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A systematic literature review and meta-analysis of real-world interventions for cognitive ageing in healthy older adults

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ABSTRACT

Activities running in community-based-settings offer a method of delivering multimodal interventions to older adults beyond cognitive training programmes. This systematic review and meta-analysis investigated the impact of randomised controlled trials (RCTs) of 'real-world' interventions on the cognitive abilities of healthy older adults. Database searches were performed between October 2016 and September 2018. Forty-three RCTs were eligible for inclusion with 2826 intervention participants and 2234 controls. Interventions to enhance cognitive ability consisted of participation in activities that were physical (25 studies), cognitive (9 studies), or mixed (i.e., physical and cognitive; 7 studies), and two studies used other interventions that included older adults assisting schoolchildren and engagement via social network sites. Meta-analysis revealed that Trail Making Test (TMT) A, $p = 0.05$, $M = 0.43$, 95% CI [-0.00, 0.86], digit symbol substitution, $p = 0.05$, $M = 0.30$, 95% CI [0.00, 0.59], and verbal fluency, $p = 0.04$, $M = 0.31$, 95% CI [0.02, 0.61], improved after specific types of interventions versus the control groups (which were either active, wait-list or passive controls). When comparing physical activity interventions against all control groups, TMT A, $p = 0.04$, $M = 0.25$, 95% CI [0.01, 0.48], and digit span forward, $p = 0.05$, $M = 0.91$, 95% CI [-0.00, 1.82], significantly improved. Results remained non-significant for all outcomes when comparing cognitive activity interventions against all control groups. Results therefore suggest that healthy older adults are more likely to see cognitive improvements when involved in physical activity interventions. In addition, TMT A was the only measure that consistently showed significant improvements following physical activity interventions. Visuospatial abilities (as measured by TMT A) may be more susceptible to improvement following physical activity-based interventions, and TMT A may be a useful tool for detecting differences in that domain.

1. Introduction

Cognitive decline can compromise the quality of life for older adults and reduce or limit their independence (Bárrios et al., 2013). Cognitive decline also predicts functional disability in later life (McGuire et al., 2006), and is associated with increased health care costs (Albert et al., 2002). Demographic trends towards increasingly older populations together with the increasing prevalence of cognitive decline with age (Sheffield and Peek, 2011) highlights the importance of effective interventions that might reduce or delay cognitive decline, or lead to cognitive ability improvements, particularly for those at higher risk (Adler, 2003).

Real-world interventions, defined as interventions that use activities running in community-based settings rather than simulated environments or close-to-real settings such as gymnasiums in hospitals or universities (e.g., Alves et al., 2013; Cassilhas et al., 2007), offer a method of delivering varied, multimodal interventions to older adults beyond cognitive training regimes that lack ecological validity and may not generalise to daily cognitive demands (Papp et al., 2009). Utilising real-world interventions might also offer opportunities to better understand how any cognitive benefits might transfer to other outcomes of importance to older adults beyond cognitive abilities, such as quality of life and functional health. In the literature, real-world interventions for older adults have been delivered individually or in group settings, within the home or in public locations (Mortimer et al., 2012; Nouchi et al., 2012). Strategies that focus on physical, cognitive and social activities, or combinations of these, have gained increased interest in recent years (Fragala et al., 2014; Myhre et al., 2016; Park et al., 2013).

Real-world physical activity interventions include, but are not limited to, aerobic and/or resistance training, yoga and dance. To date,

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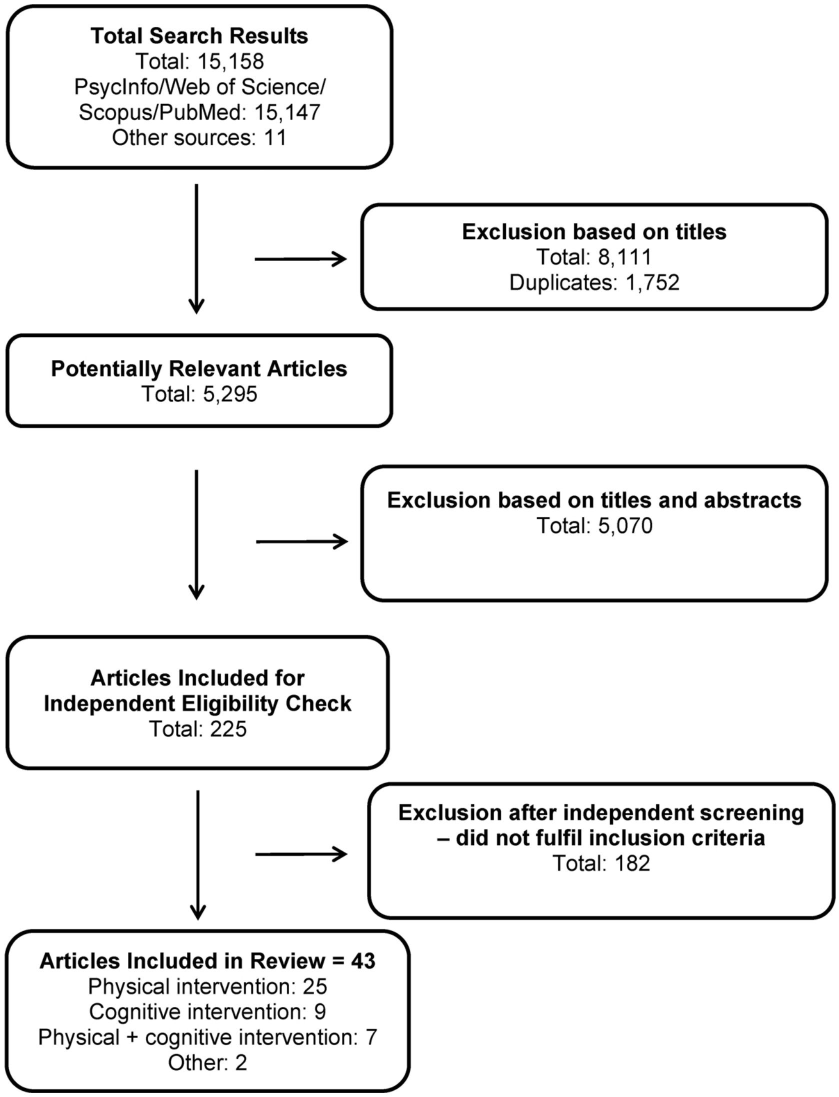


Fig. 1. Study selection flow chart.

most studies have used aerobic exercise perhaps because it improves cardiovascular fitness (Angevaren et al., 2008). Cognitive activity interventions for older adults who are relatively cognitively healthy typically aim to postpone or prevent cognitive decline by enhancing current function (Acevedo and Loewenstein, 2007). Examples have included computer (Slegers et al., 2009) and tablet training (Vaportzis et al., 2017), and videogame interventions (Nouchi et al., 2012; Van Muijden et al., 2012). Social interventions and productive activities have also produced protective effects against cognitive ageing (Fried et al., 2004). Although fewer randomized controlled trials (RCTs) of social interventions have been conducted, there is some evidence that increasing social engagement may result in cognitive improvements (Mortimer et al., 2012).

Given the potential for activities in real-world settings to be used as cognitively-beneficial interventions, it is important to understand what activities might be advantageous, and for what cognitive abilities. Also, the range of activities considered as potential interventions and/or the cognitive abilities assessed suggests a summary might better direct future research using real-world interventions. The aim of the current review and meta-analysis was, therefore, to systematically review the extant literature from RCTs of real-world interventions to determine their impact on the cognitive abilities of healthy older adults.

2. Methods

2.1. Search strategy

PubMed, PsycINFO, Scopus, and Web of Science were systematically searched for RCTs written in English. Search terms included “cognitive ageing”, “healthy”, “older adults”, “RCT”, and “intervention” (Search strategy, Appendix A). Additional articles were found from the reference lists of review articles, the authors’ own literature files and Google Scholar. We screened titles and abstracts to exclude articles that did not meet the inclusion criteria. Full texts of remaining studies were then screened for eligibility by two reviewers (E.V. and M.A.N), with disagreements resolved through discussion (Fig. 1). Database searches were performed between October 2016 and September 2018. The protocol for this systematic review was registered on PROSPERO (Central Registration Depository: CRD42017056024) and is available in full on the University of York website (https://www.crd.york.ac.uk/prospero/display_record.php?RecordID = 56024).

2.2. Selection criteria

We followed the PRISMA-statement (www.prisma-statement.org) for reporting items of this systematic review (Liberati et al., 2009; Moher et al., 2009). The selected studies were RCTs of real-world

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Alves 2013	3.15	20.52	22	2.84	19.18	25	24.1%	0.02 [-0.56, 0.59]
Smiley-Oyen 2008	160	485.2	28	71	550.5	29	29.2%	0.17 [-0.35, 0.69]
Williamson 2009	-1.23	16.43	44	-0.74	21.12	47	46.7%	-0.03 [-0.44, 0.39]
Total (95% CI)			**94**			**101**	**100.0%**	**0.04 [-0.24, 0.32]**

Heterogeneity: Tau² = 0.00; Chi² = 0.34, df = 2 (P = 0.84); I² = 0%
Test for overall effect: Z = 0.29 (P = 0.77)

Output 2.1: Stroop colour-word interference

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Best 2015	5.96	32.69	79	1	32.8	31	43.7%	0.15 [-0.27, 0.57]
Liu-Ambrose 2010	5.67	18.48	93	0.26	17.1	42	56.3%	0.30 [-0.07, 0.66]
Total (95% CI)			**172**			**73**	**100.0%**	**0.23 [-0.04, 0.51]**

Heterogeneity: Tau² = 0.00; Chi² = 0.27, df = 1 (P = 0.60); I² = 0%
Test for overall effect: Z = 1.67 (P = 0.10)

Output 2.2: Stroop colour-word - colour

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Alves 2013	0.11	6.18	22	0.3	1.91	25	50.4%	-0.04 [-0.62, 0.53]
Cassilhas 2007	0.5	0.19	39	-0.47	0.19	23	49.6%	5.04 [3.99, 6.09]
Total (95% CI)			**61**			**48**	**100.0%**	**2.48 [-2.50, 7.46]**

Heterogeneity: Tau² = 12.73; Chi² = 69.19, df = 1 (P < 0.00001); I² = 99%
Test for overall effect: Z = 0.98 (P = 0.33)

Output 2.3: Digit span forward

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Alves 2013	0.11	1.84	22	0.25	1.62	25	24.2%	-0.08 [-0.65, 0.49]
Best 2015	0.16	4.38	79	0.1	4.3	31	46.0%	0.01 [-0.40, 0.43]
Cassilhas 2007	-0.11	0.18	39	-0.14	0.18	23	29.8%	0.16 [-0.35, 0.68]
Total (95% CI)			**140**			**79**	**100.0%**	**0.04 [-0.25, 0.32]**

Heterogeneity: Tau² = 0.00; Chi² = 0.41, df = 2 (P = 0.82); I² = 0%
Test for overall effect: Z = 0.25 (P = 0.80)

Output 2.4: Digit span backward

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Best 2015	8.5949	58.4616	79	-14	54.6	31	46.1%	0.39 [-0.03, 0.81]
Liu-Ambrose 2010	9.1103	33.63	93	8.64	32.15	42	53.9%	0.01 [-0.35, 0.38]
Total (95% CI)			**172**			**73**	**100.0%**	**0.19 [-0.18, 0.56]**

Heterogeneity: Tau² = 0.03; Chi² = 1.77, df = 1 (P = 0.18); I² = 43%
Test for overall effect: Z = 1.00 (P = 0.32)

Output 2.5: Trail Making Test B - Trail Making Test A

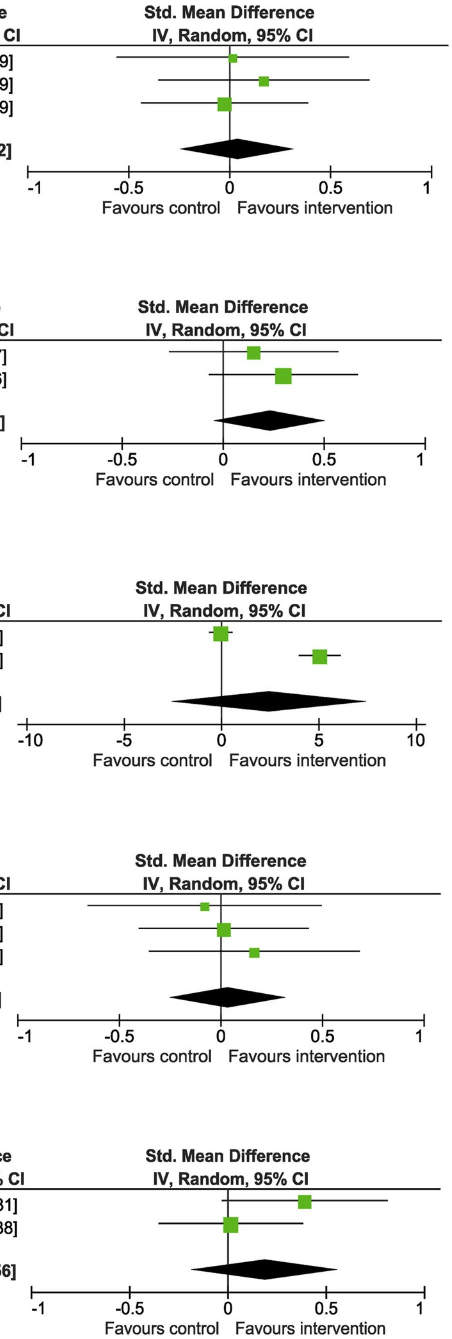


Fig. 2. Physical activity interventions versus active controls.

interventions that ran for at least two consecutive weeks. The cut-off of 2 weeks allowed the exclusion of one-off interventions that investigated immediate (acute) changes post-intervention. The studies assessed cognitive ability using at least one standardised neuropsychological or cognitive test, in healthy participants aged 60 years old and over. Real-world interventions were physical, cognitive or social activities that were either community-based or conducted within close-to-real settings such as dedicated gyms within hospital or universities. In addition, only articles that were written in English and had control groups were included. Any type of control was deemed appropriate, including active and passive control groups, for example. We excluded studies if participants had been diagnosed with any cognitive impairment or other significant medical, psychiatric, or neurological conditions, for example mild cognitive impairment (Excluded studies table, Appendix B) and studies that did not explicitly exclude participants with psychiatric or neurological conditions. Two reviewers (E.V. and M.A.N.) independently evaluated the risk of bias in the included studies according to the criteria for randomized intervention trials outlined in the Cochrane Handbook (Higgins and Green, 2011). Disagreements were discussed between the reviewers until a consensus was reached (Risk of bias table, Appendix C).

2.3. Statistical analyses

Data analyses were performed using Review Manager 5.1 software (Review Manager, 2014). We calculated treatment effects based on

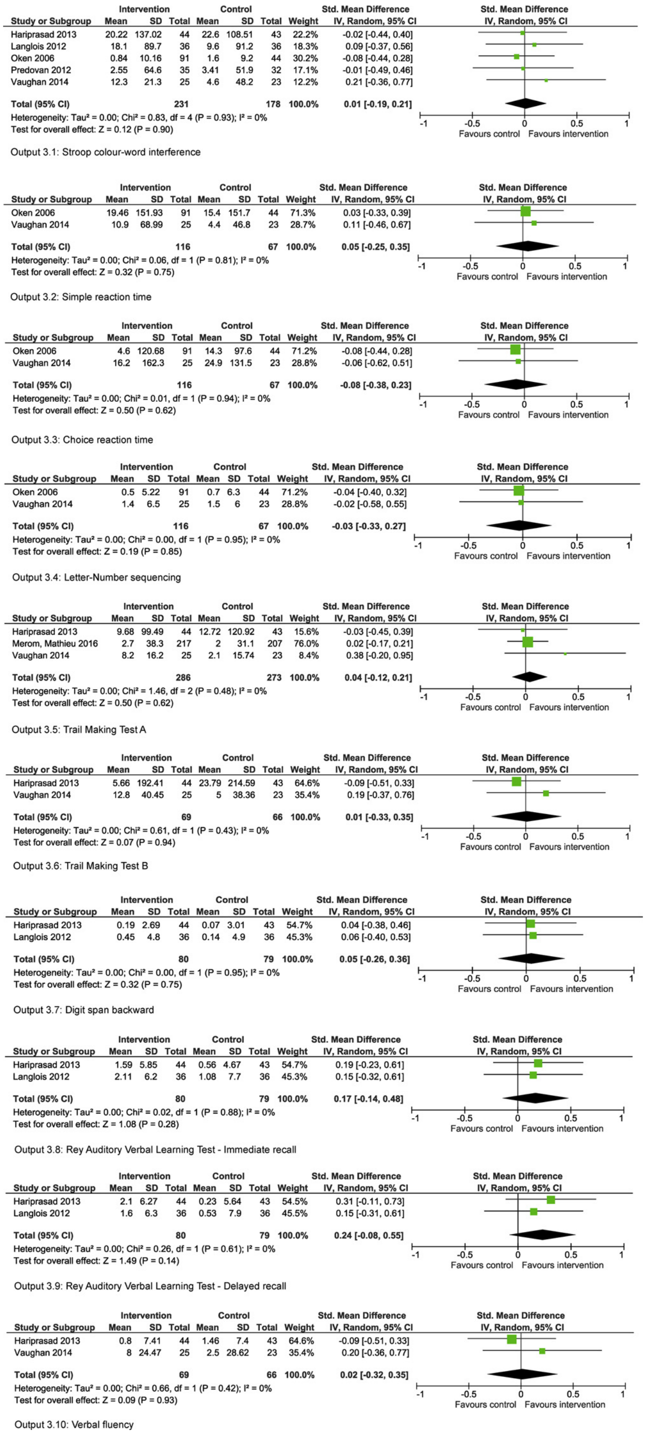


Fig. 3. Physical activity interventions versus wait-list controls.

pooled data from individual trials that were considered homogenous based on the type of intervention used (e.g., physical, cognitive). We note, however, that within intervention types (e.g., physical), a range of activities were considered (e.g., yoga, aerobic exercise, Tai Chi). All trials reported continuous data. The summary statistics required for each outcome were the mean change from baseline, the standard deviation (SD) of the mean change, and the number of participants in the intervention and control groups at baseline and post-intervention. In cases where mean change scores were not provided, they were calculated based on baseline and post-intervention means and respective SDs. As pooled trials used different rating scales or tests, we report the standardised mean difference, which is the absolute mean difference divided by the standard deviation.

To incorporate heterogeneity among studies, we used the inverse variance random-effects method to combine individual effect sizes (DerSimonian and Laird, 1986). The I^2 test was used to assess statistical heterogeneity, which describes the percentage of variability among effect estimates beyond that expected by chance. We compared physical interventions against active controls, wait-list controls and passive controls separately. In active control groups, participants received an alternative intervention that allowed comparison to the main intervention used. For example, stretching and balance classes are commonly used as a comparison to aerobic physical activity interventions; these active controls are designed such that they are comparable in the level of social engagement and time on task as the main intervention, but that the activity is at a lower level of intensity. Participants in wait-list control groups are generally treated as no-contact control groups for the duration of a study, though usually receive the intervention on completion of the study Passive control groups did not receive any kind of intervention. Overall estimates of the intervention difference are presented in forest plots (Figs. 2–4). Similarly, we compared cognitive activity interventions and mixed interventions against active, wait-list and passive controls separately (Figs. 5–7). We also conducted overall analyses to compare all physical interventions against all controls (Fig. 8), all cognitive activity interventions against all controls (Fig. 9) and all interventions against all controls (Fig. 10). We contrasted only studies that used the same measures. The figures of the overall analyses present only new outcomes; we do not present overall analyses for outcomes that were the same as those of analyses of separate control groups. For example, Nishiguchi et al. (2015) and Vidoni et al. (2015) compared physical interventions against passive controls using a logical memory test. These two studies were the only studies that used a logical memory measure. Therefore, this outcome is presented only once when comparing physical interventions against passive control groups; we do not present it when comparing physical interventions against all control groups and all interventions against all control groups. A summary of results from all individual trials are presented in Tables 1–9. To consider the possibility of publication bias influencing the outcomes, we contacted researchers to obtain additional information when necessary, and generated funnel plots. Furthermore, we conducted a weight-function model analysis (Vevea and Hedges, 1995; Vevea and Woods, 2005). The weight-function model analysis estimates a random-effects meta-analytic model, followed by an estimate of an adjusted random-effects meta-analytic model that includes weights for *p*-values intervals (e.g., $p < 0.05$ and $p > 0.05$). Finally, we examined the relationship between the duration of the interventions and effect size, and the frequency of the interventions and effect size. To achieve this, we performed mixed-effects meta-regression analyses using SPSS Macros (Lipsey and Wilson, 2001; Wilson, 2010).

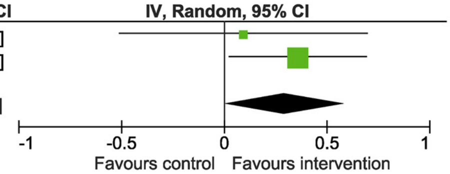
3. Results

3.1. Included studies

Forty-three RCTs were eligible for inclusion with 2826 intervention participants (intervention Ns comprised physical = 2065; cognitive = 423; mixed physical-cognitive 232; other = 106) and 2234 controls (control Ns comprised active = 1244; wait-list = 569; passive = 421). The most common type of intervention was physical activity (25 studies). Physical interventions were diverse and included resistance training, yoga, dance, aerobic exercise, water-based exercise and Tai Chi. Cognitive activity interventions (9 studies) included video games, computer training, reading and arithmetic problem solving, and brain-computer interface (a communication method based on brain neural activity; Lee et al., 2013). A few studies included a combination of physical and cognitive interventions (7 studies). The remaining interventions (2 studies) included older adults assisting schoolchildren in elementary school settings, and Facebook as a potential intervention to

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Kamegaya 2014	7.7	27.6	19	4.9	31.5	24	23.4%	0.09 [-0.51, 0.69]
Vidoni 2015	0.2	0.97	130	-0.15	0.99	48	76.6%	0.36 [0.02, 0.69]
Total (95% CI)			**149**			**72**	**100.0%**	**0.30 [0.00, 0.59]**

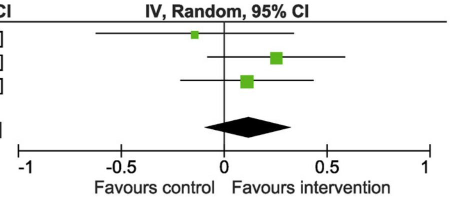
Heterogeneity: Tau² = 0.00; Chi² = 0.57, df = 1 (P = 0.45); I² = 0%
Test for overall effect: Z = 1.98 (P = 0.05)



Output 4.1: Digit symbol substitution

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Mortimer 2012	0.18	0.97	56	0.33	1.18	24	18.9%	-0.14 [-0.62, 0.34]
Vidoni 2015	0.16	1.08	130	-0.11	1.01	48	39.3%	0.25 [-0.08, 0.59]
Williams 1997	1.04	7.18	71	0.21	7.74	78	41.8%	0.11 [-0.21, 0.43]
Total (95% CI)			**257**			**150**	**100.0%**	**0.12 [-0.09, 0.33]**

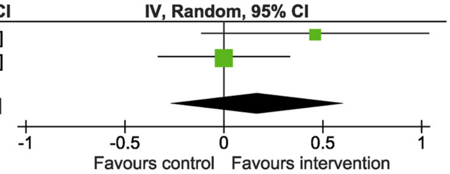
Heterogeneity: Tau² = 0.00; Chi² = 1.78, df = 2 (P = 0.41); I² = 0%
Test for overall effect: Z = 1.12 (P = 0.26)



Output 4.2: Digit span forward

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Nishiguchi 2015	4.7	5.87	24	1.3	8.4	24	36.6%	0.46 [-0.11, 1.04]
Vidoni 2015	0.41	0.73	130	0.41	0.85	48	63.4%	0.00 [-0.33, 0.33]
Total (95% CI)			**154**			**72**	**100.0%**	**0.17 [-0.27, 0.60]**

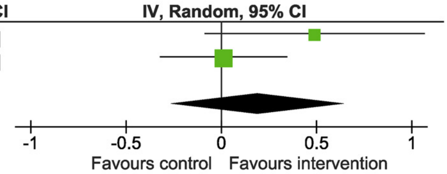
Heterogeneity: Tau² = 0.05; Chi² = 1.86, df = 1 (P = 0.17); I² = 46%
Test for overall effect: Z = 0.76 (P = 0.45)



Output 4.3: Logical memory

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Nishiguchi 2015	5.2	6.44	24	1.4	8.67	24	37.4%	0.49 [-0.09, 1.06]
Vidoni 2015	0.44	0.9	130	0.43	0.77	48	62.6%	0.01 [-0.32, 0.34]
Total (95% CI)			**154**			**72**	**100.0%**	**0.19 [-0.26, 0.64]**

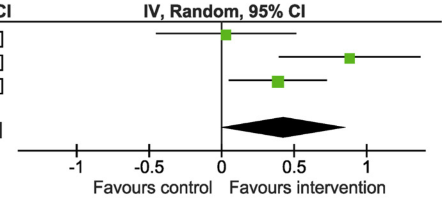
Heterogeneity: Tau² = 0.06; Chi² = 1.99, df = 1 (P = 0.16); I² = 50%
Test for overall effect: Z = 0.82 (P = 0.41)



Output 4.4: Delayed logical memory

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Mortimer 2012	4.79	18.83	56	4.24	16.63	24	30.9%	0.03 [-0.45, 0.51]
Nguyen 2012	9.9	10.7	39	0.8	9.6	34	30.7%	0.88 [0.40, 1.37]
Vidoni 2015	0.15	1.04	130	-0.24	0.89	48	38.4%	0.39 [0.05, 0.72]
Total (95% CI)			**225**			**106**	**100.0%**	**0.43 [-0.00, 0.86]**

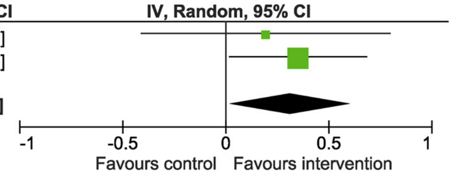
Heterogeneity: Tau² = 0.10; Chi² = 6.12, df = 2 (P = 0.05); I² = 67%
Test for overall effect: Z = 1.94 (P = 0.05)



Output 4.5: Trail Making Test A

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Kamegaya 2014	1.4	6.5	19	0.1	6.7	24	23.4%	0.19 [-0.41, 0.80]
Vidoni 2015	0.03	1.07	130	-0.32	0.75	48	76.6%	0.35 [0.02, 0.68]
Total (95% CI)			**149**			**72**	**100.0%**	**0.31 [0.02, 0.61]**

Heterogeneity: Tau² = 0.00; Chi² = 0.20, df = 1 (P = 0.65); I² = 0%
Test for overall effect: Z = 2.11 (P = 0.04)



Output 4.6: Verbal fluency

Fig. 4. Physical activity interventions versus passive controls.

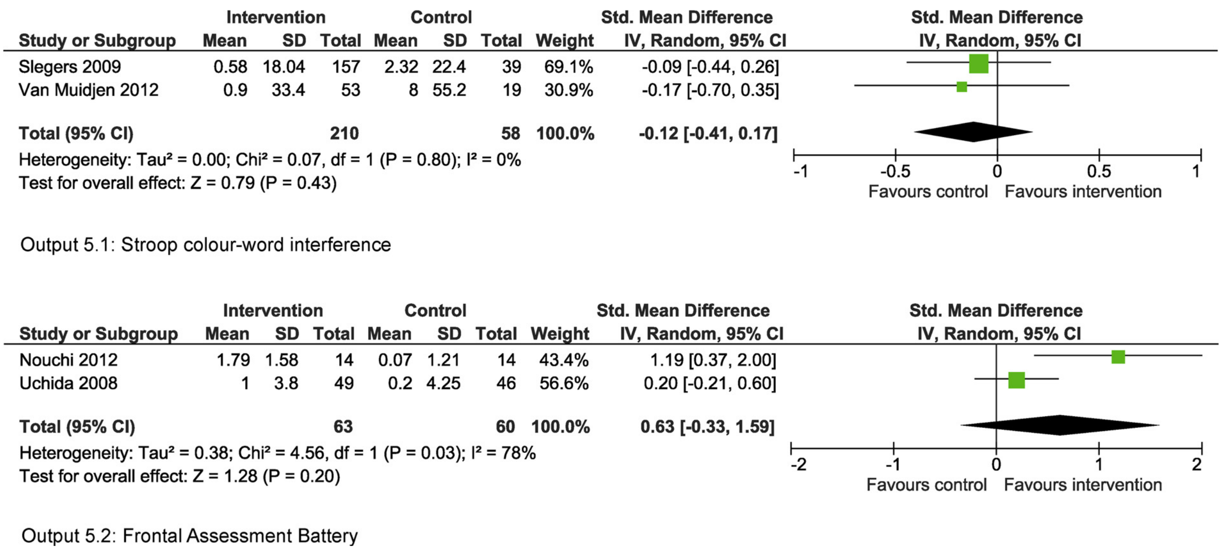


Fig. 5. Cognitive activity interventions versus active controls.

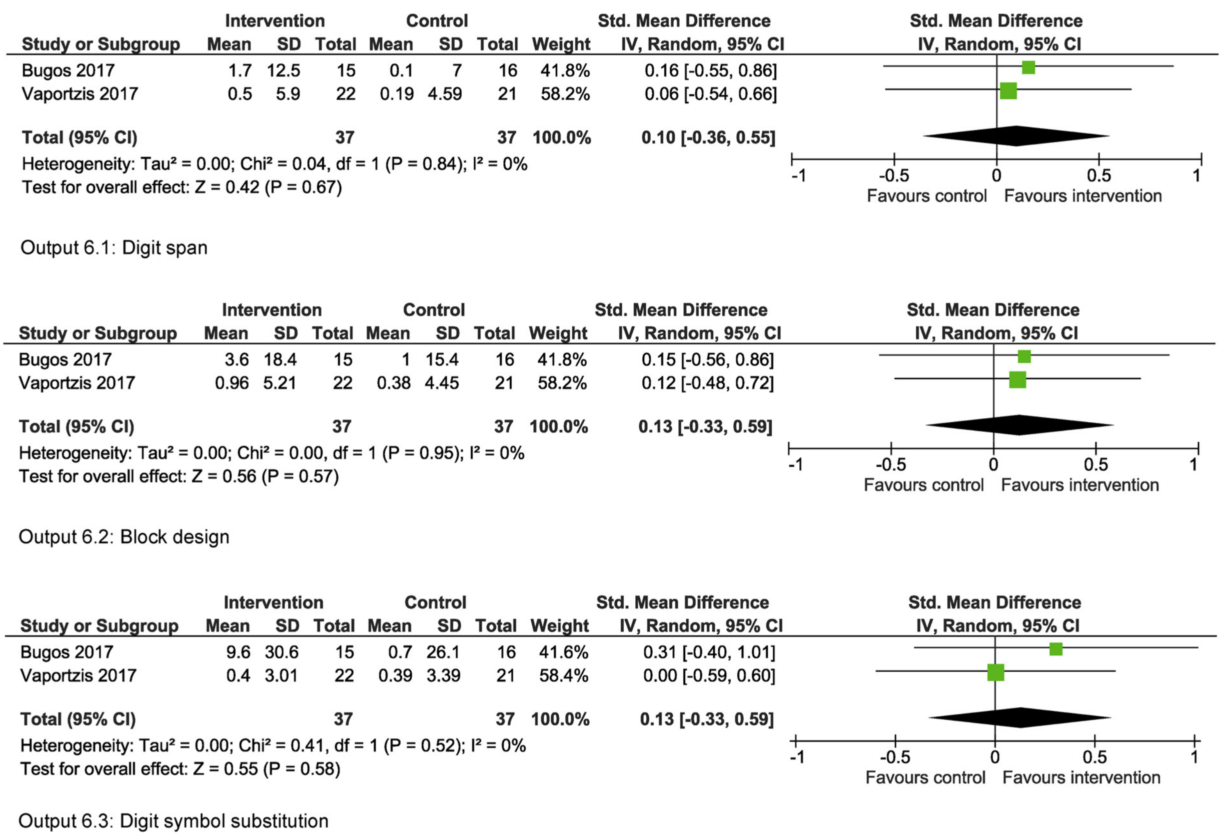


Fig. 6. Cognitive activity interventions versus passive controls.

maintain or enhance cognitive function in older adults.

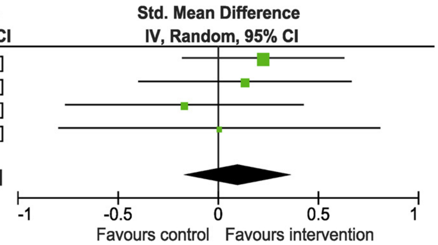
4. Categories of included studies

4.1. Physical activity interventions

4.1.1. Physical activity interventions versus active controls

Of the 11 relevant studies to be considered, 8 reported significant improvements after a physical activity intervention versus active controls on at least one measure of cognitive ability (Table 1). Meta-analysis results revealed that compared to active controls, physical interventions did not significantly improve performance on the executive function (interference) measure of Stroop (colour-word, $p = 0.77$, N studies = 3, N intervention = 94, N control = 101, $I^2 = 0\%$; colour-word minus colour, $p = 0.10$, N studies = 2, N intervention = 172, N control = 73, $I^2 = 0\%$), the working memory measures of digit span forward ($p = 0.33$, N studies = 2, N intervention = 61, N control = 48, $I^2 = 99\%$) and digit span backward ($p = 0.80$, N studies = 3, N intervention = 140, N control = 79, $I^2 = 0\%$), and TMT B minus TMT A ($p = 0.32$, N studies = 2, N intervention = 172, N control = 73, $I^2 = 43\%$; Fig. 2). Contrast was not possible for the remaining measures (detailed in Table 1) because measures were either used by one study

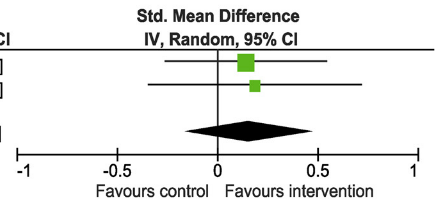
Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Barnes 2013	-0.17	0.91	94	-0.36	0.59	32	43.7%	0.22 [-0.18, 0.63]
Desjardins-Crepeau 2016	4.28	19.25	58	1.6	21.62	18	25.2%	0.13 [-0.40, 0.66]
Gill 2016	-0.37	0.74	23	-0.24	0.77	21	20.1%	-0.17 [-0.76, 0.42]
Yokoyama 2015	8.5	8.1	12	8.4	23.9	12	11.0%	0.01 [-0.79, 0.81]
Total (95% CI)			**187**			**83**	**100.0%**	**0.10 [-0.17, 0.36]**



Heterogeneity: Tau² = 0.00; Chi² = 1.23, df = 3 (P = 0.75); I² = 0%
Test for overall effect: Z = 0.73 (P = 0.47)

Output 7.1: Trail Making Test A

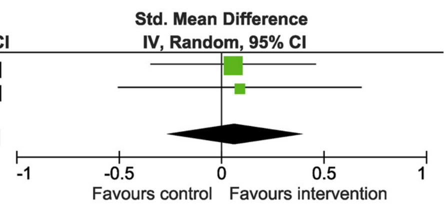
Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Barnes 2013	-0.1	0.92	94	-0.22	0.59	32	63.5%	0.14 [-0.26, 0.54]
Desjardins-Crepeau 2016	4.72	65.11	58	-7.6	67.94	18	36.5%	0.19 [-0.34, 0.72]
Total (95% CI)			**152**			**50**	**100.0%**	**0.16 [-0.16, 0.48]**



Heterogeneity: Tau² = 0.00; Chi² = 0.02, df = 1 (P = 0.89); I² = 0%
Test for overall effect: Z = 0.96 (P = 0.34)

Output 7.2: Trail Making Test B

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Barnes 2013	0.18	0.55	94	0.15	0.47	32	68.5%	0.06 [-0.35, 0.46]
Gill 2016	0.39	0.68	21	0.33	0.65	23	31.5%	0.09 [-0.50, 0.68]
Total (95% CI)			**115**			**55**	**100.0%**	**0.07 [-0.27, 0.40]**



Heterogeneity: Tau² = 0.00; Chi² = 0.01, df = 1 (P = 0.93); I² = 0%
Test for overall effect: Z = 0.39 (P = 0.70)

Output 7.3: Digit symbol substitution

Fig. 7. Mixed physical-cognitive interventions versus active controls.

only or authors did not respond to requests for additional information.

4.1.2. Physical activity interventions versus wait-list controls

Of the 6 relevant studies, 4 reported significant improvements after a physical activity intervention versus wait-list controls on at least one measure of cognitive ability (Table 2). Meta-analysis results revealed that compared to wait-list controls, physical interventions did not significantly improve performance on the executive function (interference) measure of Stroop ($p = 0.90$, N studies = 5, N intervention = 231, N control = 178, $I^2 = 0\%$), the visuospatial processing measure of Trail Making Test (TMT) A ($p = 0.62$, N studies = 3, N intervention = 286, N control = 273, $I^2 = 0\%$), the cognitive flexibility measure of TMT B ($p = 0.94$, N studies = 2, N intervention = 69, N control = 66, $I^2 = 0\%$), the reaction time measures of simple RT ($p = 0.75$, N studies = 2, N intervention = 116, N control = 67, $I^2 = 0\%$) and choice RT ($p = 0.62$, N studies = 2, N intervention = 116, N control = 67, $I^2 = 0\%$), the auditory working memory measure of letter-number sequencing ($p = 0.85$, N studies = 2, N intervention = 116, N control = 67, $I^2 = 0\%$), the working memory measure of digit span backward ($p = 0.75$, N studies = 2, N intervention = 80, N control = 79, $I^2 = 0\%$), the verbal and memory measure of RAVLT (immediate recall, $p = 0.28$, N studies = 2, N intervention = 80, N control = 79, $I^2 = 0\%$; delayed recall, $p = 0.14$, N studies = 2, N intervention = 80, N control = 79, $I^2 = 0\%$), and the verbal fluency measure of the Controlled Oral Word Association Test ($p = 0.93$, N studies = 2, N intervention = 69, N control = 66, $I^2 = 0\%$; Fig. 3). Contrast was not possible for the remaining measures (detailed in Table 2) because measures were used by one study only.

4.1.3. Physical activity interventions versus passive controls

Of the 8 relevant studies, 8 reported significant improvements after a physical activity intervention versus passive controls on at least one measure of cognitive ability (Table 3). Meta-analysis results revealed that compared to passive controls, physical interventions significantly improved performance on the visuospatial processing measure of TMT A ($p = 0.05$, N studies = 3, N intervention = 225, N control = 106, $I^2 = 67\%$), digit symbol substitution ($p = 0.05$, N studies = 2, N intervention = 149, N control = 72, $I^2 = 0\%$), and verbal fluency ($p = 0.04$, N studies = 2, N intervention = 149, N control = 72, $I^2 = 0\%$; Fig. 4). There were no significant differences on logical memory ($p = 0.45$, N studies = 2, N intervention = 154, N control = 72, $I^2 = 46\%$), delayed logical memory ($p = 0.41$, N studies = 2, N intervention = 154, N control = 72, $I^2 = 50\%$), and the working memory measure of digit span forward ($p = 0.26$, N studies = 3, N intervention = 257, N control = 150, $I^2 = 0\%$). Contrast was not possible for the remaining measures (detailed in Table 3) because measures were used by one study only.

4.2. Cognitive activity interventions

4.2.1. Cognitive activity interventions versus active controls

Of the 5 relevant studies, 3 reported significant improvements after a cognitive activity intervention versus active controls on at least one measure of cognitive ability (Table 4). Meta-analysis results revealed that compared to active controls, cognitive interventions did not significantly improve performance on the executive function (interference) measure of Stroop ($p = 0.43$, N studies = 2, N intervention = 210, N control = 58, $I^2 = 0\%$) and the Frontal Assessment Battery ($p = 0.20$, N studies = 2, N intervention = 63, N control = 60, $I^2 = 78\%$; Fig. 5). Contrast was not possible for the remaining measures (detailed in Table 4) because measures were either used by one study only or authors did not respond to requests for additional information.

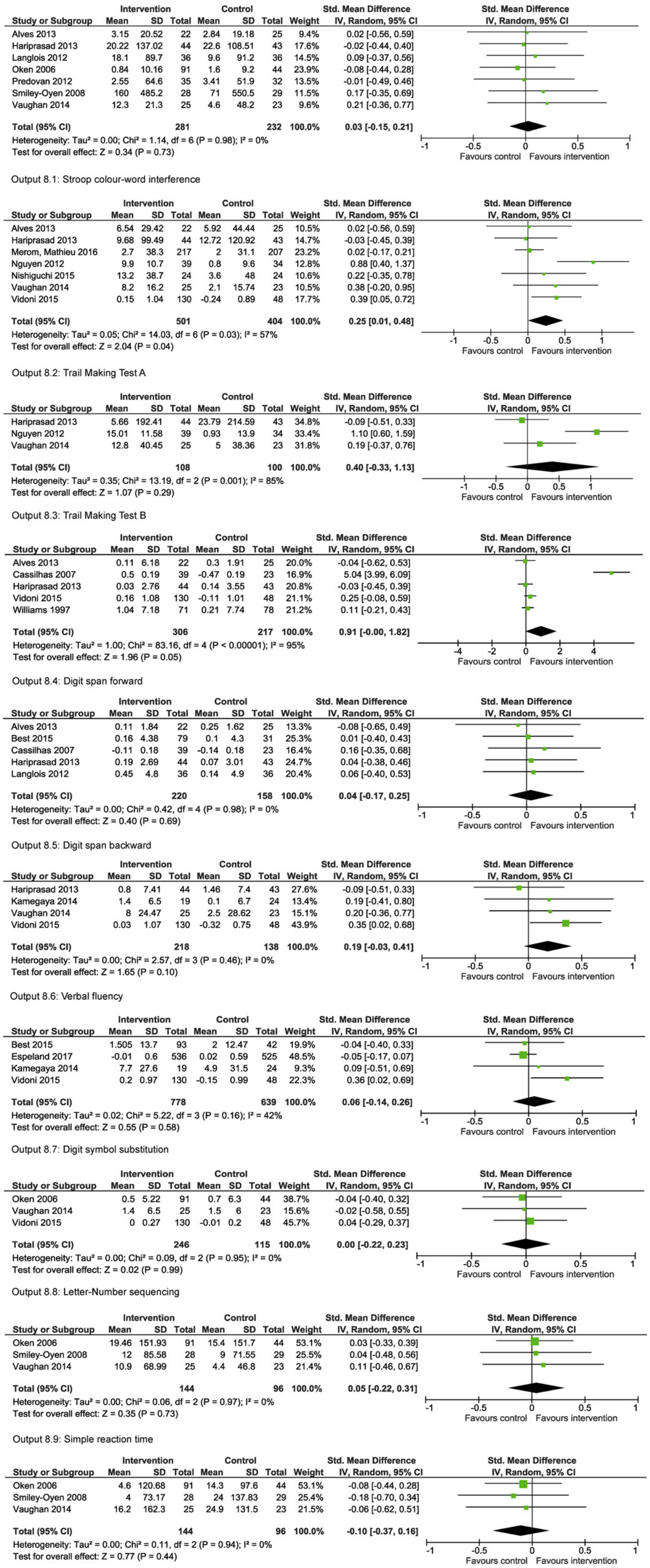


Fig. 8. Physical activity interventions versus all controls.

4.2.2. Cognitive activity interventions versus wait-list controls

Of the 2 relevant studies, 1 reported significant improvement after a cognitive activity intervention versus wait-list controls on at least one measure of cognitive ability (Table 5). However, contrast was not possible because the studies used different measures.

4.2.3. Cognitive activity interventions versus passive controls

Of the 2 relevant studies, 2 reported significant improvements after a cognitive activity intervention versus passive controls on at least one measure of cognitive ability (Table 6). Meta-analysis results revealed that compared to passive controls, cognitive interventions did not significantly improve performance on the working memory measure of digit span (average of digit span forward and backward, $p = 0.67$, N studies = 2, N intervention = 37, N control = 37, $I^2 = 0\%$), the psychomotor speed measure of digit symbol substitution ($p = 0.58$, N studies = 2, N intervention = 37, N control = 37, $I^2 = 0\%$), and the visuospatial and non-verbal problem solving measure of block design ($p = 0.57$, N studies = 2, N intervention = 37, N control = 37, $I^2 = 0\%$; Fig. 6). Contrast was not possible for the remaining measures (detailed in Table 6) because measures were used by one study only.

4.3. Mixed interventions

4.3.1. Physical-cognitive interventions versus active controls

Of the 6 relevant studies, 5 reported significant improvements after a mixed physical-cognitive intervention versus active controls on at least one measure of cognitive ability (Table 7). Meta-analysis results revealed that compared to active controls, mixed physical-cognitive interventions did not significantly improve performance on the visuospatial processing measure of TMT A ($p = 0.47$, N studies = 4, N intervention = 187, N control = 83, $I^2 = 0\%$; Fig. 7), the cognitive flexibility measure of TMT B ($p = 0.34$, N studies = 2, N intervention = 152, N control = 50, $I^2 = 0\%$) and the psychomotor speed measure of digit symbol substitution ($p = 0.70$, N studies = 2, N intervention = 115, N control = 55, $I^2 = 0\%$). Contrast was not possible for the remaining measures (detailed in Table 7) because measures were either used by one study only or authors did not respond to requests for additional information.

4.3.2. Physical-cognitive interventions versus passive controls

One study used a mixed physical-cognitive intervention versus passive controls, and found no significant differences in cognitive measures between groups (Table 8).

4.3.3. Other interventions

Two studies used unique interventions. Carlson et al. (2008) used a social activity in which older adults helped elementary school children with reading achievement, library support and classroom behaviour. Myhre et al. (2016) used a Facebook intervention to investigate its potential to maintain or enhance older adults' cognitive abilities. The outcomes of these studies are presented in Table 9, suggesting that the intervention groups significantly improved on at least one measure of cognitive ability compared with controls.

4.4. Physical and cognitive activity interventions versus all controls

4.4.1. Physical activity interventions versus all controls

A meta-analysis revealed that compared to all controls, performance was significantly improved for TMT A ($p = 0.04$, N studies = 7, N intervention = 501, N control = 404, $I^2 = 57\%$) and digit span forward ($p = 0.05$, N studies = 5, N intervention = 306, N control = 217, $I^2 = 95\%$; Fig. 8) after physical interventions. Performance did not significantly improve for verbal fluency ($p = 0.10$, N studies = 4, N intervention = 218, N control = 138, $I^2 = 0\%$), Stroop interference ($p = 0.73$, N studies = 7, N intervention = 281, N control = 232, $I^2 = 0\%$), TMT B ($p = 0.29$, N studies = 3, N intervention = 108, N control = 100, $I^2 = 85\%$), digit span backward ($p = 0.69$, N studies = 5, N intervention = 220, N control = 158, $I^2 = 0\%$), digit symbol substitution ($p = 0.58$, N studies = 4, N intervention = 778, N control = 639, $I^2 = 42\%$), letter-number sequencing ($p = 0.99$, N studies = 3,

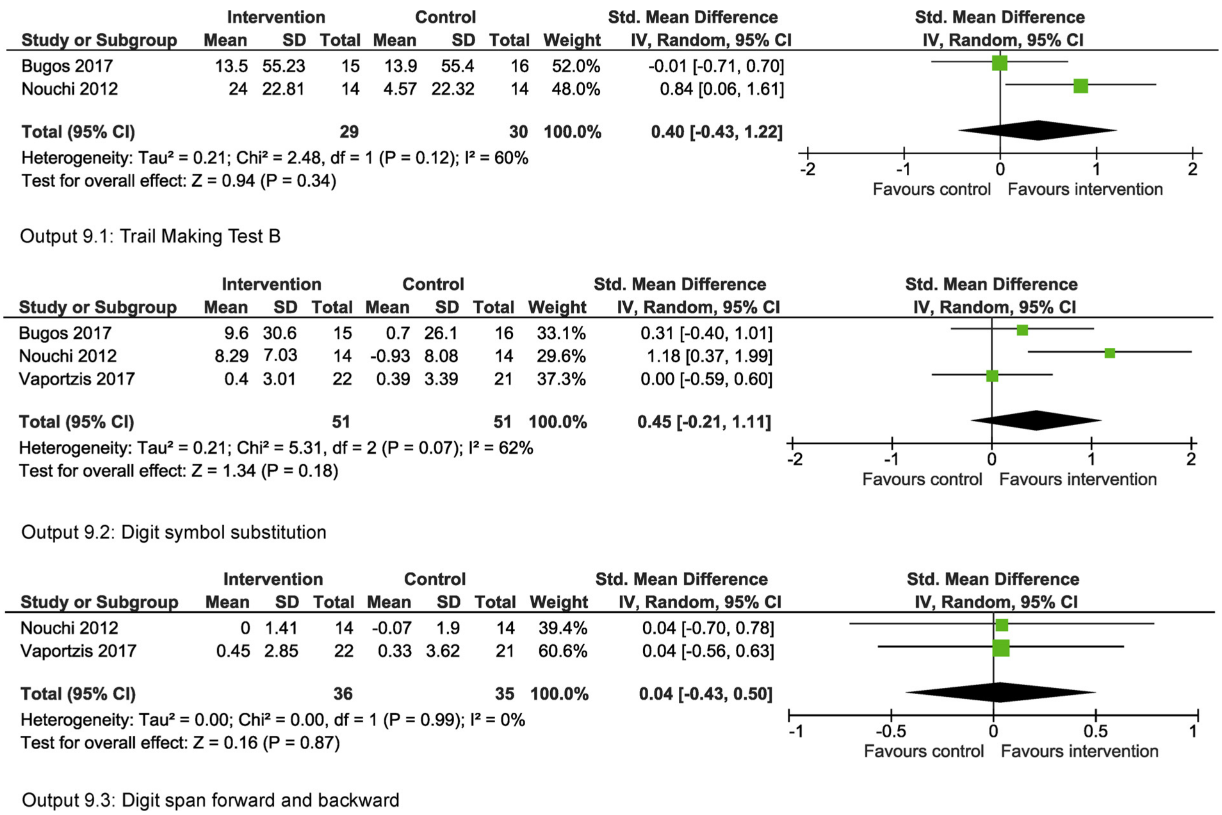


Fig. 9. Cognitive activity interventions versus all controls.

N intervention = 246, N control = 115, I^2 = 0%), and simple (p = 0.73, N studies = 3, N intervention = 144, N control = 96, I^2 = 0%) and choice RT (p = 0.44, N studies = 3, N intervention = 144, N control = 96, I^2 = 0%).

4.4.2. Cognitive activity interventions versus all controls

A meta-analysis revealed that compared to all controls, cognitive interventions did not significantly improve performance on TMT B (p = 0.34, N studies = 2, N intervention = 29, N control = 30, I^2 = 60%), digit symbol substitution (p = 0.18, N studies = 3, N intervention = 51, N control = 51, I^2 = 62%), and digit span forward and backward (p = 0.87, N studies = 2, N intervention = 36, N control = 35, I^2 = 0%; Fig. 9).

4.5. All interventions versus all controls

When all interventions were considered together, a meta-analysis revealed that compared to all controls, performance was significantly improved for TMT A (p = 0.01, N studies = 13, N intervention = 808, N control = 549, I^2 = 32%) and TMT B (p = 0.02; N studies = 8, N intervention = 379, N control = 210, I^2 = 59%; Fig. 10). Interventions did not significantly improve performance on verbal fluency (p = 0.21, N studies = 9, N intervention = 629, N control = 379, I^2 = 43%), Stroop interference (p = 0.94, N studies = 12, N intervention = 784, N control = 436, I^2 = 0%), digit span (forward: p = 0.09, N studies = 7, N intervention = 418, N control = 268, I^2 = 93%; backward: p = 0.43, N studies = 8, N intervention = 346, N control = 223, I^2 = 0%), RAVLT (immediate: p = 1.00; delayed recall: p = 0.30, N studies = 4, N intervention = 165, N control = 196, I^2 = 0%), digit symbol substitution (p = 0.13, N studies = 10, N intervention = 988, N control = 793, I^2 = 39%), Rey-Osterrieth Complex Figure (copy: p = 0.65; recall: p = 0.35, N studies = 2, N intervention = 129, N control = 53, I^2 = 98%), similarities (p = 0.17, N studies = 3, N intervention = 129, N control = 53, I^2 = 71%), block design (p = 0.11, N studies = 3, N intervention = 182, N control = 101, I^2 = 38%), Useful Field of View (divided attention: p = 0.83, N studies = 3, N intervention = 207, N control = 126, I^2 = 0%; selective attention: p = 0.18, N studies = 2, N intervention = 116, N control = 82, I^2 = 0%), Frontal Assessment Battery (p = 0.12, N studies = 3, N intervention = 135, N control = 126, I^2 = 65%) and the Boston Naming Test (p = 0.77, N studies = 2, N intervention = 220, N control = 78, I^2 = 0%).

4.6. Publication bias

Funnel plots of some outcome measures were slightly asymmetric. However, the weight-function model analysis only detected significant publication bias in the effect of digit span backward (p = 0.05; physical activity against wait-list controls) and Stroop (p = 0.05; physical activity against passive controls). These significant outcomes disappeared when physical activity interventions were compared against all controls (Stroop p = 0.13, digit span backward p = 0.23). Therefore, the core premises of this meta-analysis remain unchanged.

4.7. Meta-regression analyses

Meta-regression analyses were performed for Stroop, TMT A and digit symbol substitution for all interventions against all controls. These were the only cognitive outcomes that were reported in 10 or more studies; the Cochrane Handbook (Higgins and Green, 2011) does not recommend meta-regression for fewer than 10 studies. The results are presented in Table 10. For the duration of the intervention, the regression coefficients of Stroop and digit symbol substitution were positive, whereas the regression coefficient of TMT A was negative. For the frequency of the intervention, the regression coefficients of Stroop, TMT A and digit symbol substitution were positive. Positive coefficients suggest better performance with increased duration and/or frequency. However, only the regression coefficient for the frequency of intervention and digit symbol substitution was statistically significant (p =

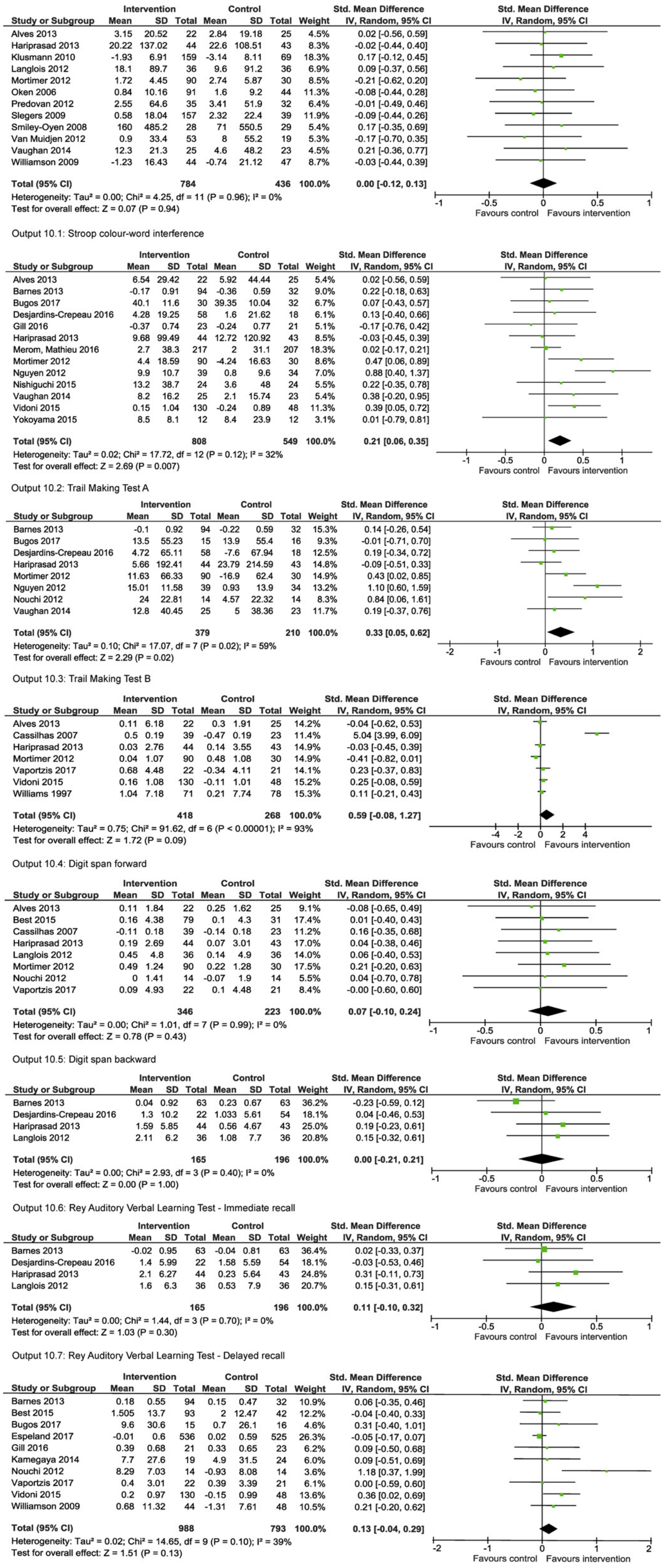


Fig. 10. All interventions versus all controls.

0.01).

5. Discussion

TMT A, digit symbol substitution and verbal fluency were the only outcomes for which performance was improved as a result of specific types of interventions compared against the different types of control groups (i.e., physical activity interventions vs passive controls). When comparing physical activity interventions against all control groups, TMT A and digit span forward performance significantly improved. Results for the cognitive activity interventions compared to all control groups suggested no improvement as a result of those activities. Finally, TMT A and B were the only outcomes that improved when comparing all interventions.

5.1. TMT

TMT is a cognitive measure that has been previously reported to discriminate between cognitively-healthy individuals and those with dementia, and has been found to be sensitive to the preclinical manifestations of Alzheimer's (Chen et al., 2000) and Huntington's disease (O'Rourke et al., 2011). Shindo et al. (2013) reported that TMT A may be a promising index of superior parietal dysfunction from their study with 56 patients with mild Alzheimer's. Ashendorf et al. (2008) reported differences in performance on TMT B between groups of healthy individuals and individuals with mild cognitive impairment and Alzheimer's disease suggesting the clinical utility of this measure in assessing dementia (N = 526). A study with 168 donepezil-treated patients with subcortical vascular disease reported that the time to complete TMT A and TMT B was the most sensitive measure of cognitive change (Dichgans et al., 2008). Our results suggest that TMT may also be a sensitive measure of cognitive change in healthy populations, as a useful screening tool for cognitive dysfunction, and additionally, a potential marker of initial cognitive improvements following brief interventions. This is consistent with a longitudinal study with cognitively-healthy participants (n = 385) that reported significant slowing for TMT B, with older participants showing the greatest change (Rasmusson et al., 1998). In the current review, TMT A, which is a measure of visuospatial abilities, was the only measure that was consistently improved following physical activity interventions. Visuospatial abilities may be more susceptible to improvement following participation in physical activities; TMT A may therefore be a particularly useful tool for detecting changes in visuospatial abilities in the context of intervention studies.

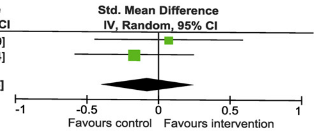
5.2. Physical activity interventions

Physical activity has substantial support in the literature as a factor that might slow cognitive decline (Kennedy et al., 2017). A recent systematic review of RCTs in community-dwelling adults aged 50 and over found that physical activity interventions improved cognitive outcomes regardless of participants' baseline cognitive status (Northey et al., 2018). A meta-analysis of 23 longitudinal studies reported that physical activity was positively associated with healthy ageing (Daskalopoulou et al., 2017). However, that meta-analysis focused on health status rather than cognitive outcomes and did not exclude lab-based interventions, making specific translation to more real-world interventions difficult. Similarly, a meta-analysis of RCTs in people with dementia found that physical activity interventions positively influenced cognitive function independent of the clinical diagnosis and the frequency of the intervention. Our results provide further support that physical activity interventions in community-based settings may improve cognitive function in healthy adults aged 60 years and older.

In addition to improvement on TMT A, we found that digit symbol substitution and verbal fluency also improved when comparing physical interventions against passive controls. A longitudinal study with 5888 participants reported that psychomotor speed, as measured by the Digit Symbol Substitution Test, may be a biomarker for risk of cognitive disorders and might provide insights into age-related cognitive changes (Rosano et al., 2016). Regarding verbal fluency, our results are consistent with a meta-analysis of physical activity training on the

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Cassilhas 2007	6.45	3.9	39	6.1	6.13	23	39.2%	0.07 [-0.44, 0.59]
Mortimer 2012	0.4	3.81	90	1	2.45	30	60.8%	-0.17 [-0.58, 0.24]
Total (95% CI)			129			53	100.0%	-0.07 [-0.40, 0.25]

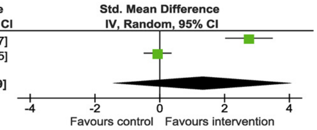
Heterogeneity: Tau² = 0.00; Chi² = 0.51, df = 1 (P = 0.48); I² = 0%
Test for overall effect: Z = 0.45 (P = 0.65)



Output 10.9: Rey-Osterrieth Complex Figure - Copy

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Cassilhas 2007	8.34	1.22	39	5.17	0.98	23	49.4%	2.75 [2.03, 3.47]
Mortimer 2012	2.61	13.93	90	3.44	4.89	30	50.6%	-0.07 [-0.48, 0.35]
Total (95% CI)			129			53	100.0%	1.33 [-1.44, 4.09]

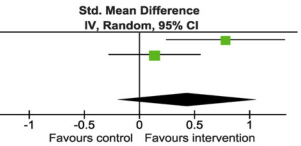
Heterogeneity: Tau² = 3.88; Chi² = 44.42, df = 1 (P < 0.00001); I² = 98%
Test for overall effect: Z = 0.94 (P = 0.35)



Output 10.10: Rey-Osterrieth Complex Figure - Recall

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Cassilhas 2007	1.06	6.05	39	-2.75	0.18	23	46.4%	0.78 [0.25, 1.32]
Mortimer 2012	1.96	3.65	90	1.48	2.87	30	53.6%	0.14 [-0.28, 0.55]
Vaportzis 2017	0	0	0	0	0	0		Not estimable
Total (95% CI)			129			53	100.0%	0.44 [-0.19, 1.07]

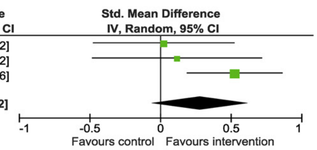
Heterogeneity: Tau² = 0.15; Chi² = 3.49, df = 1 (P = 0.06); I² = 71%
Test for overall effect: Z = 1.36 (P = 0.17)



Output 10.11: Similarities

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bugos 2017	32.2	9.83	30	32	8.11	32	30.1%	0.02 [-0.48, 0.52]
Vaportzis 2017	0.96	4.71	22	0.38	5.02	21	23.4%	0.12 [-0.48, 0.72]
Vidoni 2015	0.15	0.2524	130	0.02	0.23	48	46.5%	0.52 [0.19, 0.86]
Total (95% CI)			182			101	100.0%	0.28 [-0.06, 0.62]

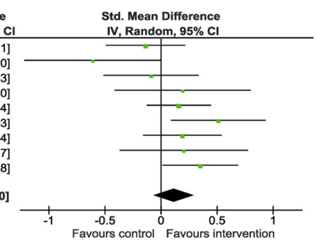
Heterogeneity: Tau² = 0.04; Chi² = 3.25, df = 2 (P = 0.20); I² = 38%
Test for overall effect: Z = 1.60 (P = 0.11)



Output 10.12: Block design

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Barnes 2013	0.01	1.04	63	0.14	0.82	63	13.4%	-0.14 [-0.49, 0.21]
Gill 2016	0.01	0.87	21	0.54	0.84	23	6.7%	-0.61 [-1.22, -0.00]
Hariprasad 2013	0.8	7.41	44	1.46	7.4	43	11.0%	-0.09 [-0.51, 0.33]
Kamegaya 2014	1.4	6.5	19	0.1	6.7	24	6.7%	0.19 [-0.41, 0.80]
Klusmann 2010	0.78	5.23	161	-0.03	4.7	69	16.2%	0.16 [-0.12, 0.44]
Mortimer 2012	-0.93	3.65	90	-2.91	4.4	30	11.0%	0.51 [0.09, 0.93]
Taylor-Piliae 2010	1.42	4.43	76	0.6	4.1	56	13.5%	0.19 [-0.16, 0.54]
Vaughan 2014	8	24.47	25	2.5	28.62	23	7.4%	0.20 [-0.36, 0.77]
Vidoni 2015	0.03	1.07	130	-0.32	0.75	48	14.1%	0.35 [0.02, 0.68]
Total (95% CI)			629			379	100.0%	0.12 [-0.06, 0.30]

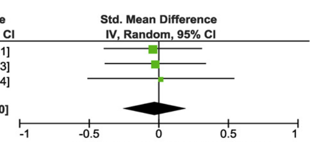
Heterogeneity: Tau² = 0.03; Chi² = 14.13, df = 8 (P = 0.08); I² = 43%
Test for overall effect: Z = 1.26 (P = 0.21)



Output 10.13: Verbal fluency

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Barnes 2013	-0.4	0.84	63	1.03	1.03	63	41.9%	-0.04 [-0.39, 0.31]
Oken 2006	11.17	111.86	91	13.9	101.29	44	39.5%	-0.03 [-0.38, 0.33]
Van Muidjen 2012	48.1	236.5	53	45	119.4	19	18.6%	0.01 [-0.51, 0.54]
Total (95% CI)			207			126	100.0%	-0.02 [-0.25, 0.20]

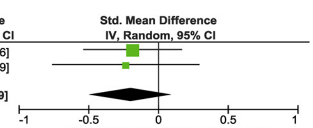
Heterogeneity: Tau² = 0.00; Chi² = 0.03, df = 2 (P = 0.98); I² = 0%
Test for overall effect: Z = 0.22 (P = 0.83)



Output 10.14: Useful Field View - Divided attention

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Barnes 2013	-0.43	0.91	63	-0.26	0.91	63	69.3%	-0.19 [-0.54, 0.16]
Van Muidjen 2012	14.6	213.99	53	65	206.46	19	30.7%	-0.24 [-0.76, 0.29]
Total (95% CI)			116			82	100.0%	-0.20 [-0.49, 0.09]

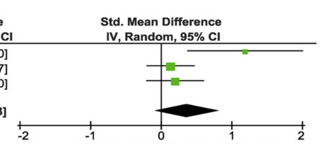
Heterogeneity: Tau² = 0.00; Chi² = 0.02, df = 1 (P = 0.88); I² = 0%
Test for overall effect: Z = 1.35 (P = 0.18)



Output 10.15: Useful Field View - Selective attention

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Nouchi 2012	1.79	1.58	14	0.07	1.21	14	20.0%	1.19 [0.37, 2.00]
Sun 2015	1.1	4.44	72	0.4	6.03	66	41.9%	0.13 [-0.20, 0.47]
Uchida 2008	1	3.84	49	0.2	4.25	46	38.1%	0.20 [-0.21, 0.60]
Total (95% CI)			135			126	100.0%	0.37 [-0.09, 0.83]

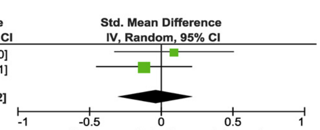
Heterogeneity: Tau² = 0.10; Chi² = 5.64, df = 2 (P = 0.06); I² = 65%
Test for overall effect: Z = 1.57 (P = 0.12)



Output 10.16: Frontal Assessment Battery

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Mortimer 2012	1.4	2.24	90	1.17	3.38	30	39.1%	0.09 [-0.32, 0.50]
Vidoni 2015	0.27	0.77	130	0.36	0.68	48	60.9%	-0.12 [-0.45, 0.21]
Total (95% CI)			220			78	100.0%	-0.04 [-0.30, 0.22]

Heterogeneity: Tau² = 0.00; Chi² = 0.60, df = 1 (P = 0.44); I² = 0%
Test for overall effect: Z = 0.29 (P = 0.77)



Output 10.17: Boston Naming Test

Fig. 10. (*continued*)

cognitive abilities of older adults with mild cognitive impairment that found a significant benefit of exercise on verbal fluency (Gates et al., 2013). When comparing physical activity interventions against all control groups, a significant improvement on digit span forward emerged. However, we found no significant differences on digit span forward as well as digit span backward when comparing all

Table 1
Characteristics of studies – physical activity interventions versus active controls.

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
Alves et al. (2013)	IG1: Resistance training + creatine supplements IG2: Resistance training + placebo supplements CG1: Creatine supplements CG2: Placebo supplements	Intrahospital gymnasium, School of Medicine, University of Sao Paolo	24 weeks 2 sessions p/w	Baseline 12 weeks Post-intervention	IG1: 12 IG2: 10 CG1: 13 CG2:12	Mini-Mental State Examination, Stroop, Trail Making Test A & B, digit span, delayed recall test (from Brief Cognitive Screening Battery)	No significant differences in any cognitive measure between groups at post-intervention and 24 weeks
Best (2015)	IG1: Resistance training x 1p/w IG2: Resistance training x 2p/w CG: Balance-toning	Local YMCA and the Center for Hip Health and Mobility	52 weeks 1 or 2 sessions p/w	Baseline Post-intervention 104 weeks	IG1: 37 IG2: 41 CG: 31	Mini-Mental State Examination, Rey Auditory Verbal Learning Test, Stroop, Trail Making Test A & B, digit span backward, digit symbol substitution	At 104 weeks follow-up, intervention groups improved significantly more on executive function and memory
Cassilhas et al. (2007)	IG1: Moderate resistance training IG2: High resistance training CG: Stretching	CEPE (Centre for Psychobiology and Exercise studies)	24 weeks 3 x 1 hour sessions p/w	Baseline Post-intervention	IG1: 19 IG2: 20 CG: 23	Digit span forward and backward (from Wechsler Adult Intelligence Scale-III), Corsi blocks forward, backward and similarities (from Wechsler Memory Scale-R), Corsi blocks forward, backward and similarities (from WMS-R), Toulouse-Pieron concentration test, Rey-Osterrieth complex figure	High resistance training group improved significantly more than controls on short-term memory, visual short-term memory, central executive function, immediate recall, long-term episodic memory and attention
Espeland et al. (2017)	IG: Multicomponent (walking, resistance, flexibility, balance) CG: Health education	Centre- and home-based	104 weeks 2 × 2 centre-based visits p/w + 3-4 home-based activity p/w controls attended 1 workshop p/w the first 26 weeks, and monthly sessions thereafter	Baseline 104 weeks	IG:536 CG: 525	Modified Mini-Mental State Examination, coding, Hopkins Verbal Learning Test-Revised, n-back, Eriksen Flanker task, task-switching	No significant differences in any cognitive measure between groups
Jonasson (2017)	IG: Aerobic CG: Stretching and toning	Sport Science Lab Umeå School of Sport Sciences	26 weeks 3 × 30-60 min sessions p/w	Baseline 26 weeks	IG: 29 CG: 29	Word encoding, form boards, letter sets, word recognition, Ravens Progressive Matrices, paper folding, spatial relations, free recall, automated operation span, digit-symbol, odd-even, letter memory, flanker task, plus-minus, digit span backward, paired associates, n-back, letter comparison, local-global, trail making task, keep track	Intervention group improved significantly more in cognition as indexed by a composite score including episodic memory, processing speed, updating and executive function tasks
Liu-Ambrose (2010)	IG1: Resistance training x 1p/w IG2: Resistance training x 2p/w CG: Balance-toning	Local YMCA and the Centre for Hip Health and Mobility	52 weeks 1 or 2 sessions p/w	Baseline 26 weeks Post-intervention	IG1: 54 IG2: 52 CG: 49	Stroop, Trail Making Test A & B, digit span forward and backward	Intervention groups improved significantly more on selective attention/conflict resolution
Merom, Grunsett et al. (2016)	IG: Ballroom dance CG: Walking	Community dance studios	35 weeks 2 sessions p/w	Baseline 3 weeks Post-intervention	IG: 60 CG: 55	Trail Making Test A & B, Stroop colour-word, digit span backward, Rey Auditory Verbal Learning Test, Brief Visuospatial Memory Test	Intervention group improved significantly more on visuospatial memory
Smiley-Oyen (2008)	IG: Aerobic exercise CG: Strength and flexibility training	A community and a university-fitness centre (closed to public during study participation)	44 weeks 3 sessions p/w	Baseline 17-22 weeks Post-intervention	IG: 28 CG: 29	Computerised Stroop, Wisconsin Card Sort Test, go/no-go, simple and 8-choice reaction time	Intervention group improved significantly more on controlled attention
Sun (2015)	IG: Tai Chi CG: Playing cards or singing	Senior activity centre	26 weeks 2 x 60 min sessions p/w	Baseline Post-intervention 6 months	IG: 72 CG: 66	Mini-Mental State Examination, Frontal Assessment Battery	Intervention group improved significantly more on cognitive function measures
Taylor-Piliae (2010)	IG1: Tai Chi IG2: Western exercise CG: Healthy ageing classes - experienced professionals	Community room of a local church for Tai Chi and YMCA for Western exercise	52 weeks Adoption phase: 26 weeks Maintenance phase: 26 weeks 1 x 45 min Tai Chi session p/w	Baseline 13 weeks 26 weeks	IG1: 37 IG2: 39 CG: 56	Animal naming, digit span forward and backward	Tai Chi group improved significantly more on cognitive-function measures than the Western exercise and control groups at 26 weeks and those

(continued on next page)

Table 1 (*continued*)

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
	provided information on topics, such as healthy eating		1 × 45-55 min Western exercise session p/w	Post-intervention			improvements were maintained at 52 weeks
Williamson et al. (2009)	IG: Moderate intensity physical activity CG: Health education sessions	Participants' homes and two field centres at Stanford University and Wake Forest University	Adoption phase: 9 weeks 3 centre-based sessions p/w Transition phase: 17 weeks 2 centre-based and 3 home-based sessions p/w Maintenance phase: 26 weeks 1 or 2 home-based sessions and 1 optional centre-based session p/w	Baseline Post-intervention	IG: 50 CG: 52	Modified Mini-Mental State Examination, digit-symbol substitution, Rey Auditory Verbal Learning Test, modified Stroop	No significant differences in any cognitive measure between groups

Note: IG = Intervention Group; CG = Control Group; p/w = per week.

interventions against all control groups. This latter finding is consistent with Öhman et al. (2014), who systematically reviewed 22 studies that investigated the effect of physical activity on cognitive performance in older adults with mild cognitive impairment or dementia and reported no significant differences on digit span test.

5.3. Cognitive and mixed interventions

Based on the meta-analyses we did not find any significant changes in cognitive outcomes in studies that used cognitive or mixed interventions. This may be due to the limited number of cognitive and mixed interventions that were included in this review. In addition, the types of cognitive and mixed interventions varied considerably. A recent review aimed to identify effective mixed interventions (for example, physical and cognitive interventions), whether they might be superior to physical or cognitive interventions alone in improving cognitive functions (and physical capacity), and whether the effects transfer to instrumental activities of daily living in older adults with normal cognition or mild cognitive impairment (Bruderer-Hofstetter, Rausch-Osthoffa, Meichtrya, Münzerc, & Niedermanna, 2018). Mixed interventions were suggested as more effective when compared against active and passive control groups. However, the Bruderer-Hofstetter et al. (2018) review did not focus on real-world interventions and included studies with healthy individuals as well as those with mild cognitive impairment. Another review evaluated potential cumulative effects by comparing cognitive outcomes following mixed physical and cognitive interventions to physical activity interventions, cognitive interventions and controls. The authors concluded that physical activity interventions may have better cognitive benefits when combined with cognitive interventions (Gheysen et al., 2018), although they included non-RCTs and did not explicitly exclude individuals with psychiatric and neurological disorders. Stanmore et al. (2017) reported positive effects of exergames on general cognitive ability and specific cognitive domains in a meta-analysis of 17 RCTs. However, this study focused on exergames only, and included both healthy and clinical populations.

5.4. Limitations of the review

We included only published data and therefore there is a possibility of overestimating intervention effects. However, 9 of the included intervention studies showed no significant post-intervention cognitive changes in older adults (Alves et al., 2013; Barnes et al., 2013; Espeland et al., 2017; Lee et al., 2013; Merom et al., 2016; Oken et al., 2006; Ordnung et al., 2017; Slegers et al., 2009; Williamson et al., 2009) somewhat mitigating publication bias. Intervention effects should be interpreted with caution as many of the effect sizes were small. These effects may be smaller than those reported in other papers (e.g., Daskalopoulou et al., 2017); however, the current estimates perhaps more accurately reflect how people would benefit via participating in real-life activities versus those in more structured or lab-based settings. The most noteworthy limitation was the divergence in methodologies and cognitive measures used across studies making meta-analyses challenging. For example, some studies reported findings from individual tests whereas others utilised composite domain scores. In addition, the tests that were used varied considerably. Methodological differences are a commonly reported issue (Kueider et al., 2012; Martin et al., 2006), emphasising the necessity of standardisation processes in cognitive intervention studies. Finally, although we think it is of interest to consider *any* physical activity as the parameter of interest, it might be important to examine specific types of physical activities. This was not possible in the current review, partly as the number of comparisons being reported was already extensive.

5.5. Conclusions

Overall, we found that TMT A was the only cognitive measure that

Table 2
Characteristics of studies – physical activity intervention versus wait-list controls.

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
Hariprasad (2013)	IG: Yoga	Home settings	26 weeks 1 session p/w	Baseline Post-intervention	IG:44 CG: 43	Mini-Mental State Examination (Indian version), Rey Auditory Verbal Learning Test, Rey complex figure test, spatial span and digit span (Wechsler Memory Scale), Controlled Oral Word Association Test, Stroop, Trail Making Test A & B	Intervention group improved significantly more on verbal fluency, immediate and delayed recall of verbal and visual memory, attention, working memory and executive function
Langlois et al., 2013 Langlois (2012)	IG1: Multicomponent training (non-frail participants) IG2: Multicomponent training (frail participants) CG1: non-frail group CG2: frail group	Gymnasium at the Research Center of the Montreal's Geriatric Institute	12 weeks 3 x 1 hour sessions p/w	Baseline Post-intervention	IG1: 19 IG2: 17 CG1: 19 CG2: 17	Mini-Mental State Examination, Trail Making Test A & B, Stroop, Rey Auditory Verbal Learning Test; letter-number sequencing, digit span backward, similarities, digit-symbol coding (from Wechsler Adult Intelligence Scale-III)	Intervention group improved significantly more on executive function, processing speed and working memory
Merom, Mathieu et al. (2016)	IG: Ballroom or folk dance	Self-care retirement villages	52 weeks 2 sessions p/w	Baseline Post-intervention	IG: 279 CG: 251	Mini-Mental State Examination, Trail Making Test A & B	No significant differences in any cognitive measure between groups
Oken et al. (2006)	IG1: Yoga IG2: Aerobic exercise	Details not in paper/no response to query	26 weeks 1 session p/w + home practice	Baseline Post-intervention	IG1:44 IG2:47 CG:44	Stroop colour and word, covert orienting, set shifting (adapted from Cambridge Neuropsychological Test Automated Battery), modified Useful Field of View; letter-number sequencing, word list delayed recall, simple and choice reaction time (from Wechsler Adult Intelligence Scale-III)	No significant differences in any cognitive measure between groups
Predovan (2012)	IG: Aerobic	Details not in paper/no response to query	13 weeks 3 x 1 hour p/w	Baseline Post-intervention	IG: 32 CG: 35	Stroop	Intervention group improved significantly more on the inhibition/switching condition of the Stroop task
Vaughan (2014)	IG: Multicomponent exercise	University campus and community-based halls	16 weeks 2 sessions p/w	Baseline Post-intervention	IG: 25 CG: 23	Trail Making test A & B, the California older adult Stroop test (Word, Interference and Total scores), Controlled Oral Word Association, Timed Up-and-Go, letter-number sequencing, simple and choice reaction time	Intervention group improved significantly more on visuospatial processing, cognitive flexibility, executive function and verbal fluency

Note: IG = Intervention Group; CG = Control Group; p/w = per week.

Table 3
Characteristics of studies – physical activity intervention versus passive controls.

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
Alghadir (2016)	IG: Multicomponent exercise	Details not in paper/no response to query	24 weeks 3 sessions p/w	Baseline Post-intervention	IG: 50 CG: 50	Loewenstein Occupational Therapy Cognitive Assessment	Intervention group improved significantly more on overall cognitive function
Kamegaya (2014)	IG: Multicomponent exercise and leisure activities (e.g., cooking, handicrafts)	Community centre	12 weeks 1 session p/w	Baseline Post-intervention	IG: 19 CG: 24	Mini-Mental State Examination, Five-Cog test (analogy, character position referencing, cued recall, verbal fluency and clock drawing), digit symbol substitution (from Wechsler Adult Intelligence Scale), Yamaguchi Kanji-Symbol substitution	Intervention group improved significantly more on abstract reasoning ability
Klusmann (2010)*	IG1: Exercise IG2: Computer	Public buildings such as schools and fitness centres	26 months 3 x 1.5 hours p/w	Baseline Post-intervention	IG1: 91 IG2: 92 CG: 76	Mini-Mental State Examination, Stroop, Rivermead Behavioural Memory Test, Free and Cued Selective Reminding Test, Trail Making Test A & B, verbal fluency (animals, food)	Intervention groups improved significantly more on delayed recall
Mortimer et al. (2012)**	IG1: Tai Chi IG2: Walking IG3: Social CG: Passive	Local park for Tai Chi and walking and community centre for social activity	40 weeks, 3 x 1 hour p/w	Baseline 20 weeks Post-intervention	IG1: 30 IG2: 30 IG3: 30 CG: 30	Chinese Mini-Mental State Examination; similarities, digit span (from Wechsler Adult Intelligence Scale-R), Bell Cancellation Test, Rey-Osterrieth Complex Figure (copying and recall), Stroop, Chinese auditory verbal learning test, category verbal fluency test; Trail Making Test A & B, clock drawing, Boston naming test, Mattis Dementia Rating Scale	Tai Chi group improved on visuospatial processing, auditory verbal learning, verbal fluency and the dementia rating scale relative to controls. The social interaction group improved significantly more on verbal fluency relative to controls
Nguyen and Kruse, (2012)	IG: Tai Chi	Details not in paper/no response to query	26 weeks 2 sessions p/w	Baseline Post-intervention	IG: 48 CG: 48	Trail Making Test A & B	Intervention group improved significantly more on visuospatial processing and cognitive flexibility
Nishiguch et al. (2015)	IG: Multicomponent exercise	Details not in paper/no response to query	12 weeks 1 X 90 min sessions p/w and daily walking sessions	Baseline Post-intervention	IG: 24 CG: 24	Mini-Mental State Examination, logical memory (modified from Wechsler Memory Scale-R); Trail Making Test A & B	Intervention group improved significantly more on memory and executive function
Vidoni et al. (2015)	IG1: Aerobic exercise 75 min IG2: Aerobic exercise 150 min IG3: Aerobic exercise 255 min	YMCA	26 weeks 3-5 sessions p/w	Baseline Post-intervention	IG1: 25 IG2: 27 IG3: 24 CG: 25	Mini-Mental State Examination, logical memory, delayed logical memory, block design, Stroop, digit symbol substitution, digit span forward and backward, letter-number sequencing, matrix reasoning, Boston Naming Test, verbal fluency (animals and vegetables), selective reminding, Trail Making Test A, Card Sort-Free Sort Description and Card Sort-Confirmed Correct Sorts (from Delis-Kaplan Executive Function System); inductive reasoning (letter and word)	Intervention groups improved significantly more on measures of simple attention, a dose-response was present for visuospatial processing - possible increased benefits at higher doses but only in those who adhered to the exercise protocol
Williams and Lord, (1997)	IG: Aerobic exercise	Existing community-based exercise program	42 weeks 2 sessions p/w	Baseline Post-intervention	IG: 94 CG: 93	Digit span forward and backward, picture arrangement (from Wechsler Adult Intelligence Scale-R), Cattell's matrices	Intervention group improved significantly more on measures of nonverbal reasoning, problem solving and short-term acquisition and retrieval

Note: IG = Intervention Group; CG = Control Group; p/w = per week.
* Study included both physical and cognitive intervention groups. Characteristics are presented once. Analysis was possible for the physical intervention only.
** Study included both physical and social intervention groups. Characteristics are presented once. Analysis was possible for the physical interventions only.

Table 4
Characteristics of studies – cognitive activity interventions versus active controls.

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
Ballesteros (2017)	IG: Video game CG: Simulation strategy game	Universidad Nacional de Educación a Distancia centres in Madrid	10-12 weeks 16 × 40-50 min sessions	Baseline Post-intervention	IG: 30 CG: 25	Mini-Mental State Examination, oddball attention, Stroop-negative priming, Corsi block, n-back	Control group improved significantly more on the oddball task. There was a marginal training effect on the n-back task. Both groups improved on the Corsi block task
Degé and Kerkovius, (2018)*	IG: Music (drumming and singing) CG1: Literature training CG2: Passive control group	Details not in paper/no response to query	15 weeks 1 x 60 min session p/w	Baseline Post-intervention	IG: 8 CG1: 7 CG2: 9	Vocabulary, matrix reasoning, digit span backward (from German Wechsler Adult Intelligence Scale-III), verbal memory, symbol sequences (from German Weschler Memory Scale-IV), digit span backward	No significant differences in any cognitive measure between groups
Nouchi et al. (2012)	IG: Videogame - Brain Age CG: Videogame - Tetris	Participants' homes	4 weeks 5 x 15 min sessions p/w	Baseline Post-intervention	IG: 14 CG: 14	Mini-Mental State Examination, Frontal Assessment Battery, Trail Making Test B, digit cancellation, digit span backward; digit symbol substitution, symbol search (from Wechsler Adult Intelligence Scale III)	Intervention group improved significantly more on executive function and processing speed
Slegers et al. (2009)	IG1: Computer training + intervention IG2: Computer training + no intervention CG1: Interested in computer training but not trained CG2: Not interested in computer training and not trained	Participants' homes; training took place in research centre	2 weeks 3 x 4 hours sessions + personal computer use for 12 months (intervention)	Baseline 4 months Post-intervention	IG1: 62 IG2: 61 CG1: 68 CG2: 45	Mini-Mental State Examination, visual verbal learning test, motor choice reaction time, letter-digit substitution, concept shifting, Stroop, Cognitive Failures Questionnaire	No significant differences in any cognitive measure between groups
Van Muijden et al. (2012)	IG: Videogames CG: Documentary group	Online (completed at home)	7 weeks 7 x 30 min sessions p/w	Baseline Post-intervention	IG: 54 CG: 20	Stroop colour-word test, stop signal test, counting span, mental counters, Useful Field of View, Raven standard progressive matrices, global-local switching test, smiling faces switching test, test of attentional performance	Intervention group improved significantly more on inhibition and inductive reasoning; control group improved significantly more on selective attention

Note: IG = Intervention Group; CG = Control Group; p/w = per week.
* Study included both active and control groups. Characteristics are presented once.

Table 5
Characteristics of studies – cognitive activity interventions versus wait-list controls.

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
Lee et al. (2013)	IG: Brain-computer interface	Details not in paper/ no response to query	8 weeks 24 sessions	Baseline Post-intervention 16 weeks	IG: 15 CG: 16	Mini-Mental State Examination, Repeatable Battery for the Assessment of Neuropsychological Status	No significant differences in any cognitive measure between groups
Uchida and Kawashima, (2008)	IG: Reading and arithmetic problems	Elementary schools	23 weeks Daily sessions and homework 4-6 times p/w	Baseline Post-intervention 52 weeks	IG: 49 CG: 46	Mini-Mental State Examination, Frontal Assessment Battery, digit symbol substitution (from Wechsler Adult Intelligence Scale-R)	Intervention group improved significantly more on the Frontal Assessment Battery and digit symbol substitution; maintenance of benefits in intervention group at follow-up

Note: IG = Intervention Group; p/w = per week.

Table 6
Characteristics of studies – cognitive activity interventions versus passive controls.

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
Bugos (2007)	IG: Individualised piano instruction	Details not in paper/no response to query	26 weeks 1 x 30 min session + 3 hours practice p/w	Baseline Post-intervention 9 months	IG: 16 CG: 15	Trail Making Test A & B; digit symbol substitution, digit span, block design, letter-number sequencing (from Wechsler Adult Intelligence Scale-III)	Intervention group improved significantly more on executive function, visuospatial processing and cognitive flexibility
Vaportzis et al. (2017)	IG: Tablet computer training	Libraries	12 weeks 1 session p/w + homework	Baseline Post-intervention	IG: 22 CG: 21	Mini-Mental State Examination; block design, similarities, digit span, matrix reasoning, arithmetic, coding, symbol search, visual puzzles, information, vocabulary (from Wechsler Adult Intelligence Scale-IV)	Intervention group improved significantly more on processing speed

Note: IG = Intervention Group; CG = Control Group; p/w = per week.

Table 7
Characteristics of studies – mixed physical-cognitive interventions versus active controls.

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
Barnes et al. (2013)	IG1: Computer intervention and aerobic exercise IG2: Computer intervention and stretching IG3: Watching educational DVD and aerobic exercise CG: Watching educational DVD and stretching	Home-based for mental activity and local YMCA for physical activity	12 weeks 3 x 1 hour sessions p/w	Baseline Post-intervention	IG1: 32 IG2: 31 IG3: 31 CG: 32	Modified Mini-Mental State Examination, Rey Auditory Verbal Learning Test, verbal fluency (letter and category), digit symbol substitution, Trail-Making Test A & B, Eriksen Flanker Test, congruent and incongruent reaction times, Useful Field of View, processing speed, divided attention, and selective attention	Global cognitive scores improved significantly over time but did not differ between groups
Desjardins-Crépeau (2016)	IG1: Multi-component exercise and dual-tasking IG2: Multi-component exercise and computer lessons IG3: Stretching, toning and dual-tasking CG: Stretching, toning and computer lessons	Gymnasium in a geriatric hospital institution	12 weeks 2 x 1 hour physical sessions and 1 x 1 hour cognitive session p/w	Baseline Post-intervention	IG1: 22 IG2: 16 IG3: 20 CG: 18	Rey Auditory Verbal Learning Test, Stroop, Trail-Making Test A & B, Baddeley Dual Task,	Intervention group improved significantly more on task-switching. Both All groups improved their processing speed and inhibition abilities. Participants in dual tasking conditions improved significantly more on task-switching.
Falbo (2016)	IG: Multi-component exercise and dual-task training CG: Multi-component exercise and single task training	Senior leisure centre	12 weeks 2 x 1 hour sessions	Baseline Post-intervention	IG: 20 CG: 16	Random number generation	Intervention group improved significantly more on inhibition
Gill (2016)	IG: Exercise and dual-tasking CG: Exercise only	Canadian Centre for Activity and Ageing	26 weeks 2-3 x 45 min sessions p/w IG: also performed dual-tasks during exercise (random arithmetic and verbal fluency)	Baseline 12 weeks Post-intervention 52 weeks	IG: 21 CG: 23	Mini-Mental State Examination, Montreal Cognitive Assessment, Trail Making Test A & B, digit symbol substitution, auditory verbal learning test, Controlled Oral Word Association	Intervention group improved significantly more on global cognitive function
Schättin (2016)	IG: Exergame CG: Balance	Senior residence dwelling	8-10 weeks 3 sessions x 30 min. p/w	Baseline Post-intervention	IG: 13 CG: 14	Mini-Mental State Examination; working memory, set-shifting/flexibility, divided attention visual and acoustic, go/no-go/ inhibition (from Test for Attentional Performance)	Intervention group improved significantly more on all measures of executive function, control group improved significantly on set-shifting
Yokoyama (2015)	IG: Multi-component exercise and concurrent cognitive task performance CG: Multicomponent exercise	Sports centre	12 weeks 3 x 1 hour sessions p/w	Baseline Post-intervention	IG: 12 CG: 13	Modified Mini-Mental State Examination, Trail Making Test A	Intervention group improved significantly more on immediate and delayed memory, attention, verbal fluency and understanding, visuospatial skills and reasoning

Note: IG = Intervention Group; CG = Control Group; p/w = per week.

Table 8
Characteristics of studies – mixed physical-cognitive interventions versus passive controls.

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
Ordnung et al. (2017)	IG: Exergame	Details not in paper/no response to query	6 weeks 2 x 1 hour session p/w	Baseline Post-intervention	IG: 14 CG: 15	Mini-Mental State Examination, Test of Attentional Performance, n-back task, go/no-go	No significant differences in any cognitive measure between groups

Table 9
Characteristics of studies – Other interventions.

Author (year)	Intervention	Setting	Duration	Data collection	N	Cognitive tests	Conclusion
Carlson et al. (2008)	IG: helped elementary school children with reading, library support and classroom behaviour CG: Wait-list	Elementary schools	17, 26, and 35 weeks of exposure 15 hours p/w	Baseline Post-intervention (after 4, 6 or 8 months of exposure depending on date of entry)	IG: 62 CG: 48	Mini-Mental State Examination, Trail Making Test A & B, Rey-Osterrieth Complex Figure Test, delayed recall, word list memory (from Iowa Established Populations for Epidemiologic Studies of the Elderly project)	Intervention group improved significantly more on executive function and memory
Myhre (2016)	IG: Facebook CG1: Online diary (active control) CG2: Wait-list	Details not in paper/no response to query	8 weeks IG: 3 x 2 hour training sessions (week 1), log in once a day, post 1 status update and 1 comment per day for 7 weeks CG1: 3 x 2 hour training sessions (week 1), 1 post per day for 7 weeks	Baseline Post-intervention	IG: 14 CG1: 13 CG2: 14	Mini-Mental State Examination; Rey Complex Figure, Rey Auditory Verbal Learning Test, digit-symbol substitution, Deary-Liewald reaction time task, Trail Making Test A & B, Controlled Oral Word Association test, category fluency, letter memory and keep track tests, global-local, letter number, Stroop, Simon task	Intervention group improved significantly more on a composite measure of updating

Note: IG = Intervention Group; CG = Control Group; p/w = per week.

Table 10
Meta-regression analyses for cognitive outcomes.

	Moderator variables					
	Intervention duration			Intervention frequency		
Cognitive outcomes	B	z	p	B	z	p
Stroop	0.01	0.82	0.41	0.05	1.31	0.19
Trail Making Test A	−0.01	−0.76	0.44	0.01	0.07	0.94
Digit symbol substitution	0.00	−0.01	0.99	0.08	2.52	0.01

was consistently improved following physical activity interventions; this finding remained significant when all interventions (physical, cognitive and mixed) were compared against all control groups (active, wait-list and passive). We did not find any significant effects of cognitive and mixed interventions in the pooled analyses. Due to the variance in measures and outcomes of cognitive interventions, we were unable to include some studies and pooled estimates were not possible for mixed interventions due to the limited number of studies. Standardised training protocols and outcome measures are required to allow pooling of homogenous data.

Conflicts of interest

All authors declare that we have no conflicts of interest.

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