University of Brasília
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Efficacy of Cognitive Training on Executive Functions in Healthy Older Adults: A Systematic Review with Meta-Analysis of Randomized Controlled Trials

by

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Dedicated to

My **family,**

who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve.

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Abstract

Objective: Systematically review randomized controlled trials on the effectiveness of cognitive training on executive functions in healthy older people. ***Methods and measures:*** This study has been registered in the International Prospective Register of Systematic Reviews (PROSPERO) with identification code CRD42021237057 and conducted in accordance with recommendations outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The outcome measures were related to inhibitory control, working memory, and cognitive flexibility. ***Results:*** Thirty-one trials were included in the qualitative synthesis (i.e., systematic review) and thirteen trials in the quantitative synthesis (i.e., meta-analysis). In the overall analysis, the cognitive training enhanced inhibitory control when measured by the Stroop task ($p < .001$) and working memory when measured by the Corsi Block task ($p = .002$). A marginal significance was found for working memory in the Digit Span task – Forward ($p = .06$). However, cognitive training did not enhance inhibitory control when measured by the Go/No-Go task ($p = .76$), working memory when measured by the Digit Span – Backward ($p = .72$) and N-Back ($p = .10$) tasks, and cognitive flexibility when measured by Trail Making – Part B ($p = .08$) and Semantic Fluency ($p = .49$) tasks. ***Conclusion:*** Mixed evidence was found for inhibitory control and working memory; cognitive flexibility showed no evidence of improvement. More research is needed to determine the specific characteristics to enhance treatment outcomes.

Keywords: aged, meta-analysis, cognitive aging, cognitive training, executive functions**.**

Resumo

Objetivo: Revisar sistematicamente ensaios clínicos randomizados sobre a eficácia do treinamento cognitivo nas funções executivas em idosos saudáveis. ***Métodos e medidas:*** Este estudo foi registrado no *International Prospective Register of Systematic Reviews* (PROSPERO) com o código de identificação CRD42021237057 e conduzido de acordo com as recomendações descritas pelo *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA). As medidas de desfecho foram relacionadas ao controle inibitório, memória de trabalho e flexibilidade cognitiva. ***Resultados:*** Trinta e um ensaios foram incluídos na síntese qualitativa (i.e., revisão sistemática) e treze ensaios na síntese quantitativa (i.e., metanálise). Na análise geral, o treinamento cognitivo melhorou o controle inibitório quando medido pela tarefa *Stroop* ($p < .001$) e a memória de trabalho quando medida pela tarefa *Corsi Block* ($p = .002$). Foi encontrada uma significância marginal para a memória de trabalho na tarefa *Digit Span – Forward* ($p = .06$). No entanto, o treinamento cognitivo não aumentou o controle inibitório quando medido pela tarefa *Go/No-Go* ($p = .76$), a memória de trabalho quando medida pelo *Digit Span – Backward* ($p = .72$) e *N-Back* ($p =. 10$) e flexibilidade cognitiva quando medida pelas tarefas *Trail Making* – Parte B ($p = .08$) e Fluência Semântica ($p = .49$). ***Conclusão:*** Evidências mistas foram encontradas para controle inibitório e memória de trabalho; flexibilidade cognitiva não mostrou nenhuma evidência de melhora. Mais pesquisas são necessárias para determinar as características específicas para melhorar os resultados do tratamento.

Palavras-chave: idoso, metanálise, envelhecimento cognitivo, treinamento cognitivo, funções executivas.

Resumo expandido

Eficácia do treinamento cognitivo nas funções executivas em idosos saudáveis: uma revisão sistemática com metanálise de ensaios clínicos randomizados

As funções cognitivas (e.g., percepção, atenção, memória, resolução de problemas, tomada de decisão, inteligência) desempenham um papel crucial em nosso funcionamento, impactando em nossas atividades da vida cotidiana (e.g., retenção de informações aprendidas, dirigir, caminhar). Estudos realizados com idosos demonstraram declínios nas funções cognitivas executivas (e.g., controle de inibição, mudança mental) que são gradualmente mediadas por uma diminuição no volume cerebral (no córtex parietal direito e pré-frontal). Com o envelhecimento, as funções executivas são uma das primeiras funções cognitivas a declinar devido a alterações micro e macroestruturais na conectividade cerebral. Assim, o objetivo da nossa investigação foi avaliar a eficácia do treino cognitivo nas funções executivas em idosos saudáveis. Ao contrário das revisões anteriores, segmentamos nossas análises por subdomínios de funções executivas (i.e., controle inibitório, memória de trabalho e flexibilidade cognitiva) e por tipo de controle (i.e., ativo ou passivo).

Método

O estudo foi registrado no *International Prospective Register of Systematic Reviews* (PROSPERO) com código de identificação CRD42021237057 e conduzido de acordo com as recomendações delineadas pelas diretrizes do grupo *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA). Direcionamos a pergunta de pesquisa usando a estrutura PICOS: População – idosos cognitivamente saudáveis; Intervenção – treinamento cognitivo para melhorar ou manter o funcionamento executivo; Comparação – grupos de controle ativo ou passivo; Resultado – medidas neuropsicológicas das funções executivas; Desenho do estudo – ensaios clínicos randomizados.

Para a síntese qualitativa (revisão sistemática), foram extraídos os seguintes dados: primeiro autor e ano, amostra, idade média, tipo de treinamento cognitivo, dose, sessões, duração, sessões por semana, resultados de funções executivas e grupos controle. Para a síntese quantitativa (metanálise), os dados contínuos para realizar a metanálise foram extraídos por um revisor e verificados por um segundo revisor. Para realizar a metanálise, adotamos o *software* de código aberto *Review Manager* versão 5.4. O principal resultado foi o *score* de mudança de pré para pós-treinamento no(s) grupo(s) experimental(is) (i.e., treinamento cognitivo) e grupo(s) de controle (i.e., ativo ou passivo).

Resultados e Discussão

A metanálise sobre o controle inibitório medido pela tarefa de *Stroop* resultou em uma significância estatística (efeito geral) a favor da intervenção de treinamento cognitivo quando comparada a controles ativos/passivos ($p < .001$). A metanálise sobre o controle inibitório medido pela tarefa *Go/No-Go* não mostrou significância estatística (efeito geral) a favor da intervenção de treinamento cognitivo quando comparada a controles ativos/passivos ($p = .76$).

A metanálise medida pela tarefa *Digit Span – Forward* na memória de trabalho resultou em uma significância estatística marginal (efeito geral) a favor da intervenção de treinamento cognitivo quando comparada a controles ativos/passivos ($p = .06$). A meta-análise medida pela tarefa *Digit Span – Backward* na memória de trabalho não mostrou significância (efeito geral) a favor da intervenção de treinamento cognitivo quando comparada a controles ativos/passivos ($p = .72$). A metanálise medida pela tarefa *Corsi Block* na memória de trabalho resultou em uma significância estatística (efeito geral) a favor da intervenção de treinamento cognitivo quando comparada a controles ativos/passivos ($p = .002$). A meta-análise medida pela tarefa *N-Back* na memória de trabalho não mostrou significância estatística (efeito geral) a favor da intervenção de treinamento cognitivo quando comparada a controles ativos/passivos ($p = .10$).

A metanálise sobre a flexibilidade cognitiva medida pela tarefa *Trail Making* não mostrou significância estatística (efeito geral) a favor da intervenção de treinamento cognitivo quando comparada a controles ativos/passivos ($p = .08$). A metanálise sobre a flexibilidade cognitiva medida por tarefas de Fluência Semântica não mostrou significância estatística (efeito geral) a favor da intervenção de treinamento cognitivo quando comparada aos controles ativos ($p = .49$).

Em comparação com outras metanálises que avaliaram a eficácia do treinamento cognitivo nas funções executivas, nossas análises mostraram resultados semelhantes. No entanto, foi possível identificar o impacto das tarefas/paradigmas neuropsicológicos adotados em cada subdomínio das funções executivas. Assim, investigações futuras podem considerar a especificidade de cada teste neuropsicológico para o respectivo domínio cognitivo. Devido a essa segmentação, realizamos metanálises com poucos estudos. Por outro lado, os resultados em tarefas/paradigmas específicos geram maior clareza quanto à eficácia das intervenções de treinamento cognitivo.

Introduction

The increase in human longevity, driven by improvements in living conditions, nutrition, medical technology, and cognitive development, has dramatically changed the prospects of future life, especially for the older people (Caswell and Zarulli, 2018; Maldonado Briegas et al., 2020). The United Nations estimates that the number of older adults (i.e., ≥ 65 years old) worldwide will rise from 0.7 billion (9 %) in 2019 to 1.5 billion (16 %) in 2050 (United Nations, 2019). Furthermore, the aging process is generally described as being closely associated with the onset of many diseases (Lazarus and Harridge, 2018); the review proposed by Jaul and Barron (2017) summarized the main age-related diseases in older adults and highlighted mild short-term memory loss, word-finding difficulty, and slower processing speed as normal parts of aging. In contrast, the review proposed by Harada et al. (2013) reported that some crystallized abilities (e.g., vocabulary) show a slower decline due to brain aging and may even improve with age because of knowledge that comes from past experiences. Therefore, there is a great and growing effort of the neuroscientific community on the nature of later life, including how to sustain cognitive health and even how to enhance it (Foster and Walker, 2021).

Cognitive functions (e.g., perception, attention, memory, problem solving, decision making, intelligence) play a crucial role in our functioning, impacting our everyday life activities (e.g., retention of learned information, driving, walking). Studies conducted with older adults have demonstrated declines in executive cognitive functions (e.g., inhibition control, mental shifting; Peng et al., 2022) which is gradually mediated by a decrease in brain volume (in the right parietal and prefrontal cortices, for instance; Fastame et al., 2022). As a result of aging, the executive functions are one of the first cognitive functions to decline due to micro and macrostructural alterations in the brain connectivity (for a functional and structural perspective, see Fjell et al., 2017). The executive functioning is a higher-order processing

activity in the brain, and it is the process by which individuals exercise conscious control over their thoughts and actions (Fan and Wang, 2022). Most related changes in executive functions are suggestive of impairment in the frontal lobes, and changes in the frontostriatal circuit (i.e., neural pathways connecting the frontal lobe to the basal ganglia) are possibly the most significant cause of impaired executive function in older people with no dementia (Lima-Silva et al., 2012). However, the human brain is inherently plastic and is continually adapting to its environment. Thus, executive functions training seems to promote cognitive and neural plasticity, even in older age (Nguyen et al., 2019).

In terms of constituents of executive functioning, a triad was proposed by Diamond (2013): inhibitory control, working memory, and cognitive flexibility. Inhibitory control is the cognitive ability to suppress or countermand a thought, action, or feeling (Spechler et al., 2016). It allows an individual to inhibit his impulses and natural, habitual, or dominant behavioural responses to stimuli in order to select more appropriate behaviours consistent with one's goals (H. Li et al., 2022). Inhibitory control can be measured using classical paradigms of experimental psychology, e.g., the Stroop task, Go/No-Go task, and the Stop-Signal task (Kang et al., 2022). Working memory is the cognitive ability that allows an individual to hold a small amount of information that can be held in mind and applied in the execution of cognitive tasks (Cowan, 2014). It is essential to all advanced thinking to learn facts or skills (Bergman Nutley and Söderqvist, 2017). Experimentally, working memory can be measured using classical paradigms, e.g., the Digit Span task, Letter/Number Sequencing task, and the Corsi Block task (Shelton et al., 2009). Cognitive flexibility is the ability that allows an individual to efficiently adjust one's behaviour according to a changing environment (Dajani & Uddin, 2015). It enables individuals to integrate external evidence into previous expectancies (Romero-Ferreiro et al., 2022). Experimentally, cognitive flexibility can be measured using classical paradigms, e.g.,

the Trail-Making Task (Part B), Wisconsin Card Sorting Task, and Fluency tasks (Takeda and Fukuzaki, 2021).

As previously mentioned, some cognitive functions — specially the executive functions — decline gradually over time as a result of the continuous aging process, i.e., non-pathological and age-associated cognitive decline (Murman, 2015). The neuropsychological literature indicate that healthy older adults showed worse performance than healthy younger adults in a variety of cognitive tasks: processing speed, inhibition, and visual-spatial ability (Ferguson et al., 2021; Kujawski et al., 2021; Langeard et al., 2021; N. Li et al., 2021). The decline of cognitive functions vary considerably, and some of them decrease during the whole adult lifespan (e.g., slower performance in tasks measuring episodic memory, word recognition, and retrieval; Verssimo et al., 2021), while others show smaller age-related declines that only become pronounced during old age (e.g., retrieval of newly learned material, and planning of response; Murman, 2015). However, older adults show better performance when compared to younger adults in tasks in which they use the wisdom and experience accumulated during their lives (e.g., judgment and problem solving tasks; Dumas, 2017).

Despite the inevitable aging process, engagement in cognitive activities (e.g., learning a new language, maintaining social connections, and undertaking cognitive training) can potentially mitigate cognitive declines (Stieger and Lachman, 2021). In this context, cognitive training is an intervention centred on the cognitive performance that uses a set of standardized behavioural task protocols that tackle cognitive functions (Golino and Flores-Mendoza, 2016), and that may be associated with other interventions (e.g., physical exercise; Anguera et al., 2022). These 'trainable' functions range from lower level processes – e.g., perception: biological motion – to higher order processes – e.g., executive functions: working memory (see Hong et al., 2021; Legault & Faubert, 2012). The efficacy is usually assessed through cognitive

evaluation (e.g., neuropsychological testing) for one or several cognitive domains before and after the intervention.

Considering that older adults have a high risk of serious cognitive diseases, identification of strategies and possible interventions for preventing cognitive decline is necessary (Giuli et al., 2016). In recent times, several devices and platforms have started to play a significant role in cognitive training since such training can potentially be undertaken at any time and accessed from anywhere (Klimova, 2016). Rapid advances in computing technology has evolved exponentially over time due to a fusion of technologies that are blurring the lines between physical, digital, and biological spheres (Park, 2016). As a result, this has enabled researchers and clinical professionals to conduct accessible and fine-tuned cognitive training using virtual reality, interactive video gaming playing, mobile setup, and other cutting-edge technologies (Ge et al., 2018).

Over the last years, a large body of evidence has suggested the efficacy of cognitive training on cognitive functioning in older adults. A review proposed by Sanjuán et al. (2020) endorsed the effectiveness of cognitive interventions. However, the authors highlighted aspects that must be met by proper experimental protocols for cognitive training (e.g., session length, total number of sessions, measures of daily functioning) in order to make the intervention more effective. Additionally, with the growing number of publications related to cognitive training applied in clinical populations, there has been an increase in the number of systematic reviews with and without meta-analysis. A meta-analysis proposed by Yun & Ryu (2022) demonstrated cognitive training was the most effective intervention in healthy older adults in comparison to cognitive stimulation (e.g., reality orientation) and cognitive rehabilitation (e.g., activities to improve the performance of daily activities). Nevertheless, systematic reviews show conflicting results (Makin, 2016; Traut et al., 2021). Some reviews find clear benefits to a trained ability – e.g., executive function in older adults with cognitive impairment (see Abd-

alrazaq et al. 2022), while other reviews yield little to no evidence of benefit from cognitive training (see Sala et al., 2019). In addition, the reviews usually assess the effectiveness of cognitive training on outcomes related to global cognition and neglect cognitive subdomains.

Therefore, and because cognitive training deals extensively with several areas (e.g., basic science, health, public policies, industry, and marketing), systematic reviews must be conducted periodically to present the state-of-the-art of the field and show its improvements in terms of methodological control. Three previous studies have performed systematic reviews with meta-analysis to address the effect of cognitive training on executive function in healthy older adults (Chiu et al., 2017; Nguyen et al., 2019; Wollesen et al., 2020). The gaps in previous studies were: (1) no registration in PROSPERO and (2) restrictions on date of publication. Thus, the aim of our investigation is to assess the effectiveness of cognitive training on executive functions in healthy older people. Unlike previous reviews, we segmented our analyses by executive functions subdomains (i.e., inhibitory control, working memory, and cognitive flexibility) as proposed by Diamond (2013), and by type of control (active or passive).

Method

The current study was registered in PROSPERO ID: CRD42021237057 and conducted in accordance with recommendations outlined by the PRISMA group guidelines (Page et al., 2021; see Supplementary Material – Appendix A for PRISMA-checklist).

Eligibility criteria

We targeted the research question using the PICOS framework: Population – cognitively healthy older adults; Intervention – cognitive training to enhance or maintain executive functioning; Comparison – active or passive control groups; Outcome –

neuropsychological measures of executive functions; Study design – randomized controlled trials.

Type of studies

We first identified and then collected peer-reviewed scientific papers of trials from online electronic databases that investigated the effect of cognitive training on executive functions outcomes in cognitively healthy older adults.

Type of participants

Due to the trials' sample heterogeneity in terms of age of the participants undergoing the intervention, the total experimental sample of each trial had to comprise (experimental and control groups) individuals aged ≥ 60 years old with normal cognitive functioning, and that have not been diagnosed with mild cognitive impairment or any form of dementia. The eligibility was confirmed by examining the baseline characteristics of the sample and the trial inclusion criteria.

Type of intervention

The intervention consisted of cognitive training alone or combined with other interventions (e.g., physical exercise, neuromodulation). We considered cognitive training as an approach that involves a set of standardized tasks designed to maintain or enhance cognitive processes (Simons et al., 2016). Interventions that significantly differ from cognitive training, such as cognitive behavioural therapy and mindfulness, were excluded.

Type of outcome measures

The outcome included performance on at least one cognitive test administered both before (baseline) and after the cognitive training program. Performance improvement was expected in executive functions in neuropsychological tests when comparing baseline pre-training and immediate post-training. In order to employ same-construct comparisons, we

categorized the outcome measures by distinct executive functions constituents: inhibitory control, working memory, and cognitive flexibility.

Information source

The following online databases were searched up to April 2021 to identify relevant trials: MEDLINE (PubMed), PsycINFO, The Cochrane Library Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science (Science and Social Science Citation Index), and SciELO (Scientific Electronic Library Online). For the identification and use of descriptors (i.e., specific keywords), we resorted to medical subject headings (MeSH) terms. To include as many trials as possible in addition to the MeSH terms, we included additional descriptors with terms not directly linked to MeSH (called "Text word"), but closely related to the investigated research topic. Subsequently, a new search was performed in additional directories up to April 2022 to identify possible updates to previously obtained trials: Epistemonikos (www.epistemonikos.org), Lens (www.lens.org), and Cognitive Training Data (www.cognitivetrainingdata.org). To elaborate the search strategy in the first two directories, we used the 2D Search open-source software (www.2dsearch.com), in which queries are formulated by manipulating objects on a two-dimensional canvas. In the Cognitive Training Data directory, we extracted the trials using Mendeley Reference Manager version 2.63 open-source software (www.mendeley.com). See Supplementary Material – Appendix B for the detailed search strategy for both searches.

Study selection and risk of bias

There were no restrictions on language and publication date. Two authors (RLO and SRF)[1] independently removed the duplicate items and performed the initial screening (i.e., titles and abstracts reading) of studies identified by the specific search strategy. Divergence in

[1] RLO: Raphael Lopes Olegário (first author and master's researcher) and SRF: Sarah Ribeiro Fernandes (co-author and undergraduate researcher).

study selection was resolved by the third author (RMJ)[2]. The two authors (RLO and SRF) subsequently read the selected studies' full text for potentially eligible studies. We utilized the Rayyan open-source free web-tool software (rayyan.qcri.org) during the entire screening process (on the advantages of Rayyan, see Ouzzani et al., 2016). The two authors (RLO and SRF) collected data about trial identification (title, authors, and year of publication), sample characteristics (sample size, mean age, standard deviation of each group), characteristics of the cognitive training, its duration (sessions), type of control group involved (active or passive), and the outcome measures (inhibitory control, working memory, and cognitive flexibility).

One author (RLO) assessed the methodological quality of the included trials in meta-analysis using the Cochrane Risk of Bias 2 tool (RoB2; for a description, see Sterne et al., 2019). This tool provides a framework for assessing the risk of bias in a single estimate of an intervention effect reported from a trial. RoB2 is structured into seven bias domains (i.e., random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other bias).

Data extraction and analysis

For the qualitative synthesis (systematic review), the following data were extracted: first author and year, sample, mean age, cognitive training type, dose, sessions, length, sessions per week, executive function outcomes, and control groups. For the quantitative synthesis (meta-analysis), the continuous data to perform the meta-analysis was extracted by one reviewer (RLO) and checked by a second reviewer (RMJ). To perform the meta-analysis, we adopted the Review Manager version 5.4 open-source software (for a description, see Cochrane, 2022). The main outcome was the change score from pre- to post-training in the experimental group(s) (i.e., cognitive training) and control group(s) (i.e., active or passive).

[2] RMJ: Rui de Moraes Jr. (co-author and research supervisor).

The analyses were conducted for each of the executive function subdomains. Precision of the mean difference was calculated for each trial by 95 % confidence intervals (CI). The trials were required to have measured participants baseline ability in the trained cognitive skill, and this measure could come from the same task that was later used for training or from a different task that assessed the same cognitive skill. Furthermore, trials were required to have measured participants cognitive training outcomes using gain scores. The continuous data values were entered into a spreadsheet (available at osf.io/64xmj), and then organized to run the meta-analysis.

The selected trials were inserted in a separate spreadsheet tab containing data referring to the pre- and post-intervention, including the sample, mean difference, and standard deviation of the experimental and control groups. Considering that the included trials had distinct populations, intervention parameters, and settings, a random effect model was employed in the meta-analysis. The heterogeneity was assessed by the I^2 statistic and 95 % CI. The following I^2 statistics were considered: 0–40 %: not important/low heterogeneity; 30 %–60 %: moderate heterogeneity; 50 %–90 %: substantial heterogeneity; 75 %–100 %: considerable heterogeneity (Deeks and Higgins, 2022). Assessment of clinical relevance was made using three categories: small effect (mean differences (MD) < 10 % of the scale; standardized mean difference (SMD) < 0.5); medium effect (MD from 10 % to 20 % of the scale; SMD from 0.5 to 0.8); large effect (MD > 20 % of the scale; SMD > 0.8) (Furlan et al., 2009). A funnel plot for identifying possible publication bias was calculated, and a sensitivity analysis was planned to identify if a specific trial changes the overall effect, by repeating the meta-analysis with one trial omitted at a time (forest plot inspection for outliers). We adopted a significance level of 5 % for all tests.

Results

Study selection

The initial search in the electronic databases yielded 3,544 trials. After removal of duplicates 2,587 trials were screened. After abstract and title screening, we assessed 75 full-texts for eligibility. We subsequently included 31 trials in the systematic review and 13 trials were selected for meta-analysis. The PRISMA-based flow diagram provides an overview of the trials selection process (Figure 1).

Characteristics of the included studies

The characteristics of the individual trials are summarized in Table 1. The publication year of the selected trials ranged from 2009 to 2022, and the participants age ranged between 59 to 82 years old. The included trials had a total of 2,783 participants of both sexes. The studies extracted from the qualitative synthesis had an average (mean ± standard deviation) of 23.63 ± 15.69 total training hours; 31.10 ± 19.06 total training sessions; 3.16 ± 1.42 sessions per week; and 50.63 ± 28.38 minutes per session. Regarding the type of cognitive training, the selected trials presented approaches based on computer (n = 20), videogame (n = 7), TV (n = 2), paper-and-pencil (n=1), ecological (n=1), and smartphone app (n=1). A total of 21 trials reported an outcome related to inhibitory control, 27 trials related to working memory, and 21 trials related to cognitive flexibility as reported by the columns IC, WM, and CF in Table 1, respectively. Regarding the control groups, 20 trials reported active control group(s) and 13 trials reported passive control group(s).

Figure 1

Flow Diagram with data related to trials screening throughout the whole process

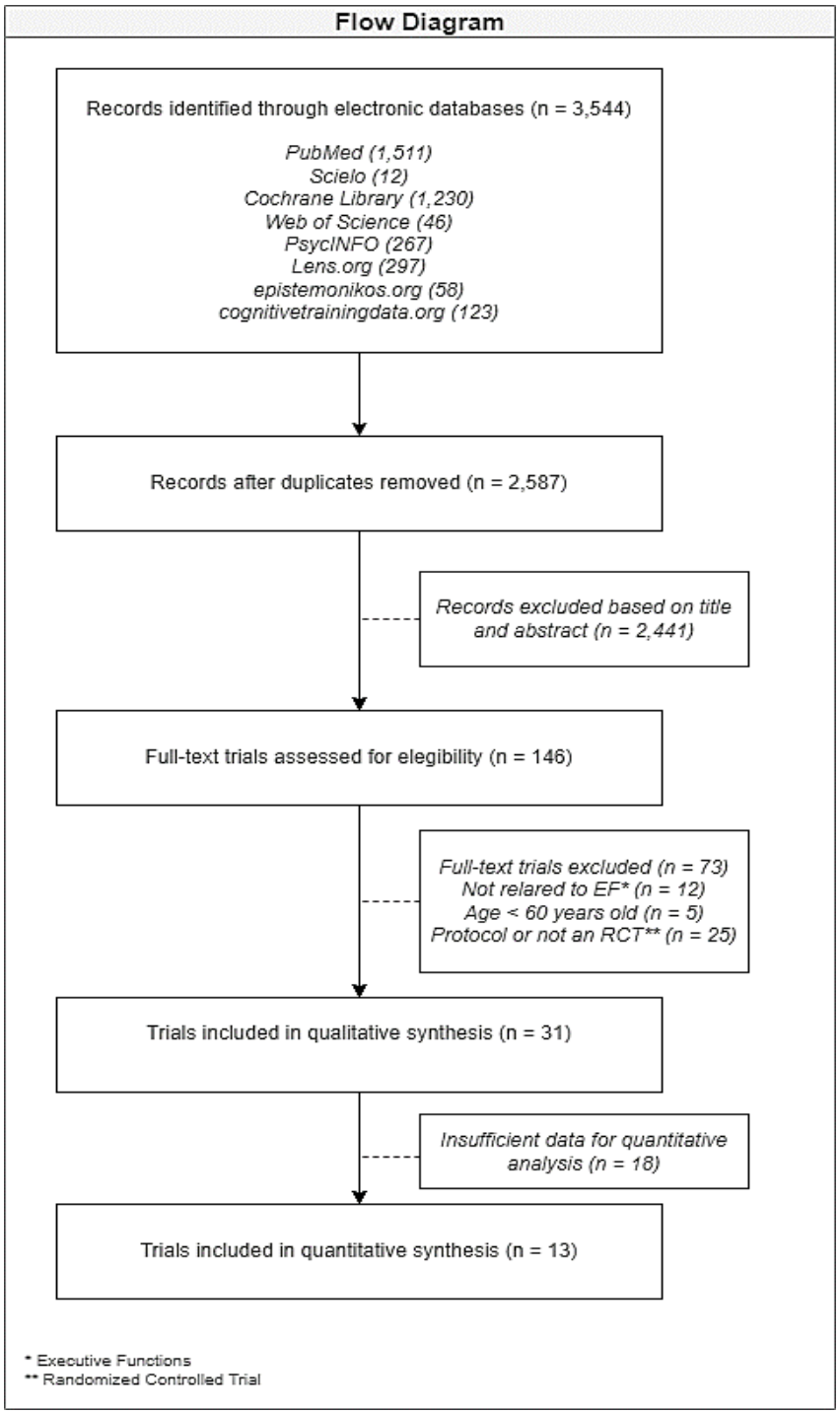


Table 1

The characteristics of individual trials.

Authors	Year	N	Mean age	CT*	[1]	[2]	[3]	[4]	IC	WM	CF	AC	PA
Nouchi et al.	2019	EG: 30 CG: 30	EG: 71.67 ± 3.62 CG: 73.11 ± 3.90	TV	10.00	30	20.00	5	✔	✔		✔	
Schoene et al.	2015	EG: 47 CG: 43	EG: 82.00 ± 7.00 CG: 81.00 ± 7.00	VG	21.95	31	27.40	3	✔	✔	✔		✔
Ballesteros et al.	2014	EG:17 CG:13	EG: 68.80 ± 5.15 CG: 69.20 ± 5.91	CP	20.00	20	60.00	2		✔	✔		✔
Shatil et al.	2014	EG: 60 CG: 59	EG: 67.70 ± 5.80 CG: 68.30 ± 5.80	TV	8.00	24	20.00	3		✔	✔	✔	
Reve and Bruin	2014	EG: 76 CG: 69	EG: 81.90 ± 6.30 CG: 81.10 ± 8.30	CP	6.00	36	10.00	3			✔	✔	
Peretz et al.	2011	EG: 66 CG: 55	EG: 68.6 ± 7.70 CG: 66.9 ± 7.30	CP	18.00	36	30.00	3		✔	✔	✔	
Adcock et al.	2020	EG: 15 CG: 16	EG: 77.00 ± 6.40 CG: 70.90 ± 5.00	VG	32.00	48	40.00	3	✔	✔	✔		✔
Simon et al.	2018	EG: 41 CG: 41	EG: 72.40 ± 5.60 CG: 73.70 ± 6.50	CP	16.67	25	40.00	5		✔	✔	✔	
Hardcastle et al.	2022	EG: 30 CG: 28	EG: 70.67 ± 3.99 EC: 71.11 ± 5.28	CP	40.00	60	40.00	5	✔	✔			✔
Nouchi et al.	2012	EG: 14 CG: 14	EG: 68.86 ± 2.07 CG: 69.31 ± 2.82	CP, VG	5.00	20	15.00	5		✔	✔	✔	
Turner et al.	2019	EG: 15 CG: 15	EG: 67.00 ± 5.87 CG: 68.08 ± 4.54	CP	20.00	10	120.00	2	✔	✔	✔	✔	

Grönholm-Nyman et al.	2017	EG: 17 CG: 16	TG: 68.76 ± 6.68 CG: 68.31 ± 8.28	CP	15.00	15	60.00	3	✔	✔	✔	✔	
Kazazi et al.	2021	EG: 26 CG: 26	EG: 65.42 ± 5.40 CG: 64.38 ± 5.00	CP	9.00	12	45.00	2	✔	✔	✔		✔
Basak et al.	2008	EG: 19 CG: 20	EG: 70.05 ± 4.94 CG: 69.10 ± 6.06	VG	23.5	15	90.00	3	✔	✔	✔		✔
Estrada-Plana et al.	2021	EG: 12 CG: 15	EG: 81.83 ± 8.86 CG: 82.93 ± 8.95	VG	10.00	5	60.00	2	✔	✔		✔	
Lee et al.	2020	EG: 29 CG:39	EG: 70.41 ± 3.56 CG: 69.69 ± 3.88	CP	35.00	50	42.00	5	✔	✔	✔	✔	
Jaeggi et al.	2020	EG: 78 CG: 77	EG: 72.33 ± 5.51 CG: 73.39 ± 5.33	CP	6.67	20	20.00	2	✔	✔			✔
Falbo et at.	2016	EG: 20 CG: 16	EG: 71.50 ± 6.70 CG: 73.70 ± 4.50	EC	24.00	24	60.00	2	✔	✔		✔	
Mozolic et al.	2011	EG: 33 CG: 33	EG: 69.40 ± 3.20 CG: 69.40 ± 2.50	CP	8.00	8	60.00	1	✔	✔	✔		✔
Smith et al.	2009	EG: 242 CG: 245	EG: 75.60 ± 6.60 CG: 75.00 ± 6.30	CP	40.00	40	60.00	5		✔		✔	
Perrot et al.	2019	EG1:12 EG2:12 CG: 11	EG1: 63.75 ±2.49 EG2: 64.67 ± 3.17 CG: 65.55 ± 2.91	VG	24.00	24	60.00	3	✔	✔	✔		✔
Eggenberger et al.	2015	EG1:24 EG2:22 CG: 25	EG1: 77.30 ± 6.30 EG2: 78.50 ± 5.10 CG: 80.80 ± 4.70	CP, VG	34.67	52	40.00	2		✔	✔	✔	
Gajewski et al.	2020	EG: 32 CG1: 33 CG2:37	EG: 71.00 ± 4.20 CG1: 71.00 ± 4.50 CG2: 70.00 ± 4.20	CP, PP	49.07	32	90.00	2	✔		✔	✔	

Weicker et al.	2018	EG1: 20 CG1:20 CG2:20	EG1: 67.80 ± 3.90 EG2: 67.70 ± 3.10 CG: 67.50 ± 5.70	CP	9.00	12	45.00	3	✔	✔	✔	✔	✔
Ten Brinke et al.	2019	EG1: 39 EG2: 38 CG: 40	EG: 71.36 ± 5.14 EG2: 72.88 ± 5.17 CG: 72.46 ± 4.11	CP	24	24	60.00	3	✔		✔	✔	
Meltzer et al.	2021	EG1: 28 EG2: 24 CG: 24	EG1: 69.57 ± 2.97 EG2: 70.08 ± 2.89 EG3: 70.00 ± 2.62	SP	40	80	30.00	5	✔	✔			✔
Nouchi et al.	2021	EG1:36 EG2: 36 CG1: 34 CG2: 36	EG1: 67.97 ± 3.12 EG2: 67.42 ±4.78 CG1: 67.59 ± 4.58 CG2: 67.86 ±4.92	CP	21.00	84	15.00	7	✔	✔		✔	
Shatil	2013	EG1: 33 EG2: 29 TG3: 29 CG: 29	EG1: 80.00 ± 5.43 EG2: 79.00 ± 5.49 EG3: 81.00 ± 5.25 CG: 79.00 ± 5.76	CP	32.00	48	40.00	3	✔	✔	✔	✔	
Gajewski and Falkenstein	2018	EG1: 35 EG2: 32 EG3: 34 CG: 40	EG1: 71.90 ± 7.40 EG2: 70.90 ± 4.10 EG3: 71.10 ± 4.50 CG: 69.90 ± 4.20	CP, PP	48.00	32	90.00	2		✔		✔	✔
Desjardins-Crépeau et al.	2016	EG1: 22 EG2: 20 CG1: 16 CG2: 18	EG1: 72.70 ±7.40 EG2: 73.20 ± 6.30 CG1: 70.90 ± 7.40 CG2: 72.5 ± 7.00	CP	72.00	36	120.00	3	✔		✔	✔	

Chen et al.	2017	EG1: 19 EG2: 17 EG3: 15 EG4: 15 CG: 20	General: 68.55 ± 5.74	EC	10.00	10	60.00	1	✔	✔

Notes. *Type of cognitive training (CT) based on the modality of intervention, [1] Total number of training hours, [2] Total number of CT sessions, [3] Single session length in minutes, [4] Number of sessions per week. Acronyms: Experimental Group (EG), Control Group (CG), TV: TV-Based, VG: Video Game-Based, CP: Computer-Based, PP: Paper-and-pencil-based, EC: Ecological Training, SP: Smartphone App Training, IC: Inhibitory Control, WM: Working Memory, CF: Cognitive Flexibility, AC: Active, PA: Passive.

The trials were conducted in the United States of America (Basak et al., 2008; Hardcastle et al., 2022; Jaeggi et al., 2020; Lee et al., 2020; Mozolic et al., 2011; Shatil, 2013; Simon et al., 2018; Smith et al., 2009; Turner et al., 2020), Canada (Desjardins et al., 2016; Meltzer et al., 2021; Ten Brinke et al., 2020), Japan (Nouchi et al., 2012, 2019, 2021), Australia (Schoene et al., 2015), Spain (Ballesteros et al., 2014; Estrada-Plana et al., 2021), Switzerland (Adcock et al., 2020; Eggenberger et al., 2015; Van Het Reve and De Bruin, 2014), Israel (Peretz et al., 2011), Germany (Gajewski et al., 2018, 2020; Van Het Reve and De Bruin, 2014; Weicker et al., 2018), France (Perrot et al., 2019), Finland (Grönholm-Nyman et al., 2017), Iran (Kazazi et al., 2021), Italy (Falbo et al., 2016), Sweden (Simon et al., 2018), China (Chiu et al., 2017) and multi-countries (Shatil et al., 2014). The location where the study was carried out (registration in the ethics committee) and location of the first author's affiliation were taken as criteria to establish the study origin.

Results of the synthesis

Here we present the meta-analyses of each executive function subdomain according to the classification proposed by Diamond (2013). Only trials that reported pre- and post-intervention data were included (i.e., mean difference and standard deviation). Based on the available data for the meta-analysis, we presented the results for the most frequent tasks conducted: Stroop and Go/No-Go tasks for inhibitory control; Digit Span (Forward and Backward), N-Back, and Corsi Block tasks for working memory; and Semantic Fluency and Trail Making – Part B tasks for cognitive flexibility[3].

[3] The Stroop task assesses the ability to inhibit cognitive interference, which occurs when the processing of a stimulus feature simultaneously affects the processing of another attribute of the same stimulus (Scarpina and Tagini, 2017). The Go/No-Go task involves a series of decisions in which participants are asked to respond to one class of stimuli, i.e., the go stimuli, but not to another class of stimuli, i.e., the no-go stimuli (Young et al., 2018). The Digit Span task involves reading out a series of strings of digits to the participants who are required to repeat them in the same or reverse order of presentation (i.e., forward and backward conditions; Tripathi et al., 2019). In the N-Back task participants are presented a series of visual stimuli and they are asked for each stimulus whether it matches a stimulus *n* trials before, which requires maintaining continuous updating and processing of information (Gajewski et al., 2018). The Corsi Block consists of a surface of scattered blocks in which the examiner taps a sequence of blocks and the participant has to repeat the sequence in the same order or backwards (Kessels et al., 2000). In the Trail Making – Part B, subjects connect 25 encircled numbers and letters in numerical

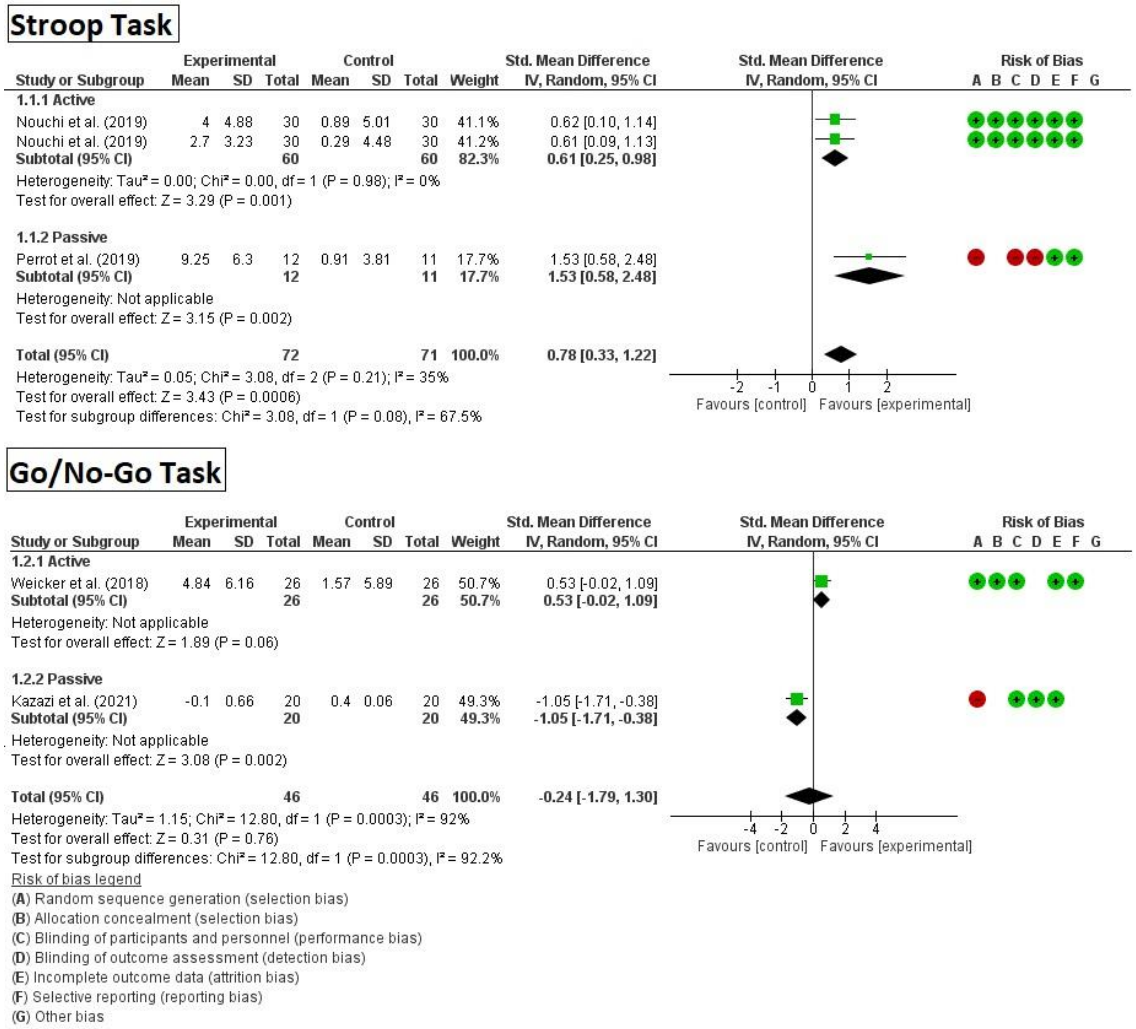
Effects on inhibitory control

The effects of cognitive training on inhibitory control were evaluated in two trials (Nouchi et al., 2019; Perrot et al., 2019), which were measured by the Stroop and Go/No-Go tasks. The meta-analysis on inhibitory control measured by the Stroop task resulted in a statistical significance (overall effect) in favour of cognitive training intervention when compared to active/passive controls (Figure 2 upper half; n = 143 participants [experimental n = 72; control n = 71 participants], random-effects model: $MD_{-score} = .78$ [.33, 1.22], $p < .001$). There was low heterogeneity in the overall analysis of cognitive training on inhibitory control ($I^2 = 35$ %; $p = .21$). Additionally, the meta-analysis resulted in a statistical significance (subgroup effect) in favour of cognitive training when compared to the active control (n = 120 participants [experimental n = 60; control n = 60 participants], random-effects model: $MD_{-score} = .61$ [.25, .98], $p = .001$; $I^2 = 0$ %, $p = .98$) and passive control (n = 23 participants [experimental n = 12; control n = 11 participants], random-effects model: $MD_{-score} = 1.53$ [.58, 2.48], $p = .002$).

and alphabetical order, alternating between numbers and letters (Linari et al., 2022). In the Semantic Fluency tasks the individuals are required to recall items. Some variations of this test include the fluency of certain classes of words or different semantic categories such as animals and fruits (Lopes et al., 2009).

Figure 2

Inhibitory Control measured by the Stroop Task and Go/No-Go Task.



Notes. Standardised mean difference effects of cognitive training compared with active/passive controls on inhibitory control outcomes in healthy older adults measured by the Stroop task (hits in the incongruent condition) and Go/No-Go task (hits in the inhibitory condition). Overall analysis conducted with a random-effects model for the Stroop task ($p < .001$) and for the Go-No/Go task ($p = .76$). The diamonds represent pooled standardised mean difference estimate of random-effects meta-analysis; I^2 represents the heterogeneity test; squares represent study-specific estimates; green circles represent low risk of bias; red circles represent high risk of bias; and the empty space represents unclear risk of bias.

The meta-analysis on inhibitory control measured by the Go/No-Go task did not show statistical significance (overall effect) in favour of cognitive training intervention when compared to active/passive controls (Figure 2 bottom half; n = 92 participants [experimental

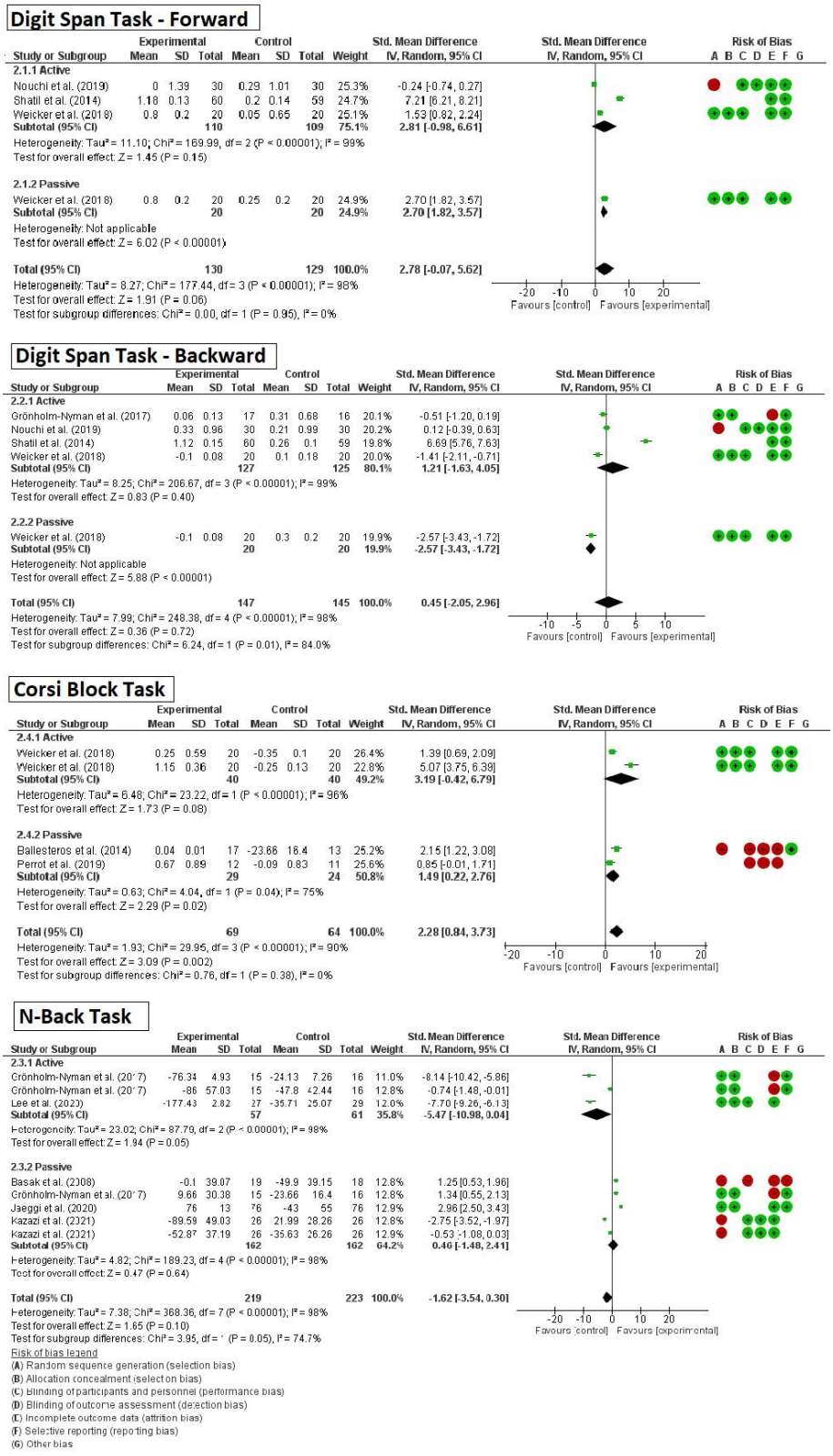
n = 46; control n = 46 participants], random-effects model: MD_{-score} = -.24 [-1.79, 1.30], p = .76). There was considerable heterogeneity in the overall analysis of cognitive training on inhibitory control (I^2 = 92 %; p < .001).

Effects on working memory

The effects of cognitive training on working memory were evaluated in eight trials (Basak et al., 2008; Grönholm-Nyman et al., 2017; Jaeggi et al., 2020; Kazazi et al., 2021; Lee et al., 2020; Nouchi et al., 2019; Shatil et al., 2014; Weicker et al., 2018), which were measured by the Digit Span (Forward and Backward), N-Back, and Corsi Blocks tasks. The meta-analysis measured by the Digit Span Task (Forward) on working memory resulted in a marginal statistical significance (overall effect) in favour of cognitive training intervention when compared to active/passive controls (see first forest plot in Figure 3; n = 259 participants [experimental n = 130; control n = 129 participants], random-effects model: MD_{-score} = 2.78 [-.07, 5.62], p = .06). The meta-analysis resulted in a statistical significance (subgroup effect) in favour of the cognitive training when compared to the passive control (n = 40 participants [experimental n = 20; control n = 20 participants], random-effects model: MD_{-score} = 2.70 [1.82, 3.57], p < .001). The meta-analysis measured by Digit Span – Backward on working memory did not show significance (overall effect) in favour of cognitive training intervention when compared to active/passive controls (see second forest plot in Figure 3; n = 292 participants [experimental n = 147; control n = 145 participants], random-effects model: MD_{-score} = .45 [-2.05, 2.96], p = .72). However, the meta-analysis resulted in a statistical significance (subgroup effect) in favour of cognitive training when compared to the passive control (n = 40 participants [experimental n = 20; control n = 20 participants], random-effects model: MD_{-score} = - 2.57 [-3.43, -1.72], p < .001). There was considerable heterogeneity in the overall analysis of cognitive training on working memory measured with both variations of the Digit Span task (I^2 = 98 %; p < .001).

Figure 3

Working Memory measured by the Digit Span, Corsi Block, and N-back tasks.



Notes. Standardised mean difference effects of cognitive training compared with active/passive controls on working memory outcomes in healthy older adults measured by the Digit Span –

Forward and Backward (score), Corsi Block (score), and N-Back (reaction time) tasks. Overall analysis conducted with a random-effects model for the Digit Span Task – Forward (p = .06), Digit Span – Backward (p = .72), Corsi Block (p = .002), and N-Back (p = .10) tasks. The diamonds represent pooled standardised mean difference estimate of random-effects meta-analysis; I^2 represents the heterogeneity test; squares represent study-specific estimates; green circles represent low risk of bias; red circles represent high risk of bias and the empty space represents unclear risk of bias.

The meta-analysis measured by the Corsi Block task on working memory resulted in a statistical significance (overall effect) in favour of cognitive training intervention when compared to active/passive controls (see third forest plot in Figure 3; n = 133 participants [experimental n = 69; control n = 64 participants], random-effects model: MD_{-score} = 2.28 [.84, 3.73], p = .002). There was considerable heterogeneity in the overall analysis of cognitive training on working memory (I^2 = 90 %; p < .001). This large heterogeneity could be a result of the data collected by the study of Weicker et al. (2018) (second study outcome). After running a sensitivity analysis without the data of Weicker et al. (2018) the heterogeneity reduced (I^2 = 51 %; p = .13) and the overall effect remained significant. Additionally, the meta-analysis resulted in statistical significance (subgroup effect) in favour of cognitive training when compared to the passive control (n = 53 participants [experimental n = 29; control n = 24 participants], random-effects model: MD_{-score} = 1.49 [.22, 2.76], p = .02; I^2 = 75 %, p = .04).

The meta-analysis measured by the N-Back task on working memory did not show statistical significance (overall effect) in favour of cognitive training intervention when compared to active/passive controls (see fourth forest plot in Figure 3; n = 442 participants [experimental n = 219; control n = 223 participants], random-effects model: MD_{-score} = -1.62 [-3.54, .30], p = .10). There was considerable heterogeneity in the overall analysis of cognitive training on working memory (I^2 = 98 %; p < .001).

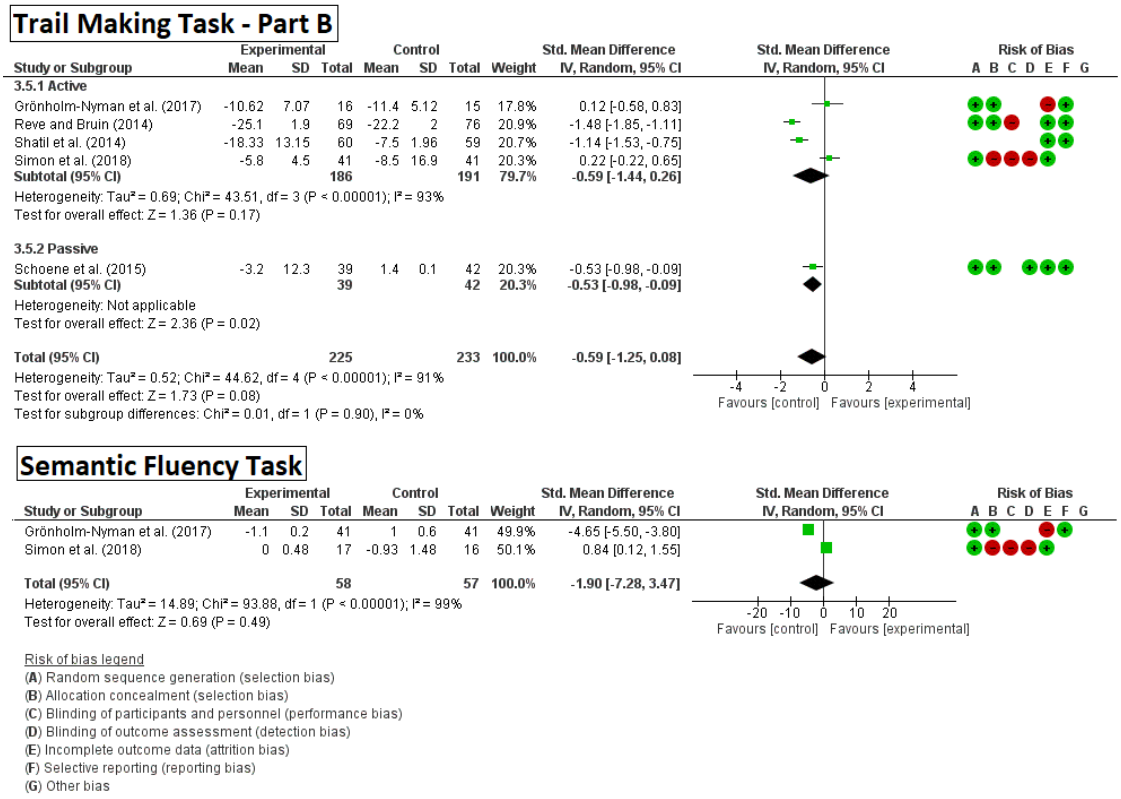
Effects on cognitive flexibility

The effects of cognitive training on cognitive flexibility were evaluated in five trials (Grönholm-Nyman et al., 2017; Schoene et al., 2015; Shatil et al., 2014; Simon et al., 2018;

Van Het Reve and De Bruin, 2014), which were measured by the Trail Making Task – Part B, and Semantic Fluency tasks. The meta-analysis on cognitive flexibility measured by the Trail Making Task did not show statistical significance (overall effect) in favour of cognitive training intervention when compared to active/passive controls (Figure 4 upper half; n = 458 participants [experimental n = 225; control n = 233 participants], random-effects model: MD_{score} = - .59 [-1.25, .08], p = .08). There was considerable heterogeneity in the overall analysis of cognitive training on cognitive flexibility (I^2 =91 %; p < .001).

Figure 4

Cognitive Flexibility measured by the Trail Making Task – Part B and Semantic Fluency Tasks.



Notes. Standardised mean difference effects of cognitive training compared with active/passive controls on cognitive flexibility outcomes in healthy older adults measured by the Trail Making Task – Part B (score in seconds) and Semantic Fluency tasks (score in seconds). Overall analysis conducted with a random-effects model for the Trail Making Task – Part B (p = .08) and Semantic Fluency Task (p = .49). The diamonds represent pooled standardised mean difference estimate of random-effects meta-analysis; I^2 represents the heterogeneity test; squares represent study-specific estimates; green circles represent low risk of bias; red circles represent high risk of bias and the empty space represents unclear risk of bias.

The meta-analysis on inhibitory control measured by Semantic Fluency tasks did not show statistical significance (overall effect) in favour of cognitive training intervention when compared to the active controls (Figure 4 bottom half; n = 115 participants [experimental n = 58; control n = 57 participants], random-effects model: MD_{-score} = -1.90 [-7.28, 3.47], p = .49). There was considerable heterogeneity in the overall analysis of cognitive training on inhibitory control (I^2 = 99 %; p < .001).

Methodological quality assessment

The methodological quality was assessed in the thirteen trials included in the meta-analysis. The trials of Lee et al. (2020), Nouchi et al. (2019) and Weicker et al. (2018) had the highest score in the seven categories (see Figure 5). The categories *incomplete outcome data* and *selective reporting* had a higher percentage of trials with low risk of bias (Figure 6).

Figure 5

Risk of bias summary: Review authors' judgements about each risk of bias item for each included trial.

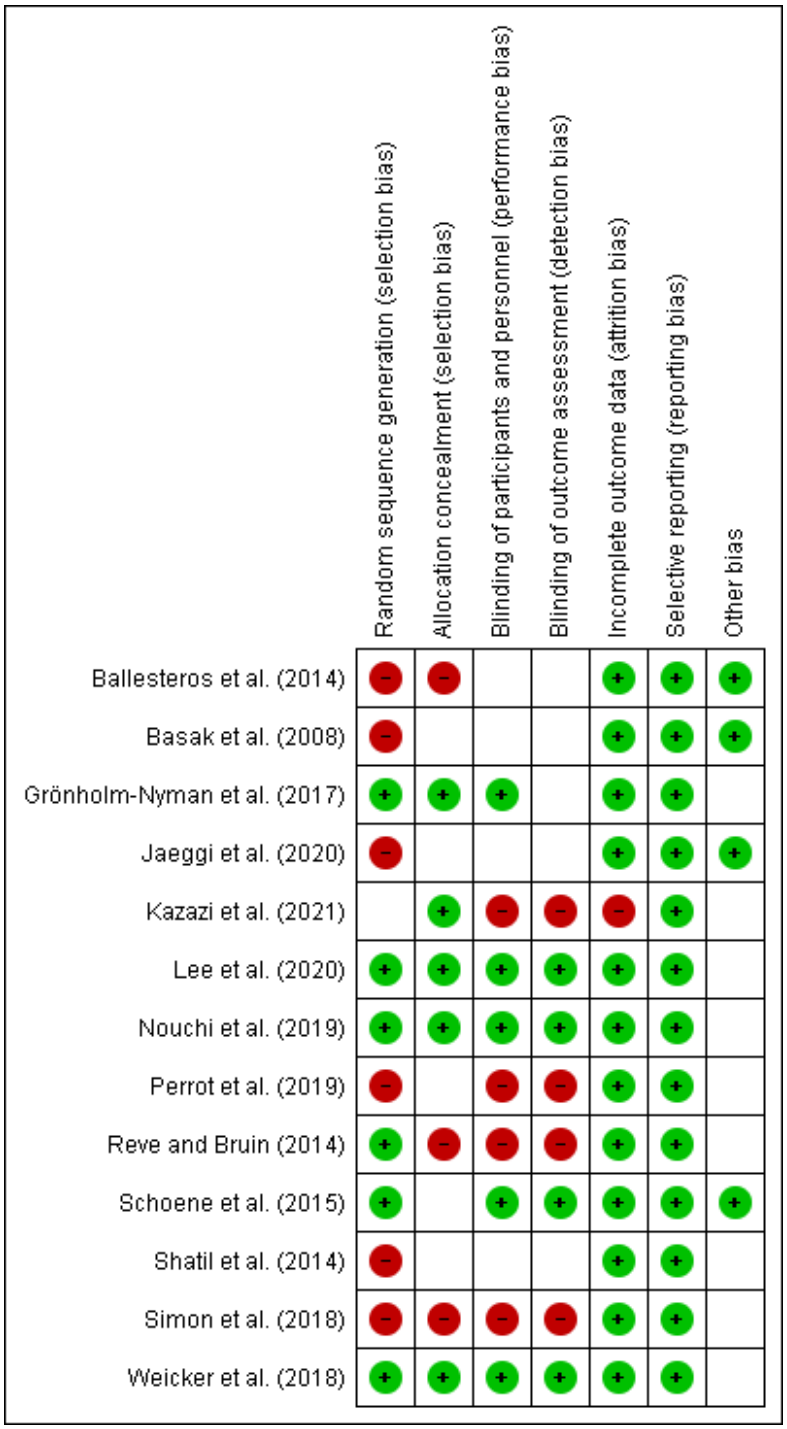
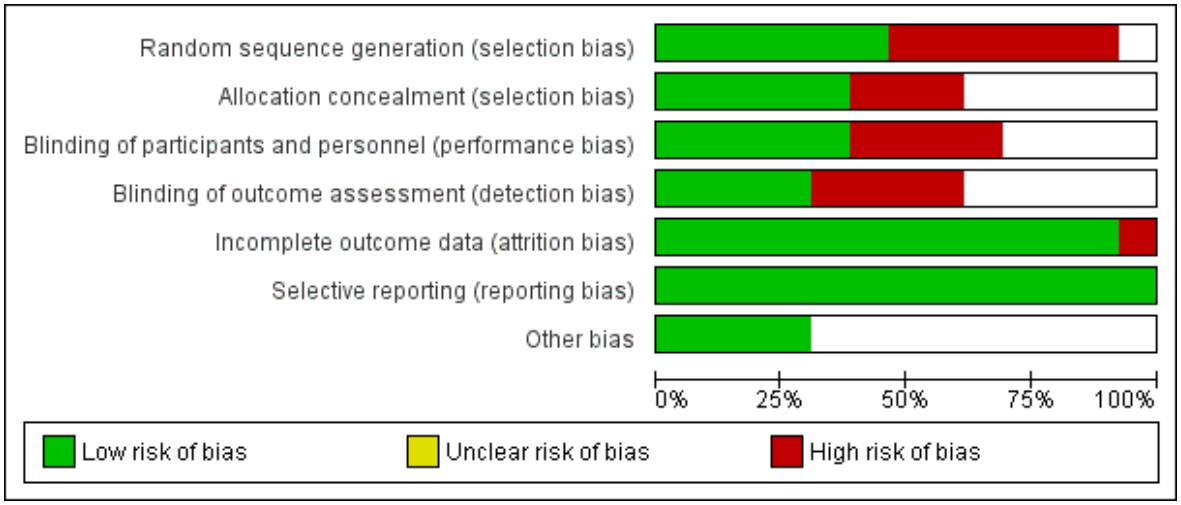


Figure 6

Risk of bias graph: Review authors' judgements about each risk of bias item presented as percentages across all included studies.



Discussion

The aim of the present systematic review with meta-analysis was to assess the effectiveness of cognitive training on executive functions in healthy older people. The triad proposed in the theoretical framework of Diamond (2013) was considered. We obtained 21 trials that evaluated inhibitory control, 27 trials that evaluated working memory, and 21 trials that evaluated cognitive flexibility from the qualitative synthesis. Most of the selected trials also assessed other cognitive functions (e.g., language, processing speed, general cognition). We gathered data from 13 trials for the meta-analysis.

Regarding the experimental design of trials, there was a predominance of interventions of cognitive training compared to active control groups (66.67 % of the trials). Most of trials adapted activities with non-cognitive applications as an active control. For example, the study of Shatil et al. (2014) was composed of family stories using memories of life milestones to build family trees and performed physical exercises based on Mind Jogging. Regarding the

number of sessions per week of cognitive training and duration, on average there were three sessions per week with an average duration of 50 minutes. Considering the older people sample, the duration of training may be exhausting. Especially for the older people, the capacity to sustain attention over time is limited, and is prone to fatigue, lapses, and fluctuations with prolonged engagement (Zanesco et al., 2018).

Effects on inhibitory control

Our meta-analysis revealed that cognitive training enhanced inhibitory control when measured by the Stroop task in favour of the experimental group. The effect size was $Z = 3.43$ (MD = .78, 95 % CI = .33 - 1.22) with low heterogeneity (I^2 = 35 %). However, the meta-analysis did not show significance when measured by the Go/No-Go task. The effect size was Z = .76 (MD = - .24, 95 % CI = -1.79 - 1.30) with considerable heterogeneity (I^2 = 92 %). The conflicting results suggest that the effectiveness of cognitive training for inhibitory control should be considered with caution. In both trials considered for meta-analysis measured by the Stroop Task, the approach was based on a video-game interface. The intervention of Nouchi et al. (2019) occurred five times a week with a total of 10 hours of training, and the intervention of Perrot et al. (2019) occurred three times a week with a total of 24 hours of training. In the trials considered for meta-analysis measured by the Go/No-Go task, the approach was based on a computer interface. The intervention of Weicker et al. (2018) occurred three times a week with a total of nine hours of training and the intervention of Kazazi et al. (2021) occurred twice a week with a total of nine hours of training. Perhaps the significance found by the Stroop task is due the type of intervention: videogame based. The literature shows broad benefits of video game playing to perceptual and cognitive abilities (Boot et al., 2013). A Bayesian network meta-analysis developed by Yang et al. (2021) showed evidence that video game interventions could be considered for the older people for improving cognitive function.

Effects on working memory

The meta-analysis revealed a marginal significance (p = .06) on the effectiveness of cognitive training for working memory when measured by the Digit Span task (Forward). The effect size was Z = 1.91 (MD = 2.78, 95 % CI = - .07 - 5.62) with considerable heterogeneity (I^2 = 98 %). Furthermore, the meta-analysis showed statistical significance when measured by the Corsi Block task. The effect size was Z = 3.09 (MD = 2.28, 95 % CI = .84 - 3.73) with considerable heterogeneity (I^2 = 90 %). In the three trials considered for meta-analysis measured by the Digit Span Task (Forward), the approach was based on TV and computer interfaces. The intervention of Nouchi et al. (2019) occurred five times a week with 10 hours of total training, the intervention of Shatil et al. (2014) occurred three times a week with eight hours of total training, and the intervention of Weicker et al. (2018) occurred three times a week with nine hours of total training. In the three trials considered for meta-analysis measured by the Corsi Block task, the approach was based on videogame and computational interfaces. For the analysis, the same trial of Weicker et al. (2018) was included. The intervention of Ballesteros et al. (2014) occurred twice a week with 20 hours of total training, and the intervention of Perrot et al. (2019) occurred three times a week with 24 hours of total training. Despite the significant results, the results should be considered cautiously: high heterogeneity was observed in both meta-analyses. In addition, no cognitive gain was found for the other tests evaluated. The meta-analysis did not show an overall significant effect for the Digit Span (p = .72; backward) and N-Back (p = .10) tasks. Unlike other meta-analyses (e.g., Wollesen et al.2020), our study showed significance for working memory when analysed on specific tests.

Effects on cognitive flexibility

The meta-analysis did not show that cognitive training enhanced cognitive flexibility when measured by the Trail Making Task – Part B. The effect size was Z = 1.73 (MD = -.59, 95 % CI = -1.25 - .08) with considerable heterogeneity (I^2 = 91 %). Furthermore, the meta-

analysis also did not show any cognitive training gain when measured by the Semantic Fluency tasks. The effect size was Z = .69 (MD = -1.90, 95 % CI = -7.28 - 3.47) with considerable heterogeneity (I^2 = 91 %). In the five trials considered for meta-analysis measured by the Trail Making Task – Part B, the approach was based on videogame, television, and computational interfaces. The intervention of Grönholm-Nyman et al. (2017) occurred three times a week with 15 hours of total training, Reve and Bruin (2014) occurred three times a week with six hours of total training, Shatil et al. (2014) occurred three times a week with eight hours of total training, Simon et al. (2018) occurred five times a week with 16.57 hours of total training, and Schoene et al. (2015) occurred 3 times a week with 22 hours of total training. For the meta-analysis measured by the Semantic Fluency tasks, the same trials of Grönholm-Nyman et al. (2017) and Simon et al. (2018) were included.

Considerations and limitations

Compared to other meta-analyses that evaluated the effectiveness of cognitive training on executive functions (see Chiu et al., 2017; Nguyen et al., 2019; Wollesen et al., 2020), our analyses showed similar results. However, it was possible to identify the impact of neuropsychological tasks/paradigms adopted in each subdomain of the executive functions. Thus, future investigations may consider the specificity of each neuropsychological test for the respective cognitive domain. Due to this segmentation, we ran meta-analyses with few studies. Conversely, results on specific tasks/paradigms generate better clarity regarding the effectiveness of cognitive training interventions.

Our study also presents a limitation regarding the types of the selected trials. We have not restricted combined trials (i.e., cognitive training plus a second intervention), and made no distinction regarding the type of training sessions (simultaneous training or sequential training). However, most studies with multiple interventions also implemented multiple control groups.

Conclusion

Mixed evidence was found for inhibitory control and working memory; cognitive flexibility showed no evidence of improvement. More research is needed to determine the specific characteristics to enhance treatment outcomes.

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Data availability

Data and outputs of all analyses are available at osf.io/64xmj.

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Appendix A

PRISMA-checklist

Section and Topic	Item #	Checklist item
TITLE		
Title	1	Identify the report as a systematic review.
ABSTRACT		
Abstract	2	See the PRISMA 2020 for Abstracts checklist.
INTRODUCTION		
Rationale	3	Describe the rationale for the review in the context of existing knowledge.
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.
METHODS		
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).

Section and Topic	Item #	Checklist item
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data
		conversions.
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.
RESULTS		
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.
Study characteristics	17	Cite each included study and present its characteristics.
Risk of bias in studies	18	Present assessments of risk of bias for each included study.
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of
		the effect.
	20c	Present results of all investigations of possible causes of heterogeneity among study results.
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.
DISCUSSION		
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.
	23b	Discuss any limitations of the evidence included in the review.

Section and Topic	Item #	Checklist item
	23c	Discuss any limitations of the review processes used.
	23d	Discuss implications of the results for practice, policy, and future research.
OTHER INFORMATION		
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.
	24c	Describe and explain any amendments to information provided at registration or in the protocol.
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.
Competing interests	26	Declare any competing interests of review authors.
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.

Note. Source: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n7

Appendix B

Detailed Search Strategy

The following search strategy is based on Boolean Logic Operators (AND, OR and NOT) and specific descriptor-qualified strategy method of search. We show here the full strategy with the descriptors (keywords) used and the resulting ones in each database.

Efficacy of Cognitive Training on Executive Functions in Healthy Older Adults: Systematic Review with Meta-Analysis of Randomized Controlled Trials[4]

Population: Cognitively healthy older adults, (*i.e.*, with no cognitive impairment).
Intervention: Cognitive training to enhance or maintain executive functioning.
Comparison: Unconsidered.
Outcome: Executive functions, near and far transfer measures, including cognitive and behavioural related outcome.
Design: Randomized clinical trials.
Databases (number of articles): Cochrane Central (1,230); PsycINFO (267); Web of Science (46); Pubmed/MEDLINE (1,511); Scielo (12); Epistemonikos (38); Lens (274) and Cognitive Training Data (94).

Database 1
Cochrane Central (https://www.cochranelibrary.com/)
Search date on 8th April 2021

1. Population:

#1 MeSH: elderly (52,206)
#2 MeSH: "middle aged" (349,127)
#3 Text word: "older people" (5,493)
#4 Text word: "healthy older people" (147)
#5 Text word: aged (518,778)
#6 = #1 OR #2 OR #3 OR #4 OR #5 (542,550)

2. Intervention:

#7 MeSH: "cognitive therapy" (7,001)

#8 MeSH: "cognitive therapies" (135)

#9 Text word: "cognitive stimulation" (418)
#10 Text word: "cognitive rehabilitation" (1,190)
#11 Text word: "cognitive training" (2,701)
#12 Text word: "brain training" (223)
#13 = #7 OR #8 OR #9 OR #10 OR #11 OR #12 (108,855)

4

MeSH: The Medical Subject Headings. The MeSH thesaurus is a controlled and hierarchically-organized vocabulary produced by the National Library of Medicine. It is used for indexing, cataloging, and searching of biomedical and health-related information.
Text word: Descriptor created by the authors of this manuscript.

3. Outcomes:

#14 MeSH: cognition (27,530)
#15 MeSH: cognitions (1,649)
#16 MeSH: "cognitive function" (104,439)
#17 MeSH: "cognitive functions" (3,209)
#18 MeSH: “cognitive aging” (222)
#19 MeSH: “executive function” (5,179)
#20 MeSH: “executive functions” (1,535)
#21 MeSH: “executive control” (378)
#22 MeSH: “executive controls” (1)
#23 = #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20 OR #21 OR #22 (37,498)

4. Design:

#24 MeSH: “clinical trial” (667,336)
#25 MeSH: “trial protocol” (4,122)
#26 MeSH: “intervention study” (15,013)
#27 MeSH: “clinical trial protocol” (1,401)
#28 MeSH: “controlled clinical trial” (264,990)
#29 Text word: “randomized clinical trial” (54,538)
#30 MeSH: “randomized controlled trial” (894,024)
#31 = #24 OR #25 OR #36 OR #27 OR #28 OR #29 OR #30 (1,081,002)

5. Combining PICO elements:

#32 = #6 AND #13 AND #23 AND #31 (1,230) *

Obs:

* Filter: Trials

Database 2

PsycINFO (https://www.apa.org/pubs/databases/psycinfo)
Search date on 8th April 2021

1. Population:

#1 MeSH: elderly (23,883)
#2 Text word: “older people” (4,875)
#3 Text word: aged (13,713)
#4 = #1 OR #2 OR #3 (24,553)

2. Intervention:

#5 MeSH: “cognitive therapy” (2,555)
#6 Text word: “cognitive rehabilitation” (635)
#7 = #5 OR #6 (3,188)

3. Outcomes:

#8 MeSH: cognition (21,633)
#9 MeSH: "cognitive function" (3,719)
#10 = #8 OR #9 (25,330)

4. Design:

#11 MeSH: “clinical trial” (4,111)
#12 = #11 (4,111)

5. Combining PICO elements:

#13 = #4 AND #7 AND #10 AND #12 (267) *

Obs:

* Filter: Title (in each term), Human (Population group), PsycArticles (Section)

Database 3

Web of Science (https://www.webofknowledge.com/)
Search date on 8th April 2021

1. Population:

#1 MeSH: elderly (54,054)
#2 MeSH: ‘middle aged’ (6,012)
#3 Text word: ‘older people’ (7,885)
#4 Text word: aged (239,684)
#5 = #1 OR #2 OR #3 OR #4 (295,380)

2. Intervention:

#6 MeSH: ‘cognitive therapy’ (12,464)
#7 Text word: ‘cognitive stimulation’ (998)
#8 Text word: ‘cognitive training’ (3,234)
#9 = #6 OR #7 OR #8 (16,028)

3. Outcomes:

#10 MeSH: cognition (54,232)
#11 MeSH: ‘cognitive function’ (12,867)
#12 MeSH: ‘executive function’ (12,585)
#13 = #10 OR #11 OR #12 (75,589)

4. Design:

#14 MeSH: ‘clinical trial’ (918,714)
#15 MeSH: ‘controlled clinical trial’ (381,519)
#16 Text word: ‘randomized clinical trial’ (391,969)
#17 MeSH: ‘randomized controlled trial’ (437,029)
#18 = #14 OR #15 OR #16 OR #17 (1,100,194)

5. Combining PICO elements:

#32 = #5 AND #9 AND #13 AND #18 (46) *

Obs:

* Filter: AK (author keywords) in Population, Intervention and Outcome. ALL (all) in Design.

Database 4

Pubmed/MEDLINE (https://pubmed.ncbi.nlm.nih.gov/)
Search date on 8th April 2021

1. Population:

#1 MeSH: elderly (5,605,074)
#2 MeSH: “middle aged” (4,500,808)

#3 Text word: “older people” (36,004)
#4 Text word: “healthy older people” (373)
#5 Text word: aged (5,548,231)
#6 = #1 OR #2 OR #3 OR #4 OR #5 (5,613,233)

2. Intervention:

#7 MeSH: “cognitive therapy” (3,463)
#8 MeSH: “cognitive therapies” (294)
#9 Text word: “cognitive stimulation” (887)
#10 Text word: “cognitive rehabilitation” (2,037)
#11 Text word: “cognitive training” (3,079)
#12 Text word: “brain training” (263)
#13 = #7 OR #8 OR #9 OR #10 OR #11 OR #12 (9,425)

3. Outcomes:

#14 MeSH: cognition (601,763)
#15 MeSH: cognitions (601,763)
#16 MeSH: "cognitive function" (39,399)
#17 MeSH: "cognitive functions" (18,765)

#18 MeSH: “cognitive aging” (3,249)
#19 MeSH: “executive function” (26,717)
#20 MeSH: “executive functions” (10,119)
#21 MeSH: “executive control” (4,010)
#22 MeSH: “executive controls” (6)
#23 = #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20 OR #21 OR #22 (609,431)

4. Design:

#24 MeSH: “clinical trial” (739,564)
#25 MeSH: “trial protocol” (6,344)
#26 MeSH: “intervention study” (10,715)
#27 MeSH: “clinical trial protocol” (4,758)
#28 MeSH: “controlled clinical trial” (109,271)
#29 Text word: “randomized clinical trial” (31,367)
#30 MeSH: “randomized controlled trial” (559,969)
#31 = #24 OR #25 OR #26 OR #27 OR #28 OR #29 OR #30 (1,021,405)

5. Combining PICO elements:

#32 = #6 AND #13 AND #23 AND #31 (1,511)

Obs:

Filter: Clinical Trial, Randomized Controlled Trial, Humans

Database 5

Scielo (https://www.scielo.org/)
Search date on 8th April 2021

1. Population:

#1 MeSH: elderly (10,876)

#2 MeSH: ‘middle aged’ (985)
#3 Text word: ‘older people’ (2,251)
#4 Text word: ‘healthy older people’ (152)
#5 Text word: aged (23,594)
#7 = (#1) OR (#2) OR (#3) OR (#4) OR (#5) (31,614)

2. Intervention:

#7 MeSH: ‘cognitive therapy’ (921)
#8 Text word: ‘cognitive training’ (757)
#10 = (#7) OR (#8) (1,595)

3. Outcomes:

#11 MeSH: cognition (2,423)

4. Design:

Unconsidered.

5. Combining PICO elements:

#12 = (#7) AND (#10) AND (#11) (12)

Database 6

Epistemonikos (http://www.epistemonikos.org/)

First Search

Search date on 16th April 2021

(title:((elderly OR "older people" OR aged) AND ("clinical trial" OR "randomized controlled trial" OR "randomized clinical trial") AND ("cognitive training" OR "cognitive therapy") AND ("executive function" OR cognition)) OR abstract:((elderly OR "older people" OR aged) AND ("clinical trial" OR "randomized controlled trial" OR "randomized clinical trial") AND ("cognitive training" OR "cognitive therapy") AND ("executive function" OR cognition)))

Obs:

Filters: Publication type (primary study), Studies design (RCT), Pubmed Central (ALL)

Total = 38

Second Search

Search date on 30th April 2021

(title:((elderly OR "older people" OR aged) AND ("clinical trial" OR "randomized controlled trial" OR "randomized clinical trial") AND ("cognitive training" OR "cognitive therapy") AND ("executive function" OR cognition)) OR abstract:((elderly OR "older people" OR aged) AND ("clinical trial" OR "randomized controlled trial" OR "randomized clinical trial") AND ("cognitive training" OR "cognitive therapy") AND ("executive function" OR cognition)))

Obs:
Filters: Publication type (primary study), Studies design (RCT), Pubmedcentral (ALL)

Total = 20

Database 7
Lens (www.lens.org)

First Search
Search date on 16th April 2021

Scholarly Works (274) = (elderly OR ("older people" OR aged)) AND (("clinical trial" OR ("randomized controlled trial" OR "randomized clinical trial")) AND (("cognitive training" OR "cognitive therapy") AND ("executive function" OR cognition)))

Obs:
Filters: Publication Type (Journal Article), Subject Matter (Mesh Reading = Aged), Field of Study (cognition), randomized controlled trial

Total = 274

Second Search
Search date on 30th April 2021

Scholarly Works (274) = (elderly OR ("older people" OR aged)) AND (("clinical trial" OR ("randomized controlled trial" OR "randomized clinical trial")) AND (("cognitive training" OR "cognitive therapy") AND ("executive function" OR cognition)))

Obs:
Filters: Publication Type (Journal Article), Subject Matter (Mesh Reading = Aged), Field of Study (cognition), Date range (2021 - 2022), randomized controlled trial

Total = 23

Database 8
Cognitive Training Data (https://www.cognitivetrainingdata.org/studies-cognitive-training-benefits/)

First Search
Search date on 16th April 2021
The data was extracted from the source with Mendeley web importer plugin

Total = 94

Second Search
Search date on 30th April 2021
Date range (years 2021 and 2022)
The data was extracted from the source with Mendeley web importer plugin

Total = 29