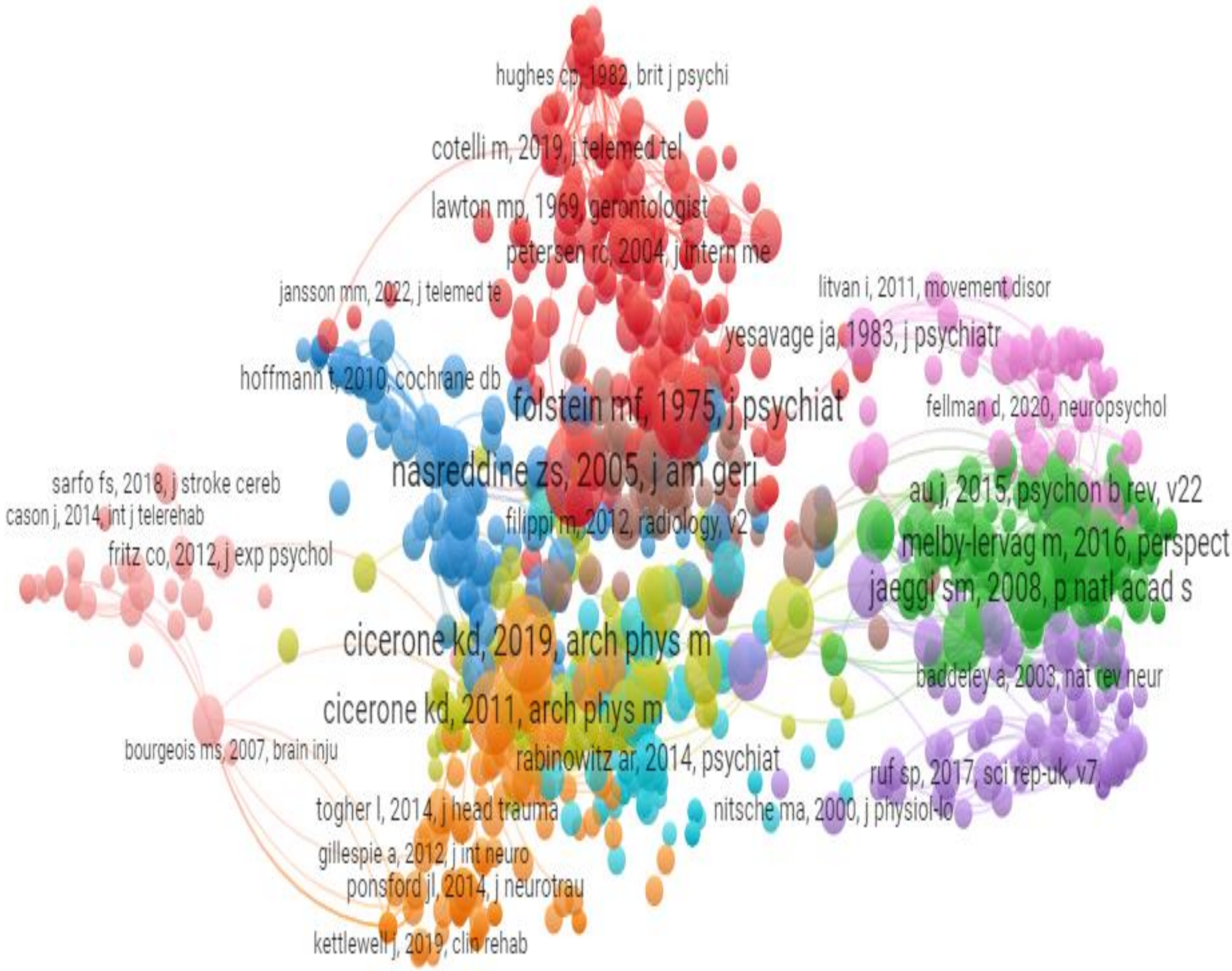
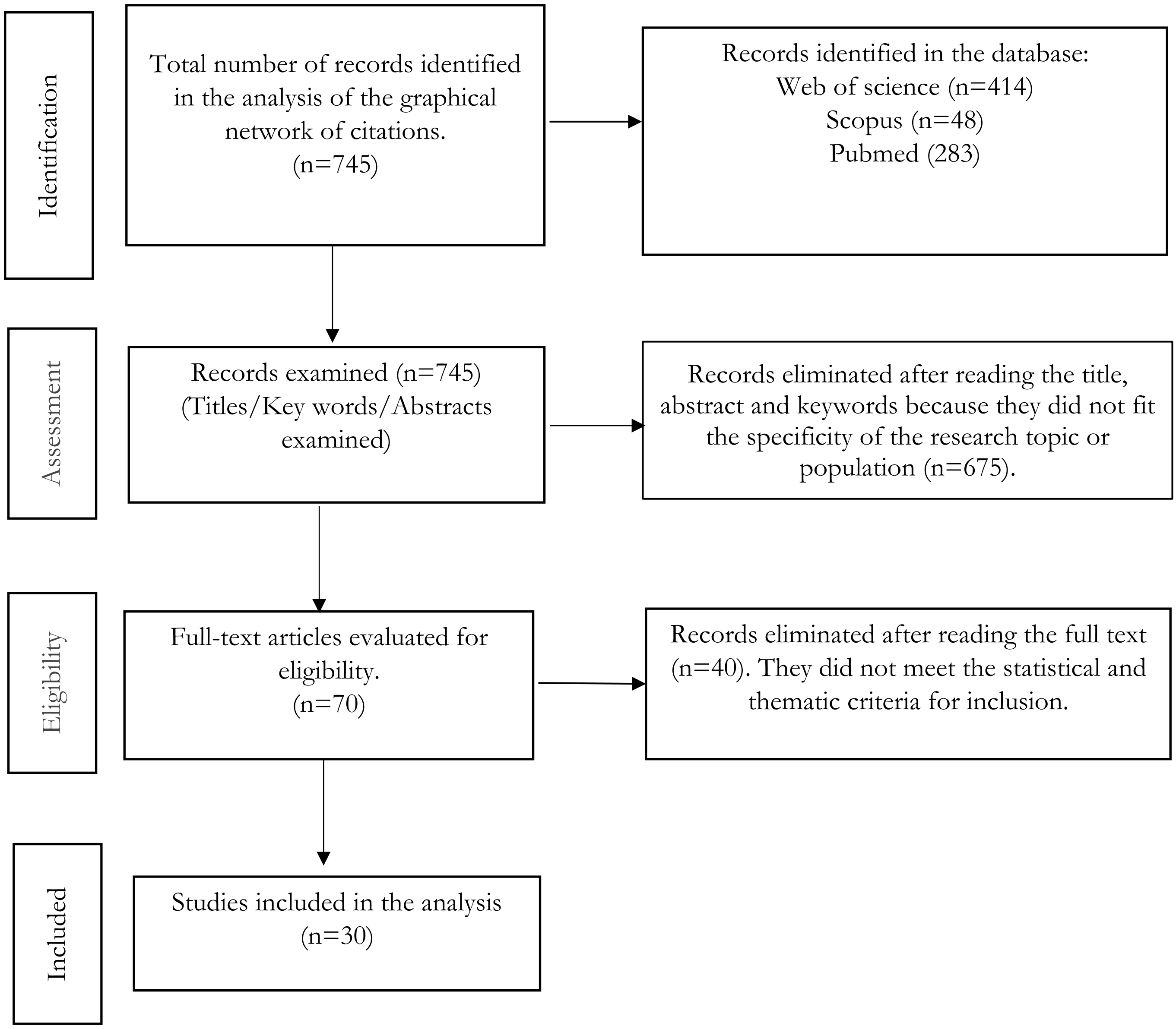


Figure 1. *Final Citation Network (Research Communities)*

PRISMA Flow Diagram Showing Selection Methodology



3. Results

A total of 745 articles were identified, and 675 were eliminated after reviewing the title, abstract, and keywords due to their lack of relevance to the specific research topic or population. After applying inclusion and exclusion criteria, 1334 articles were removed, and 70 were assessed for eligibility. Out of these, only 30 met the criteria for quality and were related to working memory training and technological innovation in older adults with mild neurocognitive disorder. Please refer to Table 2 for the included articles in the review.

Table 2. Studies Included in the Systematic Review

Study	Subject (Sample size)	Female %	Mean age (years)	Type of intervention	Evaluation instruments
(Fiatarone et al., 2014)	MCI (100)	68%	70 yr..	Physical Training Training computerized	ADAS-Cog List Learning Memory Memory Domain Attention/Speed SDMT
(Hughes et al., 2014)	MCI (20)	70%	78 yr..	Interactive video games	MMSE CAMCI
(Styliadis et al., 2015)	MCI (56)	45%	70 yr..	Physical Training Training computerized	MMSE CDR
(Barban, et al., 2016)	MCI (106) Alzheimer (81) CS (114)	57%	73 yr..	Training computerized Reminiscence therapy	MMSE RAVLT FAS
(Gooding et al., 2016)	MCI (74)	42%	76 yr..	Training computerized Cognitive Vitality Training	MMSE BSRT LM
(Hyer et al., 2016)	MCI (68)	52%	75 yr..	Training computerized	RBANS MMSE CDR CFQ FAQ WM Span Board, Letter Number Sequencing Trail Making A-B
(Manera et al., 2016)	MCI (28) Dementia (29)	43%	75 yr..	Virtual reality	MMSE TA

(Bahar-Fuchs et al., 2017)	MCI (9) MrNPS (11) Ambos (25)	45%	66 yr..	Training computerized	ACE-III RAVLT RCFT MARS MMQ Digit Span Digit-Symbol Coding Logical Memory
(Djabelkhir, 2017)	MCI (19)	68%	75 yr..	Training computerized Computerized cognitive engagement	MMSE Digit Span Wechsler Trail Making A-B
(Savulich et al., 2017)	aMCI (42)	40%	75 yr..	Training computerized	MMSE CANTAB PAL BVMT-R
(Damirchi et al., 2018)	MCI (33)	100%	67 yr..	Computerized physical and cognitive training	MMSE Digits Wechsler
(Hsieh et al., 2018)	MCI (60)	72%	78 yr..	Virtual reality Tai Chi	MMSE CASI
(Amjad et al., 2019).	MCI (38)	50%	60 yr..	Cognitive Games Xbox 360 Kinect	MMSE MOCA
(Flak et al., 2019)	MCI (64)	34%	65 yr..	Training computerized	WMS-III Digit Span backward, WMS-III Spatial Span backward, WMS-III Letter-Number Sequencing, CVLT-II Trial Making B

(Jirayucharoensak et al., 2019).	aMCI (65) CS (54)	100%	71 yr..	Neurofeedback training	MOCA TMSE CANTAB
(Li et al., 2019)	MCI (141)	53%	70 yr..	Online cognitive training	MMSE ACER AVLT SDS
(Liao et al., 2019)	MCI (34)	68%	73 yr..	Virtual reality Traditional physical and cognitive training	MMSE MOCA
(Park et al., 2019).	MCI (20)	80%	70 yr..	Mixed reality Computerized training	CERAD MMSE
(Yang et al., 2019)	MCI (66)	52%	78 yr..	Virtual interactive training	DS MMQ MMSE MOCA
(Lee et al., 2020)	MCI (46)	39%	74 yr..	Robotic cognitive intervention	K-MMSE SVLT
(Park et al., 2020).	MCI (35)	48%	75 yr..	Virtual reality	MOCA Digit Span Test
(Manenti et al., 2020)	MCI (49)	51%	75 yr..	Virtual reality	RAVLT
(Thapa et al., 2020)	MCI (68)	76%	72 yr..	Virtual reality	MMSE
(Torpil et al., 2021)	MCI 61)	59%	70 yr..	Virtual reality	LOTCA-G
(Kim et al., 2021)	MCI (22) CS (22)	84%	74 yr..	Virtual reality	CERAD
(Maeng et al., 2021)	MCI (31) CS (25)	81%	73 yr..	Virtual reality	Digit span Word list memory CERAD

(Ownby et al., 2021).	MCI-VIH (46)	19%	57 yr..	Computerized training	Digit Span Wechsler, HVLT-R
(Ramnath et al., 2021)	MCI (45)	50%	72 yr..	Interactive video games	MMSE Stroop N-Back
(Duff et al., 2022)	aMCI (113)	76%	77 yr..	Computerized training	RBANS
(Lim et al., 2023)	MCI (24)	70%	74 yr..	Interactive video games	K-MMSE K-MoCA SVFT TMT-B N-Back

Note: MCI, Mild Neurocognitive Disorder Cluster; MrNPS, mood-related neuropsychiatric symptom cluster; aMCI, amnestic mild neurocognitive disorder; CS, healthy control group; MCI-HIV, Human Immunodeficiency Virus Associated Mild Neurocognitive Disorder Cluster; ADAS-Cog, Alzheimer's Disease Assessment Scale-cognitive subscale; SDMT, Symbols and Digits Test; MMSE, Mini-Mental State Examination; CAMCI, The Computerized Assessment of Mild Cognitive Impairment; RBANS, Repeatable Battery for the Assessment of Neuropsychological State; CFQ, Cognitive Failure Questionnaire; FAQ, Functional Activities Questionnaire; CDR, Clinical Dementia Rating Scale; WM Span Board, Wechsler Memory Scale-Third Edition Span Board subtest; AT, attention tasks; ACE-III, Addenbrooke Cognitive Examination; RAVLT, Rey Verbal Learning Test; FAS, phonological fluency test; minimental state test, BSRT, Buschke selective recall test, LM, Logical Memory Subtests, , RCFT, Rey Complex Figure Test; MARS, Memory Awareness Rating Scale; MMQ, Meta Memory Questionnaire;, CANTAB PAL, The Cambridge Neuropsychological Test Automated Battery Paired Associates Learning; BVMT-R, The Brief Visuospatial Memory Test-Revised; CASI, Screening Instrument; WMS-III, Wechsler Memory Scale 3.ed; CVLT-II, California Verbal Learning Test Second Edition; TMT A-B, Trail-Making Test for Screening, Part A and B; MoCA, Montreal Cognitive Assessment; TMSE, Thai Mental State Examination; CANTAB, Cambridge Automated Battery of Neuropsychological Tests; ACER, Addenbrooke's cognitive examination-revised; AVLT, the auditory verbal learning test; SDS, symbol digit substitution test; CERAD, Consortium to Establish an Alzheimer's Disease Registry; DS, Digit span; SVLT, Seoul Verbal Learning Test; LOTCA-G, Loewenstein Occupational Therapy Cognitive Assessment-Geriatric; HVLT-R: Hopkins Verbal Learning Test—Revised; K-MMSE, Korean Mini-Mental State Exam; K-MoCA, the Montreal Korean Cognitive Assessment; SVFT, the Semantic Verbal Fluency task; TMT B, the Tracing Test-B; N-Back, working memory task.

The result of the analysis of the systematic review studies allowed finding three approaches: computerized training, virtual reality and video games, and robotics, all related to working memory training with technological innovation in older adults with mild neurocognitive disorder.

3.1 Effect of computerized working memory cognitive training in patients with mild neurocognitive disorder.

Fourteen studies were related to computerized cognitive training, involving a total of 1038 individuals with mild neurocognitive disorder, 81 with Alzheimer's disease, 46 with human immunodeficiency virus (HIV), and 36 with mood-related neuropsychiatric symptoms. Of the participants, 57% were female, with an average age of 71 years. In the study by Fiatarone et al. (2014), the effects of resistance training and cognitive training on mild neurocognitive disorder were assessed. They found that strength training significantly improved overall cognitive function, with sustained executive and global benefits over 18 months, while cognitive training alone attenuated the decline in the memory domain at 6 months. Besides, Ownby & Kim (2021) investigated computerized training in patients with neurocognitive disorder associated with HIV and found that participant ratings of the intervention were positive, with attention and psychomotor speed measures suggesting positive effects of the intervention.

Moreover, Damirchi et al. (2018) investigated the mental, physical, and combined effects of these two types of training on cognitive performance, serum levels of brain-derived neurotrophic factor, and Irisin hormone in women diagnosed with mild neurocognitive disorder. They found a positive effect of mental training on cognitive parameters, accompanied by an elevation in serum neurotrophic levels, suggesting that mental training is a more useful, safe, and persistent strategy to attenuate the progression of mild neurocognitive disorder.

Gooding et al. (2016) compared three methods of computerized cognitive training for older adults with subclinical mild neurocognitive disorder and found no significant differences between the computerized cognitive training groups and the cognitive vitality training group in measures of verbal learning or memory. Thus, in the research conducted by Gooding et al. (2016), they demonstrate that computerized cognitive training is more beneficial when incorporated into a therapeutic environment rather than standalone, and the computerized cognitive training group performed better than the active control group in a measure of verbal learning and a measure of verbal memory.

Furthermore, Styliadis et al. (2015) evaluated the neuroplastic effects of combined physical and computerized cognitive training in older adults at risk of dementia. They found that combined physical and cognitive training showed indices of a positive effect on neuroplasticity in patients with mild neurocognitive disorder and that electroencephalogram (EEG) could serve as a potential index of gains in cognitive impairments and neurodegeneration.

On the other hand, Hyer et al. (2016) developed a cognitive training program to improve working memory in older adults with mild neurocognitive disorder, and both intervention groups showed improvement over time. The Cogmed program was significantly superior to the Sham programs in Span Board in spatial memory and subjective memory complaints as reported with the Cognitive Failures Questionnaire (CFQ). The Cogmed group also demonstrated better performance on the Functional Activities Questionnaire (FAQ). In view of the above, the results suggest that working memory improved in both groups of older adults with mild neurocognitive disorder.

However, Cogmed performed better in a central measure of working memory and obtained higher satisfaction ratings (Hyer et al., 2016). Nonetheless, in the research conducted by Flak et al. (2019), it was investigated whether an adaptive computerized working memory training program based on Cogmed would be effective in improving working memory capacity and other neuropsychological functions compared to a non-adaptive working memory training program in older adult patients with mild neurocognitive disorder. Yet, no differences were found between the two types of working memory training, nor in other domains of cognitive function.

Moreover, Li et al. (2019) demonstrated how multimodal cognitive training helps patients with mild neurocognitive disorder obtain cognitive benefits, especially in memory, attention, and executive function. Functional neuroimaging provided consistent evidence of neural activation. Even so, after one year of follow-up and following the last training session, the effects were not significant.

On the other hand, according to the research conducted by Bahar-Fuchs et al. (2017), computerized cognitive training showed greater improvement in composite measures of memory, learning, and global cognition. Participants in the study who experienced mood-related neuropsychiatric symptoms during the computerized cognitive training condition also reported improved mood at 3-month follow-up and reported using fewer memory strategies in post-intervention and follow-up assessments.

Similarly, Djabelkhir (2017) examined the feasibility of a computerized cognitive stimulation (CCS) program and a computerized cognitive engagement (CCE) program, and then compared their effects in older adults with mild neurocognitive disorder, demonstrating the benefits of both cognitive intervention programs and suggesting their potential to improve episodic memory, thus becoming a promising approach to slowing down cognitive symptoms associated with dementia. In this way, computerized programs have the potential to improve processing speed, providing new perspectives to bridge the digital divide and promote social inclusion for patients. Likewise, in the study by Yang et al. (2019), the development and effectiveness of interactive virtual working memory training for older adults with mild neurocognitive disorder were evaluated, and it was found that the applied program allowed older adults to maintain their working memory and reduce the rate of cognitive decline.

In view of the above, Savulich et al. (2017) argued in their research studies that episodic memory significantly improved in the cognitive training group. They observed how "gamified" cognitive training can enhance visuospatial skills in individuals with mild amnestic neurocognitive disorder. Gamification maximizes engagement with cognitive training by increasing motivation and complements pharmacological treatments in mild amnestic neurocognitive disorder and mild Alzheimer's disease. After all, larger controlled trials are needed to replicate and expand these findings to further advance scientific knowledge.

From another perspective, Jirayucharoensak et al. (2019) examined the clinical efficacy of a neurofeedback training system on cognitive performance in patients with mild amnestic neurocognitive disorder and healthy older subjects, finding that neurofeedback significantly improved rapid visual processing and spatial working memory. But, there was no significant effect on pattern recognition memory and short-term visual memory, which are other features of mild amnestic neurocognitive disorder. The study demonstrated that neurofeedback training selectively enhances sustained attention, strategy, and executive functions but no other cognitive deficits.

To further analyze computerized cognitive training in mild amnestic neurocognitive disorder, the research study conducted by Duff et al. (2022) was found, which reveals how a parallel clinical trial examines the short- and long-term efficacy of computerized cognitive plasticity training. In the short term, participants in the active control group playing computer games outperformed participants in the experimental group in the primary cognitive outcome of composite scores of auditory attention and memory. Yet, there were no differences between the groups in two secondary outcomes: composite global cognitive score and long-term daily functioning rating.

3.2 Effect of Virtual Reality Strategies on Working Memory in Patients with Mild Neurocognitive Disorder.

Ten studies related to virtual reality were found. There were 398 individuals with mild neurocognitive disorder and 29 with dementia, with 71% of the participants being women, with an average age of 73 years. Manera et al. (2016) demonstrated that participants with mild neurocognitive disorder and dementia reported high satisfaction and interest in the task and reported feelings of safety, low discomfort, anxiety, and fatigue. Additionally, participants preferred the virtual reality condition compared to the pen-and-paper condition, even if the task was more difficult. Interestingly, apathetic participants showed a stronger preference for the virtual reality condition than non-apathetic participants. These findings suggest that virtual reality-based training can be considered a suitable tool for improving adherence to cognitive training in older adults with mild neurocognitive disorder.

In the same line, Park et al. (2019) found in their research that individuals with mild neurocognitive disorder who participated in mixed reality training showed significantly higher performance in visuospatial working memory compared to those who participated in conventional training. Moreover, Park et al. (2020) observed that cognitive-motor rehabilitation based on virtual reality can help improve motivation for rehabilitation and cognitive function, including memory and attention, in older adults with mild neurocognitive disorder more effectively than conventional cognitive rehabilitation. Similarly, in the research conducted by Manenti et al. (2020), improvement in memory, language, and visuoconstructional skills was observed after completing an in-home cognitive virtual reality treatment, which identified a higher rate of improvement compared to standard cognitive stimulation.

From the study by Hsieh et al. (2018), virtual reality-based Tai Chi exercise showed a protective effect on some cognitive and physical functions in older adults with cognitive impairment. The more appealing the program, the greater the improvement in cognitive performance. Similarly, Liao et al. (2019) demonstrated that a twelve-week physical and cognitive training program based on virtual reality led to significant improvements in dual-task walking performance in older adults with mild neurocognitive disorder, which can be attributed to improvements in executive function.

On the other hand, Thapa et al. (2020) assessed the effect of a virtual reality-based intervention program on cognition in older adults with mild neurocognitive disorder, and analysis of the group interactions revealed that the intervention group exhibited significantly improved executive function and resting-state brain function. On top of that, gait speed and mobility also significantly improved between and after the follow-up. The virtual reality training program improved cognitive and physical function in patients with mild neurocognitive disorder compared to controls. Encouraging patients to engage in virtual reality and game-based training can be beneficial for preventing cognitive decline.

In line with the previously mentioned research, Torpil et al. (2021) argued that a virtual reality-based intervention targeting cognitive functions in older adults with mild neurocognitive disorder in a control and clinical group is effective, as they observed improvements in orientation, visuospatial perception, visuomotor organization, thought processing, attention, and concentration functions in the virtual reality group compared to the control group. However, it is important to note that in the study conducted by Kim et al. (2021), they explored the associations between cognitive reserve and the effects of cognitive training using virtual reality and observed that there was better performance in the total score of the Consortium to Establish a Registry for Alzheimer's Disease Neuropsychological Battery (CERAD) in cognitively normal participants with higher scores in the education subdomain of the cognitive reserve questionnaire.

Thus, among patients with mild neurocognitive disorder, none of the scores for the education, work activity, and leisure time subdomains were related to a change in the total CERAD scores. The total score of the questionnaire did not predict global cognitive improvement in either group. On the other hand, in the research conducted by Maeng et al. (2021), a virtual reality-based cognitive training program was designed for older adults with mild neurocognitive disorder and normal cognition, and cognitive improvement was observed in the ability to learn new information, visuospatial construction ability, and frontal lobe function in both groups. In the initial evaluation based on a simulated illness questionnaire, the clinical group reported significantly more disorientation and nausea than the cognitively normal elderly group. Even so, both groups showed a reduction in discomfort as the virtual reality-based cognitive training program progressed.

3.3 Effect of Video Game and Robotics Strategies on Working Memory in Patients with Mild Neurocognitive Disorder.

Five studies related to video games and robotics were found. There were 173 individuals with mild neurocognitive disorder, with 60% of the participants being women, with an average age of 71 years. In the studies from Hughes et al. (2014), the feasibility and potential efficacy of an interactive Wii video game test to improve cognitive function were evaluated compared to health education in a community sample of older adults with mild neurocognitive disorder. Interactive video games showed moderate effects in favor of the Wii group, and a larger-scale trial is needed. Similarly, Amjad et al. (2019) found beneficial effects of Xbox 360 Kinect games after short- and long-term interventions in subjects with mild neurocognitive disorder. Therefore, these games can serve as potential therapeutic candidates for mild neurocognitive disorder.

On the other hand, Ramnath et al. (2021) demonstrated that an active intervention using interactive video games was more effective than conventional multimodal exercise in improving executive and global cognitive performance and functional capacity in older adults with subjective memory complaints. Likewise, Lim et al. (2023) confirmed the efficacy and safety of cognitive rehabilitation training using a serious game for older adults with mild neurocognitive disorder, and the results indicated that the study group participating in home-based serious game training showed immediate improvement in scores on the Korean version of the Mini-Mental State Exam, the Montreal Korean Cognitive Assessment, and the Semantic Verbal Fluency task compared to the control group, and the effects of home-based serious game training continued after one month. Thus, serious brain training games are considered useful for improving cognitive function.

The last finding was from the research study proposed by Lee et al. (2020), which evaluated a four-week home-based robotic cognitive intervention for patients with mild neurocognitive disorder. They found that there were no significant baseline clinical or demographic differences between the robot and control groups after the cognitive intervention. However, the robot group showed greater improvement in working memory, but further studies with larger sample sizes and longer study periods are needed to demonstrate the effects of these programs on other cognitive domains in patients with mild neurocognitive disorder.

4. Discussion

This systematic review presents three perspectives that dominate the study of working memory training with technological innovation in older adults with mild neurocognitive disorder. The findings support the sensitivity and ecological validity of neuropsychological rehabilitation mediated by virtual reality, computerized training, video games, and robotics, demonstrating that the use of technology in therapies versus traditional approaches helps achieve better results. It effectively promotes cognitive skills, basic and instrumental abilities, and social communication through safe, controllable, and repeatable training modes, making the development of such tools increasingly attractive for healthcare professionals.

Understanding that as individuals age, the demands of the environment significantly decrease, leading to a process of "untraining" of cognitive skills. Consequently, there is a reduction in the performance of daily activities, resulting in insufficient stimulation of cognitive functions (Calero & Navarro, 2006). Additionally, other factors come into play, such as level of education, level of physical activity, dietary habits, emotional well-being, social and affective support, among others (Blasco & Meléndez, 2006). These factors serve as protective factors, defined as personal characteristics or environmental factors that increase the likelihood of individuals maintaining good health and acquiring beneficial physical and mental capabilities for the aging process.

It is also important to consider cognitive neuroplasticity when stimulating cognitive function. Cognitive neuroplasticity refers to the capacity of the nervous system to generate new dendrites and synapses from remaining neurons, thus maintaining the efficiency of neural circuits. This process occurs when appropriate and sustained stimulation through practice leads to beneficial changes in the structure and function of the brain (Vega et al., 2016). Hence, the significant development of technology in recent years arises from the need to personalize and improve specialized care for individuals with cognitive difficulties due to neurological conditions. The incorporation of technology into interventions represents a therapeutic innovation, making them more didactic, creative, and flexible.

Cognitive assessment, neuropsychological rehabilitation, and research on non-pharmacological interventions in patients with mild neurocognitive disorder have become the focus of dementia prevention in recent years. Cognitive training and stimulation provided through digital devices are promising strategies to maintain cognitive function in healthy older adults and rehabilitate individuals with mild neurocognitive disorder (Zhang et al., 2019). Computerized cognitive interventions are not only useful for improving cognition, memory, and attention, but they also have a positive influence on the psychosocial functioning of older adults with mild neurocognitive disorder by enhancing functionality in daily activities and enabling the use of compensatory strategies (Hill et al., 2017). Similarly, it has been demonstrated that the beneficial effects of computerized cognitive training are maintained in both the short and long term in individuals with preserved cognitive function (Ten Brinke et al., 2018).

Given the above, it is important to consider that the combination of physical exercise with cognitive training is a popular intervention in dementia prevention trials and guidelines. Gavelin et al. (2021) suggest that simultaneously combined interventions are effective in promoting cognitive and physical health in older adults and, consequently, should be preferred over single-domain training implementation. In the same vein, Meng et al. (2022) also found combined interventions to be effective in improving cognition in older adults with mild neurocognitive disorder.

Over and above that, in analyzing other studies, it was found that virtual reality technology is an emerging intervention and has gradually become a complementary therapy for various conditions such as cerebral palsy, depression, Parkinson's disease, and mild neurocognitive disorder (Roosink et al., 2016). Virtual reality utilizes human senses such as sight, touch, and movement to control a virtually created environment. Its advantage lies in simulating real-life experiences (Rizzo et al., 2000) and providing short-term feedback (Liao Y. et al., 2019) based on the individual's performance through the creation of a virtual environment.

In view of the above, virtual reality technology allows patients to exercise within a limited space, thereby reducing healthcare costs as it does not require the presence of a neuropsychologist like more traditional therapies but can also be utilized at home. Compared to traditional treatment, virtual reality improves patient motivation and engagement (Kim et al., 2017). Also, virtual reality technology not only allows precise control of the environment but also enables adjusting the difficulty level according to the patient's skill level. Due to its accessibility and safety, it is convenient for patients to use it temporarily at home, which is beneficial for rehabilitation implementation (Hwang & Park, 2018).

Considering the advantages of virtual reality usage, it is imperative to understand that the compensatory model of brain plasticity shows that an aging brain can better maintain or conserve cognitive functions by increasing activation in frontal, temporal, and parietal brain regions (Lustig et al., 2009). The advantage of virtual reality is that it provides timely feedback to patients with mild neurocognitive disorder and increases stimulation in their cognitive and motor areas, thereby improving cognitive functions and activities of daily living (Coyle et al., 2015).

On the other hand, information and communication technologies can also play a key role in the treatment, stimulation, and rehabilitation of patients (Robert et al., 2014). This is the underlying idea behind the current use of serious games, which are a broader replication of video game resources that integrate games and serious purposes. In fact, recently, some studies have started employing serious games with individuals with mild and major neurocognitive disorder as a cutting-edge intervention, focused on non-pharmacological approaches, and can be defined as interventions that directly or indirectly target cognition, as opposed to interventions primarily focusing on behavior, mood, or physical function (Bahar-Fuchs et al., 2017).

Therefore, these interventions are often designed to promote intellectual stimulation and minimize cognitive decline. The progressive decline in cognitive functions is indeed a clinical feature of major neurocognitive disorder, and it has been found to be associated with impairment in activities of daily living (Tomaszewski et al., 2020. Thus, intervention aimed at preventing and rehabilitating such decline can promote longer independent living at home and reduce the burden on patients and their families.

On the other hand, robotics in cognitive rehabilitation offers promising training and assistance methods to mitigate cognitive deficits, and recent advancements in robotics and information and communication technology are expected to enhance human healthcare and aid patients with cognitive impairment in exercise and therapy. Faced with a severe shortage of healthcare personnel and a heavy caregiver burden, robots can help and care without incurring physical and emotional strain (Taheri et al., 2018).

In view of the above, the goal of cognitive rehabilitation with robotics is to provide cognitive training to vulnerable individuals with cognitive disabilities that can complement their caregivers or therapists (Doraiswamy et al., 2020). Nevertheless, robotics poses significant ethical challenges for cognitive rehabilitation or training, and ethical considerations regarding human dignity, safety, legality, and social factors need to be considered (Villaronga, 2016).

Lastly, memory training rehabilitation with technological innovation in older adults with mild neurocognitive disorder mediated by virtual reality, computerized training, video games, and robotics holds significant potential as it allows the generation of situations related to activities of daily living and functional skills such as physical, intellectual, and occupational activity. However, to maintain or improve working memory functioning, it is important for individuals to face new learning experiences with constant challenges, such as cognitive training targeting a specific cognitive function (Binotti et al., 2009). Cognitive training alone represents a protective factor for mental health, allowing for stimulation and development of skills that promote social interaction, problem-solving, and the maintenance of cognitive reserve.

5. Strengths and limitations

The systematic review of the literature made it possible to identify the main works on working memory training with technological innovation in older adults with mild neurocognitive disorder, presenting a wide range of possibilities with experimental methodological designs of high scientific rigor to establish clinical strategies for intervention and rehabilitation, but there were limitations given that studies published only in English were included, given that the databases where the search was conducted include research published in that language, and it is recommended that future research include databases with publications in Spanish so that the Latin American population can be included.

6. Conclusion

This review has shown support for the hypothesis of improved cognitive performance in older adults with mild neurocognitive impairment with working memory training mediated by technological innovation through virtual reality, computerized training, video games and robotics, demonstrating sensitivity and ecological validity of neuropsychological rehabilitation. However, longitudinal studies on the interventions are required to assess long-term transfer and relevance in reducing the prevalence of major neurocognitive disorder.

Additionally, the exercise carried out constitutes a valuable exploratory input for health professionals interested in technological innovation in neuropsychological rehabilitation processes, and allows identifying the opportunity to delve deeper into this research topic given that there are few publications for the Latin American case, according to the high quality standards in scientific publications; taking into account that the main studies are published in the main neuroscience journals of the world. Finally, it is recommended for future studies to aim for a larger sample size, to reduce variability in intervention design and measures applied, and to strive to clarify whether there are additional benefits to implementing multimodal interventions.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any potential conflict of interest.

Authors' contribution

DMM, DMA, and DLM worked on the conceptualization of the systematic review, analysis, methodology, supervision, validation, visualization, writing, editing, and preparation of the manuscript.

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