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Effects of working memory training on cognition in healthy older adults: a systematic review

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ABSTRACT. The working memory (WM) training in older adults can benefit their cognition. However, there is a dearth of literature reviews on the subject. **Objective:** This study aimed to investigate and evaluate the effects of WM training on the cognition of healthy older adults, in individual and group interventions reported in the literature. **Methods:** This is a systematic review involving a qualitative analysis of publications on the SciELO, LILACS, and MEDLINE databases carried out between March and June 2021. **Results:** A total of 47 studies were identified and analyzed, comprising 40 in older adults only and 7 comparing older and younger adults, investigating individual or group WM training or other types of intervention focused on WM effects. **Conclusions:** Both individual and group intervention contributed to the maintenance and/or improvement of cognition in older adults exploiting brain plasticity to promote mental health and prevent cognitive problems that can negatively impact quality of life of this group.

Keywords: Memory, Short-Term; Cognitive Aging; Executive Function; Spatial Memory; Mental Health.

EFEITOS DO TREINO DE MEMÓRIA OPERACIONAL NA COGNIÇÃO DE IDOSOS SAUDÁVEIS: UM ESTUDO DE REVISÃO SISTEMÁTICA

RESUMO. O treino da memória operacional (WM) com idosos pode gerar benefícios em sua cognição. Entretanto, há escassez de revisões da literatura sobre o tema. **Objetivo:** Investigar e avaliar, na literatura, os efeitos do treino da WM na cognição de idosos saudáveis, em intervenções individuais e grupais. **Métodos:** Estudo de revisão sistemática realizado entre março e junho de 2021, utilizando-se as bases Scientific Electronic Library Online (SciELO), Literatura Latino-Americana e do Caribe em Ciências da Saúde (LILACS) e Medical Literature Analysis and Retrieval System Online (MEDLINE). **Resultados:** Foram identificados e analisados 47 estudos, 40 apenas com idosos, e sete comparativos entre idosos e adultos mais jovens, que realizaram treino individual ou em grupo com foco nos efeitos na WM. **Conclusões:** Os trabalhos analisados mostraram que ambos os tipos de intervenções podem contribuir para a manutenção e/ou melhoria da cognição de pessoas idosas, aproveitando sua plasticidade cerebral e, portanto, para a promoção de sua saúde mental e para a prevenção de problemas cognitivos que podem interferir em sua qualidade de vida.

Palavras-chave: Memória de Curto Prazo; Envelhecimento Cognitivo; Função Executiva; Memória Espacial; Saúde Mental.

INTRODUCTION

The growth in the population of older people has led to a shift in epidemiological profile, changes that pose a major challenge to health systems worldwide. Multidisciplinary, preventive actions involving monitoring of the aging process are needed to reduce this burden[1].

A prevalent health issue associated with aging is dementia. According to the World

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Health Organization[2], the number of individuals presenting some degree of dementia syndrome may triple by 2050 compared with 2012 levels, with low- to middle-income countries set to be most affected[3].

Memory is a cognitive function that can be negatively impacted by different types of dementia or cognitive impairments that are precursors of a dementia syndrome diagnosis. Working memory (WM) is a type of short-term memory involved in the concurrent storage and processing of information before and during the execution of a given task[4,5].

Literature reveals that memory can be understood as long term or short term. The first is associated with the permanent storage of information, which can be retrieved and recalled at any time. The second, in turn, is related to the ability to memorize a limited amount of information over a short period of time. Long-term memory is subdivided into episodic, semantic, autobiographical, prospective, procedural, preactivation, and conditioning memory. While short-term memory refers to immediate memory and WM[6].

According to the literature review by Chai et al., different models describe the concept of WM, among which two stand out. The first is known as the multicomponent WM model, in which WM is seen as a system capable of providing information for the execution of more complex cognitive activities. In this model, there is a center that manages visuospatial skills, speech therapy, and multimodal information related to episodic memory, forming the WM. The second model highlights the influence of attentional cognitive ability in the formation of WM, in addition to identifying this subtype of memory as an integrated part of long-term memory[7].

Working memory is one of the most affected cognitive functions in the aging process. The literature explains that the areas of the prefrontal cortex, the region responsible for the functioning of WM, can suffer more significant impacts over time, which impairs the execution of tasks that require the processing and temporary storage of information, such as visuospatial information and verbal. Through visuospatial memory, the individual has the ability to understand their own spatial location, as well as the arrangement of objects in spaces and the identification of colors, textures, and shapes. Verbal memory is related to the skills of remembering, evoking, and understanding words, either written or verbal[8].

In this context, nonpharmacological interventions, including cognitive interventions, emerge as viable strategies for preventing cognitive decline and promoting mental health. Intervention strategies as a way of maintaining and improving the functioning of cognitive skills are possible due to the brain's plasticity capacity. Neuroplasticity refers to the increase in the formation of the number of dendrites, axons, and synapses, from external events, which favor cognitive functionality[9].

The deliberate practice of one or more cognitive skills via standardized activities is referred to as cognitive training (CT), which can be characterized as strategy-based cognitive training (SCT) or procedure-based cognitive training (PCT). The SCT is configured as an intervention with an emphasis on compensatory practices in which a facilitator provides instructions and resources that help in the execution of specific tasks and activities that present some commitment. The use of lists, calendars, and organization methods are some examples[10].

In relation to PCT, this modality aims to achieve better functioning of specific cognitive functions, but does not provide compensatory strategies as in the model mentioned above. Due to this characteristic, the PCT presents a greater possibility of obtaining benefits for other skills in addition to the trained one[11]. An example of this type of cognitive intervention is WM training, which aimed at stimulating cognition through exercises for enhancing attention, memory performance, and concentration[5]. Brum[5] demonstrated the effectiveness of WM training in cognitively healthy older adults, who showed performance gains on cognitive tests performed pre- and post-intervention.

Brum et al.[12] carried out a study using individual WM training involving an adaptive scheme that allowed difficulty levels to be personalized. The results showed that three sessions of individual training promoted long-term gains in the cognitive skills trained plus a transfer effect to nontrained skills. The benefits, however, extended to include improvements in fluid intelligence, text comprehension, processing speed, and activities of daily living (ADLs).

From the research studies on the effects of WM training, those that present transfer results allow the association of this training modality to greater neuroplasticity, since the more cognitive regions are stimulated, the better performance of the respective functions is achieved, new skills are learned, and available cognitive resources are put to better use[13].

Although the results by Brum et al were positive, there are controversies in the literature about the benefits of close transference (for WM) and distant transference (for other cognitive skills) in WM training. The meta-analysis conducted by Sala et al, for example, aimed to investigate the effects of WM training on the cognitive abilities of the elderly. Only trained skills demonstrate significant improvement, indicating the absence of general benefits[14].

Recent evidence suggests WM training interventions in healthy older adults can potentiate brain plasticity, leading to not only near-transfer effects in performance on tasks measured within the same CT construct but also nontrained and far-transfer effects, improving performance on tasks measured under constructs not targeted by the CT. Factors such as age and education level can influence the short- and long-term effects[15].

In the meta-analysis, Karbach and Verhaeghen[11] analyzed the efficacy of WM training in enhancing the capacity and functioning of WM, and of executive functions training, focused on improving performance on dual-task, inhibitory and interference control, task switching, and general forms of attention, comparing the differences between young adults and older. The findings showed gains in the cognitive skills trained and small-to-moderate transfer effects to the global cognitive system. The authors concluded that training based on WM processes and executive functions was highly effective, suggesting that this type of cognitive intervention in older adults can help promote healthy aging[11].

Other more recent meta-analyses have evaluated the results of WM training, considering transfer effects as well as long-term effects. However, unlike what the present review proposes to do, there was no comparison between effects in young and elderly adults[14,16-18], or samples with multiple age groups were included, or only computerized CT was considered[19].

The objective of this systematic review, involving a qualitative analysis, was to investigate and evaluate the effects of WM training on the cognition in healthy older adults, based on individual and group interventions reported in the literature.

METHODS

A systematic review involving a qualitative analysis was conducted between March and June 2021. All relevant articles published in Portuguese or English were selected according to predefined inclusion and exclusion criteria. The SciELO, LILACS, and MEDLINE electronic databases were searched using the following combination of keywords: (idosa OR idoso OR idosos OR idosas) OR (elder OR "older person" OR "older persons" OR "older people" OR "senior citizen" "senior citizens" OR elderly OR "aging people" OR "aging person" OR "aging persons" OR "older adult" OR "older adults") AND ("intervenção cognitiva" OR "intervenções cognitivas" OR "treino cognitivo" OR "cognitive intervention" OR "cognitive interventions" OR "cognitive training") AND ("memória operacional" OR "memória de trabalho" OR "working memory" OR "operational memory") AND (envelhecimento OR aging).

Inclusion criteria were as follows: randomized clinically controlled trials published in Portuguese or English in scientific journals from 2011 onward; CT interventions focused on WM training, individual or group based; healthy participants aged over 60 years; and the use of cognitive and/or neuropsychological tests to determine the effects of the interventions.

The exclusion criteria adopted were as follows: publications of masters' dissertations, book chapters, doctoral theses, letters to the editor, case studies, systematic and meta-analysis reviews, and research protocols; studies involving cognitive interventions combined with physical training, other types of intervention, and/or multimode intervention studies; participants aged <60 years (in studies of older adults only) presenting cognitive impairment or risk of developing dementia or cognitive decline; trials performed in residential care homes, such as Long-term Care Facilities (LTCFs); and studies that do not assess intervention effects on cognitive performance of participants.

To guide the stages of identifying, screening, and determining eligibility of studies, two independent reviewers performed the steps of the Statement of Preferred Reporting Items for Systematic Reviews and Meta-Analyzes (PRISMA)[20]. The initial identification of studies entailed searches of the databases specified. During the screening stage, duplicate studies were removed and titles and abstracts analyzed by applying the predefined inclusion and exclusion criteria. For the eligibility stage, the selected studies were read in full and analyzed against the same criteria. The studies remaining after this stage were included in the review.

The scope of the study's systematic review was registered on the International Prospective Register of Systematic Reviews (PROSPERO)[21] under registration number CRD42021245439. In addition, the included studies were rated for quality according to the Downs and Black Checklist[22]. This evaluation tool devised by Downs and Black comprises 27 items distributed between 5 sub-scales: reporting or assessment (10 items), external validity (3), internal validity of the measurements described and outcome bias (7), Confounding factors (6), and Power (1). Checklist items were scored 0 or 1, except for the item assessing the reporting of confounding factors, which score 0–2 points, and the item on power (item 27) modified as per other studies[22,23], whose original scoring of 0–5 points was changed to score 0 or 1 point, with a score of 1 given if the article reported calculation of power and/or sample size and 0 if these calculations had not been performed. Thus, the total scores on the Checklist ranged from 0 to 28 points. To improve the reading of the data obtained, scores were converted into percentages for each domain and an overall mean total score for all domains was calculated. A system for classifying the quality of articles was defined as follows: ≤0.39 poor, 0.40–0.69 regular, 0.70–0.79 good, and ≥0.80 excellent.

RESULTS

A total of 229 studies were retrieved in the initial search, 6 of which were subsequently excluded because they were duplicates. Titles and abstracts of the remaining 223 studies were read and screened for relevance to the review and selected according to the inclusion and exclusion criteria. Thus, 71 articles were read in full and, after rigorous application of the criteria, a further 24 were excluded, of which 4 did not have a control group and a training group, 3 did not evaluate the effects of the intervention, 9 did not use a strategy directed to WM, 5 included elderly and nonelderly in the same groups, 2 had a group of elderly people with mild cognitive impairment (MCI), and 1 was published in Spanish. The study selection process is shown in the flow diagram[20] depicted in Figure 1.

The objectives, methods, and results of the 47 studies selected for analysis are listed in Tables 1 and 2. Regarding the sample profiles, 40 studies involved older adults only, of which 34 performed WM training. Of this total, 25 applied individual interventions[13,24-57]. Seven studies of older adults performed a variety of interventions centered on WM effects, comprising two with individual training[58,59] and five with group training[60-63]. The other seven studies analyzed involved young and older adults who underwent individual WM training, comparing the performance of the two age groups[64-70].

The number of participants in the studies involving older adults only ranged from 14 to 235 subjects and maximum age was 95 years. Intervention duration ranged from 1 to 26 weeks, with a minimum of 5 and maximum of 50 sessions, and session length of 20–150 min each. Follow-up assessments took place within a period of 3 years post-intervention.

In studies comparing younger and older adults, the number of participants ranged from 43 to 123, mean age of older adults was 60–77 years, age of younger adults was 19–36 years, intervention duration was 2–5 weeks, and the number of sessions ranged from 10 to 25, with session duration of 10–60 min. Follow-up assessments were carried out within a period of 18 months post-intervention.

Finally, according to the scores for the categories of the methodological quality Checklist, none of the articles scored <0.68 points and 43 scored >0.70, attaining

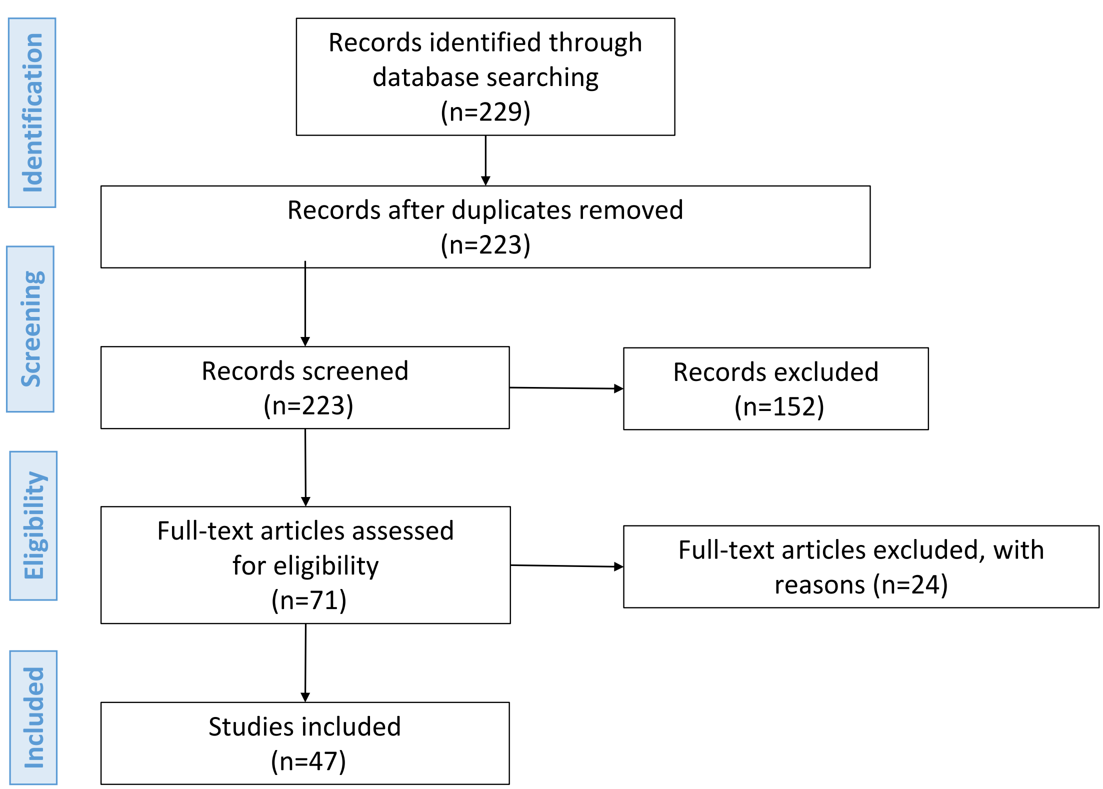

Figure 1. Flowchart of study search and review process.

Table 1. Studies with older adults.

Authors	Objectives	Methods	Results found
Richmond et al.[42]	To investigate gains in WM through WM training in older adults and whether near- and far-transfer effects to other measures exist.	n=40; age=60–80; intervention: individual, 4–5 weeks, 4–5 sessions of 20–30 min per week; study groups: WM training (n=21), active control (n=19); assessments: pre- and post-test.	Primary outcome: the training group showed the ability to inhibit the repetition of items already retrieved from memory and in a measure of attention (self-report); Transfer effects: short-term memory and WM; Long-term effects: not mentioned.
Irigaray et al.[50]	To verify the effects of an attention, memory, and executive functions training intervention on the cognition of healthy older adults.	n=76; age=60–89; intervention: group based, 12 weeks, 1 session of 90 min per week; study groups: WM training (n=38), passive control (n=38); assessments: pre- and post-test.	Primary outcome: better performance in tasks of attention, WM, language (inferences and spontaneous writing), constructional praxis, problem-solving, and executive functions; Transfer effects: not mentioned; Long-term effects: not mentioned.
van Muijden et al.[56]	To test whether CCT with online games can improve cognitive control in healthy older adults.	n=72; age=60–77; intervention: group based, 7 weeks, 1 session of 30 min per day; study groups: online games (n=53), active control: documentary (n=19); assessments: pre- and post-test.	Primary outcome: the study as a whole provides only modest support for the potential of video game training to improve cognitive control in healthy older adults; Transfer effects: inhibition and inductive reasoning; Long-term effects: not mentioned.
Anguera et al.[24]	To examine whether older adults participating in CCT (neuroRacer game) in multitasking mode showed improvement in multitasking performance on the game and in cognitive control abilities.	n=46; age=60–85; intervention: individual, 4 weeks, 3 sessions of 60 min per week; study groups: MTT (n=16), active control (n=15), passive control (n=15); assessments: pre- and post-test; follow-up: 6 months.	Primary outcome: older adults improved multitasking performance; Transfer effects: WM (delayed recognition task with and without distraction) and sustained attention; Long-term effects: yes, after 6 months.
Borella et al.[13]	To examine whether verbal WM training can improve WM performance in old-old individuals and to what extent it can promote and maintain transfer effects on tasks not trained directly.	n=36; age=75–87; intervention: individual, 2 weeks, 3 sessions of 60 min; study groups: verbal WM training (n=18), active control (n=18); assessments: pre- and post-test; follow-up: after 8 months.	Primary outcome: there was improvement in verbal memory performance; Transfer effects: inhibitory mechanisms; Long-term effects: yes, after 8 months.
McAvinue et al.[40]	To examine the efficacy of a WM training scheme to improve WM capacity in a group of older adults.	n=36; age=64–79; intervention: individual, 5 weeks, 5 sessions of 30 min per week; study groups: WM training (n=19), active control (n=17); assessments: pre- and post-test; follow-up: 3 and 6 months.	Primary outcome: there was expansion of short-term auditory memory, but no improvement was identified in WM overall; Transfer effects: episodic long-term memory; Long-term effects: yes, after 3 and 6 months.
Netto et al.[54]	To examine the effects of a WM training program on processing of WM and other related cognitive functions in healthy older adults.	n=20; age=60–80; intervention: group based, 12 weeks, 1 session of 90 min per week; study groups: WM training (n=9), passive control (n=11); assessments: pre- and post-test.	Primary outcome: significant improvements were found in focused attention, learning, and short-term and episodic memory in the training group. In the control group, improvements were found, in a more modest way, in concentrated attention and episodic memory; Transfer effects: episodic memory; Long-term effects: not investigated.
Borella et al.[29]	To test the efficacy of visuospatial WM training for transfer effects and maintenance of these effects in young-old and old-old.	n=80; age=65–84; intervention: individual, 2 weeks, 3 sessions of 60 min; study groups: WM training (n=20, 65–75 years; n=20, 76–84 years), active control (n=20, 65–75 years; n=20, 76–84 years); assessments: pre- and post-test; follow-up: after 8 months.	Primary outcome: participants in the training group showed improvement in visuospatial WM performance; Transfer effects: Verbal WM; Long-term effects: transfer effects were not maintained after 8 months.

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Table 1. Continuation.

Authors	Objectives	Methods	Results found
Stamenova et al.[45]	To examine the potential transfer effects of a recollection training paradigm and determine which cognitive functions are predictors of training effects.	n=51; mean age=68; intervention: individual, 2 weeks, 3 sessions of 20–30 min per week; study groups: recollection training n=30), active control (n=21); assessments: pre- and post-test; follow-up: 4 weeks.	Primary outcome: there were quite significant training gains with the trained recall tasks, but the transfer effects were relatively weak; Transfer effects: verbal learning, visuospatial memory, and WM (weak); Long-term effects: not investigated.
Stepankova et al.[46]	To examine the effects of a CCT WM intervention on nontrained measures of WM and visuospatial skills in healthy older adults.	n=65; age: 65–74 years; intervention: individual, 5 weeks, 2 or 4 sessions of 25 min per week; study groups: low-frequency WM CCT (n=20), high-frequency WM CCT (n=20), passive control: (n=25); assessments: pre- and post-test.	Primary outcome: improvement was found in the performance of older adults in training with the N-Back task and transfer effects; Transfer effects: WM and visuospatial skills; Long-term effects: not investigated.
Strenziok et al.[47]	To test whether CT provides far-transfer effects to attentional control demands mediated by the dorsal attention network and trained sensory cortex.	n=42; age: 69.70±6.9; interventions: individual, 6 weeks, 6 sessions of 60 min per week; study groups using games: BF (n=14), SF (n=14), RON (n=14); assessments: pre- and post-test.	Primary outcome: results showed that auditory perception CT (BF) may be particularly effective as an intervention against cognitive decline; Transfer effects: problem-solving and reasoning; Long-term effects: not investigated.
Zimmermann et al.[57]	To determine whether differences in older adults exist between structured WM training program and poetry-based stimulation program.	n=14; age=62–74; intervention: group, 6 weeks, 12 sessions of 120 min; study groups: WM training (n=8), active control: poetry (n=6); assessments: pre- and post-test.	Primary outcome: the WM group improved performance on measures of WM, inhibition, and cognitive flexibility, while the Poetry group improved on verbal fluency and narrative speech tasks; Transfer effects: executive functions; Long-term effects: not investigated.
Zinke et al.[49]	To investigate the effects of a process-based training intervention in a mixed sample of older adults and explore possible moderators of training and transfer effects.	n=80; age=65–95; intervention: individual, 3 weeks, 3 sessions of 30 min per week; study groups: WM training (n=40), passive control (n=40); assessments: pre- and post-test; follow-up: 9 months.	Primary outcome: there was significant improvement for the three trained tasks (visual-spatial, verbal and executive WM); Transference effects: verbal and fluid intelligence; Long-term effects: yes, after 9 months.
Basak and O'Connell[27]	To assess the role of cognitive control in WM training, comparing two different strategies for optimizing cognition in older adults during a short period of time.	n=46; age=60–86 years; intervention: individual, 2 weeks, 5 sessions of 60 min; study groups: predictable WM training (n=22), unpredictable WM training (n=24); assessments: pre- and post-test; follow-up: after 8 weeks.	Primary outcome: there were significant improvements in WM and episodic memory; Transfer effects: episodic memory; Long-term effects: not investigated.
Binder et al.[28]	To test whether multidomain CT promotes improvement in high-level executive functions and in each component function of CT, and also increase the likelihood of overlap with measures of transfer and demands of ADLs in older adults.	n=84; age=64–75; intervention: individual, 10 weeks, 5 sessions of 45–60 min per week; study groups: imbibition (n=22), visuomotor function (n=21), spatial navigation (n=20); multidomain (inhibition, visuomotor function and spatial navigation, n=21); assessments: pre- and post-test; follow-up: 6 months.	Primary outcome: training promoted improvements in executive functions, distal transfer, and attention; Transfer effects: executive attention control; Long-term effects: yes, after 6 months.
Cantarella et al.[33]	To assess the efficacy of verbal WM training in older adults, in terms of specific gain and transfer effects to everyday life competences and reasoning skills.	n=36; age=65–75; intervention: individual, 6 weeks, 2 sessions of 30–40 min per week; study groups: WM training (n=18), active control (n=18); assessments: pre- and post-test.	Primary outcome: there were benefits in trained skills; Transfer effects: everyday tasks and logical reasoning; Long-term effects: not investigated.

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Table 1. Continuation.

Authors	Objectives	Methods	Results found
Cujzek and Vranic[58]	To investigate whether practice on computerized card games would transfer to performance of old-old on tasks measuring the cognitive skills required by this cognitively stimulating activity.	n=29; intervention: individual, 6 weeks, 2 sessions of 30 min per week; study groups: digital card games (n=15, age =72.60±9.83), active control: digital dice game (n=14, age= 73.71±9.97); assessments: pre- and post-test; follow-up: 4 months.	Primary outcome: there were improvements in reasoning skills were only in the training group. Traditional board games are perceived as much more enjoyable than traditional strategy training and extensive practice tasks, and this pleasure can ensure greater motivation and adherence of long-lived elderly to video game training; Transfer effects: not mentioned; Long-term effects: yes, after 4 months.
Heinzel et al.[71]	To investigate whether changes induced by training on neuronal activation in older adults reflect increases in processing efficiency, whether transfer effects accompany the overlap of neuronal activation and whether this overlap is related to near- and far-behavioral effects.	n=29; age=60–75; intervention: individual, 4 weeks, 3 sessions of 45 min per week; study groups: WM training (n=15), passive control (n=14); assessments: pre- and post-test.	Primary outcome: WM performance improved with training; Transfer effects: executive functions, processing speed, and fluid intelligence; Long-term effects: not investigated.
Ji et al.[51]	To determine whether inhibition training can stimulate differential plasticity in inhibitory processes (access, exclusion, and contention) and lead to far-transfer to WM skills and Gf related to inhibition, and also to other less related skills.	n=34; age=61–81; intervention: group based, 4 weeks, 3 sessions of 45–60 min per week; study groups: inhibition training (n=18), active control (n=16); assessments: pre- and post-test; follow-up: after 3 months.	Primary outcome: there were performance improvements in all three inhibitory processes trained; Transfer effects: process of exclusion and fluid intelligence; Long-term effects: yes, after 3 months.
Loosli et al.[53]	To investigate whether resistance to PI can be effectively improved by WM training with different PI demands.	n=25; age=68.8±5.5; intervention: group, 2 weeks, 4 sessions of 30 min per week; study groups: high PI (n=14), low PI (n=11); assessments: pre- and post-test; follow-up: after 2 months.	Primary outcome: there was an overall improvement in WM performance in both training groups. Resistance to PI can be reduced in the elderly by short, repetitive WM training; Transfer effects: not investigated; Long-term effects: not investigated.
Toril et al.[59]	To investigate the effects of videogame training on visuospatial WM and episodic memory of health older adults.	n=39; intervention: individual, 7–8 weeks, 15 sessions of 60 min; study groups: memory training (n=19, 70±6.73), passive control (n=20, 73.2±6.5); assessments: pre- and post-test; follow-up: 3 months.	Primary outcome: there was an improvement in performance in all games trained, mainly in visuospatial WM assessment tasks, but also episodic memory and short-term memory; Transfer effects: episodic memory; Long-term effects: yes, after 3 months.
Wilkinson and Yang[48]	To examine long-term maintenance of inhibition training benefits in older adults.	n=56; age=60–84; intervention: individual, 2 weeks, 3 sessions of 30 min per week; study groups: inhibition training with feedback (n=14), with summarized feedback (n=14), without feedback (n=14), passive control (n=14); assessments: pre- and post-test; follow-up: 1 year (n=33) and 3 years (n=26).	Primary end point: the results demonstrate the durability of gains from inhibition training in the elderly for a period of up to 3 years; Transfer effects: not investigated; Long-term effects: yes, within 1 and 3 years.
Borella et al.[32]	To test the efficacy of adaptive WM in older adults and compare its effects with same WM training together with the use of strategy based on construction of visual mental images.	n=54; age=65–75; intervention: individual, 2 weeks, 3 sessions of 30–40 min; study groups: WM (n=18), WM + construction of visual mental image strategy (n=18) and active control (n=18); assessments: pre- and post-test.	Primary outcome: the combination of teaching an effective strategy with a WM training procedure increases WM performance, encouraging the use of efficient strategies that are flexibly implemented; Transfer effects: verbal and visuospatial WM, short-term memory, processing and reasoning speed; Long-term effects: yes, after 6 months.

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Table 1. Continuation.

Authors	Objectives	Methods	Results found
Guye and von Bastian[35]	To investigate training gains and transfer effects after a process-based WM training intervention in older adults.	n=142; age=65–80; intervention: individual, 5 weeks, 5 sessions of 30–45 min per week; study groups: WM training (n=68), active control: visual search training (n=74); assessments: pre- and post-test.	Primary outcome: results suggest that WM training is not an effective way to improve general cognitive functioning in old age; Transfer effects: none; Long-term effects: not investigated.
Heinzel et al.[36]	To investigate whether single-task WM training and training-related alterations in neural activity might support performance in a dual-task setting, thus assessing transfer effects to higher order control processes in the context of dual-task coordination.	n=38; age=60–72; intervention: individual, 4 weeks, 3 sessions of 45 min per week; study groups: WM training (n=18), passive control (n=16); assessments: pre- and post-test.	Primary outcome: the results indicate that 12 N-Back numerical training sessions can improve performance in the trained task; Transfer effects: performance on a dual task; Long-term effects: Not investigated.
Payne and Stine-Morrow[41]	To examine the effects of a CCT on changes in verbal WM and language comprehension in healthy older adults.	n=41; age=61–75; intervention: individual, 3 weeks, 5 sessions of 30 min per week; study groups: WM training (n=22), active control (n=19); assessments: pre- and post-test.	Primary outcome: WM training participants showed improvements in untrained verbal WM tasks and selective improvements in untrained dimensions of language, including sentence memory, verbal fluency, and understanding of syntactically ambiguous sentences. The results suggest that WM is plastic even in old age, at least in the short term; Transfer effects: untrained verbal measures of WM; Long-term effects: not investigated.
Degé and Kerkovius[61]	To investigate the effect of music training on WM (verbal, visual, and central executive processing).	n=24; age=77±4.33; intervention: group based, 15 weeks, 1 session of 60 min per week; study groups: musical training program (n=8), active control (n=7), passive control (n=9); assessments: pre- and post-test.	Primary outcome: the study provides preliminary support for the conclusion that musical training (percussion and singing) may have an influence on verbal and visual WM in old age; Transfer effects: not investigated; Long-term effects: not investigated.
Lebedev et al.[37]	To assess whether solving complex reasoning problems involves the same cognitive processes as solving WM tasks.	n=53; age=65–75; intervention: individual, 4 weeks, 5 sessions of 40 min per week; study groups: WM training (n=27), active control: perceptual correspondence (n=26); assessments: pre- and post-test.	Primary outcome: WM training promoted little improvement in complex reasoning. The use of WM training interventions to try to achieve effects that carry over to broader cognition should be reconsidered; Transfer effects: none; Long-term effects: not investigated.
Simon et al.[44]	To evaluate the efficacy of CCT focused on WM in healthy older adults.	n=82; age=65–89; intervention: individual, 5 weeks, 5 sessions of 60 approx. 40 min per week; study groups: CCT adaptive WM (n=41), active control: CCT nonadaptive WM (n=41), assessments: pre- and post-test.	Primary outcome: adapted WM CCT appears more effective than nonadapted training in older adults of different cultural backgrounds. There was evidence of improvement in trained tasks and in an untrained task of WM and processing speed; Transfer effects: distal transfer in WM (low); Long-term effects: not investigated.
Weicker et al.[55]	To evaluate the efficacy of a CCT WM training program (WOME).	n=60; age=60–79; intervention: group based, 4 weeks, 3 sessions of 45 min per week; study groups: high-level WM (WOME: n=20), active control: low level WM (n=20), passive control (n=20); assessments: pre- and post-test; follow-up: after 3 months.	Primary outcome: WOME led to a significant improvement in WM performance on an untrained transfer task and there was evidence of a positive impact on everyday life; Transfer effects: WM (low); Long-term effects: there were no long-term effects after 3 months.

Continue…

Table 1. Continuation.

Authors	Objectives	Methods	Results found
Borella et al.[30]	To assess gains related to WM training, in short and long term in abilities required in everyday life, and in cognitive measures in old-old adults.	n= 32; age=75–85, intervention: individual, 2 weeks, 3 sessions of 30–40 min; study groups: WM training (n=8), active control (n=14); assessments: pre- and post-test.	Primary outcome: there were specific gains in the CWMS task and in the TIADL in the short term; Transfer effects: solving everyday problems; Long-term effects: yes, at follow-up, gains in CWMS were maintained after 9 months.
Borella et al.[31]	To examine whether music listening together with WM training in healthy older adults could enhance short- and long-term gains in transfer effects of training.	n=72; age= 65–75; intervention: individual, 2 weeks, 3 sessions of 60 min per week; study groups: Mozart WM training (n=19), Albinoni WM training (n=19), white noise WM training (n=16), active control (n=18); assessments: pre- and post-test; follow-up: after 6 months.	Primary outcome: regardless of the listening condition, the trained groups outperformed the control group. The Albinoni group showed greater short-term specific training gains on the CWMS task; Transfer effects: reasoning; Long-term effects: yes, after 6 months.
Matysiak et al.[39]	To investigate the impact of WM training on variety of cognitive tasks performance among older adults and the impact of the initial WM capacity on the training efficiency.	n=84; age=66; intervention: individual, 5 weeks, 5 sessions per week; study groups: WM training (n=42), active control: memory training (n=42); assessments: pre- and post-test.	Primary outcome: there were improvements in WM training and memory in all cognitive tests, except for inhibition and short-term memory; Transfer effects: N-back task (WM and attention) in the elderly; Long-term effects: not investigated.
Schmicker et al.[43]	To examine whether value-based decision-making can be improved in the elderly by CT.	n=31; age=60–75; intervention: group based, 5 days, 1 session of 45 min per day; study groups: attention training (n=12), WM training (n=10) and passive control (n=9); assessments: pre- and post-test.	Primary outcome: attentional filter training improves the performance of older adults in a decision-making task by alleviating disadvantageous behaviors. WM training provided improvement in WM; Transfer effects: none; Long-term effects: not investigated.
Wong et al.[63]	To assess whether learning a new language in older adults is beneficial.	n=235; age=60–85; intervention: group based, 26 weeks, 1 session of 60 min per week; study groups: language training (n=53), active control: computer games (n=51), passive control: music appreciation (n=49); assessments: pre- and post-test; follow-up: after 3 months.	Primary outcome: the study provides preliminary evidence that cognitively engaging activities (foreign language learning and computer games), even only in old age, have the potential to improve cognitive functions in older adults; Transfer effects: not investigated; Long-term effects: yes, after 3 months.
Berggren et al.[60]	To assess whether foreign language learning in older age is a promising avenue for combatting age-related cognitive decline.	n=160; age=65–75 years; intervention: in group, 11 weeks, 2 sessions of 150 min per week; study groups: language training (n=90); passive control (n=70); assessments: pre- and post-test.	Primary outcome: results demonstrate that an initial language course aimed at healthy older adults is unlikely to have any substantial effect on overall cognitive ability; Transfer effects: not investigated; Long-term effects: not investigated.
Ghavidel et al.[34]	To assess the efficacy of a WM training program on visuospatial and verbal WM in older female adults.	n=45; age=60–75; intervention: individual, 14 weeks, 2 sessions of 30–45 min per week; study groups: WM training (n=25), active control (n=20); assessments: pre- and post-test.	Primary outcome: the results support the feasibility of using CCT among elderly women and point to positive results of WM training in their visuospatial and verbal WM; Transfer effects: not investigated; Long-term effects: not investigated.
Guo et al.[62]	To investigate whether a musical instrument training program can improve cognitive function and neural efficiency on fMRI in musically naïve older adults.	n=53; age=61–85; intervention: group based, 16 weeks, 1 session of 60 min per week; study groups: Key-HIT program (n=27), active control (n=26); assessments: pre- and post-test.	Primary outcome: results provide important new insight into training-related plasticity, demonstrating that the Key-HIT program can improve verbal memory and neural efficiency in older adults; Transfer effects: verbal memory; Long-term effects: not investigated.

Continue…

Table 1. Continuation.

Authors	Objectives	Methods	Results found
Maraver et al.[38]	To examine the efficacy of an executive control training focusing on WM and inhibition in healthy older adults.	n=44; age=65.07±3.91; intervention: individual, 4 weeks, 3 sessions of 60 min per week; study groups: WM training and inhibition (n=22), active control (n=22); assessments: pre- and post-test.	Primary outcome: there were specific improvements between sessions, such as processing speed and executive control; Transfer effects: response inhibition; Long-term effects: not investigated.
Kazazi et al.[52]	To investigate the effect of CT on improving WM, selective attention and QoL of elderly people with normal cognitive function.	n=52; age=60+; intervention: group, 12 sessions, 2 sessions of 45 min per week; study groups: CCT ARAM (n=26), active control (n=26); assessments: pre- and post-test; follow-up: 3 months.	Primary outcome: when considering the results of this study, enhancement of specific cognitive domains (selective attention and WM) could improve overall cognition. Transfer effects: quality of life; Long-term effects: yes, after 3 months.

fMRI: functional magnetic resonance imaging; TIADL: timed instrumental activities of daily living; CWMS: Categorization Working Memory Span Task; WM: working memory; N-Back: rapid information updating task, typical for training and assessing WM; CCT: computerized cognitive training; Key-HIT: Keyboard harmonica instrument training; RON: Rise of Nations; BF: Brain Fitness; LE: low ecological (baixa conexão com atividades diárias); HE: high ecological(high connection with everyday activities); Gf: fluid intelligence; PI: proactive interference (reduced recall accuracy and slower reaction time due to previously relevant, but now irrelevant WM content); ARAM: Attentive Rehabilitation of Attention and the Memory; QoL: quality of life; ADLs: activities of daily living.

moderate-to-high score and good-to-excellent quality rating for the articles reviewed. Mean overall score for articles across all categories was 0.81 out of 1.0 in fulfilling Down and Black methodological quality requirements. The breakdown of scores by domain was as follows: reporting 0.95, external validity 0.51, bias/internal validity 0.62, confounding 0.99, and power 0.56 (Table 3).

DISCUSSION

The aim of this study was to investigate and evaluate the effects of WM training on the cognition of healthy elderly people, based on individual and group interventions reported in the literature. A total of 47 eligible studies with a wide range of objectives were selected for review.

As can be seen, the analyzed studies presented a variety of research methods and objectives related to WM training, among which the evaluation of the intervention effects on trained and untrained cognitive skills stands out[28-33,35,39,42,49-52,54,56,71,72]. Transfer effects were mentioned in 36 articles, representing a significance related to the benefits of WM training.

These results corroborate the outcomes identified in the meta-analysis by Karbach and Verhaeghen. The analyses presented by these authors showed that 100% of the evaluated studies whose focus was on WM training presented close or distant transference effects. In this systematic review, 76.5% described at least one observed effect. It should be noted that eight studies did not investigate transfer effects[34,48,50,53,58,60,61,63].

In contrast, three reviewed articles found no transfer effect from WM training[35,37,43]. This outcome was also found in other studies, such as the one by Goghari and Lawlor-Savage[72]. When comparing the effects of WM training with logic and planning training in groups of healthy elderly, the authors found that there was an improvement in the cognitive functions of both groups; however, transfer effects were not observed even in the training focused on WM. As described, the conclusions suggest that some variables interfered in the results, for example, the participants' high cognitive reserve[73].

Cognitive reserve is understood as the use of mechanisms for adaptation and flexibility of cognitive functions in the face of changes caused by the natural or pathological process of cognitive aging. Despite being a characteristic common to all people, some have greater cognitive reserve compared to others. This is due to different variables, the high level of education, and greater involvement in leisure activities, for example, which are associated with greater capacity for cognitive reserve.

Other important factors related to cognitive performance refer to neurogenesis (capacity to form new neurons) and neuroplasticity (formation of new synaptic connections). Like cognitive reserve, both depend on exposure to stimulating factors, such as CT[9].

The improvement in the performance of certain cognitive functions observed in the studies included in this review validates the hypotheses related to cognitive plasticity from training, since healthy elderly people achieved better results in performing activities after undergoing interventions. In this sense, some researchers highlighted the cognitive plasticity observed at the conclusion of their studies, including prefrontal neuroplasticity[13,24,34,41,46,49,51,59]

Table 2. Studies comparing older and younger adults.

Authors	Objectives	Methods	Results found
von Bastian et al.[70]	To investigate whether intensive WM training promotes enhancements in WM and reasoning performance in a YA and OA comparative setting.	n=57 OA, 62–77 years, n=66 YA, 19–36 years; intervention: individual, 4 weeks, 20 sessions of 10 min; study groups: WM training (n=27 OA, n=34 YA), active control (n=30 OA, n=32 YA); assessments: pre- and post-test.	Primary outcome: elderly and mature adults had better WM performance on the trained tasks and on an untrained task, but there was no distal transfer to reasoning. Transfer effects: complex amplitude; Long-term effects: not investigated.
Brehmer et al.[64]	To investigate training gains, transfer effects after and their maintenance after intensive WM CCT in YA and OA.	n=45 OA, 60–70 years, n=55 YA, 20–30 years; intervention: individual, 5 weeks, 5 sessions of 26 min per week; study groups: WM training (n=26 OA, n=29 YA), active control: low level WM (n=19 OA, n=26 YA), assessments: pre- and post-test; follow-up: after 3 months.	Primary outcome: training and transfer gains were slightly greater for YA than for OA on some tasks, but comparable across age groups on others; Transfer effects: distal transfer to sustained attention and activities of daily living; Long-term effects: Yes, after 3 months.
Heinzel et al.[66]	To investigate to what extent WM in OA can be improved by adapted WM training and to compare training gains between YA and AO.	n=30 OA, 60–75 years, n=30 YA, 22–30 years; intervention: individual, 4 weeks, 3 sessions of 45 min per week; study groups: WM training (n=15 OA, n=25 YA), passive control (n=15 OA, n=15 YA); assessments: pre- and post-test.	Primary outcome: the results indicate an improvement in central executive processing that may facilitate WM and dual-task coordination and point out that distal transfer is possible in the elderly; Transfer effects: short-term memory, episodic memory, and processing speed; Long-term effects: not investigated.
Sandberg et al.[68]	To investigate whether an intervention for executive functioning, addressing several basic processes (updating, shifting, and inhibition), can induce transfer effects in YA and OA.	n=30 OA and 29 YA; intervention: group based, 5 weeks, 3 sessions of 45 min per week; study groups: executive process training (n=15 OA, 69.73±5.02/n=16 YA, 26.25±4.01), passive control (n=15 OA, 68.8±4.8/n=13 YA, 24.62±3.4); assessments: pre- and post-test.	Primary outcome: training provided improvements in the lettering task and proximal transfer was observed in numerical updating and inhibition tasks in YA and elderly adults; Transfer effects: update and Inhibit; Long-term effects: not investigated.
Chan et al.[65]	To examine how visuospatial WM training improves finger movement sequential accuracy in YA and OA.	n=22 OA, age=70±4.01, n=26 YA, 21±1.37; intervention: individual, 10 days, 10 sessions of 60 min; study groups: WM training (n=12 OA, n=13 YA), active control (n=10 OA, n=13 YA); assessments: pre- and post-test.	Primary outcome: with CCT of visuospatial WM, there was an improvement in visuospatial WM and the ability to learn finger sequences with visual aids explicitly in YA and OA; Transfer effects: proximal transfer for all facets of WM in general; Long-term effects: not investigated.
Sandberg and Neely[69]	To examine long-term maintenance of training gains and transfer effects in YA and OA after an executive training program (Sandberg et al.,[68]).	n=24 OA and 19 YA; intervention: group based, 5 weeks, 3 sessions of 45 min per week; study groups: executive functions training (n=14 OA, 71.6±5/n=11 YA, 27.5±3), passive control (n=10 OA, 71.2±5.3/n=8 YA, 25.1±3.1); assessments: pre- and post-test; follow-up: 18 months.	Primary outcome: YA improved performance on two complex WM tasks immediately after training; Transfer effects: proximal transfer for a numerical update task; Long-term effects: yes, for a period of 18 months in early and late adulthood.
Rolle et al.[67]	To assess age-related differences in distributed attention and plasticity of this ability in response to CT in YA and OA groups.	n=40 OA, 61–75 years, n=42 YA, 20-28 years; intervention: individual, 2 weeks, 5 sessions of 30 min per week; study groups: spatial attention training (n=20 OA, n=21 YA), active control (n=20 OA, n=21 YA); assessments: pre- and post-test.	Primary outcome: training effects provide evidence that effective attentional allocation can be trained and improved regardless of age and result in the transfer of benefits to an WM task. Transfer effects: WM. Long-term effects: not investigated.

fMRI: functional magnetic resonance imaging; WM: working memory; N-Back: rapid information updating task, typical for training and assessing working memory; OA: older adults; YA: younger adults; CCT: computerized cognitive training.

Table 3. Results of the downs and black checklist for the present systematic review.

Downs and black checklist	n	Mean	Standard deviation	Minimum	Median	Maximum
Reporting score (converted)	47	10.38	0.64	9.00	10.00	1100
External validity score (converted)	47	1.55	0.62	1.00	1.00	3.00
Internal validity and outcome bias score (converted)	47	4.34	0.81	3.00	4.00	7.00
Confounding factors score (converted)	47	5.91	0.28	5.00	6.00	6.00
Power score (converted)	47	0.81	0.06	0.68	0.79	0.96
Overall score (converted)	47	10.38	0.64	9.00	10.00	11.00
Overall score (original, no conversion)	47	22.74	1.80	19.00	22.00	27.00

Regarding the long-term effects after the interventions, 12 studies showed associated results. Effects were noticed after 3[51,59,63,64], 4[58], 6[24,28,32,40], 8[13], 9[49], and 36 months[48]. While two studies did not identify long-term effects after 8[29] and 3[55] months of follow-up. The remaining studies included did not investigate the long-term effects of training.

Five recently published meta-analyses investigated the long-term effects of memory training in healthy older adults[14,16-19], but Hou et al.[18] reported that four of these reviews present important inconsistencies that prevent a specific conclusion on these effects, for example, with the absence of a methodological standard and limitations regarding the reporting of follow-up time of the analyzed studies, which represents a lack of clarity regarding the effects to be long term.

The most recent meta-analysis[18], exploring the objectives, methods, and results of 22 studies, concluded that there was maintenance of long-term effects after WM training, both for shorter periods (<6 months) and for longer periods (>6 months), showing similarities in the observed effects.

In short, the literature is not consistent in reporting transfer effects and long-term effects of WM training in elderly individuals. This literature review, as well as studies by Karbach and Verhaeghen[11] and Hou et al.[18], reported both follow-up effects and untrained skills, while studies by Schwaighofer et al.[19], Teixeira-Santos et al.[16], Sala et al.[14], and Nguyen et al.[17] showed no significant long-term benefits and close or distant transfer effects.

Individual or group interventions

Regarding the methods adopted, there was a prevalence of individual interventions, among which 27 had only elderly people as participants and 7 compared young adults and elderly people. The other studies (13) conducted strategies in groups. No significant differences were observed in the results of the two intervention modalities, with transfer effects and long-term effects in both individual and group interventions.

The benefits associated with individual cognitive intervention are described by Justo-Henriques et al.[74]. According to the authors, individual sessions allow the customization of activities and a greater approach to the participant, which promotes greater engagement. In addition, when performing an individual intervention, the facilitator is able to recognize the specific demands of the individual and focus on training the most compromised skills, favoring the achievement of benefits after the intervention.

Cognitive group training allows for social interactions, which, as mentioned by Ordonez et al.[75], can alleviate social isolation and the perception of loneliness. Engaging in group activities generates benefits for quality of life, well-being, and mental and cognitive health and is even capable of reducing the chances of developing or worsening dementia[76].

Comparison between young adults and seniors

Seven individual WM training studies compared the performance of younger and older adults. The benefits of memory training for both younger and older subjects were reported across all studies; however, training in various executive processes induced fewer transfer effects to the untrained cognitive abilities of older participants.

Although, as already mentioned, based on the results obtained by other studies, the elderly benefit from transfer effects to untrained cognitive skills, theories explain why these effects are more expressive in younger people[77]. The concepts of brain reserve and cognitive reserve are part of this explanation.

While the cognitive reserve is intended for functional adaptations and flexibilities, the brain reserve is related to individual anatomical characteristics. It is these reserves that allow the elderly to compensate for the deficits caused by the aging process or a pathology. When recruiting neural resources, the elderly person may be able to perform tasks in the same way as a young person; however, in tasks that require greater neuronal activation, due to high complexity, compensatory resources tend not to be sufficient, causing differences in performance of young and old[77].

It is also possible to find in the literature hypotheses that the elderly show more significant improvements in cognitive performance after training compared to younger adults[78-80]. The researchers attribute this outcome to the already existing high-performance capacity of young people, which limits the expansion and achievement of even better results.

The differences in the intensity of the transference effects for young and old submitted to WM training found in this review corroborate most of the reviews and meta-analyses carried out with this theme[78-80]. However, a difference was found with the results of the most recent meta-analysis, in which significant transfer effects were found in the elderly compared to the younger ones[11].

Overall, the interventions involving older adults only showed positive effects on cognitive performance, albeit in the form of WM training gains for the target cognitive ability or transfer effects of this type of training, as well as other types of WM-related CT. The studies also reported transfer effects of the training performed to everyday functions in older adults, with consequent improvements in quality of life.

Positive effects were also reported by the studies comparing the performance of older adults with young adults, including the possibility of promoting far-transfer effects in older adults, although contrasting with reported difficulty inducing these effects through training of different executive processes.

Thus, it was concluded that WM training, as well as different types of WM-related CT, can contribute to the maintenance and/or improvement of cognition in older people, recruiting their brain plasticity to promote mental health and prevent cognitive problems which can negatively impact their quality of life.

Limitations of the study include the difficulty performing a more comprehensive review of the wide variety of studies, published within the time window, investigating WM training and directly or indirectly related cognitive skills to determine the efficacy of nonpharmacological interventions aimed at enhancing cognitive performance of older adults.

Therefore, future studies with interventions focusing on specific aspects of WM and executive functions should be conducted in both healthy and cognitively impaired young-old and old-old.

Authors' contributions. TBLS: conceptualization, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, visualization, writing – original draft, writing – review & editing. TNO: conceptualization, formal analysis, investigation, methodology, project administration, supervision, visualization, writing – original draft, writing – review & editing. GS: conceptualization, investigation, methodology, visualization, writing – original draft, writing – review & editing. APBM: conceptualization, investigation, methodology, visualization, writing – original draft, writing – review & editing. CERV: conceptualization, investigation, methodology, visualization, writing – original draft, writing – review & editing. GAI: conceptualization, investigation, methodology, visualization, writing – original draft, writing – review & editing. GAS: conceptualization, investigation, methodology, visualization, writing – original draft, writing – review & editing. PPL: conceptualization, funding acquisition, investigation, methodology, resources, visualization, writing – original draft, writing – review & editing. LCM: conceptualization, funding acquisition, investigation, methodology, resources, visualization, writing – original draft, writing – review & editing. SMDB: conceptualization, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, visualization, writing – original draft, writing – review & editing.

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