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REVIEW ARTICLE

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The effectiveness of exercise interventions targeting sleep in older adults with cognitive impairment or Alzheimer's disease and related dementias (AD/ADRD): A systematic review and meta-analysis

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Summary

Sleep loss is associated with reduced health and quality of life, and increased risk of Alzheimer's disease and related dementias. Up to 66% of persons with Alzheimer's disease and related dementias experience poor sleep, which can predict or accelerate the progression of cognitive decline. Exercise is a widely accessible intervention for poor sleep that can protect against functional and cognitive decline. No previous systematic reviews have investigated the effectiveness of exercise for sleep in older adults with mild cognitive impairment or Alzheimer's disease and related dementias. We systematically reviewed controlled interventional studies of exercise targeting subjectively or objectively (polysomnography/actigraphy) assessed sleep in persons with mild cognitive impairment or Alzheimer's disease and related dementias. We conducted searches in PubMed, Embase, Scopus and Cochrane-Library ($n = 6745$). Nineteen randomised and one non-randomised controlled interventional trials were included, representing the experiences of 3278 persons with mild cognitive impairment or Alzheimer's disease and related dementias. Ten had low-risk, nine moderate-risk, and one high-risk of bias. Six studies with subjective and eight with objective sleep outcomes were meta-analysed (random-effects model). We found moderate- to high-quality evidence for the beneficial effects of exercise on self-reported and objectively-measured sleep outcomes in persons with mild cognitive impairment or Alzheimer's disease and related dementias. However, no studies examined key potential moderators of these effects, such as sex, napping or medication use. Our results have important implications for clinical practice. Sleep may be one of the most important modifiable risk factors for a range of health conditions, including cognitive decline and the progression of Alzheimer's disease and related dementias. Given our findings, clinicians may consider adding exercise as an effective intervention or adjuvant strategy for improving sleep in older persons with mild cognitive impairment or Alzheimer's disease and related dementias.

KEYWORDS
Alzheimer's disease, dementia, exercise, mild cognitive impairment, sleep

1 | INTRODUCTION

Sleep plays vital roles in brain health, including regulating clearance of proteins (e.g. β-amyloid) linked to neurodegenerative disorders (Irwin & Vitiello, 2019; Namsrai et al., 2023). Nearly half of persons over the age of 65 years experience difficulty initiating or maintaining sleep (Brabbins et al., 1993; Desforges et al., 1990; National Sleep Foundation, 2013; Unruh et al., 2008), and up to 65% report disrupted or non-restorative sleep (Foley et al., 1999). Sleep loss is associated with increased risk of falls, social disengagement, and reduced quality of life in older adults (Stone & Xiao, 2018). Poor sleep also increases the risk of mortality (Parthasarathy et al., 2015) and a range of morbidities ranging from cardiovascular disease and dementia to Alzheimer's disease and related dementias (AD/ADRD; Stone & Xiao, 2018).

Up to 66% of persons with AD/ADRD report or experience poor sleep, and it can predict or accelerate the progression of cognitive decline (Djonlagic et al., 2021; Irwin & Vitiello, 2019; Targa et al., 2021). Sleep disorders, including insomnia, restless legs syndrome and sleep apnea can often appear in the preclinical stage of AD/ADRD, and changes in sleep patterns in older adults can increase the risk of AD/ADRD (Hahn et al., 2014; Irwin & Vitiello, 2019). Sleep disturbances induce systemic and central nervous system inflammation, neurophysiological changes, and increased tau and β-amyloid burden in the brain that may drive the onset and progression of AD/ADRD disease (Irwin & Vitiello, 2019). Poor sleep has also been linked to declines in functional connectivity between brain regions and networks linked to cognitive decline in AD/ADRD disease and other neurodegenerative disorders (Zhang et al., 2022).

Sleep disorders are also one of the leading causes of caregiver stress and institutionalisation for persons with AD/ADRD (Wilfling et al., 2020; Winblad et al., 2016). In older adults and persons with AD/ADRD, the combination of sleep problems and medications used to treat poor sleep may also increase the risk of falls (Min et al., 2016), while a history of falls also considerably increases the risk of institutionalisation, morbidity and mortality in persons with AD/ADRD (Allan et al., 2009; Min et al., 2016; Morris et al., 1987; Myers et al., 1991). Caregivers of persons with AD also experience increased risk of insomnia, mental and physical health difficulties, and increased mortality, with considerable costs to healthcare systems and communities (Bentley et al., 2022; Skaria, 2022). Insomnia is also associated with considerably higher healthcare costs and healthcare resource utilisation in persons with ADRD compared with those without insomnia (Wickwire et al., 2023).

1.1 | Interventions for sleep

Non-pharmacological strategies play an important role in treating poor sleep (Rios et al., 2019; Wilfling et al., 2023). Cognitive-behavioural therapy for insomnia (CBTi) is the preferred first-line treatment for insomnia disorder (Morin et al., 2006). However, it often requires 6–10 treatment sessions, may be expensive and difficult to access (Feuerstein et al., 2017; Koffel et al., 2018; Perils & Smith, 2008; Zachariae et al., 2016). Deficits in cognition, executive function, arousal and awareness associated with AD/ADRD progression may also make CBTi unfeasible in later stages of dementia or AD/ADRD (Huntley et al., 2021; Karr et al., 2018; Tahami Monfared et al., 2022). Additionally, CBTi typically achieves success in only two-thirds of participants (Huang et al., 2022a; Koffel et al., 2018; Morin et al., 2009), and is particularly effective for improving subjective, rather than objective (sleep architecture) sleep outcomes (Perrault et al., 2022). This may be an important consideration, given that loss of normal non-rapid eye movement (NREM) sleep slow-wave activity has been linked to cognitive impairment in older adults and pathophysiological changes in AD (Lee et al., 2020; Mander et al., 2015; Mander et al., 2016; Marshall et al., 2006; Ngo et al., 2013; Weiner et al., 2023).

Medications such as benzodiazepine receptor agonists and sedative antidepressants can be effective short-term (1–12 weeks) treatments, but do not treat the root causes of sleep loss (Matheson & Hainer, 2017). Sleep loss in persons with AD or dementia may be caused by a variety of factors, ranging from age-related changes to the brain, age-related changes in sleep and circadian rhythms, sleep apnea, parasomnias such as rapid eye movement (REM) behaviour disorder, chronic illnesses, medication effects, impaired mobility, environmental influences (e.g. institutionalisation), reduced brain performance, or AD/ADRD disease progression (Fung et al., 2012; Fung et al., 2016; Irwin & Vitiello, 2019; Li et al., 2022; Neikrug & Ancoli-Israel, 2010; Van Erum et al., 2018; Wang & Holtzman, 2020). The adverse effects of medications used to treat poor sleep, including daytime drowsiness, sedation and dependence, may also limit their acceptability for patients and their caregivers (Fitzgerald & Vietri, 2015). There is also limited evidence for the effectiveness of pharmacological treatment of insomnia in persons with dementia (McCleery & Sharpley, 2020).

Exercise is a promising, widely accessible, highly customisable intervention for sleep difficulties that can be performed in most settings, by persons of almost any ability, inexpensively or cost-free

(Kredlow et al., 2015; Li et al., 2023). Exercise refers to intentional, structured physical activity, or physical activity that is planned and repetitive with a goal of improving or maintaining health or physical fitness (Caspersen et al., 1985; Garber et al., 2011a). Physical activity includes any bodily movement produced by skeletal muscles that results in energy expenditure, and can include occupational, household, sports, exercise, conditioning or other activities (Caspersen et al., 1985; Garber et al., 2011a).

Exercise is associated with a range of benefits for health and quality of life in older adults (Kredlow et al., 2015; Livingston et al., 2020). It may also protect against functional and cognitive decline in older age, and benefits cognition and several neuropsychiatric symptoms, such as depression, mood and agitation in persons with AD/ADRD (Liu et al., 2022; Memon et al., 2020; Meng et al., 2020). Exercise also targets sleep physiology, including NREM slow-wave activity (Aritake-Okada et al., 2019; Kline et al., 2021; Memon et al., 2022; Park et al., 2021), which has been linked to memory consolidation in older adults (Djonlagic et al., 2021; Marshall et al., 2006; Ngo et al., 2013; Weiner et al., 2023).

There is a robust bidirectional relationship between exercise and sleep (Kline et al., 2021). Strong evidence supports the beneficial effects of exercise on sleep quality and decreased use of sleep medications in older adults (Kline et al., 2021; Kredlow et al., 2015; Vanderlinden et al., 2020). However, less is known about the effectiveness of exercise for sleep problems in older adults with cognitive decline, dementia or AD/ADRD (Kline et al., 2021). To the best of our knowledge, no previous systematic reviews have investigated the effectiveness of exercise or structured physical activity interventions targeting sleep in older adults with cognitive impairment or AD/ADRD. A systematic review of current evidence is needed to support clinical care for older adults affected by cognitive decline and guide future research. This systematic review critically appraises and meta-analyses available evidence to determine the effectiveness of exercise interventions targeting subjective or objective sleep outcomes in older adults with mild cognitive impairment (MCI) or AD/ADRD.

2 | METHODS

Our systematic review and meta-analysis were conducted following the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2021), and reported along the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Page et al., 2021; PRISMA checklist is included in the supporting information). The protocol (CRD42021289528) was registered on PROSPERO (Booth et al., 2012).

2.1 | Eligibility criteria for the systematic review

Eligible studies met the following criteria:

P: included participants ≥ 60 years old with cognitive impairment, MCI or AD/ADRD, or extractable data for that age group.

Participants must have a clinical diagnosis of MCI or AD/ADRD at baseline. Diagnosis of MCI must be made according to recognised criteria, such as the recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for AD (Albert et al., 2011; McKhann et al., 2011), Petersen's criteria (P-MCI; Petersen, 2011) or the Diagnostic and Statistical Manual of Mental Disorders (DSM; Association AP, 2013), or using validated cognitive screening tools (e.g. Montreal Cognitive Assessment [MoCA]; Nasreddine et al., 2005; Mini Mental State Examination [MMSE]; Nasreddine et al., 2005) and qualitative clinical information.

Diagnosis of AD must be made according to recognised criteria, including the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) criteria (McKhann et al., 1984), the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for AD (McKhann et al., 2011), the Diagnostic and Statistical Manual of Mental Disorders criteria (Association AP, 2013), or other method of formal medical diagnosis reported in the paper.

I: interventional studies of exercise (any mode, frequency, duration).

C: control interventions: no treatment, wait-list control, educational or non-exercise interventions.

O: sleep quantity, quality or architecture, measured objectively (actigraphy, polysomnography[PSG]) or by self-report (e.g. Pittsburgh Sleep Quality Index [PSQI]; Buysse et al., 1989; sleep diaries, …), reported as a categorical or continuous outcome.

Study design: controlled, interventional studies.

2.2 | Exclusion criteria

Single-subject, uncontrolled or observational studies, case series, or studies reporting sleep as a dichotomous outcome were excluded. Studies of participants with disorders highly associated with poor sleep and difficulty exercising such as stroke, cerebral vascular accident or major psychiatric disorders (other than MCI or AD/ADRD) were excluded (Zielinski et al., 2019). We did not restrict eligibility by the study location or study sample size.

2.3 | Eligibility for meta-analysis

To be eligible for meta-analysis, papers included in the systematic review had to report sleep quantity, quality or architecture, measured objectively (actigraphy, PSG) or by self-report (e.g. PSQI; Buysse et al., 1989; sleep diaries, …) as a continuous outcome. To minimise

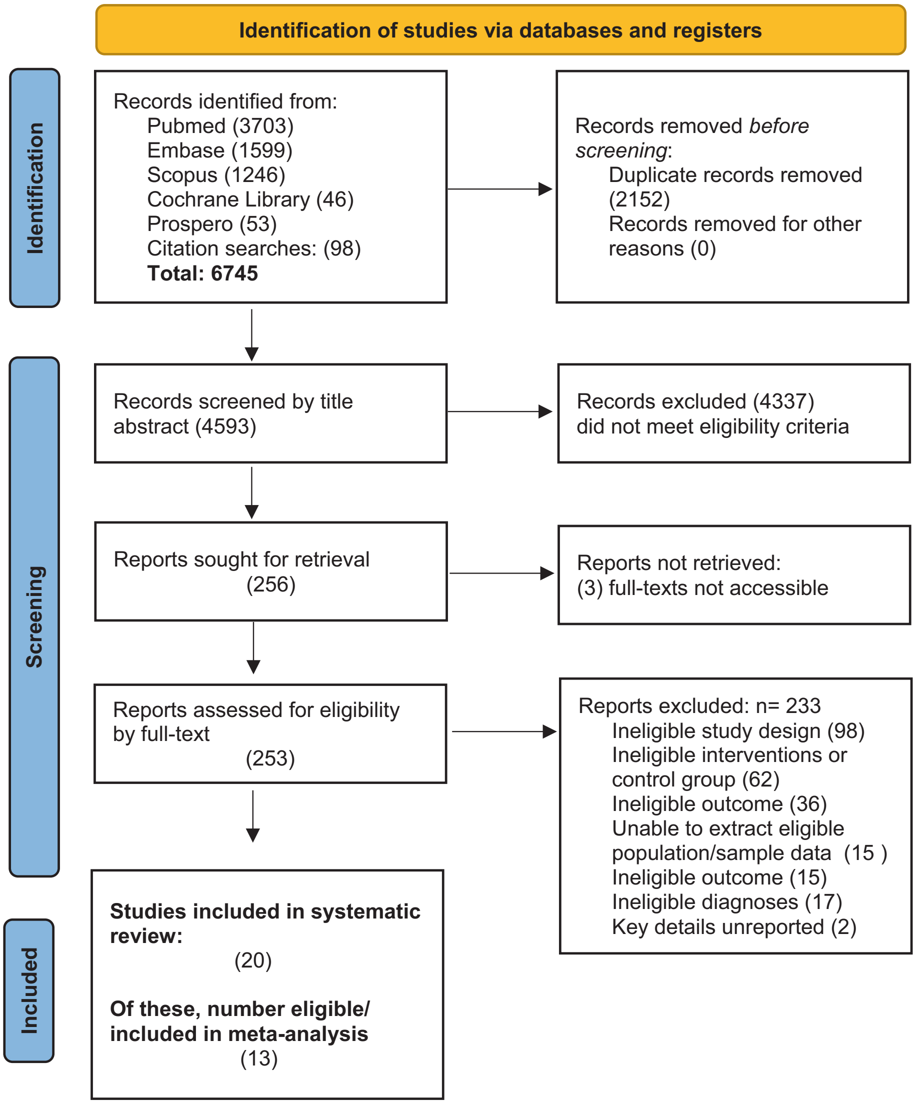

FIGURE 1 PRISMA flow chart.

the potential for biased pooled treatment effects arising from poor study quality, we limited our meta-analyses to studies with low or moderate risk of bias on the Cochrane ROB, excluding those at high risk of bias.

2.4 | Information sources and search strategy

We conducted systematic searches with keywords and Medical Subject Heading (MeSH) terms related to physical activity, exercise, sleep, cognitive impairment, MCI, dementia or AD/ADRD, from inception and without language restrictions on PubMed, Embase, the Cochrane Library, Scopus and PROSPERO (supplemental material). To ensure literature saturation, we undertook citation searching and re-ran keyword searches on PubMed limited to the most recent 12 months to capture papers not yet indexed under MeSH.

Records identified through the literature and citation-list searches were imported to the Mendeley reference management program, and duplicates were removed. We also created a Microsoft Excel spreadsheet with the records identified through our literature and citation searches, and visually scanned for duplicates to confirm no duplicates were missed. In our selection process, two reviewers (AP and EF) independently screened a selection of 100 records from our search results against our eligibility criteria to pre-test and refine our eligibility criteria and establish inter-rater reliability. Subsequently, these two reviewers independently screened all search results against our eligibility criteria, first by title and abstract and then by full text (Figure 1). Full-texts for all potentially eligible studies were retrieved. When necessary, study authors were contacted for additional information to resolve questions about papers' eligibility or acquire additional data for data extraction or synthesis, and registered or published study protocols were consulted when available. Disagreements about eligibility were resolved through consensus. Records not meeting our inclusion criteria were excluded, and the reason for exclusion was recorded at the full-text screening.

2.5 | Data extraction and data items

A data extraction sheet was developed with Microsoft Excel and pilot tested with 10 randomly selected eligible papers. One reviewer (AP) performed the initial data extraction for all included papers, and a second reviewer (EF) checked the data extraction. We extracted data for study characteristics (authors, year, design, population), sample characteristics (age, gender, diagnoses) at baseline, exercise interventions (mode, intensity, duration, frequency) and effect measures.

2.6 | Effect measures

We extracted data for self-reported or objectively measured sleep outcomes (sleep duration, sleep architecture and microarchitecture, and sleep quality) measured through actigraphy, PSG, sleep diaries and subjective assessments, including the PSQI (Buysse et al., 1989), Insomnia Severity Index (ISI; Bastien, 2001), Mini-Sleep Questionnaire (MSQ; Gorenstein, 1983), Neuropsychiatric Inventory (NPI; Cummings et al., 1994), Sleep Disorders Inventory (SDI; Tractenberg et al., 2003), and customised sleep quality tools as continuous treatment effect estimates (mean differences and measures of variance). We extracted measures of treatment effect from included studies that were adjusted for potential confounding variables over reported estimates that were not adjusted for potential confounding. Where studies used multiple follow-up periods, we used data from the first follow-up period after the end of the intervention period (most recent).

2.7 | Risk of bias

The risk of bias was assessed with the Cochrane Collaboration's Revised Tool to Assess Risk of Bias in Randomised Trials (RoB-2; Sterne et al., 2019) for randomised trials, and Risk Of Bias In Non-randomised Studies – of Interventions (ROBINS-I) tools (Sterne et al., 2023) for non-randomised trials. Two reviewers (AP and EF) independently assessed studies for risk of bias. Any disagreements were resolved through discussion and consensus.

2.8 | Data synthesis

Papers were categorised by study population, as either a study of persons with MCI or of persons with AD/ADRD, as described in our eligibility criteria. Exercise intensity was categorised as low, moderate or high, according to how they were reported by the study authors, or based on the American College of Sports Medicine (ACSM) guidelines (Garber et al., 2011b). Sleep outcome measures were categorised as either subjective (PSQI or self-reported sleep measures) or objective (actigraphy or PSG). All sleep outcome measures in this systematic review were synthesised as mean-differences between the exercise and non-exercise groups and measures of variance (e.g. standard deviation or standard error) with the Cochrane Collaboration's Review Manager 5.41 (RevMan 5.41) systematic review and meta-analysis software (Higgins et al., 2021). The results of these syntheses are described narratively in the systematic review, as summary of findings in Tables 1 and 2, and graphically (for meta-analyses) in Figures 3 and 4.

2.9 | Meta-analysis

We expected clinical diversity and heterogeneity between studies resulting from variable samples (e.g. mean ages, proportion of men and women, and clinical presentation of MCI or AD/ADRD), study locations and settings, differences in interventions and their doses, and effect sizes. Following the guidance of the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2021), we conducted inverse-variance weighted random-effects (Der Simonian and Laird) meta-analyses with RevMan 5.41 (Higgins et al., 2021). With RevMan, we derived mean differences in sleep outcomes between experimental and control groups to calculate pooled intervention effect estimates (Higgins et al., 2021). These were displayed graphically with Forest plots (Deeks & Higgins, n.d.; Anzures-Cabrera & Higgins, 2010; Ryan, 2014).

We assessed statistical heterogeneity using "*t* (Irwin & Vitiello, 2019)", Chi2 (significance level: 0.1) and "*I* (Irwin & Vitiello, 2019)" statistics (Higgins et al., 2021). Statistical heterogeneity was also evaluated graphically in Forest plots (Anzures-Cabrera & Higgins, 2010; Higgins & Green, 2011; Ryan, 2014). We conducted sensitivity analyses to determine if any one study contributed significantly to heterogeneity in meta-analysis (Higgins et al., 2021). Subgroup analyses were not conducted, given the small number (13) of studies meta-analysed, low power and increased risk of a high false-positive rate (Patsopoulos et al., 2008). Meta-regression was not conducted, as there were insufficient studies eligible for meta-analysis reporting characteristics to be modelled in meta-regression. It is recommended that at least 10 studies in a meta-analysis should be available for each characteristic modelled in a meta-regression (Higgins et al., 2021). In order to minimise the risk of bias due to missing results (arising from reporting biases), we also checked the reporting of outcomes in each study as part of our risk of bias assessments, and compared these with study protocols or registrations when they were available.

2.10 | Additional sensitivity analyses

We also conducted sensitivity analyses by risk of bias (keeping only papers with low risk of bias) to assess the robustness of our meta-analysed results (Anzures-Cabrera & Higgins, 2010; Higgins & Green, 2011; Ryan, 2014).

TABLE 1 Exercise interventions for sleep in persons with MCI.

Study	MCI and diagnosed MCI Sample and age	Exercise intensity 1: Low 2: Mod. 3. High	Exercise and/or control intervention	Sleep measures	Main findings (sleep)	Risk of bias
Alessi et al. (1999)	$N = 29$ (26 female) mean age 88.3 years nursing home dwelling older adults with dementia (mean MMSE 13.3) and urinary incontinence	1	Exercise: 5 days per week over 14 weeks physical activity program: structured arm and leg exercises, sit-to-stands, and walking or wheelchair propulsion Control: night-time environmental program meant to reduce intrusive nursing care at night (light, noise, procedures, etc)	OSAI and 5 nights of actigraphy Observations to assess sleep versus wakefulness, time spent in bed, and agitation	Participants in the exercise intervention group showed increased total sleep time, longer sleep episodes, and less daytime sleepiness and agitation compared with the non-exercise group Baseline sleep percentage (ex-group) 51.7 (95% CI: 42.8. 60.6) Follow-up: 62.5 (95% CI: 50.6, 74.4)	Mod
Bademli et al. (2019))	$N = 60$ (25 female) ≥ 65 years old Mean age 71.5 years Diagnosed MCI, living in nursing homes, and baseline PSQI 5–21	2	Exercise: 20-week, 4 times/week physical activity program: 10-min warm-up, 20-min rhythmic exercises, 10-min cool down exercises, and 40-min of free walking Control: non-exercise control	PSQI Baseline scores exercise group: 13.04 ± 2.06 Control 12.14 ± 2.46	PSQI measured sleep quality of improved considerably (md −9.01 [−10.06, −7.96] after a 20-week physical activity program compared with the control group	Mod
Chan et al. (2016)	$N = 52$ (44 female) ≥ 60 years old With cognitive impairment: MMSE score of 13–26, PSQI >5	1	Exercise: twice weekly, 60-min TCQ sessions for 2 months Control: non-exercise, observation-only group	PSQI (Chinese) at baseline, 2 months and 6 months Baseline scores: exercise group 10.2 Control 9.8	Participants in the TCQ group reported better sleep quality (PSQI mean difference of −1.80 global score), sleep duration ($p = 0.003$), habitual sleep efficiency ($p = 0.002$) than the control group The TCQ group's sleep duration increased +48 min, sleep efficiency increased 9.1%	Mod
Choi and Sohng (2018)	$N = 77$ (59 female) ≥ 65 years old (mean age 78.2 years) Community-dwelling, MMSE 19–26	2	Exercise: 30–40-min sessions of floor seated exercise, 4 times per week for 12 weeks following ACSM guidelines Control: non-exercise, “usual care” control group	PSQI Baseline scores Exercise group 6.12 ± 2.72 Control group 5.83 ± 2.64	The exercise program had no significant effect on sleep quality: mean difference 1.00 (2.15 to 0.15), p 0.087. However, the authors note: “considering that the previous month, which served as a reference for the measurement of sleep quality, was part of the hottest summer ever with 22 tropical nights, it might have been difficult for the FSEP to fully affect the participants' sleep quality scores”	Low

TABLE 1 (Continued)

Study	MCI and diagnosed MCI Sample and age	Exercise intensity 1: Low 2: Mod. 3. High	Exercise and/or control intervention	Sleep measures	Main findings (sleep)	Risk of bias
Vaz Fragoso et al. (2015)	$N = 1635$ (1098 female) 70–89 years old mean age 79 years Community-dwelling adults with mobility and cognitive impairments, MMSE	2	Exercise: walking 5 times per week (moderate intensity) with a goal of 150 min per week, as well as 5 times per week strength, flexibility and balance training exercises at moderate-intensity over 24 months Control: health education only	ISI, ESS and PSQI at baseline, 6, 18 and 30 months Baseline PSQI: 5.9 for both groups	Compared with health education, structured physical activity reduced the likelihood of developing poor sleep quality (PSQI >5) over the intervention period, but no statistically significant effect on existing poor sleep quality (PSQI) or the ISI or ESS	Low
Karydaki et al. (2017)	$N = 49$ (all female) Mean age 72.6 years Adults with MCI (Petersen criteria) confirmed by MMSE scores	n/a	Exercise group a: twice weekly, 45-min resistance training exercises (no intensity described) over 12 weeks Non-exercise control group	PSQI at baseline and at 12 weeks Baseline PSQI: exercise group 6.1 Control group 7.4	Compared with the control group, the exercise group reported significantly improved subjective sleep quality-global PSQI score ($t = 2.335$, df15, $p = 0.03$) at the 12-week assessment	Mod
Li et al. (2021a)	$N = 41$ (36 female) ≥ 60 years old (mean age 72.2 years) Assisted living facility-dwelling, sedentary adults with MCI, MoCA ≥ 18	2	Three, 60-min, moderate-intensity resistance training (elastic band) exercise sessions per week for 12 weeks with at least 48 hr between sessions Control group: no exercise control group	Actigraphy: non-dominant wrist for 3–4 consecutive days at baseline and post-intervention Sleep diaries	Compared with the control group, resistance training decreased sleep fragmentation and improved sleep quality in older adults with MCI, with statistically significant increase in sleep efficiency (9.9%, 95% CI: 5.1, 14.7) and decreased WASO −52.3 min (95% CI: 76.9, 27.6) Total sleep time increased in the exercise group, but not statistically significantly: 23.6 min (95% CI: −18.4, 65.6)	Low
Song and Yu (2019)	$N = 120$ (90 female) ≥ 60 years old community-dwelling, sedentary adults with MCI, MoCA 18–26	2	3 times per week, 60-min exercise sessions of a moderate-intensity aerobic exercise program over 16 weeks Control: 16-week health education program	PSQI Self-reported sleep quality Baseline PSQI Exercise: 9.47 ± 3.66 Control: 8.98 ± 3.94	A statistically significant change (improvement) in PSQI was found in the exercise compared to control group: −1.257 (−1.609, −0.825) $p < 0.001$ d = 0.89	Low
Song et al. (2023)	$N = 89$ (68 female) ≥ 60 years old	2,3		PSQI Baseline PSQI exercise: 11.07 ± 2.65	Participants in the exercise group had significantly greater reduction in	Low

(Continues)

TABLE 1 (Continued)

Study	MCI and diagnosed MCI Sample and age	Exercise intensity 1: Low 2: Mod. 3. High	Exercise and/or control intervention	Sleep measures	Main findings (sleep)	Risk of bias
	(mean age 76 years), community-dwelling older adults with MCI, MoCA 19–26		3 times per week, 60-min group moderate intensity aerobic dancing program over 16 weeks Intensity monitored with Borg scale (12–14) Control: health education with no exercise	Control: 10.66 ± 3.14	PSQI total scores (b: 1.74; 95% CI, 3.41, 0.08; $p = 0.04$), and statistically significantly improved sleep duration, sleep latency and sleep efficiency compared with the control group	
Wang et al. (2020)	$N = 116$ (68 female) ≥ 60 years old (mean age 63.3 years), community-dwelling older adults with diagnosed MCI (Portet et al., 2006 criteria), MoCA < 26	2	3 times per week, 60-min supervised limbs-exercise sessions over 12 weeks: 10-min limbering-up exercise, 40-min of upper and lower limbs exercise, followed by a 10-min relaxation exercise Waitlist control	PSQI Baseline PSQI Exercise: 9.25 ± 3.85 Control 8.63 ± 3.56	Compared with the control group, the exercise group reported improved sleep quality (PSQI), with a mean difference (95% CI) of −2.5 (95% CI: −351, 0.39), Cohen's *d* of 0.87	Mod

Abbreviations: CI, confidence interval; ESS, Epworth Sleepiness Scale; ISI, Insomnia Severity Index; MCI, mild cognitive impairment; MMSE, Mini Mental State Examination; MoCA, Montreal Cognitive Assessment; OSAI, Observational Sleep Assessment Index; PSQI, Pittsburgh Sleep Quality Index; TCQ, Tai chi; WASO, wake after sleep onset.

TABLE 2 Exercise interventions for sleep in persons with dementia, AD/ADRD.

	Dementia or AD/ADRD	Exercise intensity 1: Low 2: Mod. 3. High	Exercise and/or control intervention	Sleep measure	Main findings (sleep)	RoB
Eggermont et al. (2010)	*N* = 79 (63 female) ≥ 70 years old (mean age 84.3 years), participants with diagnosed AD/ADRD (in medical record), mild-to-moderate cognitive impairment (MMSE >10)	1	Exercise: indoor walking program, 30 min per day, five times per week for 6 weeks Control: indoor social visit (no exercise) for 30 min, five times per week over the 6 weeks	Actigraphy: Actiwatch worn on the dominant wrist Baseline sleep efficiency: Exercise: 74.01 (SD 9.37) Control: 70.0 (SD 10.11)	Participants in the walking program did not show a beneficial effect on night-time restlessness or other actigraphy-measures sleep parameters compared with the control group	Mod
Hoffmann et al. (2016)	*N* = 200 (87 female) 50–90 years old community-dwelling persons with mild–moderate AD according to NINDS-ADRDA criteria and MMSE >19	2,3	3 weekly group exercise sessions supervised by a Physiotherapist over 16 weeks The first 4 weeks leg strengthening exercises, the remaining 12 weeks: moderate- to high-intensity aerobic exercise (70%–80% of maximal HR) on an ergometer bicycle, cross-trainer, and treadmill Control: usual care (no exercise)	The 12-item NPI-12	Compared with the control group, the exercise group showed improved (decreased) scores on the NPI's Sleep and Night-time behavioural change components at the end of the intervention period	Low
Kumar et al. (2014)	*N* = 77 (15 female) ≥ 60 years old (mean age 69 years) with mild/moderate dementia based on DSM-IV criteria and neurological evaluation: MMSE ≤ 23, confirmation by neurological exam, Clinical Dementia Rating Scale and Blessed Dementia Rating Scale	2	Ten sessions of 20–30 min of exercise and structured physical activity over 5 weeks delivered by occupational therapists Control: standard activities without exercise or structured physical activity	WHOQOL-BREF, which includes sleep and rest under the physical health and level of independence domain	Participants in the exercise group reported improved sleep quality and decreased daytime sleepiness, compared with the control group	Mod
Landi et al. (2004)	*N* = 30 (15 female) nursing home-dwelling older adults with AD and/or dementia according to DSM-IIIR criteria The mean age or age range were not reported in the paper	2	Exercise: moderate-intensity exercise program (combination of aerobic or endurance activities, strength training, balance and flexibility training) Control: usual care, with no added exercise or physical activity	Sleep data for participants collected with The Minimum Data Set Instrument for Nursing Homes (MDS-NH) for the baseline and 4-week follow-up	Participants in the exercise group had a statistically significant reduction in sleep disorders at the 4-week follow-up *Note: the units of measurement for outcome variables are not included in the paper, making it impossible to identify what units were measured (e.g. %, frequency, number of occurrences, etc)	High
	N = 132 (73 female) (mean age 81.7 years)	1	Exercise: 30 min of continuous walking daily over 2 months		Participants in the walking group had moderate effect size improvements	Low

(Continues)

TABLE 2 (Continued)

	Dementia or AD/ADRD	Exercise intensity 1: Low 2: Mod. 3. High	Exercise and/or control intervention	Sleep measure	Main findings (sleep)	RoB
McCurry et al. (2011)	persons with AD (medical records) and two or more sleep problems occurring several times a week, measured with the 7-item SDI (Tractenberg et al., 2003)		Control: contact control (no exercise), light exposure group, walking and light group (not included in this meta-analysis)	Wrist actigraphy and caregiver ratings of participant sleep quality on the SDI (Tractenberg et al., 2003) Baseline SDI: Exercise group: 1.0 (SD 0.3) Control 0.8 (SD 0.2) >69% all participants had sleep problems at baseline	in total sleep time (30.80 min, 95% CI: −23.94, 85.54), higher sleep efficiency (1.00 95% CI: −6.01, 8.01), and fewer (but not statistically significant) night-time awakenings (−0.80, 95%CI: −5.67, 4.07) compared with control group Significant differences remained after adjustment for participant age, sex, depression, comorbidity, cognitive impairment and sleep apnea No significant improvements seen on the SDI	
Nascimento et al. (2014)	$N = 35$ (19 female) Mean age 76.8 ± 6.8 years persons with AD diagnosed according to DSM-IV TR and ADRDA criteria and mild–moderate dementia on the CDR	2	Exercise: 60 min of moderate-intensity (60%–80% HRmax) resistance, and aerobic exercise 1 day per week for 6 months Control: no exercise, usual care	MSQ scores Baseline MSQ: Exercise: 26.7 (SD 4.1) Control: 20.2 (SD 4.6)	Compared with control group, participants in the exercise group had statistically significant improvement in sleep scores (reduced sleep disturbances) on the MSQ, (mean difference of −1.10, $p = 0.01$)	Low
Namazi et al. (1995)	$N = 22$ (14 females) Mean age 80.73 years (SD 5.83) institutional-dwelling persons with AD/ADRD according to NINDS-ADRDA criteria	2	Exercise: 40 min of moderate intensity, multimodal aerobic exercise daily for 4 weeks Control: social activity (no exercise)	Customised sleep log: sleeping soundly; resting (awake, but in bed), awakened: (just awakened by staff, noises or other patients but still in bed), awake and out of bed doing normal things (walking, talking, sitting in room), awake and in the bathroom, or restless, for 12 hr per night over 4 weeks	Compared with the control group, the exercise group showed a greater increase in "sleeping soundly" (25% increase, mean difference of 530.00 episodes, 95% CI:278.7, 781.3) after the intervention	Mod
Öhman et al. (2017)	$n = 210$ (81 females) 65 years or older, mean age 77.8 years (5.2) Community-dwelling persons with AD/ADRD according to NINDS-ADRDA criteria, and evaluated by a geriatrician or neurologist	2	Exercise: 60 min, 2 days per week over 12 months Two exercise groups: a. Group-based: aerobic and strength exercise, balance training. b. Individual/ home-exercise group: aerobic exercises (Nordic walking, exercise bike), strength and balance training	The NPI: sleeping problems item Baseline: Exercise group 0.96 (2SD 0.38) Control: 0.97 (SD 2.50)	Compared with the control group, participants in the exercise intervention did not show statistically significant improvements in sleep on the NPI	Low

TABLE 2 (Continued)

	Dementia or AD/ADRD	Exercise intensity 1: Low 2: Mod. 3. High	Exercise and/or control intervention	Sleep measure	Main findings (sleep)	RoB
			Control: usual care and health education			
Richards et al. (2011)	*N* = 193 (116 female) Mean age 81.8 ± 8.1 years Nursing home and assisted living-dwelling persons with dementia and/or AD and MMSE 4 or greater (mean MMSE 19.8, range 4–28)	3	Exercise group: 3 days per week of high-intensity resistance strength training and 2 days of walking for 45 min over 7 weeks Control: usual care or social activity with no exercise	Portable (in home) PSG for 2 nights at baseline and 2 nights at 7 weeks (post-intervention) Baseline AHI: Exercise group 16.2 (SD 14.6) Control 18.8 (SD 18.3)	Compared with the control group, the exercise group: increased total sleep time of 23.7 min (MD 25.10 min, 95% CI: 21.99, 28.21), improved sleep efficiency (MD 6.80, 95% CI 6.18, 7.42), increased NREM sleep (9.30 min, 95% CI: 6.08, 12.52) and REM sleep (15.80 min, 95% CI: 14.37, 17.23), sleep-onset latency increased in the exercise group compared with the control (MD 8.80 min, 95% CI: 6.67, 10.93)	Low
Stella et al. (2011)	*N* = 32 (20 female) Mean age 77.8 years (5.8) Sedentary community-dwelling persons with mild to moderate AD/ADRD according to NINDS-ADRDA criteria, evaluated by a clinician and diagnosis also reported by their caregivers	2	Exercise: moderate-intensity aerobic exercise for 60 min, three times per week on non-consecutive days over 6 months Control: usual care, non-exercise group	NPI Sleep disturbance mean at baseline: Exercise group 2.8 (SD 4.2) Control 4.4 (5.6)	Compared with the control group, the exercise group had statistically significantly greater reduction in sleep disturbances on the NPI (mean difference −2.4, 95% CI: −5.20, −0.4)	Mod

Abbreviations: AD/ADRD, Alzheimer's disease and related dementias; AHI, apnea–hypopnea index; CDR, Clinical Dementia Rating; CI, confidence interval; DSM, Diagnostic and Statistical Manual of Mental Disorders; HR, heart rate; MMSE, Mini Mental State Examination; MSQ, Mini-Sleep Questionnaire; NPI, Neuropsychiatric Inventory; NREM, non-rapid eye movement; PSG, polysomnography; REM, rapid eye movement; SDI, Sleep Disorders Inventory.

2.11 | Publication bias

There was an insufficient number of studies for any one meta-analysed outcome for funnel plots or Egger's tests for publication bias (minimum of 10 recommended by the Cochrane Collaboration and Cochrane Handbook of Systematic Reviews) (Higgins et al., 2021). In meta-analyses with a small sample of studies per outcome, the power of these tests is too low to distinguish real asymmetry from chance (Higgins et al., 2021). As a result, funnel plots or Egger's tests for publication bias were not undertaken.

3 | RESULTS

Our searches yielded 6745 publications (Figure 1). After duplicates were removed, 4593 papers were screened against our eligibility criteria by title and abstract. Two-hundred and fifty-six papers were deemed eligible or likely eligible. Full-text manuscripts were sought for these 256 papers. We were unable to access full-text manuscripts for three papers after extensive searches in online databases (see Methods), internet searches, and interlibrary loan requests (Hernandez et al., 2011; Weiy, 2010; Zhicheng et al., 2021). After full-text screening, 20 interventional trial papers were eligible for inclusion in the systematic review and 12 in the meta-analysis (Table 1). Ten papers were assessed at low-risk of bias, nine as some-concerns or moderate, and one as high-risk (Figure 2a,b).

3.1 | Sample characteristics

The 20 included studies represent the experiences of 3278 persons, 2066 of which were female (63%), with a mean age of 68 years (range 55–95 years), recruited from community, clinical, and research settings. Included papers were published from 1995 to 2022, with a mean sample size of 158 participants.

3.2 | Interventions (Table 1)

A wide range of exercise interventions and dosages were reported, ranging from once-weekly (Nascimento et al., 2014) to daily bouts (Bademli et al., 2019; McCurry et al., 2011) over 4 (Namazi et al., 1995) to 104 weeks (Vaz Fragoso et al., 2015), for 30 minutes (Choi & Sohng, 2018) to 80 minutes (Bademli et al., 2019). Four papers investigated low-intensity exercises, including low-intensity aerobic exercise, physical activity, elastic band or resistive exercise, overground walking programs, and light Tai Chi (Alessi et al., 1999; Chan et al., 2016; Eggermont et al., 2010; McCurry et al., 2011).

Moderate-intensity exercises were most frequently investigated (12 trials), including aerobic exercise, cycling or bicycle ergometry, resistance or strength training, walking programs, Tai Chi, yoga, or combinations of moderate-intensity exercises (Bademli et al., 2019; Choi & Sohng, 2018; Kumar et al., 2014; Landi et al., 2004; Li et al., 2021a; Namazi et al., 1995; Nascimento et al., 2014; Öhman et al., 2017; Song & Yu, 2019; Stella et al., 2011; Vaz Fragoso et al., 2015; Wang et al., 2020). Two studies investigated the effects of moderate to vigorous intensity (MTVA; MacIntosh et al., 2021) exercise, including aerobic dance (Song et al., 2023) and combined aerobic and strength training exercises (Hoffmann et al., 2016). Two studies investigated the effects of high-intensity exercises (Hoffmann et al., 2016; Richards et al., 2011), including cycling or treadmill exercise, resistance training, or combinations of high-intensity exercises at greater than 80% maximal heart rate.

3.3 | Sleep outcomes

A variety of assessment tools were used to collect sleep outcomes, including actigraphy, PSG, sleep diaries and subjective assessments, including PSQI (Buysse et al., 1989b), ISI (Bastien, 2001), MSQ (Gorenstein, 1983), NPI (Cummings et al., 1994), SDI (Tractenberg et al., 2003) and customised sleep quality tools.

3.4 | Sleep outcomes in persons with cognitive impairment or MCI

Nine studies investigated the effects of exercise on sleep in persons with MCI (excluding diagnosed AD/ADRD or dementia) or MMSE scores between 19 and 24 (mean 22.3) or MoCA scores between 18 and 25 (mean 22.05; details in Table 1). Exercise interventions improved self-reported sleep outcomes in persons with MCI. Only one study assessed the effects of exercise on objective sleep outcomes in persons with MCI (Li et al., 2021a). Li et al. (2021) reported that a 12-week, moderate-intensity resistance training program improved both actigraphy and subjectively measured sleep, with statistically significantly increased sleep efficiency and decreased wake after sleep onset and sleep fragmentation in 62 assisted living facility older adults (mean age 72.2 years) with MCI (Li et al., 2021a).

Among the remaining eight studies, a range of exercise modalities, intensities, frequencies and durations were reported. Two studies investigated the effects of low-intensity exercise on sleep in older adults with MCI. Alessi et al. (1999) investigated the effects of 14 weeks of daily, low-intensity physical activity on sleep and agitation in 29 nursing home-dwelling older adults (mean age 88.3 years) with MCI (Alessi et al., 1999). Participants in the exercise intervention showed increased total sleep time, longer sleep episodes, and less daytime sleepiness and agitation compared with the non-exercise group. Chan et al. (2016) found that a low-intensity Tai chi (TCG) exercise program increased sleep duration (+48 min), sleep efficiency, and improved sleep quality on the PSQI in 52 community-dwelling, sedentary older adults with cognitive impairment and poor sleep (PSQI score > 5 at baseline; Chan et al., 2016).

The majority of studies with persons with MCI investigated the effects of moderate-intensity exercise on sleep. Bademli et al. (2018) found that a 20-week, moderate-intensity exercise and walking

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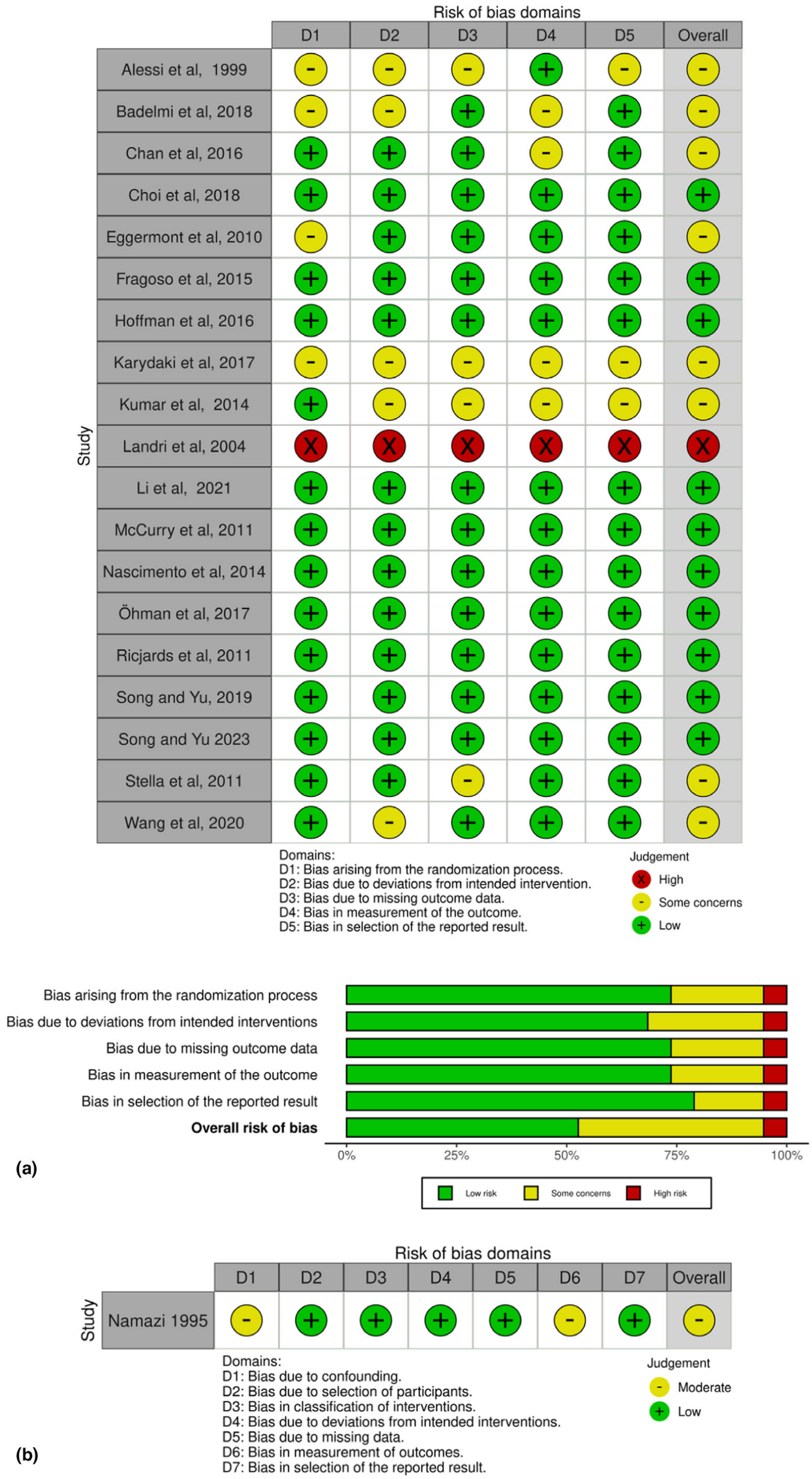
FIGURE 2 Risk of bias assessments: (a) RoB-2; (b) ROBINS-I.



Study or Subgroup	Mean Difference	SE	Weight	Mean Difference IV, Random, 95% CI
Badelmi 2009	−9.91	2.5891	1.7%	−9.91 [−14.98, −4.84]
Wang 2020	−2.45	0.5403	14.9%	−2.45 [−3.51, −1.39]
Karydaki 2017	−1.9	1.0761	7.2%	−1.90 [−4.01, 0.21]
ChanYu 2016	−1.8	0.7961	10.5%	−1.80 [−3.36, −0.24]
Song 2023	−1.74	0.8521	9.7%	−1.74 [−3.41, −0.07]
Song 2019	−1.257	0.1796	21.8%	−1.26 [−1.61, −0.90]
Choi 2018	−1	0.6332	13.1%	−1.00 [−2.24, 0.24]
Fragoso 2015	−0.53	0.2306	21.1%	−0.53 [−0.98, −0.08]
Total (95% CI)			**100.0%**	**−1.54 [−2.23, −0.86]**

Heterogeneity: $Tau^2 = 0.52$; $Chi^2 = 26.50$, df = 7 (P = 0.0004); $I^2 = 74\%$
Test for overall effect: Z = 4.43 (P < 0.00001)

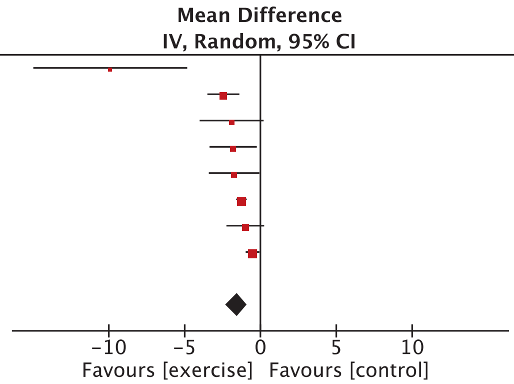


FIGURE 3 Forest plot, Pittsburgh Sleep Quality Index (PSQI) in adults with mild cognitive impairment (MCI).

Study or Subgroup	Mean Difference	SE	Weight	Mean Difference IV, Random, 95% CI
15.5.1 Total Sleep Time (min)				
Li 2021	23.6	21.429	4.9%	23.60 [−18.40, 65.60]
McCurry 2011	35	5.1391	85.7%	35.00 [24.93, 45.07]
Richards 2011	25.1	15.5068	9.4%	25.10 [−5.29, 55.49]
Subtotal (95% CI)			**100.0%**	**33.51 [24.18, 42.83]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.59$, df = 2 (P = 0.74); $I^2 = 0\%$				
Test for overall effect: Z = 7.04 (P < 0.00001)				
15.5.2 Sleep efficiency (%)				
Alessi 1999	10.7	1.7569	22.5%	10.70 [7.26, 14.14]
Eggermont 2010	−1.78	3.7753	12.2%	−1.78 [−9.18, 5.62]
Li 2021	9.9	2.449	18.4%	9.90 [5.10, 14.70]
McCurry 2011	4.9	0.4761	28.8%	4.90 [3.97, 5.83]
Richards 2011	5.4	2.509	18.1%	5.40 [0.48, 10.32]
Subtotal (95% CI)			**100.0%**	**6.40 [3.03, 9.78]**
Heterogeneity: $Tau^2 = 10.09$; $Chi^2 = 17.19$, df = 4 (P = 0.002); $I^2 = 77\%$				
Test for overall effect: Z = 3.72 (P = 0.0002)				

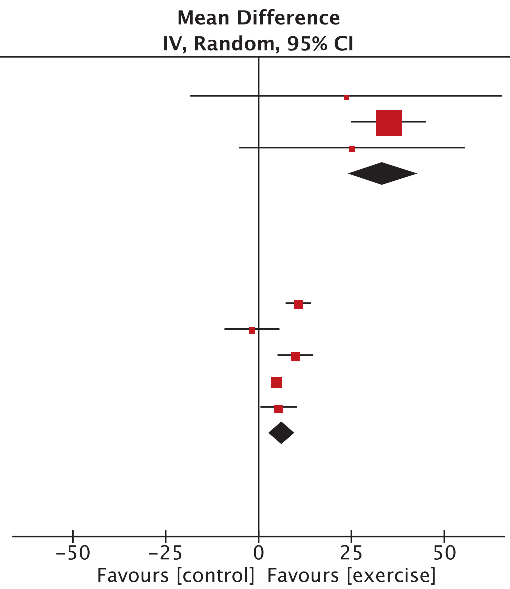


FIGURE 4 Forest plot, objective sleep measures.

program improved sleep quality on the PSQI (MD −9.0) and cognition in 77 sedentary, nursing home-dwelling persons over 65 years of age with MCI (Bademli et al., 2019). Choi et al. (2018) investigated the effects of a 12-week, four times per week seated yoga exercise program on sleep, physical fitness and depression in community-dwelling, sedentary older adults with MMSE scores ≥ 19 (Choi & Sohng, 2018). Participants in the exercise group reported a small but not statistically significant improvement in sleep quality on the PSQI. The authors noted, however, that sleep quality was measured during the hottest summer recorded in Korea, with 22 nights of extreme heat during the reference-month, possibly countering the effects of the intervention on participants' sleep quality.

Fragoso et al. (2015) found that a 24–30-month, moderate-intensity exercise program reduced the likelihood of participants developing poor sleep quality (PSQI >5) over the intervention period, and produced a small improvement in sleep quality in a sample of 1635 community-dwelling, sedentary older adults (aged 70–89 years) with cognitive impairment (Figure 2; Vaz Fragoso et al., 2015). Karydaki et al. (2017) investigated the effects of a 12-week resistance training program on subjective sleep quality in women with MCI, finding that resistance training improved subjective sleep quality (decreased global PSQI score; Karydaki et al., 2017).

Song et al. (2019) investigated the effects of a 16-week moderate-intensity aerobic exercise program on health-related quality of life, including sleep quality, and cognitive function in 120 sedentary, community-dwelling older adults with MCI (Song & Yu, 2019). Compared with participants in the health-education control group, participants in the aerobic exercise group reported significantly greater improvement in sleep quality on the PSQI. In a separate study of a 16-week, moderate-intensity aerobic dance exercise program, Song et al. (2023) also found that aerobic dancing (MTVA) significantly improved overall sleep quality (PSQI), sleep duration, sleep efficiency and sleep-onset latency in older adults with MCI and poor sleep (Song et al., 2023).

Finally, Wang et al. (2020) found that a 24-week, thrice-weekly moderate-intensity exercise program significantly improved sleep quality (lower PSQI scores) in a sample of 116 sedentary, community-dwelling older adults (mean age 68 years) with MCI (Wang et al., 2020). Sleep quality also had a strong mediating effect on the effects of the exercise program on participants' cognitive function.

3.5 | Sleep outcomes in persons with AD/ADRD

Ten studies examined the effects of exercise or physical activity interventions on sleep outcomes in persons with AD/ADRD (7) or dementia (3), finding exercise had beneficial effects on their sleep quality (Table 2). Eggermont (2010) investigated the effects of a 30-min walking program on sleep and sleep disturbances in 79 older adults aged ≥ 70 years with AD/ADRD (Eggermont et al., 2010). Participants in the walking program did not show improved night-time restlessness or actigraphy-measured sleep compared with the control group. However, it was possible that participants may not have had sufficient sleep disturbances at baseline to show a treatment effect. The timing of the physical activity interventions also varied frequently and may have influenced the study results (Kline et al., 2021).

Hoffman et al. (2016) found that a 16-week, moderate-to-high-intensity aerobic exercise program decreased sleep disturbances in a sample of 200 persons aged 50–90 years with mild AD (Hoffmann et al., 2016). Kumar et al. (2014) investigated the effects of a 5-week, Occupational Therapist-delivered exercise and structured physical activity program (OTP), finding that OTP improved sleep quality and decreased daytime sleepiness in a sample of 77 persons with dementia (Kumar et al., 2014).

Landi et al. (2004) investigated the effects of a 4-week, moderate-intensity exercise program on behavioural problems, including sleep disturbances, in a pilot study with 30 nursing-home-dwelling persons with dementia (Landi et al., 2004). Compared with the control group, the exercise group showed a statistically significant reduction in sleep disturbances at the 4-week follow-up. The study has several important limitations, however, including poor or absent reporting of participant's age, who delivered the intervention or how often, who collected outcome data or when, and no reporting of the units of measurement used for outcome assessments.

McCurry et al. (2011) investigated 30 daily minutes of continuous walking in a study of 132 persons with AD/ADRD, finding that participants in the exercise group had significantly greater improvements in sleep duration and quality than the control groups, even after adjustment for participant age, sex, depression, comorbidity, cognitive impairment and sleep apnea (McCurry et al., 2011).

Nascimento et al. (2014) found once-weekly, moderate-intensity multimodal exercise was associated with statistically significant improved sleep and reduced sleep disturbances in a randomised-controlled trial (RCT) of 35 persons with AD/ADRD (Nascimento et al., 2014).

Namazi et al. (1995) found a multimodal, moderate-intensity exercise program increased sleep quality and duration in a sample of 22 institutional-dwelling persons with AD/ADRD, but a small sample size and large range of MMSE scores at baseline may have influenced the results (Namazi et al., 1995). Öhman's secondary analysis of the Finnish Alzheimer Disease Exercise (FINALEX) trial (Pitkälä et al., 2013) found that exercise did not lead to statistically significant changes in sleep problems in community-dwelling persons with AD/ADRD (Öhman et al., 2017). However, they used only the NPI to assess sleep outcomes. The NPI has only one item (11) assessing sleep by caregiver reports of sleep behaviours but not changes in frequency or sleep quantity (Cummings et al., 1994). A high proportion of participants also took medications that may have influenced their sleep or response to the interventions.

Richards et al. (2012) found high-intensity exercise improved sleep quantity and efficiency, and increased minutes of REM sleep in institutional-dwelling persons with dementia and AD/ADRD (Richards et al., 2011). A high proportion (43%) of participants had sleep apnea, and whether their apnea was treated during the study was not reported. However, when apnea was included as a covariate in the authors' statistical models, it did not have a statistically significant effect on the relationship between exercise and total sleep time. Finally, Stella et al. (2011) investigated the effects of a 6-month, thrice-weekly aerobic and balance exercise program on neuropsychiatric symptoms, including sleep disturbances, in 32 community-dwelling persons with mild to moderate AD/ADRD (Stella et al., 2011). Compared with the control group, the exercise group attained statistically significantly greater reduction in sleep disturbances on the NPI.

3.6 | Meta-analyses

In total, 13 papers reported continuous data for sleep outcomes and were eligible for meta-analysis (Alessi et al., 1999; Bademli et al., 2019; Chan et al., 2016; Choi & Sohng, 2018; Eggermont et al., 2010; Karydaki et al., 2017; Li et al., 2021a; McCurry et al., 2011; Richards et al., 2011; Song et al., 2023; Song & Yu, 2019; Wang et al., 2020). Of the remaining seven papers, one was at high risk of bias and was excluded from meta-analysis (Landi et al., 2004). One did not report data with sufficient detail to allow meta-analysis, only displaying sleep outcome results visually on a graph (we were unable to determine the actual values from the graph; Hoffmann et al., 2016). The remaining five papers reported custom sleep metrics that could not be pooled with data from other papers for meta-analysis (Namazi et al., 1995), or used sleep outcome measures for which less than two papers reported outcomes (Kumar et al., 2014; Nascimento et al., 2014; Öhman et al., 2017; Stella et al., 2011).

Seven studies, representing the experiences of 1986 participants with MCIs or MCI in exercise and non-exercise interventions were eligible for meta-analysis (Figure 3). Exercise interventions had a statistically significant beneficial effect on PSQI-assessed sleep quality in persons with MCI (−1.54, 95% confidence interval [CI]: −2.23, −0.86).

3.7 | Objectively measured sleep

Five studies, representing the experiences of 446 persons with MCI or AD/ADRD, assessed sleep with actigraphy (four studies; Alessi et al., 1999; Eggermont et al., 2010; Li et al., 2021b; McCurry et al., 2005) or PSG (one study; Richards et al., 2011), and were eligible for meta-analysis (Figure 4). Only total sleep time and sleep efficiency were reported by more than two studies. Exercise interventions had a statistically significant beneficial effect on participants' total sleep time (increased by 34 min) and sleep efficiency (improved by 6%).

3.8 | Heterogeneity

Substantial heterogeneity was found in pooled meta-analyses of PSQI-assessed sleep and pooled sleep efficiency, while no heterogeneity for total sleep time. The heterogeneity found for PSQI assessed sleep and sleep efficiency may be influenced by clinical variability and lack of uniformity among exercise interventions and samples. Sensitivity analyses did not reveal any one study contributing significant heterogeneity in either case.

No one study, when removed during sensitivity analysis, significantly modified the pooled treatment effect estimates for the effect of exercise interventions and PSQI-assessed sleep quality in Figure 3. Only the study by Eggermont et al. (2010), when removed, modified the effect of exercise on sleep efficiency, which increased to 7.52% (95% CI: 4.08, 10.95); however, heterogeneity was unchanged. Eggermont did not find a beneficial effect on night-time restlessness or other actigraphy-measures sleep parameters after a 6-week, low-intensity exercise intervention. However, it was possible that participants may not have had sufficient sleep disturbances at baseline to show a treatment-effect, and the timing of the physical activity interventions also varied frequently, both of which may have influenced the study results (Kline et al., 2021).

4 | DISCUSSION

This systematic review investigated the effectiveness of exercise interventions targeting sleep in older adults with MCI or AD/ADRD. To the best of our knowledge, this is the first systematic review and meta-analysis of exercise interventions targeting sleep in this population. It represents the experiences of 3278 persons with MCI or AD/ADRD across 20 interventional studies. We found moderate- to high-quality evidence for the beneficial effects of exercise on self-reported and objectively measured sleep in older adults with cognitive impairment and persons with AD/ADRD.

Exercise interventions resulted in statistically significant improvements in subjective sleep quality in persons with mild to moderate cognitive impairment (PSQI −1.54, 95% CI: −2.23, −0.86), as well as improved sleep efficiency and total sleep time (Figures 1 and 2), emphasising the beneficial effects of exercise for sleep in this population. Exercise of any intensity, from low to high, improved sleep quality in older adults with cognitive impairment. This is significant, given that persons with cognitive impairment or AD/ADRD may also experience physical deconditioning or motor difficulties, and low- and moderate-intensity exercise may be more feasible for them (Bartlett et al., 2009).

A variety of potential mechanisms underlying the effects of exercise on sleep have been proposed, ranging from exercise-induced reduction in systemic inflammation, changes in neurotransmitters regulating sleep, increased growth hormone and brain-derived neurotrophic factor, changes in heart rate variability, body temperature, autonomic function, and entrainment of circadian rhythms and sleep–wake cycles (Kredlow et al., 2015; McGinty & Szymusiak, 1990; Uchida et al., 2012). Exercise interventions in a generally sedentary population of persons with cognitive impairment may also increase exposure to other factors associated with improved sleep, such as daylight, social activity, and decreased daytime napping (Liu et al., 2022; Livingston et al., 2020; Memon et al., 2020; Meng et al., 2020). These factors could not be accounted for in this systematic review, but offer important targets for future research.

4.1 | Alzheimer's disease and related dementias (AD/ADRD)

Fewer controlled studies investigated the effects of exercise on sleep in persons diagnosed with AD/ADRD. However, the available studies did find improved sleep quality and quantity as a result of exercise in persons with AD/ADRD. Mounting evidence suggests that poor sleep influences disease progression and cognitive decline in persons with AD/ADRD (Djonlagic et al., 2021; Irwin & Vitiello, 2019; Targa et al., 2021; Wang & Holtzman, 2020). Exercise can improve sleep and may have the potential to attenuate cognitive decline and neurodegeneration in AD/ADRD. A larger body of RCTs has investigated exercise interventions targeting cognition in persons with AD/ADRD, finding that increased physical activity and exercise improve cognitive function and may delay cognitive decline (Du et al., 2018). The mediating role of sleep in these effects has been underexplored, however.

Much else remains unknown about the effects of exercise on sleep in persons with AD/ADRD. For example, only one RCT investigated the effects of exercise on PSG-measured sleep outcomes (Richards et al., 2011). No RCTs investigated the effects of exercise on sleep microarchitecture such as NREM slow-wave activity or sleep spindles. These have also been under-investigated in studies of exercise targeting sleep in healthy older adults. This creates important evidence gaps, given that multiple facets of sleep neurophysiology are strongly associated with cognitive performance in older adults (Djonlagic et al., 2021), biomarkers of neurodegeneration and risk of AD/ADRD (Irwin & Vitiello, 2019; Wang & Holtzman, 2020). Better understanding of the mechanisms underpinning the effects of exercise on brain processes during sleep could lead to more effective exercise interventions aimed at maintaining or improving the memory functions of sleep (Roig et al., 2022). This may be of particular importance for older adults, persons at early stages of cognitive decline, and those at risk of AD/ADRD and their caregivers.

4.2 | Recommendations for future research

Our systematic review highlights important areas in need of further investigation. Given the many physical and mental health benefits associated with both increased physical activity and improved sleep, these areas for future research are critical for clinicians, policymakers and the public to make informed choices about exercise interventions targeting improved sleep, activity, and quality of life in older adults with cognitive impairment.

For example, the optimal time of day to perform exercise or minimum exercise dosage required to influence sleep in older adults remains uncertain. As a result, the optimal amount of exercise needed to improve sleep in older adults with cognitive impairments, or older adults generally, cannot be determined with certainty with currently available evidence. Previous systematic reviews and meta-analysis of exercise interventions targeting cognition in persons with MCI or dementia have found that multicomponent exercise combining aerobic and resistance training tends to be the most effective in protecting global cognition and executive function in persons with MCI, while resistance training is associated with slowing the progression of cognitive decline (Huang et al., 2022b). Meta-analyses of exercise interventions targeting sleep in older adults report larger treatment effects for moderate-intensity exercise (exercise at 60% of maximal oxygen uptake, VO2max, or maximal heart rate for age) on insomnia ($d = 0.87$, 95% CI: 1.68, 0.06; Amiri et al., 2021), and moderate-intensity aerobic exercise has been associated with greater increases in cognition and memory than light or vigorous exercise (Karamacoska et al., 2023; Ludyga et al., 2016; Northey et al., 2018). The greatest benefits for sleep quality in older adults have been reported with exercise programs combining moderate-intensity aerobic and resistive exercise training (Hasan et al., 2022). However, the optimal exercise modality for influencing sleep in persons with MCI or AD/ADRD cannot be determined from the evidence we reviewed.

The most influential moderators of the relationships between exercise and sleep in older adults, such as age, sex, gender (or gender-related roles) or disease progression, also remain unclear. For example, none of the studies we reviewed reported sleep outcomes for men and women separately, despite 63% of the participants in the studies included in our systematic review being female. Biological sex has been shown to contribute to variations in sleep (Cross et al., 2019; Mong & Cusmano, 2016), risk of dementia (Anstey et al., 2021) and Alzheimer's disease (Brady et al., 2024; Niu et al., 2017), physiological responses to exercise (Ansdell et al., 2020), and effects of exercise on cognitive outcomes in older adults (Barha et al., 2017). Meta-analyses have found higher rates of insomnia (Cross et al., 2019; Zeng et al., 2020), poor memory performance (Cross et al., 2019; Zhao et al., 2022), and prevalence of dementia (Anstey et al., 2021) and AD (Niu et al., 2017) among women than men. Sex differences have also been found in various risk factors for AD and dementia (Anstey et al., 2021; Kim et al., 2018), and gender has been shown to influence the risk of cognitive decline or dementia (Brady et al., 2024). Larger treatment effect sizes have also been reported for women than men in studies of exercise targeting cognition (Barha et al., 2017), though less is known about sex differences in studies of exercise and sleep. Few studies have examined sex differences in the effectiveness of exercise interventions targeting sleep in older adults, though some evidence suggests exercise leads to greater self-reported measures of sleep quality in females than males (Sharif et al., 2015).

Sleep disturbances increase functional impairment and disease progression, and negatively affect cognitive function in persons with AD/ADRD (Targa et al., 2021). Exercise may improve sleep disturbances and has the potential to attenuate neurodegeneration in AD/ADRD. However, much is unknown about the effects of exercise on sleep in this population. For example, few RCTs have investigated the effects of exercise on PSG-measured sleep or sleep microarchitecture (e.g. slow-wave activity; Aritake-Okada et al., 2019; Djonlagic et al., 2021; Kline et al., 2021; Memon et al., 2022; Park et al., 2021) in persons with AD/ADRD, to the best of our knowledge. Only one paper in this review included PSG-assessed sleep architecture, but it did not report sleep microarchitecture metrics (Richards et al., 2011). This represents an important knowledge-gap, given that NREM slow-wave activity has been linked to memory consolidation in older adults (Aritake-Okada et al., 2019; Djonlagic et al., 2021; Kline et al., 2021; Marshall et al., 2006; Memon et al., 2022; Ngo et al., 2013; Park et al., 2021; Weiner et al., 2023), and loss of normal NREM sleep slow-wave activity has been linked to cognitive impairment in older adults and pathophysiological changes in AD (Lee et al., 2020; Mander et al., 2015; Mander et al., 2016; Marshall et al., 2006; Ngo et al., 2013; Weiner et al., 2023).

The effects of exercise on sleep architecture and microarchitecture in older adults has generally been under-investigated. A larger body of RCTs has investigated exercise interventions targeting cognition in persons with AD/ADRD, finding that exercise improves cognitive function and may delay cognitive decline in persons with AD/ADRD (Du et al., 2018); however, the mediating role of sleep in these effects has been underexplored. Better understanding of the mechanisms underpinning exercise and sleep and their effects on brain processes during sleep could provide important information leading to more effective exercise interventions aimed at maintaining or improving the memory functions of sleep (Roig et al., 2022). This may also be of particular importance for persons with cognitive decline or those at risk of AD/ADRD and their caregivers.

Additional research is also needed to understand the pathogenesis of sleep dysfunction in AD/ADRD to facilitate more effective treatments targeting sleep, including exercise. These may include primary mechanisms, such as AD/ADRD-related loss of neurons in the basal forebrain, hypothalamus, thalamus, midbrain or circadian regulating areas, synucleinopathies, and orexinergic system dysfunction (Irwin & Vitiello, 2019). Secondary (indirect) mechanisms may include poor sleep hygiene, co-morbidities, medication side-effects, nocturia and a variety of environmental factors (Irwin & Vitiello, 2019). Greater understanding of the interactions and effects of these mechanisms will facilitate identification of the most effective exercise therapies for sleep in persons with AD/ADRD (Memon et al., 2020).

4.3 | Strengths and limitations

Our review has several strengths. We followed a carefully developed protocol with comprehensive search strategies, including grey literature, and found studies in several languages and settings that had not previously been meta-analysed, to the best of our knowledge. However, publication bias could not be investigated in our review. Another strength is that we included only studies with low or moderate risk of bias in our meta-analyses, and 19 of the 20 studies we systematically reviewed were appraised as having either low (nine studies) or moderate (10 studies) risk of bias.

There are also limitations in this review. No studies examined key potential moderators of the relationship between exercise and sleep, such as sex, daytime napping, medication use or the time-of-day participants exercised. It was also not possible to meta-analyse data for the effectiveness of exercise interventions on sleep in persons with AD/ADRD. The variability among available studies may reflect the complexities of administering exercise interventions with persons with reduced cognitive capacity or frailty. The evidence-base for exercise and sleep in older adults with cognitive impairment shares these limitations, including heterogeneic study designs, samples, and unanticipated confounding factors and inherent biases that may distort the magnitude of treatment effects and the results of meta-analyses (Higgins et al., 2021). We limited meta-analysis to controlled studies with low to moderate risk of bias to minimise these effects, and our eligibility criteria were designed to reduce potential confounding in our analyses.

Additionally, the majority of studies included in this systematic review utilised self-reported or caregiver-reported sleep outcome measures, such as the PSQI, ISI or the SDI (Tractenberg et al., 2003), rather than objective sleep measures such as PSG or actigraphy. Previous research with older adults with cognitive decline, reduced functional capacity or insomnia has found that they are more likely to show greater discordance between self-reported (e.g. the PSQI or sleep diaries) and objective sleep measures (Hughes et al., 2018; Martin et al., 2017; Van Den Berg et al., 2008). Vulnerable older adults also either underestimate or overestimate their sleep efficiency when it is compared with objective wrist actigraphy or PSG (Hughes et al., 2018; Martin et al., 2017; Van Den Berg et al., 2008). Sleep diaries and subjective assessments may also be challenging for older adults with cognitive impairments to complete, requiring caregiver assistance (Martin et al., 2017).

Objective sleep measures such as actigraphy or the gold-standard PSG can offer more accurate and less biased measures of sleep and responses to exercise in older adults with MCI or AD/ADRD. PSG also allows for assessment of the effects of exercise on sleep microarchitecture in persons with MCI or AD/ADRD. More research assessing the effects of exercise on sleep and sleep microarchitecture is needed, and could help facilitate the development of effective interventions for sleep and cognitive decline in older adults and person with MCI or AD/ADRD. However, in-lab PSG is expensive, can be burdensome and difficult to complete for persons in advanced stages of AD/ADRD (Urrestarazu & Iriarte, 2016). It can also be difficult to access (Matar et al., 2018; Vaughan et al., 2016). Nevertheless, the continued development and feasibility of wearable, electroencephalogram (EEG) headbands for in-home monitoring of sleep and sleep neurophysiology offers important opportunities to overcome the difficulties of performing in-lab PSG with persons with AD/ADRD (Pulver et al., 2024).

Both subjective and objective sleep outcomes are important in understanding the effects of exercise on sleep in older adults with cognitive decline. Subjective measures provide valuable information about persons' perceived and experienced sleep outcomes (Hughes et al., 2018; Landry et al., 2015; Westerlund et al., 2016). Future research can supplement subjective sleep assessments with actigraphy to provide a more complete picture of sleep patterns and responses to exercise in older adults with MCI or AD/ADRD. The proliferation and continued development of wearable sleep devices also offers important opportunities to supplement self-reported sleep measures with objective data that can be obtained unobtrusively in older adults with MCI or AD/ADRD (Bianchi, 2018; Matar et al., 2018; Pulver et al., 2024).

4.4 | Implications for practice or policy

The results of our systematic review have important implications for clinical care, gerontology, public health and health promotion, given the many physical and mental health benefits associated with both improved exercise and improved sleep (Liu et al., 2022; Memon et al., 2020; Meng et al., 2020). Sleep may be one of the most important modifiable risk factors for a range of health conditions, including cognitive decline and the progression of AD/ADRD (Irwin & Vitiello, 2019; Winblad et al., 2016). The number of people with AD/ADRD is expected to triple to more than 132 million by 2050, with the greatest increase expected in low- and middle-income countries (Organisation WH, 2017; Organization WH, 2021). This will present profound challenges for families, communities and societies in resource-constrained settings (Organisation WH, 2017; Organization WH, 2021). With aging, increasingly sedentary populations and growing incidence of AD/ADRD, the need for sustainable, accessible and effective interventions, like exercise, for both poor sleep and AD/ADRD is pressing.

Exercise is a widely accessible, cost-effective intervention for sleep difficulties. It is also associated with a range of benefits for cognitive performance, health and well-being, and quality of life in older adults (Langlois et al., 2013). Exercise interventions may also be used to target lifestyle factors and health conditions associated with increased risk of poor sleep or cognitive decline and dementia. For example, poor cardiometabolic health, including hypertension and diabetes, obstructive sleep apnea, and depression each increase the risk of poor sleep or cognitive decline and dementia in older adults (Baumgart et al., 2015; Dregan et al., 2013). Exercise has been shown to be an effective adjuvant treatment for these conditions and other health and lifestyle factors influencing health outcomes in older adults (García-Hermoso et al., 2020; Posadzki et al., 2020). Regular exercise can contribute to the management of cardiovascular and lifestyle risk factors, and help reduce the risk of cognitive decline and dementia in older adults (Baumgart et al., 2015; De la Rosa et al., 2020).

Exercise may also be an important complement to other therapeutic interventions for poor sleep in persons with, or at increased risk of, AD/ADRD (De la Rosa et al., 2020; González-Martín et al., 2023). For example, it is now recommended as an adjunct to CBTi, the first-line treatment for insomnia (Passos et al., 2023; Riemann et al., 2023). Available evidence also suggests that multimodal interventions that include exercise are effective from both poor sleep and functional and cognitive decline in older adults (Belleville et al., 2023; Falck et al., 2019; Falck et al., 2020; Wilfling et al., 2023). Promoting increased exercise, improved sleep and other lifestyle changes in older adults in the presymptomatic and prodromal stages of dementia has the potential to delay the progression of dementia in up to one-third of cases worldwide (De la Rosa et al., 2020).

5 | CONCLUSION

This systematic review includes 20 studies examining the effectiveness of exercise interventions targeting sleep in older adults with MCI or AD/ADRD. We found moderate- to high-quality evidence for the beneficial effects of exercise on sleep in older adults with cognitive impairment and AD/ADRD. The results of our systematic review support the development and dissemination of effective exercise interventions for sleep difficulties in older adults. We found that exercise of any intensity (low, moderate or high), and a range of frequencies and duration can improve subjectively and objectively measured sleep in this population. This has important implications for clinical care and public health. Improving sleep through exercise may support cognition and memory functions in older persons with MCI or AD/ADRD, and also support secondary prevention of sleep-related health problems. Given our findings and previous research showing that exercise is also associated with a range of benefits for physical and mental health, clinicians may consider adding exercise as an effective intervention or adjuvant strategy for improving sleep in older persons with cognitive impairment or AD/ADRD.

AUTHOR CONTRIBUTIONS

Arsenio Páez: Conceptualization; writing – original draft; methodology; writing – review and editing; software; formal analysis; project administration; data curation; supervision; validation; visualization; investigation. **Emmanuel Frimpong:** Investigation; methodology; writing – review and editing; formal analysis. **Melodee Mograss:** Conceptualization; writing – review and editing; supervision. **Thien Thanh Dang-Vu:** Conceptualization; methodology; writing – review and editing; formal analysis; supervision.

CONFLICT OF INTEREST STATEMENT

The authors assert that they have no competing interests of conflicts of interests to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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