

Review

Exercise interventions for older adults: A systematic review of meta-analyses

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Abstract

Background: The evidence concerning which physical exercise characteristics are most effective for older adults is fragmented. We aimed to characterize the extent of this diversity and inconsistency and identify future directions for research by undertaking a systematic review of meta-analyses of exercise interventions in older adults.

Methods: We searched the Cochrane Database of Systematic Reviews, PsycInfo, MEDLINE, Embase, CINAHL, AMED, SPORTDiscus, and Web of Science for articles that met the following criteria: (1) meta-analyses that synthesized measures of improvement (e.g., effect sizes) on any outcome identified in studies of exercise interventions; (2) participants in the studies meta-analyzed were adults aged 65+ or had a mean age of 70+; (3) meta-analyses that included studies of any type of exercise, including its duration, frequency, intensity, and mode of delivery; (4) interventions that included multiple components (e.g., exercise and cognitive stimulation), with effect sizes that were computed separately for the exercise component; and (5) meta-analyses that were published in any year or language. The characteristics of the reviews, of the interventions, and of the parameters improved through exercise were reported through narrative synthesis. Identification of the interventions linked to the largest improvements was carried out by identifying the highest values for improvement recorded across the reviews. The study included 56 meta-analyses that were heterogeneous in relation to population, sample size, settings, outcomes, and intervention characteristics.

Results: The largest effect sizes for improvement were found for resistance training, meditative movement interventions, and exercise-based active videogames.

Conclusion: The review identified important gaps in research, including a lack of studies investigating the benefits of group interventions, the characteristics of professionals delivering the interventions associated with better outcomes, and the impact of motivational strategies and of significant others (e.g., carers) on intervention delivery and outcomes.

Keywords: Intervention; Meta-analyses; Old; Physical exercise; Systematic review

1. Introduction

Demographics are changing globally with the shift toward an aging population. Over the past 50 years, the number of adults over age 65 has tripled, and by 2050, older people will represent 25% of the population worldwide.^{1–3}

Despite advances in medicine, health care, and social conditions, longer life expectancy is not necessarily matched with increased health.⁴ Engagement in exercise has multiple health benefits and can slow some of the negative effects of aging.⁵ For example, exercise improves physiological outcomes in older people who have gone through long periods of sedentary lifestyle,⁶ nonagenarians,⁷ and older individuals with frailty⁸ or sarcopenia.⁹ Exercise is defined as “planned, structured and repetitive physical activity”.¹⁰

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In recent years, guidelines have been developed for exercise levels appropriate for older adults. The World Health Organization recommends that older adults engage in ≥ 150 min of moderate-intensity aerobic exercise or ≥ 75 min of vigorous-intensity aerobic exercise per week or an equivalent combination of the two.¹¹ To produce numerous benefits, including cardiorespiratory and muscular fitness, this exercise should be performed in bouts of 10 min or more.^{11,12} Weight-bearing activities can help maintain bone and functional health.¹² Staying physically active also reduces noncommunicable disease, depression, and cognitive decline. Additional health benefits can be obtained by gradually increasing the weekly time dedicated to exercise.^{11,12}

Older adults who have poor mobility should still engage in exercise at least 3 times a week to strengthen major muscle groups, maintain or improve balance, and reduce the risk of falls.^{11,12} Older adults who cannot exercise due to poor health conditions should, as much as possible, engage in physical activity that is commensurate with their abilities.¹¹ The UK Chief Medical Officers' Physical Activity Guidelines state that even a minimal level of physical activity (e.g., standing), as opposed to being sedentary, generates some health benefits.¹²

These guidelines reflect the widespread consensus that "If physical activity were a drug, we would refer to it as a miracle cure, due to the great many illnesses it can prevent and help treat."¹² Despite the overall view that exercise is beneficial, the evidence around which exercise characteristics (e.g., type of exercise, intensity, duration, and frequency) are most effective for older adults is fragmented. Different types of exercise interventions have been delivered to healthy^{13–33} and nonhealthy older adults^{34–46} in different types of settings (e.g., community,^{23,47} residential care homes,^{38,39} private homes^{24–27}) and with various types of support (e.g., provided by professionals¹⁶ or students⁴¹). These interventions are aimed at improving a range of outcome measurements, such as physical functioning,^{13,33,48} falls,^{14,34} and mental functioning.^{29,44,45} The diversity of these interventions generates inconsistent findings in studies that examine them and makes comparisons among different studies (and exercise configurations) highly challenging.

We sought to characterize the extent of this diversity and inconsistency in study findings and to identify future directions for practice and research by undertaking a systematic review and synthesis of the literature on exercise among older people. The research questions we posed were:

- How diverse are the characteristics of exercise interventions for older adults?
- How inconsistent are the findings around outcome parameters and improvement of health through exercise interventions?
- Is it possible to determine which interventions are most effective in achieving certain outcome parameters?

We aimed to answer these questions through the following goals:

- Objective 1: reporting on the characteristics of exercise interventions for older adults.
- Objective 2: investigating which outcome parameters significantly improved through various intervention characteristics (e.g., type and duration).
- Objective 3: identifying and ranking the interventions that are linked to the greatest improvements in outcome parameters.

2. Methods

A systematic literature review of meta-analyses was deemed appropriate to synthesize and organize into a manageable format the wealth of evidence available from multiple sources.⁴⁹ The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.⁵⁰ [Supplementary Table 1](#) shows where in our review each of the items in the checklist was addressed. A protocol for our review was published in the international database of prospectively registered systematic reviews in health and social care (PROSPERO).⁵¹

2.1. Search

The search strategy ([Supplementary Table 2](#)) was based on the Population, Intervention, Comparison, Outcome worksheet for conducting systematic reviews⁵² and was developed by an expert librarian from the University of Nottingham. Two searches were performed (one in December 2018 and one in March 2020) in 8 databases: the Cochrane Database of Systematic Reviews, PsycInfo, MEDLINE, Embase, CINAHL, AMED, SPORTDiscus, and Web of Science.

2.2. Study selection and appraisal

All initial records were imported into Endnote. Duplicate records were removed. Three authors (CDL, AL, and VvdW) carried out title and abstract screening and eliminated ineligible studies. Each record was independently screened by 2 authors to ensure accuracy in selection. The same authors then screened the full texts of the remaining records against the inclusion/exclusion criteria (see below). Each record was, again, independently screened by 2 authors, and any disagreement was discussed to reach consensus. The number of records excluded and the reasons for exclusion were recorded. The references of the included reviews were screened to identify additional eligible studies.

2.2.1. Inclusion criteria

The literature review we conducted included:

- Meta-analyses that synthesized measures of improvement (e.g., effect sizes) on any outcome identified in studies of exercise interventions. An operational definition of exercise is given in the Introduction Section.
- Meta-analyses that included studies of any type of exercise, including its duration, frequency, intensity, and mode of

delivery. If the intervention included multiple components (e.g., exercise and cognitive stimulation), effect sizes must have been computed separately for the exercise component.

- Meta-analyses of studies in which participants were 65 years of age or older, or if the age inclusion criterion for the study was below 65 years of age or was not reported, the overall sample mean for age had to be at least 70 years old.
- Meta-analyses that were published in any year or language.

2.2.2. Exclusion criteria

The review we conducted excluded:

- Literature reviews that did not include meta-analyse data; empirical studies; conference abstracts; or any other type of paper (e.g., editorials).
- Literature reviews of studies in which participants were younger than 65 years of age, or, if the age inclusion criterion of the review was younger than 65 years of age or not reported, the overall sample mean was also below 70 years of age.
- Literature reviews that did not include an exercise component (e.g., studies focused only on functional ability or physical activity).

2.3. Study-quality appraisal

Three raters (CDL, AL, and VvdW) independently assessed the quality of the included reviews using the Critical Appraisal Skills Programme (CASP) checklist for systematic reviews.⁵³ Each article was appraised by 1 rater only. The highest possible score of the quality appraisal was 10, with higher scores showing higher quality.

2.4. Data extraction and synthesis

Data extraction was guided by the 3 objectives. An *ad hoc* form, informed by the Cochrane data extraction form,⁵⁴ was used. The form was first piloted in a random sample of 3 reviews and then was used to extract study characteristics (i.e., author, year, number of studies included, population, sample size, and participants' ages), interventions characteristics (i.e., setting, type of intervention, duration, and frequency), and findings from the meta-analyses (review outcomes and measures of improvements). The data were extracted by the main author (CDL) and checked for accuracy by 2 other authors (AL and VvdW).

The characteristics of the reviews and of the interventions (Objective 1) were reported through narrative synthesis. In relation to the parameters improved through exercise (Objective 2), 1 author (CDL) synthesized the data into outcomes as they emerged from the individual reviews. The outcomes were then grouped by the same author into themes (i.e., umbrella outcomes). The process was checked for accuracy by 2 authors (AL and VvdW). Identification of the interventions linked to the largest improvement in outcome parameters (Objective 3) was carried out by identifying the highest values for improvement by outcome, recorded across the reviews.

Different studies used different measures to report on effect size (Table 1). To assist with comparing effect sizes across the

Table 1
Measures for effect sizes used in the studies.

Effect size measure	Abbreviation
Standard mean deviation	SMD
Hedge's <i>g</i>	<i>g</i>
Mean deviation	MD
Odds ratio	OR
Incidence rate ratio	IRR
Rate ratio	RaR
Mean weighted effect size	MWES
Relative risk	RR
Weighted mean difference	WMD

various studies, absolute value test statistics (AVTS) were calculated following the procedure outlined by Altman and Bland.⁵⁵ AVTS are a measure of statistical significance regarding the strength of the effect size (i.e., the larger the AVTS the more significant the effect). Using the effect-size point estimates and their corresponding 95% confidence intervals (95% CIs), we calculated the standard error and AVTS for each result as follows:

$$SE = (95\%CI \text{ upper bound} - 95\%CI \text{ lower bound}) / (2 \times 1.96)$$

$$AVTS = \left| \text{effect size} / SE \right|$$

Where the underlying measure was an odds ratio or a risk ratio, we first log-transformed the effect sizes and corresponding 95%CI before calculating their standard errors and AVTS. Once the AVTS for each study were computed, we then aggregated them by outcome/exercise/sample types using means and medians to aid our interpretation of the results. This allowed us to rank the interventions based on their aggregated effect sizes.

3. Results

3.1. Study selection

The initial search (December 2018) retrieved 1305 sources. Upon title and abstract screening, 985 were deemed ineligible, and 61 were removed because they were duplicates. The full texts of 259 sources were screened against the inclusion/exclusion criteria. A total of 116 sources were removed because they were not meta-analyses, 85 were removed because they had an age inclusion criterion below 65 or a mean age below 70, and 20 were removed because they did not involve exercise interventions. A total of 35 meta-analyses were included. After screening the reference lists of the included meta-analyses, 3 additional meta-analyses were added, for a total of 38.

The second search (March 2020) limited sources to those published between December 2018 (the ending month and year of the initial search) and March 2020. The search retrieved 118 sources. Upon title and abstract screening, 72 were deemed ineligible, and 8 were removed because they were duplicates. The full texts of 38 sources were screened against the inclusion/exclusion criteria. Of these sources, 6 were removed because they were not meta-analyses, 13 were removed because they had an age

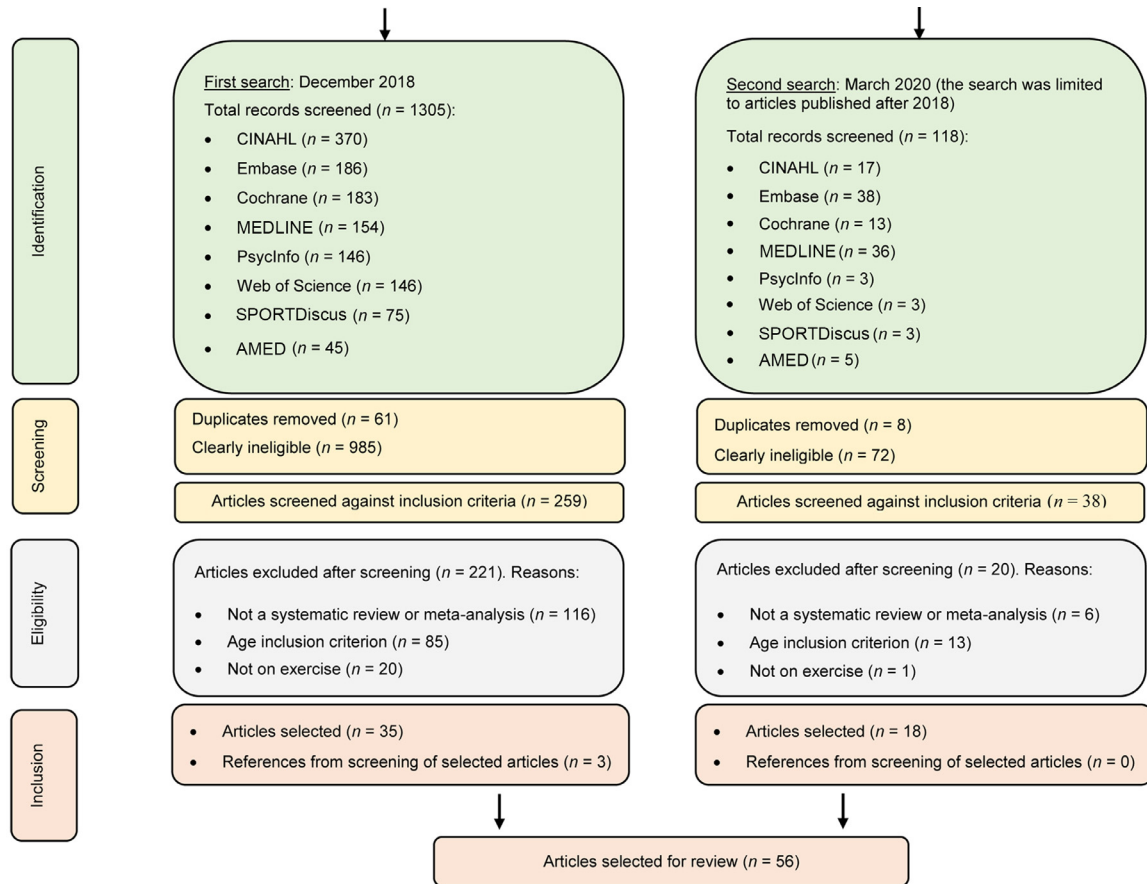


Fig. 1. Selection of papers.

inclusion criterion below 65 or a mean age below 70, and one was removed because it did not involve an exercise intervention. The 18 meta-analyses identified as eligible from the second search were added to the 38 identified in the first search, for a total of 56 meta-analyses included in our review.

Study selection is reported in Fig. 1 through a PRISMA flow diagram.⁵⁰

3.2. Study quality appraisal

Results from the quality appraisal are reported in Table 2. One review (2%) scored 4 points,²⁹ 4 reviews (7%) scored 6 points,^{13,25,40,44} 9 reviews (16%) scored 8 points,^{20–22,30–32,36,45,46} 19 reviews (34%) scored 9 points,^{14–16,18,19,23,26,28,34,35,37,38,41,43,47,48,56–58} and 23 (41%) scored 10 points.^{17,27,33,39,42,59–75} The items with the highest scores had clarity in the focus of the review and had higher scores for the appropriateness of included papers ($n = 56$, 100%). The items with lowest scores had lower scores for the inclusion of all relevant studies ($n = 40$; 71%) and for balance between benefits and costs ($n = 44$; 79%).

3.3. Review characteristics

The characteristics of the included reviews are reported in Table 3. The reviews were conducted between 2000 and 2020.

They were all in English, except for one in Portuguese.³⁴ The number of studies included in the meta-analyses ranged from 4⁴¹ to 238²⁷ (mean = 28, SD = 38). The reviews focused on healthy older adults ($n = 33$; 59%),^{13–26,28–33,47,48,57,58,60–63,65,67,70,72,75} older adults with physical health problems (including reduced physical capacity and frailty) ($n = 15$; 27%),^{34–36,38,39,43,57,61,64,66,69,71–74} people with cognitive impairment or dementia ($n = 9$; 16%),^{37,56,40–42,44,45,58,61} older adults with mental health conditions (i.e., depression) ($n = 2$; 4%),^{46,68} and postmenopausal women ($n = 1$; 2%).³¹ The age inclusion criteria varied: in half of the meta-analyses ($n = 29$; 52%) it was 65 years old,^{13–16,18–21,24,26,27,30,31,35–37,39,44,48,56,57,63,64,68–71,73,74} and in a third of the meta-analyses ($n = 22$; 39%) it was 60 years old.^{17,23,25,26,28,29,34,40,41,43,46,47,59–61,65–67,72–75} A total of 32 reviews (57%) reported the mean age of the participants in the included studies (range = 70–84, mean = 75, SD = 4).^{15–18, 21–23,25–30,33,37,41–44,47,56–63,70–73} Although the age-inclusion criterion was not reported in 3 meta-analyses (5%)^{38,42,45} and was below 60 years of age in two of them (4%),^{58,62} these 5 meta-analyses were still included in the review because the mean age of participants was above 70 (per the inclusion criteria).

The number of participants included in the meta-analyses was not reported in 4 cases (7%).^{13,19,32,62} In the remainder of the cases, it ranged from 291 to 159,910 (mean = 6713; SD = 26,415). Healthy older adults totaled 287,890; older adults with cognitive

Table 2
Quality appraisal.

Main author, year	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Y (n)
Antoniak (2017) ¹⁶	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Arent (2000) ³²	Y	Y	Y	U	Y	Y	U	Y	Y	Y	8
Burton (2015) ⁴¹	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Chan (2015) ⁴²	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Cheng (2018) ²³	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Chou (2012) ³⁸	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Crocker (2013) ⁵⁹	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
de Souto-Barreto (2017) ²⁹	Y	Y	U	Y	U	Y	N	N	U	N	4
de Souto-Barreto (2019) ⁶⁰	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Fairhall (2011) ²⁸	Y	Y	Y	Y	Y	Y	Y	U	Y	Y	9
Falck (2019) ⁶¹	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Farlie (2019) ⁶²	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Finnegan (2019) ⁶³	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Garcia-Hermoso (2020) ⁵⁷	Y	Y	Y	U	Y	Y	Y	Y	Y	Y	9
Gates (2013) ⁴⁴	Y	Y	U	Y	Y	N	N	U	Y	Y	6
Giné-Garriga (2014) ³⁹	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Guo (2014) ⁴⁰	Y	Y	U	N	U	Y	Y	U	Y	Y	6
Heinzel (2015) ⁴⁶	Y	Y	Y	Y	U	Y	Y	Y	U	Y	8
Heyn (2004) ⁵⁶	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Heyn (2008) ³⁷	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	9
Hill-Westmoreland (2002) ²²	Y	Y	N	Y	Y	Y	Y	Y	Y	U	8
Hu (2016) ²⁴	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Jung (2009) ²⁵	Y	Y	N	U	Y	Y	Y	Y	N	U	6
Karr (2014) ³⁰	Y	Y	U	Y	Y	Y	Y	Y	Y	U	8
Kuijlaars (2019) ⁶⁴	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Kumar (2016) ²⁶	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	9
Labott (2019) ⁶⁵	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Lacroix (2017) ¹⁵	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Liang (2018) ⁴⁵	Y	Y	U	Y	Y	Y	Y	Y	Y	U	8
Liao (2017) ¹⁷	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Liao (2019) ⁶⁶	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Liu (2017) ³⁴	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Marin-Cascales (2018) ³¹	Y	Y	U	Y	Y	Y	Y	Y	Y	N	8
Marinus (2019) ⁶⁷	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Miller (2019) ⁶⁸	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Naseri (2018) ⁴⁷	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	9
Pengelly (2019) ⁶⁹	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Pessoa (2017) ¹³	Y	Y	U	Y	Y	U	U	Y	Y	N	6
Robertson (2002) ²¹	Y	Y	Y	N	Y	Y	Y	N	Y	Y	8
Rogan (2017) ¹⁹	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	9
Sanders (2019) ⁵⁸	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	9
Sansano-Nadal (2019) ⁷⁰	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Sexton (2019) ⁷¹	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Sherrington (2019) ⁷²	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Sohng (2005) ¹⁴	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	9
Steib (2010) ⁴⁸	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	9
Taylor (2018) ¹⁸	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	9
Tricco (2017) ²⁷	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Van Abbema (2015) ³³	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Verweij (2019) ⁷³	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Wright (2018) ³⁶	Y	Y	Y	Y	Y	Y	Y	Y	N	N	8
Wu (2015) ⁴³	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	9
Yamamoto (2016) ³⁵	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	9
Yeun (2017) ²⁰	Y	Y	Y	N	Y	Y	Y	Y	N	Y	8
Zhang (2020) ⁷⁴	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Zhao (2019) ⁷⁵	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Y (n)	56	56	40	49	54	55	53	51	52	44	

Notes:

Item 1. Did the review address a clearly focused question?

Item 2. Did the authors look for the right type of papers?

Item 3. Do you think all the important, relevant studies were included?

Item 4. Did the review's authors do enough to assess quality of the included studies?

Item 5. If the results of the review have been combined, was it reasonable to do so?

Item 6. What are the overall results of the review? (i.e., Are the review's "bottom line" results clear?)

Item 7. How precise are the results?

Item 8. Can the results be applied to the local population?

Item 9. Were all important outcomes considered?

Item 10. Are the benefits worth the harms and costs?

Abbreviations: N = no; U = uncertain; Y = yes.

Table 3
Review characteristics, as reported in the individual studies.

Main author, year	Studies included (<i>n</i>)	Target population	Sample size (<i>n</i>)	Age (year)	Review outcome
Antoniak (2017) ¹⁶	7	Older adults	792	Mean age: 72.8	Musculoskeletal health (i.e., muscle strength, bone mineral density, Timed Up & Go, lean mass, balance, endurance, sit-to-stand test, normal walking speed, and chair stand)
Arent (2000) ³²	32	Older adults	Not reported	Inclusion: >60	Mood (i.e., negative and positive affect)
Burton (2015) ⁴¹	4	Older adults with dementia or cognitive impairment	336	Mean age: 80	Mean falls and faller status (i.e., faller vs. non-faller)
Chan (2015) ⁴²	7	Older adults with dementia or cognitive impairment	781	Mean age: 80	Number of falls
Cheng (2018) ²³	49	Older community dwellers	27,740	Age range: 67.5–88.0; mean age: 73.0	Falls-related outcomes (number of fallers, length of follow-up, effect of the intervention)
Chou (2012) ³⁸	8	Frail older adults	1068	Age range: 75.3–86.8	Physical function assessed by the Timed Up & Go test, gait speed, or Berg Balance Scale, performance in ADLs evaluated by the validated questionnaire or reliability inventory, and QoL evaluated by the Medical Outcomes Study 36-Item Short-Form Health Survey
Crocker (2013) ⁵⁹	13	Older residents in long-term facilities	2379	Mean age: 84	Independence in ADLs measured through Barthel Index, FIM, Katz Index of Independence in ADL, Physical Self-Maintenance Scale and the Minimum Data Set
de Souto-Barreto (2017) ²⁹	5	Older adults	2878	Mean age: 75.2	Onset of dementia and cognitive impairment
de Souto-Barreto (2019) ⁶⁰	40	Older adults	21,868	Mean age: 73.1	Risk of falls, fractures, hospitalizations, and mortality
Fairhall (2011) ²⁸	15	Older adults	3616	Mean age: 74.6	Participation in life roles
Falck (2019) ⁶¹	48	Healthy older adults, or frail, or with cognitive impairment	6281	Mean age: 73	Physical and cognitive function
Farlie (2019) ⁶²	95	Older adults	Not reported	Mean age: 74.5	Balance
Finnegan 2019) ⁶³	24	Older community dwellers	7818	Mean age: 70	Rate of falls
Garcia-Hermoso (2020) ⁵⁷	99	Healthy older adults and clinical older adults	28,523	Mean age: 74	Mortality, falls and fall-associated injuries, fractures, physical function, quality of life, and cognition
Gates (2013) ⁴⁴	14	Older adults with cognitive impairment	1695	Age range: 65–95; mean age: 76	Validated neuro-psychological test of cognition reported at baseline and follow-up
Giné-Garriga (2014) ³⁹	19	Frail older adults	2063	Inclusion: >65	Performance-based measures of physical function such as mobility, gait, muscular strength, balance, endurance and disability in ADLs
Guo (2014) ⁴⁰	111	Older adults with/without cognitive impairment	51,551	Age range: 64.5–89.0	Number of falls
Heinzel (2015) ⁴⁶	18	Older adults with depression	1063	Inclusion: >60	Depression
Heyn (2004) ⁵⁶	30	Older adults with cognitive impairment and dementia	2020	Age range: 66–91; mean age: 80	Physical fitness
Heyn (2008) ³⁷	41	Older adults with/without cognitive impairment	2921	Age range: 68–91; mean age: 81	Endurance and strength outcomes
Hill-Westmoreland (2002) ²²	12	Older adults	4074	Mean age: 76.5	Number of falls
Hu (2016) ²⁴	10	Older adults	2850	Age range: 64–84	Number of falls

(continued on next page)

Table 3 (Continued)

Main author, year	Studies included (<i>n</i>)	Target population	Sample size (<i>n</i>)	Age (year)	Review outcome
Jung (2009) ²⁵	6	Older adults	957	Mean age: 76.5	Fear of falling, as measured by Falls Efficacy Scale, the Activities-Specific Balance Confidence Scale and the Survey of Activities and Fear of Falling in the Elderly
Karr (2014) ³⁰	25	Older adults	1878	Mean age: 74	Executive function (working memory, inhibition, executive attention, problem solving, and fluency)
Kuijlaars (2019) ⁶⁴	9	Older patients with hip fractures	602	Inclusion: >65	Mobility, ADLs, endurance, gait, balance, and strength
Kumar (2016) ²⁶	30	Older adults	2878	Inclusion: ≥65	Fear of falling measured through scales measuring falls efficacy, balance confidence, and concern or worry about falling
Labott (2019) ⁶⁵	24	Healthy community dwellers	3018	Inclusion: >60	Handgrip strength
Lacroix (2017) ¹⁵	11	Older adults	621	Age range: 65.3–81.1; mean age: 73.6	Balance and muscle strength
Liang (2018) ⁴⁵	17	Older adults with cognitive impairment or Alzheimer's disease	1747	Age range: 70–83	Cognition
Liao (2017) ¹⁷	17	Older adults	892	Mean age: 73.4	Body composition and physical function
Liao (2019) ⁶⁶	19	Hospitalized, institutionalized or community-dwelling elderly individuals with a high risk of sarcopenia or frailty and physical limitations	1888	Inclusion: >60	Muscle mass, sarcopenia, leg strength, or physical function
Liu (2017) ³⁴	23	Older adults with reduced physical capacity	2019	Inclusion: >60	Muscle strength of the lower extremity, physical functioning, ADLs, and falls
Marin-Cascales (2018) ³¹	10	Postmenopausal older women	462	Inclusion: >65	Bone health (total, femoral neck, and lumbar spine bone mineral density)
Marinus (2019) ⁶⁷	17	Older adults	982	Inclusion: >60	Peripheral blood brain-derived neurotrophic factor concentrations
Miller (2019) ⁶⁸	15	Older adults with depression	596	Inclusion: >65	Depression
Naseri (2018) ⁴⁷	16	Older adults recently discharged from hospital to the community	3290	Age range: 70–84; mean age: 77	Falls
Pengelly (2019) ⁶⁹	11	Older cardiac adults	1797	Inclusion: >65	Physical and cognitive function
Pessoa (2017) ¹³	9	Older adults	Not reported	Inclusion: ≥65	Muscle strength and quality of life
Robertson (2002) ²¹	4	Older adults	1016	Age range: 65–97; mean age: 82.3	Number of falls and number of injuries resulting from falls
Rogan (2017) ¹⁹	33	Older adults	Not reported	Inclusion: >65	Postural control (static, dynamic, and functional balance)
Sanders (2019) ⁵⁸	36	Adults with/without cognitive impairments	2007	Mean age: 73	Cognition
Sansano-Nadal (2019) ⁷⁰	12	Older community dwellers	1991	Mean age: 76	Time spent doing exercise at 6-month follow-up
Sexton (2019) ⁷¹	14	Older adults living with a health condition or impairment	921	Mean age: 81	Impairment, activity, and participation levels
Sherrington (2019) ⁷²	108	Older community dwellers	23,407	Mean age: 76	Falls
Sohng (2005) ¹⁴	8	Older adults	843	Age range: 71–84	Falls, balance, and muscle strength
Steib (2010) ⁴⁸	29	Older adults	1313	Inclusion: ≥65	Strength and function

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Table 3 (Continued)

Main author, year	Studies included (n)	Target population	Sample size (n)	Age (year)	Review outcome
Taylor (2018) ¹⁸	18	Older adults	765	Mean age community-dwelling participants: 75.6; mean age hospitalised or nursing home older participants: 85.3	Physical performance
Tricco (2017) ²⁷	238	Older adults	159,910	Mean age: 78.1	Injurious falls and fall-related hospitalisations
Van Abbema (2015) ³³	25	Older adults	2389	Mean age: 75.8	Gait speed
Verweij (2019) ⁷³	15	Older adults discharged from hospital	1255	Mean age: 74	Mobility and hospital readmission
Wright (2018) ⁵⁶	11	Nutritionally vulnerable older adults	1459	Inclusion: ≥ 65	Physical functioning, quality of life, and nutritional status
Wu (2015) ⁴³	14	Older adults, older patients after stroke, and older adults with diabetes	1225	Mean age: 70.3	Quality of sleep
Yamamoto (2016) ³⁵	5	Older adults with coronary heart disease	291	Inclusion: ≥ 65	Muscle strength, exercise capacity, and mobility
Yeun (2017) ²⁰	19	Older adults	649	Inclusion: ≥ 65	Flexibility and balance
Zhang (2020) ⁷⁴	22	Community-dwelling frail older adults	2456	Inclusion: > 65	Physical functioning, ADL, quality of life
Zhao (2019) ⁷⁵	25	Older adults	7076	Inclusion: > 60	Falls-related injuries and hospitalization

Abbreviations: ADL = activities of daily living; FIM = functional independence measure; QoL = Quality of Life.

impairment/dementia totaled 63,100; older adults with physical health problems totaled 14,060; older adults with mental health conditions totaled 1659; and postmenopausal women totaled 462.

In relation to study outcomes, 26 meta-analyses (46%)^{13–20,33–39,48,56,57,61,62,64–66,69,70,74} focused on physical functioning (e.g., strength), physical health, and physical exercise (including mobility); 18 (32%)^{14,21–27,34,40–42,47,57,60,63,72,73} focused on falls-related outcomes (e.g., number of falls), injuries, and mortality; 10 (18%)^{28,34,36,38,43,57,59,64,71,74} focused on independence in activities of daily living (ADLs), quality of life, quality of sleep, and functioning in society (participation); 10 (18%)^{29,30,44,45,57,58,61,67,69,71} focused on brain functioning (e.g., cognition); 3 (5%)^{16,31,66} focused on musculoskeletal health and bone density; and 3 (5%)^{32,46,68} focused on mood.

3.4. Objective 1: characteristics of exercise interventions

The characteristics of exercise interventions (Table 4) were extremely diverse. In relation to delivery setting, 24 (43%) interventions,^{14,16,21,24–27,29,34,38–42,44,46,60,64,65,70,71,73–75} were delivered in the participants' homes, 14 (25%)^{16,24–26,29,34,38–44,59} were delivered in residential retirement homes, 14 (25%)^{14,18,21,23,27,36,43,44,46–48,68,69,71} were delivered in community settings (e.g., community centers), 11 (20%)^{14,18,27,28,36,40,43,69–71,73} were delivered in health care settings (e.g., hospitals), and 6 (11%)^{16,18,28,33,36,40} were delivered in care homes/nursing homes. The interventions were delivered in multiple settings in 50% of the reviews ($n = 28$).^{14,16,18,24–29,34,36,38–44,46,60,65,68–71,73–75} The setting was not reported or specified in 19 reviews (34%).^{13,15,17,19,30–32,35,37,45,56–58,61–63,66,67}

Intervention duration varied as well. A total of 9 interventions (16%) lasted up to 24 weeks (6 months);^{17,20,32,35,43,46,67,68,73} 26 (46%) lasted between 25 and 52 weeks (6–12 months);^{13–15,18,19,24,26,28,30,31,33,34,38,39,41,42,44,48,56,58,59,64,66,69,71,74} and 11 (20%) lasted more than 53 weeks (more than 12 months).^{16,27,29,37,45,57,60,61,63,65,72} This information was not reported in 9 reviews (16%).^{21–23,25,40,47,62,70,75} Regarding intervention frequency (i.e., number of sessions per week), 7 reviews (12%)^{13,14,16,18,42,67,70} included interventions requiring participants to exercise up to 3 times a week, 12 (21%)^{15,19,20,30,32,33,35,36,41,44,58,60} up to 5 times a week, and 23 (41%)^{17,24,26,28,29,31,38,39,43,46,48,56,57,59,61,64–66,69,71–74} more than 5 times a week. This information was omitted in 12 (21%) reviews.^{21–23,25,27,40,45,47,62,63,68,75}

The interventions were either wholly based on physical exercise ($n = 43$; 77%)^{13–21,24,26,28–36,39–43,46,48,57,58,60–63,66–75} or had several components (one of which was exercise) ($n = 11$; 20%).^{22,23,25,27,38,47,56,59,64,65,71} A total of 9 reviews (16%)^{22,23,25,27,42,45,47,56,70} did not specify the type of physical exercise. A total of 31 reviews (55%) did provide details on physical exercise, which included strength, power, and resistance training (e.g., weights, Thera-band);^{14–17,20,21,26,28,32–39,41,44,46,48,57–61,64–69} 24 (43%) included endurance (i.e., cardio fitness, aerobics, dancing, cycling),^{14,15,28–30,32–34,37–39,44,46,57,60,61,64–66,68,69,72–74} 17

Table 4
Characteristics of exercise interventions.

Main author, year	Type of exercise	Setting	Intervention duration	Intervention frequency
Antoniak (2017) ¹⁶	Supervised, progressive exercise sessions, including a warm-up and strengthening exercises, using commercial weight and pulley machines, therabands, weighted vests and whole-body vibration machines for resistance balance	Home, retirement community, nursing homes, service flats, or cloistered communities	3–24 months	24–156 sessions
Arent (2000) ³²	Exercise such as cardiovascular, resistance training, or a combination	Not reported	1–12 weeks	Any
Burton (2015) ⁴¹	Strength, balance, and mobility exercises supervised by physiotherapists, occupational therapists, or physiotherapy students who were trained and supervised by physiotherapists	Residential care or home	3–12 months	1–5 per week
Chan (2015) ⁴² Cheng (2018) ²³	Home-based individual and group physical exercise (1) Usual care (no specific fall intervention), (2) education, (3) risk assessment and suggestion, (4) exercise, (5) medical care, (6) hazard assessment and modification, (7) combination of education and risk assessment, (8) combination of education and exercise, (9) combination of risk assessment and exercise, (10) combination of exercise and hazard assessment, and (11) multifactorial intervention, including 3 or more interventions	Residential care or home Community (excluding hospital, nursing home or other long-term care facilities)	3–12 months Not reported	1–5 every 2 weeks Not reported
Chou (2012) ³⁸	Flexibility, low or intensive resistance, aerobic, coordination, balance, and Tai Chi exercises; repetitive performance of ADLs and task-oriented or gait training	Residential care or home	3–12 months	1–7 per week
Crocker (2013) ⁵⁹	Group exercise classes, including resistance training or individual sessions of physiotherapy and/or occupational therapy	Long-term care facilities	10 weeks–12 months	2–6 per week
de Souto-Barreto (2017) ²⁹ de Souto-Barreto (2019) ⁶⁰	Tai Chi or multicomponent exercises or aerobic exercises Aerobics, resistance training, Tai Chi, dance, or multicomponent	Residential care or home Home or community	12–24 months 12 months+	2–6 per week 1.5–5 per week
Fairhall (2011) ²⁸	Single interventions (e.g., endurance, strength, balance) or a component of multiple interventions, one of which is physical exercise	Aged care facilities or hospital settings	1.5–12 months	1–7 per week
Falck (2019) ⁶¹	Aerobic, resistance, and multicomponent	Not reported	2 months+	1+ per week
Farlie (2019) ⁶²	Balance exercises	Not reported	Not reported	Not reported
Finnegan (2019) ⁶³	Gait, balance, and functional training, Tai Chi, walking	Not reported	6–24 months	Not reported
Garcia-Hermoso (2020) ⁵⁷	Multicomponent exercise, muscle strength, aerobic training, and Tai Chi	Home or community setting	52–208 weeks	1–7 per week
Gates (2013) ⁴⁴	Various types, including aerobic exercise, walking, resistance training, balance and aerobic training, balance and coordination training, Tai Chi, and face exercises	Gymnasiums, YMCA, local community, care center, residential site, or private home	6–52 weeks	2–4 per week

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Table 4 (Continued)

Main author, year	Type of exercise	Setting	Intervention duration	Intervention frequency
Giné-Garriga (2014) ³⁹	Combinations of aerobic, balance, flexibility, endurance and strength exercises; combinations of balance and strength exercises; strength exercise programs; a stretching intervention; activities related to maintain and improve performance in ADLs; progressive resistance-training program using weighted vests; the addition of visual computer feedback to balance training; whole-body vibration with exercise; or Tai Chi	Residential care or home	10 weeks–12 months	1–7 per week
Guo (2014) ⁴⁰	Various single or multicomponent physical exercise interventions and Tai Chi	Medical centers, hospitals, nursing homes, care homes, and private homes	Not reported	Not reported
Heinzel (2015) ⁴⁶	Aerobic exercise, resistance training, alternative exercise (Tai Chi, Qigong, dancing), and combined aerobic and resistance exercise	Community, including individual homes	6–24 weeks	1–6 per week
Heyn (2004) ⁵⁶	Walking (mobility training), combined walking with different types of isotonic exercises, chair exercises, aerobic dance, strength training with weights, stationary cycling combined with exercises, and skill-based functional exercise	Not reported	2–112 weeks	1–6 per week
Heyn (2008) ³⁷	Exercise programs, rehabilitative exercises, fitness, or recreational therapy	Not reported	2–40 weeks	2–6 per week
Hill-Westmoreland (2002) ²²	Exercise-focused interventions only and exercise interventions with risk modification	Not reported	Not reported	Not reported
Hu (2016) ²⁴	Tai Chi	Residential care or home	6–12 months	16–120 h per week
Jung (2009) ²⁵	Interventions for preventing falls or the fear of falling, including combined exercise and education intervention, an exercise intervention only, or a hip protector	Residential care or home	Not reported	Not reported
Karr (2014) ³⁰	Aerobic and nonaerobic exercise	Not reported	4–52 weeks	1–5 per week
Kuijlaars (2019) ⁶⁴	Aerobics, walking, strength exercises, resistance, weights, functional exercises, balance training, stretching, cognitive and behavioral strategies, environment modification, counseling, and self-efficacy motivational strategy	Home	1–12 months	2–7 per week
Kumar (2016) ²⁶	Tai Chi and yoga, balance training, and strength and resistance training	Home or places of residence without nursing care or rehabilitation	12–26 weeks	1–4 per week
Labott (2019) ⁶⁵	Aquatics, walking, flexibility exercises, aerobics, strength, balance, cognitive tasks, cycling, thera band, TRX training, chair exercises, endurance, recreational training, resistance training, whole-body vibration, dancing, Tai Chi, and calisthenics	Home and community	1–36 months	1–10 per week
Lacroix (2017) ¹⁵	Resistance, static/dynamic balance, strength, flexibility, endurance and stretching exercises, and Tai Chi	Not reported	4–44 weeks	2–5 per week
Liang (2018) ⁴⁵	Physical exercise (unspecified)	Not reported	12–54 weeks	Not reported
Liao (2017) ¹⁷	Resistance exercises	Not reported	8–24 weeks	2–7 per week
Liao (2019) ⁶⁶	Resistance, aerobic training, and multicomponent exercise	Not reported	3–9 months	2–7 per week

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Table 4 (Continued)

Main author, year	Type of exercise	Setting	Intervention duration	Intervention frequency
Liu (2017) ³⁴	Progressive resistance strength exercise and multimodal exercise, including strengthening, balance, stretching, endurance, and aerobic exercise	Residential care or home	5 weeks–1 year	2–3 per week
Marin-Cascales (2018) ³¹	Whole-body vibration	Not reported	12–52 weeks	2–7 per week
Marinus (2019) ⁶⁷	Strength, resistance, or multicomponent exercise	Not reported	6–24 weeks	2–3 per week
Miller (2019) ⁶⁸	Aerobic, resistance, or mind–body exercise	Community or residential care	4–16 weeks	Not reported
Naseri (2018) ⁴⁷	Falls prevention interventions, including home hazard modification, home exercise program, and cholecalciferol therapy	Community	Not reported	Not reported
Pengelly (2019) ⁶⁹	Aerobic and resistance training	Inpatient, outpatient, home-based, or community	1 week–6 months	1–7 per week
Pessoa (2017) ¹³	Whole-body vibration	Not reported	6–52 weeks	2–3 per week
Robertson (2002) ²¹	A program of muscle strengthening and balance-retraining exercises designed specifically to prevent falls and individually prescribed and delivered at home by trained health professionals	Private home	Not reported	Not reported
Rogan (2017) ¹⁹	Whole-body vibration	Not reported	10–52 weeks	3–5 per week
Sanders (2019) ⁵⁸	Aerobic, anaerobic, and multicomponent or psychomotor exercise	Not reported	4–52 weeks	1–5 per week
Sansano-Nadal (2019) ⁷⁰	Unspecified exercise	Community, hospital, home	8 weeks–24 months	2–3 per week
Sexton (2019) ⁷¹	Seated exercise	Residential care facilities, day care centres, home, hospital	6 weeks–7 months	1–7 per week
Sherrington (2019) ⁷²	Balance and functional exercises, resistance exercises, flexibility training, Tai Chi, dance, and walking	Community	5–130 weeks	1–3 per week
Sohng (2005) ¹⁴	Strength, balance, stretching, endurance, mobility, physiotherapy, and walking	Community, including private home, geriatric hospital inpatients, and outpatients	1–12 months	1–3 per week
Steib (2010) ⁴⁸	Resistance training, including progressive resistance training, power training, eccentric resistance training, isometric resistance training, and functional task training	Community	8–52 weeks	2–7 per week
Taylor (2018) ¹⁸	Exercise-based AVGs	Community, care homes, and acute hospital	3–30 weeks	2–3 per week
Tricco (2017) ²⁷	Exercise; combined exercise and vision assessment and treatment; combined exercise, vision assessment and treatment, and environmental assessment and modification; combined clinic-level quality improvement strategies (e.g., case management), multifactorial assessment and treatment (e.g., comprehensive geriatric assessment), calcium supplementation, and vitamin D supplementation	Private home, clinics, and community	1–260 weeks	Not reported
Van Abbema (2015) ³³	Progressive resistance training, endurance and strength training, Tai Chi, balance training, salsa-dancing training, or agility training	Community and long-term care institutions	9–48 weeks	1–5 per week

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Table 4 (Continued)

Main author, year	Type of exercise	Setting	Intervention duration	Intervention frequency
Verweij (2019) ⁷³	Walking, endurance exercises, strengthening exercises, and balance and stretching exercises	Nursing facilities, outpatient clinics, or home	2 weeks–12 months	1–6 per week
Wright (2018) ³⁶	High-intensity and/or progressive resistance training, Nordic walking, and intensive physiotherapy rehabilitation	Community, acute settings, and care centers	12 days–9 months	1–5 per week
Wu (2015) ⁴³	Meditative movement interventions, including Tai Chi, yoga, and Qigong	Community, long-term residential homes for the elderly, outpatient departments of rehabilitation facilities/hospitals, community seniors' centers, and physicians' offices	12–24 weeks	1–7 per week
Yamamoto (2016) ³⁵	Resistance training	Not reported	6–24 weeks	3–5 per week
Yeun (2017) ²⁰	Resistance exercise using elastic bands	Community	5–20 weeks	1–4 per week
Zhang (2020) ⁷⁴	Aerobic, endurance, resistance or strength exercise; flexibility training and balance training; and multicomponent exercise	Community, home	8–48 weeks	1–7 per week
Zhao (2019) ⁷⁵	Balance exercises, walking, and multicomponent exercise	Community, home	Not reported	Not reported

Abbreviations: ADL = activities of daily living; AVGs = active video games; TRX = total resistance exercise; YMCA = Young Men's Christian Association.

(30%) included meditative movement (i.e., Tai Chi, Qigong, yoga), mind–body exercises, and psychomotor exercises;^{15,24,26,33,38–40,43,44,46,57,58,60,63,65,68,72} 18 (32%) included balance and coordination (e.g., gait training);^{14,15,21,26,28,33,34,38,39,41,62–65,72–75} 11 (20%) included walking or mobility;^{14,36,37,41,44,63–65,72,73,75} 10 (18%) included flexibility and stretching;^{14,15,34,38,39,64,65,72–74} 7 (12%) included ADLs plus functional exercise;^{37–39,48,63,64,72} 6 (11%) included whole-body vibration;^{13,16,19,31,39,65} 4 (7%) included physiotherapy and physical rehabilitation;^{14,36,56,59} 3 (5%) included occupational and recreational therapy;^{56,59,65} 1 (2%) included agility training;³³ and 4 (7%) included other types of training (i.e., face training, exercise-based active videogames, aquatics, chair-based exercises, and calisthenics).^{18,44,65,71} A total of 25 reviews (45%) focused on multiple exercise interventions.^{14–16,21,23,25–30,32–34,36–41,44,48,56,58–61,63–66,68,69,72,75}

3.5. Objective 2: outcome parameters improved through exercise

3.5.1. Physical functioning, physical health, and physical exercise

Most reviews reported improvements in muscle strength.^{15–19,34–39,56,65,66,69,70,73} In healthy older adults, improved strength of the lower limbs was reported following progressive resistance training and multimodal exercises, the former producing larger sized effects (standard mean deviation (SMD) = 0.33) than the latter (SMD = 0.16).³⁴ Resistance training was also found to significantly increase lower- (SMD = 0.63; $p < 0.05$) and upper-extremity muscle strength (SMD = 1.18; $p < 0.05$).³⁵ Small but significant effects ($p < 0.01$) on handgrip strength were found in 1 review (SMD = 0.28; $p < 0.05$).⁶⁵ Supervision by clinicians during resistance training produced statistically significant effect sizes in improving overall muscle strength (SMD = 0.51; $p < 0.04$).¹⁵ Specifically, 10–29 additional supervised sessions produced the largest improvements (SMD = 1.12; $p < 0.05$).¹⁵

Nutritional supplementation plus exercise were linked to greater improvements in limb strength compared to exercise alone (SMD = 0.33; $p < 0.05$).³⁶ Muscle strength of the lower limbs was significantly improved when healthy older adults received vitamin D3 alongside supervised progressive exercise, compared to exercise or vitamin D3 separately (SMD = 0.98; $p < 0.01$).¹⁶ Protein supplementation plus resistance training produced greater leg-strength gains than physical exercise alone (SMD = 0.69; $p < 0.01$).¹⁷ One review found significant effects of exercise plus protein supplementation in older adults with sarcopenia and risk of frailty on handgrip (SMD = 0.44; $p < 0.01$) and leg strength (SMD = 0.65; $p < 0.01$).⁶⁶ Greater improvements in the combined exercise-and-protein-supplementation group were found among older adults with body mass indexes above 30 (SMD = 0.87; $p > 0.05$).¹⁷ Exercise also significantly improved muscle strength in people with cognitive impairment and dementia, following a walking and mobility training intervention (Hedge's $g = 0.75$; $p < 0.01$).³⁷ It was found that in cardiac patients, a higher volume of exercise yielded a significantly

positive effect on functional recovery (mean deviation (MD)=27; $p < 0.01$) and a trend toward improvement in cardiopulmonary capacity (MD=0.72; $p > 0.07$).⁶⁹

In relation to balance, it was found that multimodal exercise significantly improved dynamic standing balance in healthy individuals (SMD=0.46; $p < 0.01$).³⁴ Exercise-based active video games produced larger effect sizes than conventional exercise in Berg Balance scores (MD=4.33; $p < 0.05$).¹⁸ The positive effects of exercise extended to less physically able participants. Whole-body vibration was found to benefit dynamic balance in participants with physical limitations (SMD=-0.15; $p < 0.05$) and in those in need of care (SMD=-0.90; $p < 0.05$).¹⁹ Supervision during exercise led to larger improvements in static steady-state balance (SMD=0.28; $p < 0.01$), dynamic steady-state balance (SMD=0.35; $p > 0.05$), proactive balance (SMD=0.24; $p > 0.05$), and balance test batteries (SMD=0.53; $p < 0.05$).¹⁵

The reviews reported consistent improvements in gait speed following exercise. Multimodal exercise improved maximal (SMD=0.31; $p < 0.05$) and habitual gait speed (SMD=0.50; $p < 0.01$).³⁴ Positive effects in both normal (MD=0.06; $p < 0.01$) and fast gait speed (MD=0.08; $p < 0.01$) were also reported.³⁹ Two reviews investigated improvements in the Short Physical Performance Battery.^{16,39} Improvement in the test scores was reported following a combination of different exercise modalities (MD=1.87; $p < 0.01$)³⁹ and through physical exercise and vitamin D (SMD=1.09; $p > 0.05$).¹⁶ Improvement in the sit-to-stand test was reported in 2 reviews.^{18,34} These reviews found that the sit-to-stand test was significantly improved as a result of multimodal exercises (SMD=0.26; $p < 0.05$) and exercise-based video games (MD=3.99; $p < 0.05$). Results in the Timed Up & Go (TUG) test were less consistent. Although it was found that resistance exercise using elastic bands significantly increased TUG times (MD=2.39; $p < 0.01$),²⁰ progressive resistance training (SMD=-0.02) or multimodal exercise interventions (SMD=-0.41; $p > 0.05$) had no significant effects on TUG times.³⁴

Two reviews investigated the long-term outcomes of exercise.^{70,73} One study found that the exercise interventions improved exercise time in participants immediately postintervention (SMD=0.18; $p < 0.05$) and at the 6-month follow-up (SMD=0.30; $p < 0.05$).⁷⁰ However, long-term effects at the 1-year follow-up (SMD=0.27; $p > 0.05$) and 2-year follow-up (SMD=0.03; $p > 0.05$) were lost.⁷⁰ Another review found that older patients recently discharged from hospital walked an average of 23 m more than controls in the 3 months following delivery of rehabilitation exercises ($p > 0.05$).⁷³

3.5.2. Falls-related outcomes, injuries, and mortality

Several reviews investigated number of falls.^{14,21-27,34,40-42,47,57,60,63,72} Participation in exercise interventions resulted in falls reduction in noninstitutionalised (OR=0.78; $p < 0.01$) and institutionalised participants (OR=0.80; $p < 0.01$).^{22,40} Sherrington calculated, based on a risk of 850 falls in 1000 people followed over 1 year (data obtained from 59 studies included in the meta-analysis), that

participants in exercise interventions experienced 195 fewer falls than controls.⁷²

Multimodal exercise showed a particularly positive effect on reducing falls. In home-based muscle strengthening and balance-retraining interventions delivered by therapists, the overall reduction of falls was 35% (IRR=0.65; $p < 0.05$).²¹ A reduced falls rate resulted from multimodal exercise interventions in older adults with reduced physical capacity (RR=0.63; $p < 0.05$)³⁴ and in participants with cognitive impairment (RaR=0.68; $p < 0.01$)³⁴ and dementia (MD=-1.06; $p < 0.01$).^{41,42}

The association between delivery setting and number of falls was investigated in 1 review,⁴⁷ which reported that home interventions did not significantly reduce the falls rate (rate ratio (RaR)=1.27; $p > 0.05$). Large effects sizes in falls reduction were instead obtained through integrating physical exercise with falls-reduction strategies, such as home visits and environment modification (OR=0.75; $p < 0.05$)⁴⁰ or risk modification (mean weighted effect size (MWES)=0.06; $p < 0.01$) and comprehensive risk assessment (MWES=0.12; $p < 0.01$).²² Interventions combining exercise and education (OR=0.65) were more effective than those combining exercise and hazard assessment or hazard modification (OR=0.66).²³

The benefits of exercise on falls rate extended beyond the active intervention period. Finnegan found significant lasting effects of exercise at a 12-month follow-up (RaR=0.79; $p < 0.01$).⁶³ A significant reduction in falls at 12 months was also reported in another review (MWES=0.09; $p < 0.01$).²²

The risk of falling following exercise interventions was explored in 4 reviews.^{24,25,34,41} Strength, mobility, and balance exercises delivered in group-based interventions reduced the risk of falling by 32% (RR=0.68; $p < 0.01$).⁴¹ A 21% protective effect against risk of falls resulted from a multimodal exercise intervention.¹⁴ One review that looked at the effectiveness of Tai Chi in healthy older adults found a significantly reduced pooled estimated odds ratio for falls.²⁴ The effect declined 6 months after the end of the active intervention.²⁵

Two reviews investigated fear of falling.^{25,26} Significantly reduced fear resulted from exercise alone (MWES=0.02; $p < 0.05$), a combination of physical exercise and education (MWES=0.24; $p < 0.05$), interventions delivered in the community (MWES=0.22; $p < 0.05$) and in participants' homes (MWES=0.41; $p < 0.05$).²⁵ This review found that fear of falling decreased at 4-month follow-up (MWES=0.24; $p < 0.05$),²⁵ but another review²⁶ found that the positive effects were not statistically significant at a 6-month follow-up (SMD=0.17; $p > 0.05$). The same review²⁶ found no significant effect on fear of falling based on type of exercise, exercise frequency, duration of intervention, or falls risk status of participants, but it did find a significant effect of group (SMD=0.49; $p < 0.05$) over individual delivery (SMD=0.14; $p > 0.05$).

Eight reviews^{21,27,42,47,57,60,73,75} looked at injuries resulting from falls, hospitalization resulting from falls, and mortality resulting from falls. One review found that muscle strengthening and balance exercises reduced the number of participants

suffering injuries from falls (IRR = 0.65; $p < 0.05$) or being admitted to hospital because of a fall (OR = 0.52; $p < 0.05$).²¹ Another review confirmed that exercise significantly decreased the risk of injurious falls (RR = 0.74; $p < 0.05$) and resulting fractures (RR = 0.84; $p < 0.05$).⁷⁷ Exercise was also linked to a reduction in injurious falls when combined with vision assessment or treatment (OR = 0.17; $p < 0.05$) or with environmental assessment or modification (OR = 0.30; $p < 0.05$).²⁷ In 2 other reviews, however, the rate ratio for fractures related to falls did not change significantly with exercise (RaR = 1.47; $p > 0.05$),⁴² and exercise delivered at home did not significantly reduce the falls injury rate (RaR = 1.16; $p > 0.05$).⁴⁷ In 2 reviews, exercise was reported not to have a significant effect on mortality (RR = 0.93; $p > 0.05$ and RR = 0.96; $p > 0.05$).^{57,60}

3.5.3. Independence in activities of daily living, quality of life, quality of sleep, and functioning in society

Several reviews investigated independence in ADLs.^{34,59,64,74} A nonsignificant ($p > 0.05$) effect of progressive resistance (SMD = 0.13) or multimodal exercise programs (SMD = 0.37) on ADLs was reported among older adults with reduced physical capacity.³⁴ However, exercise improved independence in ADLs among older adults in residential care (SMD = 0.24; $p < 0.01$)⁵⁹ and among community-dwelling frail older adults (SMD = 0.54; $p < 0.01$).⁷⁴

Quality of life was the primary outcome in 4 reviews.^{13,43,57,74} Exercise programs did not produce significant effects on quality of life in healthy participants (RaR = 0.04; $p > 0.05$)⁵⁷ or frail individuals (weighted mean difference = -0.18; $p > 0.05$),³² (MD = 0.10; $p > 0.05$),⁷⁴ except for whole-body vibration, in measures including social function (SMD = 0.73; $p < 0.01$) and vitality (SMD = 0.78; $p < 0.01$).¹³

Meditative movement interventions produced larger effects on quality of sleep than did sleep therapy or usual care (SMD = -0.70; $p < 0.01$), regardless of the type and duration of the intervention.⁴³ The impact of exercise on participation in society (i.e., individual functioning at the societal level) was investigated in 1 review.²⁸ The authors found that multicomponent interventions with an exercise component produced larger effects than exercise alone, although the difference was not statistically significant (SMD = 0.22; $p > 0.05$).²⁸

3.5.4. Brain functioning

Brain functioning was the primary outcome in 10 reviews.^{29,30,44,45,57,58,61,67,69,71} In healthy older adults, it was found that Tai Chi and aerobic exercises did not reduce the risk of cognitive impairment (RR = 1.12; $p > 0.05$) or decline (RR = 0.90; $p > 0.05$), but it reduced the risk of dementia (RR = 0.57; $p > 0.05$), though not significantly.²⁹ It was also found that seated exercise had a significantly positive effect on cognition (SMD = 1.20; $p < 0.01$).⁷¹ Another review⁶⁷ found that a single aerobic/strength exercise bout was able to increase peripheral blood brain-derived neurotrophic factor concentrations (SMD = 2.21; $p < 0.05$) and that an exercise program comprising aerobic/strength training increased these

concentrations significantly (SMD = 4.72; $p < 0.01$). The effectiveness of resistance and aerobic exercise on cognition (Hedge's $g = 0.24$; $p < 0.01$) was reported in another review.⁶¹ Garcia-Hermoso et al.⁵⁷ found improvements in healthy adults' cognition following involvement in long-term (i.e., more than 12 months) interventions (RR = 0.24; $p < 0.01$).

In regard to the effects of exercise on cognitive functioning in people with cognitive impairment or dementia, 1 review found significant effects on verbal fluency (mean deviation (MD) = 1.32; $p < 0.01$) and nonsignificant effects on cognitive flexibility (MD = 6.76; $p > 0.05$) and delayed memory (MD = -0.01; $p > 0.05$).⁴⁴ Another review found no effects on overall cognition (MWES = 0.21; $p > 0.05$) but a significant effect on executive attention (MWES = 0.15; $p < 0.05$).³⁰ Greater effects were generated when exercise was delivered in group sessions (MWES = 0.12; $p < 0.01$)⁴⁵ and in sessions with short durations and high frequencies ($d = 0.43-0.50$),⁵⁸ but no significant effects resulted from different intervention characteristics, such as length (MWES = 0.00; $p > 0.05$) and frequency (MWES = 0.12; $p > 0.05$).⁴⁵ When comparing physical exercise intervention to computerised cognitive training, music therapy, and nutrition therapy, the former produced the largest improvement in cognition (SMD = 0.35; $p < 0.05$).⁴⁵

3.5.5. Musculoskeletal health, bone density, and muscle mass

Musculoskeletal health was explored in 3 reviews.^{16,31,66} It was found that whole-body vibration had no significant postintervention effects on total (MD = 0.00; $p > 0.05$) and femoral neck (MD = 0.01; $p > 0.05$) bone mineral density (BMD) in postmenopausal women, but improvements in BMD of the lumbar spine (MD = 0.02; $p < 0.05$)³¹ were found.

In comparison to participants who did not receive the intervention, the same review did not find significant improvements in BMD among participants who did receive the intervention in total (MD = -0.01; $p > 0.05$), femoral neck (MD = 0.02; $p > 0.05$), and lumbar spine BMD (MD = 0.02; $p > 0.05$).³¹ When dividing participants by age group, the authors found no significant differences in BMD of the femoral neck in women younger than 65 years of age pre- and post-intervention (MD = 0.02; $p > 0.05$), but they did find a significant difference in BMD of the lumbar spine (MD = 0.01; $p < 0.05$).³¹

A review comparing exercise-only vs. multimodal interventions in older adults identified statistically significantly larger improvements for BMD of the femoral neck in the combined interventions (SMD = 0.02; $p > 0.05$).¹⁶

A review focusing on older adults with sarcopenia and frailty risk found that muscle-strengthening exercise and protein supplementation produced significant improvements in the whole-body lean mass (SMD = 0.66; $p < 0.01$) and appendicular lean mass (SMD = 0.35; $p < 0.01$).⁶⁶

3.5.6. Mood

Three reviews focused on the effect of exercise on mood.^{32,46,68} Significant mood improvement resulted from cardiovascular and resistance training in healthy older adults (SD = 0.38; $p < 0.05$).³² The effect size was larger for

Table 5
Ranking of interventions, based on aggregated effect sizes.

Intervention type	Mean AVTS	Median AVTS	Number of studies
Resistance training	5.00	3.75	9
Meditative movement interventions	4.92	4.92	2
Exercise-based active videogames	3.60	3.60	2
Tai Chi	3.46	3.96	3
Alternative exercise	3.12	3.12	1
Aerobic exercise	2.63	2.45	7
Multimodal exercise	2.60	2.44	3
Physical exercise (unspecified)	2.45	2.41	87
Nonmultimodal exercise	1.76	1.76	1
Whole-body vibration	1.63	1.22	18
Overall	2.58	2.45	133

Abbreviation: AVTS = absolute value test statistics.

physically active ($SD = 0.27$; $p < 0.05$) compared to physically inactive ($SD = 0.19$; $p < 0.05$) participants. Two reviews tested the effect of different interventions in reducing depression.^{46,68} Heinzel et al.⁴⁶ found that, compared to control conditions at post-treatment, there was a significant reduction in depression following aerobic exercise ($SMD = -0.64$; $p < 0.05$), resistance training ($SMD = -0.76$; $p < 0.05$), and alternative exercise (i.e., Tai Chi, Qigong, dancing) ($SMD = -0.97$; $p < 0.05$). When differentiating by intervention characteristics, the authors identified a significant effect size for supervised training ($SMD = -0.77$; $p < 0.05$).⁴⁶ Miller et al.⁶⁸ found that the largest improvement in depressive symptoms resulted from mind-body exercise (Hedge's $g = -0.87$ to -1.38), followed by aerobic exercise (Hedge's $g = -0.51$ to -1.02) and resistance exercise (Hedge's $g = -0.41$ to -0.92).

3.6. Objective 3: ranking of interventions based on aggregated effect sizes

Table 5 ranks interventions based on their aggregated effect sizes, from largest to smallest improvements. In brief, the largest effect sizes were found for interventions based on resistance training. The smallest effect sizes were found for whole-body vibration interventions.

4. Discussion

This systematic review of meta-analyses synthesized the evidence concerning exercise interventions in older adults in order to characterise the extent of the diversity and inconsistency of the literature in this area. We also aimed to identify gaps in the literature in order to suggest future directions in research.

Overall, our review found that resistance training supported by nutritional supplementation significantly improved muscle strength, whereas multimodal exercises and whole-body vibration, particularly if supervised, produced significant balance improvements. Resistance training and multimodal exercises may improve general physical performance measures. The evidence for exercise interventions in reducing falls and fear of falling was inconsistent. The effect may depend on the place where the individual lives, whether the individual was part of a clinical

group, the setting of the intervention, and the integration of additional strategies into the intervention, such as home modifications and nutritional supplementation. It was found, however, that multimodal exercise interventions reduced the risk of falling. The evidence regarding exercise in reducing falls-related injuries was inconsistent, and the effectiveness of interventions may depend on additional intervention components, such as environmental or visual assessments. Overall, our review showed that quality of life may be improved through some forms of exercise (whole-body vibration) and in some groups (healthy older adults) but not in others (people with frailty). Regular meditative movement exercise may be beneficial for quality of sleep. The evidence regarding exercise for improving cognitive function and preventing cognitive impairment was inconsistent, but physical exercise may be more effective than music, nutritional therapies, or cognitive training.

Our work is characterised by certain strengths and limitations. In relation to limitations at the level of the individual meta-analyses, most meta-analyses included multicomponent (e.g., resistance and endurance training) interventions and did not report results separately for individual components, making it difficult to associate exercise type with effect sizes. In some instances, there was no description of the type of exercise investigated in the meta-analysis and was referred to only as "exercise". The meta-analyses were also extremely heterogeneous in the target populations, number of studies, number of participants included in the studies, and primary outcomes.

There were also limitations pertaining to this review. Each meta-analysis was appraised for quality by 1 rater only, which might have caused single-rater bias. There are also limitations inherent in the use of the CASP. For example, the CASP does not attribute a score to reporting of sample size, which is key information required for power calculation of intervention effectiveness. Despite the lack of this information, 2 meta-analyses still scored 8 and 9 on the CASP. Therefore, we urge caution in interpreting the results of our quality appraisals because they reflect the quality of the meta-analyses only in relation to the specific aspects included in the CASP. Also, given the diversity of the studies included in our review, it was impossible to meta-analyze data. Although we were not able to synthesize a pooled estimate from all the studies, we generated a comparison metric (AVTS) for each study and then grouped the studies based on type by using means and medians. This gave us an indication of which study types appeared to generate the strongest or weakest effect sizes. However, caution is needed when drawing conclusions from our findings, given that we combined very different interventions and that the AVTS metric is based, in many instances, on data aggregated from a limited number of reviews. Nonetheless, the aggregated metrics represent essential groundwork, which can inform future literature reviews with a narrower scope. For example, given the potential largest effect of resistance training, future research could explore whether the effects of this type of exercise also extend to "nonclinical" outcomes, such as changes in physical activity behavior (i.e., increased engagement of participants in exercise following delivery of resistance training interventions). This is

particularly relevant, considering that, in order to achieve maximum benefits, adherence to exercise is crucial⁷⁶ but that research has evidenced poor adherence to exercise among older adults.^{77–79}

The AVTS suggests that studies delivering resistance training show the largest improvements. This is in line with previous research, adding to the evidence that resistance training is beneficial for musculoskeletal health, promotes the maintenance of functional abilities, and protects from osteoporosis, sarcopenia, and lower-back pain.⁸⁰ There is also mounting evidence of the protective effect of resistance training against health conditions typically associated with aging, including diabetes, heart disease, and cancer.⁸⁰ Research has found that a positive impact on insulin resistance, resting metabolic rate, glucose metabolism, blood pressure, body fat, and gastrointestinal transit time can be obtained even through two 20-min resistance-training sessions a week.⁸⁰

In relation to the other types of interventions, Tai Chi and meditative movements exercise studies reported larger effect sizes than those delivering purely physical types of exercise such as aerobics, though it must be recognized that the AVTS for these studies was based on fewer reviews. It might be that less physically intensive types of exercises are more suitable to an aging population, thus generating more improvements.

The promising results of exercise-based videogames emerging from the AVTS reflect the growing evidence of the benefits of assisting technology (AT) in improving the lives of older adults. AT is defined as “any device or system that allows an individual to perform a task that they would otherwise be unable to do, or increases the ease and safety with which the task can be performed”,⁸¹ and its contribution to older people’s independence and autonomy has been evidenced in a number of studies. Despite the promising results, however, there is contradictory evidence concerning older people’s acceptance of AT.^{82,83} Acceptability, in the context of physical exercise for older people, where low levels of engagement in the prescribed programs are common,⁸⁴ is a crucial aspect for ensuring adherence to an exercise regime and, thus, to an intervention’s effectiveness.

The AVTS revealed that larger effect sizes were obtained through multimodal interventions (e.g., resistance and cognitive training) as opposed to nonmultimodal formats. This is in line with previous evidence concerning the benefits of multimodal exercises, such as dual-tasking (i.e., undertaking a physical and cognitive task simultaneously),⁸⁵ resulting in a growing popularity of exercise programs featuring multimodal interventions for people with dementia and cognitive impairment.⁸⁶ It was also found that integration of physical exercise with preventive or educational initiatives (e.g., falls education) was associated with larger effect sizes than for exercise programs without such initiatives. This finding echoes recent theoretical developments in behavior-change theories and points to the crucial role of information and education about physical exercise (and its benefits) in efforts to boost motivation for initiating and adhering to exercise programs.⁸⁷

This review also evidenced important gaps in research that need to be addressed. Our review of studies of group exercises

suggests that this delivery format yields effect sizes similar to those that individual exercises yield, on several outcomes. There might be added value to group delivery that goes beyond the physical benefits. For example, group activities may promote social integration and maintenance of a social identity role, particularly among individuals who are at risk of social exclusion, such as older people living in rural areas⁸⁸ and those with dementia.⁸⁹ The motivational argument also seems to validate group delivery. Participants in group interventions can encourage each other and boost intrinsic motivation to engage in physical exercise.⁹⁰ In the context of a group program, there is also the potential for information sharing among participants. Given the inconsistency of the evidence about group exercises, however, it is crucial to generate further evidence in order to examine the potential of this format.

Few of the meta-analyses we reviewed reported long-term adherence to exercise or its impact after the intervention period had finished. In the few instances where adherence to and benefits of interventions were investigated longitudinally, the results were inconsistent. It would be useful, therefore, to explore the long-term effects of interventions, which can go beyond the mere physical benefits and strategies for how best to obtain them. Research has found, for example, that the input of professionals’ delivering exercise interventions might represent a resource for long-term engagement in physical activity because these professionals can provide information about services and support networks available in the community which, in turn, might help older people maintain physical activity levels⁹¹ and gain long-term benefits.

Physical health outcomes were the primary focus of 80% of the reviews, whereas psycho-socio-emotional variables (e.g., mood and affect, quality of life, independence) amounted only to roughly 20%. It was also surprising to note that only 1 multimodal intervention⁶⁴ featured motivational strategies. Given the relevance of motivation in mediating adherence to exercise interventions (and, in turn, their effect on physical outcomes),^{84,92} further research in this area is needed.

Interestingly, none of the interventions focused on the role of significant others (e.g., family, friends, and caregivers) in contributing to improved outcomes. In the context of physically or cognitively impaired individuals in particular, carers might become key agents in intervention success.⁹³ It is, therefore, pivotal to conduct research in this area. None of the reviews investigated or described which characteristics of professionals or which dynamics in the professional-client rapport were associated with greatest effect sizes. Previous literature indicates that the technical knowledge and skills of trained professionals ensure optimal adherence to exercise.⁹¹ The motivational support provided by professionals can also be instrumental for higher uptake and, in turn, greater improvements in intervention outcomes. Further research, therefore, is also needed in this respect.

5. Conclusion

This review found that exercise interventions for older adults are extremely diverse and that the findings from the

included studies were mostly inconsistent. We were able to aggregate some of the effect sizes reported in the meta-analyses, which seem to suggest that the most effective interventions were resistance training, meditative movement interventions, and exercise-based active videogames. We advocate for further, more focused review work in order to confirm the trends we have identified in our review. Our review also identifies important gaps in research, including a lack of studies investigating the benefits of group interventions, the characteristics of professionals' delivering the interventions associated with better outcomes, the impact of motivational strategies on intervention outcomes, and the impact of significant others (e.g., carers) on intervention delivery.

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Authors' contributions

CDL developed the protocol of this manuscript, ran the database searches, selected the included meta-analyses, appraised their quality, extracted data, developed and revised the manuscript; AL developed the protocol of this manuscript, ran the database searches, selected the included meta-analyses, and appraised their quality; AdB ran the statistical analyses; RHH contributed to the development of the protocol and revised the manuscript; JRFG, SS, PL, and AB revised the manuscript; VvdW developed the protocol of this manuscript, ran the database searches, selected the included meta-analyses, appraised their quality, and revised the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Supplementary materials

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