Aging Clinical and Experimental Research (2025) 37:169
https://doi.org/10.1007/s40520-025-03065-w

SYSTEMATIC REVIEW

Effect of physical activity interventions on physical and mental health of the elderly: a systematic review and meta-analysis

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Received: 31 January 2025 / Accepted: 29 April 2025

Abstract

Objective This meta-analysis aimed to systematically assess whether physical activity (PA) can improve physical health(PH) and mental health(MH) in elderly.

Method To conduct this meta-analysis, four databases were searched from the start to October 24, 2024 (Web of Science and PubMed in English, CNKI and Wanfang Data Knowledge Service Platform in Chinese). Eligibility criteria included (1) study populations aged≥60 years of normal elderly, with no gender restrictions; (2) the experimental group included PA interventions; (3) the control group consisted of non-PA interventions or usual activities; (4) assessment results from health evaluation tools and psychological scales; (5) the research design was a controlled experimental study. The Cochrane bias risk tool was used to assess the quality of evidence for each study. Among 4,151 potential related articles, 9 met the criteria for inclusion in this review.

Results The PA intervention shows a high degree of statistical heterogeneity in the overall results for the PH of the elderly (I^2=93.8%, $p<0.01$). The effect size of the PA intervention on the PH of the elderly is 0.86 (95% CI: 0.08, 1.64), which is statistically significant. Subgroup analysis showed that in intervention frequency, the heterogeneity for interventions less than three times per week is low ($I^2 = 25.6\%$); in intervention duration, interventions lasting less than 30 min is relatively high, the direction of the study results is quite consistent. The overall effect size is 2.32 (CI: 1.45, 3.20), indicating statistical significance; in overall intervention duration, the overall effect size for interventions lasting less than 12 weeks is (CI: 0.08, 1.59), while the effect sizes for the other two subgroups include 0, indicating non-significant results. The overall results for the MH of the elderly also exhibit a high degree of statistical heterogeneity (I^2=95.3%, $p<0.01$). The effect size of the PA intervention on the MH of the elderly is -0.22 (95% CI: -1.46, 1.03), which is not statistically significant. Subgroup analysis also showed no statistically significant differences. The PH and MH of the elderly may potentially improve through PA interventions, although further research is needed to clarify whether these benefits hold clinical significance beyond statistical significance.

Conclusion PA interventions with a frequency of less than 3 times per week, each session lasting less than 30 min, and a total duration not exceeding 12 weeks may be more effective in improving the PH of the elderly. This study did not identify the optimal dosage for improving the MH of the elderly. These findings highlight the potential benefits of PA for PH in the elderly but underscore the need for more rigorous studies to determine optimal intervention parameters and to explore the clinical significance of PA for both PH and MH.

Keywords Physical activity · Physical health · Mental health · Elderly

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Introduction

The issue of population aging is a severe challenge faced globally and a significant problem that urgently needs to be addressed in socioeconomic development. According to the United Nations, individuals aged 60 years or older are classified as elderly [1]. According to the United Nations, a country or region is considered to be aging socially if the proportion of elderly individuals aged 65 and above reaches over 7%, or if those aged 60 and above reach over 10%. Relevant statistics indicate that the phenomenon of population aging in the twenty-first century will be unprecedented in human history, with one in nine individuals being aged 60 and above, and it is projected that by 2050, this will increase to one in five [2]. Population aging is not only a change in demographic structure but also impacts the development of various fields, including society and the economy [3].

In 1948, the WHO proposed a three-dimensional concept of health, stating that comprehensive health should include physical health, mental health, and social health, which further expanded the evaluation of health [4]. Given the specificity of social health, we consider it as a strategy to promote the physical and mental well-being of the elderly in the future. Based on this, the physical and mental health in this study mainly refers to the PH and MH of the elderly. Although the life expectancy of humans continues to increase rapidly in most countries, this does not necessarily mean an increase in healthy life expectancy, as a series of issues related to physical and mental health increase with the age of the elderly [5]. Relevant studies indicate that diseases among the elderly arise not only from infectious diseases but also from non-communicable diseases represented by physical health issues like obesity and chronic diseases, as well as psychological health issues such as emotional disturbances and depression, which remain major health problems that urgently need to be addressed.

The PH and MH of the elderly is crucial for their families and contributes to their quality of life. To promote healthy aging, scientifically and reasonably ensuring the physical and mental health of the elderly is one of the focal issues of multiple disciplines, including medicine and sports science. The WHO has already indicated the key role of exercise in healthy aging [6]. As the elderly age, they may experience a decline in muscle strength and an increase in body weight [7], leading to a series of physical and mental health problems, including an increased risk of chronic diseases such as coronary heart disease and type 2 diabetes. The fitness functions of PA vary, some regulate the body, while others regulate the mind, and different sports have distinct characteristics. A large number of studies have shown that PA has a positive effect on promoting the PH and MH of the elderly [8, 9]. For example, an experimental study indicated that the group of elderly individuals engaged in aerobic plus strength training showed significantly greater increases in stroke volume at rest compared to the group engaged solely in aerobic exercise, along with significant gains in muscle strength, demonstrating that physical exercise can effectively improve the physical fitness of the elderly [10]. Another study's findings suggest that PA is one of the main factors in improving the physical condition of the elderly and alleviating their anxiety, playing an important role in reducing levels of anxiety and depression and enhancing physical fitness [11]. Despite research findings indicating numerous benefits of PA interventions for the elderly, some studies have yielded inconsistent results, leading to uncertainties about the effectiveness of these interventions.

How to maintain the physical and mental health of the elderly has become a major focus of research and discussion in contemporary society, making the search for suitable PA to enhance their well-being a current research hotspot. Therefore, it is necessary to quantify the impact of PA interventions on the physical and mental health of the elderly through meta-analysis, thereby exploring the effectiveness of exercise interventions and their actual effects on outcomes. Furthermore, it is essential to investigate the potential moderating effects of different intervention durations, cycles, and frequencies on physical and mental health, in order to provide health support for the well-being of the elderly.

Materials & methods

Protocol registration and reporting

The protocol for this systematic review was registered in advance on the Open Science Framework (OSF) platform under the code number DOI https://doi.org/10.17605/OSF.IO/P8TD5(accessed on November 1, 2024). Our reporting adheres to the PRISMA 2020 [12].

Eligibility criteria

Types of studies and population

Studies were eligible for inclusion if they involved participants with a mean age of ≥60 years at enrolment, in accordance with the WHO definition of elderly. We did not restrict studies based on maximum age, follow-up period, sample size, participant characteristics, or study setting. Both small and large sample studies were considered, as long as other inclusion criteria were met. Only peer-reviewed published studies were included; grey literature and unpublished studies (e.g., conference abstracts) were excluded. Eligible trials used a no-exercise control group (e.g., wait-list or no intervention). Studies were excluded if the control group received any active intervention, such as usual physical activity, stretching, or therapeutic exercise.

Types of exposure factors

Eligible studies had to measure and report physical activity exposure in accordance with the definition from the physical activity Research Network. This includes: (1) Different types of exercise, such as interval training, resistance training, yoga, and aerobics; (2) Varying intensity levels of physical activity, including different intensities of resistance training.

Types of outcomes

Eligible outcomes must assess either PH, MH, or both. All valid measures of PH (e.g., physical fitness, body composition, body function) and MH (e.g., psychological status, mood changes) were included. Studies with composite health outcomes addressing both PH and MH were also eligible.

Information sources and search strategy

We conducted a search of PubMed, Web of Science, China National Knowledge Infrastructure (CNKI), and Wanfang databases from the establishment of the database up to October 24, 2024. We manually checked references and citation tracking for all included reports and related reviews. Additionally, we collaborated with an academic expert with knowledge of systematic review search methods to develop our search strategy, covering key concepts: Exercise, Health (such as mental health and physical health), and elderly (such as Aged). Our language selection includes both Chinese and English. For example, in PubMed, our search is shown in Table 1.

Selection process

The literature was imported into Endnote X9 software for de-duplication, the titles and abstracts were read for initial screening, and the remaining literature was downloaded in full and screened. The extracted literature was then compared by two of the study authors (K.Q., Z.W.), the decision to include the article was made through a joint discussion with a third researcher.

Data extraction

Data extraction was performed using a standardized Microsoft Excel form. Initially, both reviewers (Z.W. and K.Q.) independently piloted the data extraction process to ensure consistency and clarity. Subsequently, one reviewer (Z.W.) extracted data from the included English-language studies, and the second reviewer (K.Q.) independently verified the extracted information to ensure accuracy. Any discrepancies were resolved through discussion, and if necessary, adjudicated by a third reviewer. Researchers fluent in the necessary languages extracted data from non-English reports. We extracted detailed information, including study characteristics, sample details, exercise exposure, physical and mental health outcomes, and statistical methods. Adjusted and unadjusted estimates, such as risk ratios (RR), odds ratios (OR), and variance measures (e.g., 95% CI), were extracted as reported in the original documents. When multiple adjusted models were reported, we extracted estimates with more potential confounding factors to reduce the overall risk of residual confounding. Potential confounding factors were categorized by exercise dose, including exercise duration, frequency, and time.

Study risk of bias assessment

The quality of the included studies was assessed using the Cochrane risk of bias assessment criteria, which evaluates the potential bias in randomized controlled trials (RCTs) across several key domains: (1) Random allocation methods: This dimension assesses whether the method of random sequence generation was adequately described and whether the allocation process was properly implemented. Studies with unclear or poorly described randomization procedures may introduce selection bias, affecting the credibility of the results. (2) Allocation concealment: This evaluates whether the process of concealing allocation was implemented to prevent predictable assignment of participants to specific groups. If allocation concealment was not properly implemented, this could introduce selection bias, potentially affecting the internal validity of the study. (3) Blinding of subjects and investigators: This domain assesses whether participants and investigators were blinded to the allocation groups to minimize performance and detection bias. Lack of blinding could lead to bias in participant behavior or outcome assessments. (4) Outcome assessment blinding: This dimension examines whether those assessing the outcomes were blinded to group assignments. If assessors were not blinded, it could lead to detection bias, particularly for subjective or behavioral outcomes. (5) Data integrity: This refers to the completeness of the data and whether any discrepancies in the data collection or reporting process could affect the validity of the results. Inadequate handling of missing data or inappropriate statistical methods to account for missing data could introduce bias and affect the robustness of conclusions. (6) Selective reporting: This evaluates whether all predefined outcomes were reported or if there was selective reporting based on the results. Selective reporting introduces reporting bias, distorting the overall findings and limiting the generalizability of the study results.

Table 1 Retrieval

Retrieval process
#1 (Aged[Title/Abstract]) OR (Elderly[Title/Abstract])
#2 ((((((((((((((((((((((((((Exercise[Title/Abstract]) OR (Exercises[Title/Abstract])) OR (Physical Activity[Title/Abstract])) OR (Activities, Physical[Title/Abstract])) OR (Activity, Physical[Title/Abstract])) OR (Physical Activities[Title/Abstract])) OR (Exercise, Physical[Title/Abstract])) OR (Exercises, Physical[Title/Abstract])) OR (Physical Exercise[Title/Abstract])) OR (Physical Exercises[Title/Abstract])) OR (Acute Exercise[Title/Abstract])) OR (Acute Exercises[Title/Abstract])) OR (Exercise, Acute[Title/Abstract])) OR (Exercises, Acute[Title/Abstract])) OR (Exercise, Isometric[Title/Abstract])) OR (Exercises, Isometric[Title/Abstract])) OR (Isometric Exercises[Title/Abstract])) OR (Isometric Exercise[Title/Abstract])) OR (Exercise, Aerobic[Title/Abstract])) OR (Aerobic Exercise[Title/Abstract])) OR (Aerobic Exercises[Title/Abstract])) OR (Exercises, Aerobic[Title/Abstract])) OR (Exercise Training[Title/Abstract])) OR (Exercise Trainings[Title/Abstract])) OR (Training, Exercise[Title/Abstract])) OR (Trainings, Exercise[Title/Abstract])))
#3 (((((((Health[Title/Abstract]) OR (Normality[Title/Abstract])) OR (Normalities[Title/Abstract])) OR (Normalcy[Title/Abstract])) OR (Normalcies[Title/Abstract])) OR (Individual Health[Title/Abstract])) OR (Health, Individual[Title/Abstract])))
#4 ((((Mental Health[Title/Abstract]) OR (Health, Mental[Title/Abstract])) OR (Mental Hygiene[Title/Abstract])) OR (Hygiene, Mental[Title/Abstract])))

#5 #1 and #2 and #3 and #4

Each domain was assessed for risk of bias, with studies rated as having low risk, high risk, or some concerns based on the clarity and adequacy of their procedures. The overall risk of bias was determined by synthesizing the assessments of the individual domains. The risk of bias assessments have important implications for the interpretation of the findings. Studies with a high risk of bias may provide less reliable estimates of the intervention effects, whereas those with low risk of bias are more likely to yield robust and generalizable results. Therefore, the potential influence of bias on the outcomes should be taken into consideration when interpreting the results of this review.

Statistical methods

Among the nine studies reviewed in this systematic review, there were differences in the measurement dimensions of individual studies, which required merging during the data extraction process. Since the data were presented as continuous variables, they were transformed according to standard methods. To assess the combined effect, we calculated weighted mean differences (WMDs) and 95% confidence intervals (CIs). We applied a random-effects model for the meta-analysis to account for potential variability across studies. The random-effects model is appropriate given the heterogeneity across studies in terms of participant characteristics, intervention types, and outcome measures. We assessed heterogeneity among studies using the I^2 statistic and Chi-square test. A random-effects model was applied due to the expected clinical and methodological heterogeneity across studies. If substantial heterogeneity was identified ($I^2 > 50\%$), we conducted subgroup analyses to explore potential sources of variation. Subgroup variables included intervention type, duration of intervention, and outcome category (physical health vs. mental health vs. both). Sensitivity analyses were also conducted by excluding studies with high risk of bias to assess the robustness of the findings. Subgroup analysis involved categorizing studies based on factors such as intervention type and participant characteristics to identify sources of variation. Sensitivity analysis was conducted by excluding studies with high risk of bias to examine whether these studies influenced the overall results. Forest plots were used to visually inspect the degree of heterogeneity across studies and to detect any potential publication bias. The findings of the forest plots provided additional context for interpreting the results of the meta-analysis.

Equity, diversity and inclusion statement

Based on our commitment to inclusivity and rigor, we placed no restrictions on participant characteristics (e.g., gender, ethnicity, culture, and socioeconomic status), research context or environment (e.g., region, urban, community), and publication languages (Chinese and English) to maximize the inclusion of potential data. Our review team is dedicated to promoting equity, diversity, and inclusion, reflecting a gender-balanced composition from various cultural backgrounds and career stages, including researchers from different time periods. Additionally, we will focus on current research trends in this meta-analysis to ensure that included studies can cover a wide range of sample characteristics, enhancing the generalizability and applicability of the research findings. This diversity not only strengthens the rigor of the research but also provides valuable perspectives and insights for future related studies.

Patient and public involvement

There was no patient or public involvement in this study.

Results

Study selection

Two reviewers (Z.W. and K.Q.) independently screened the studies retrieved from the four electronic databases based on the predefined inclusion and exclusion criteria. After initial screening of titles and abstracts, and later full-text assessment, any disagreements were discussed and resolved through consensus. If consensus could not be reached, a third reviewer was consulted to arbitrate and finalize the inclusion decision. After eliminating 1,723 duplicates, 2,428 studies remained; after reviewing titles and abstracts, 2,346 studies were removed, leaving 82 studies, the reasons for the exclusion of 2,346 studies are as follows: (1) 1,078 studies were not relevant to the research topic; (2) 1,268 studies were reviews, commentaries, case reports, or theoretical articles rather than the original studies required for the meta-analysis. After full-text review, 73 studies were excluded, among the 73 excluded studies, 18 were removed due to the unavailability of full text, while 55 were excluded due to incomplete or non-extractable data. resulting in 9 studies that were ultimately included in the meta-analysis. The study selection process is illustrated in Fig. 1.

Characteristics of included literature

Through systematic searches and other sources, a total of 503 participants from 9 recent articles published by 2024 were included in this study, comprising 14 experimental control studies conducted among individuals aged 60 years and older (Table 2). Notably, among the 14 studies, 8 were from China, 2 each from South Korea and Iran, and 1 each from the United Kingdom and Italy.

Risk of bias assessment

The quality assessment, shown in Fig. 2, was conducted using the Cochrane risk of bias assessment criteria to evaluate the methodological quality of the included studies. Most of the studies were rated as having a low risk of bias in randomization and blinding of outcome assessors, indicating a high level of methodological rigor in these areas. However, several studies exhibited some concerns or high risk in allocation concealment and handling of missing data. Specifically, studies with unclear randomization methods or incomplete reporting of data could have introduced selection or detection biases, potentially skewing the results. Overall, most of the studies received quality scores of Grade A or B, indicating a moderate to high quality level, as illustrated in Fig. 2. Despite these concerns, the overall methodological quality of the included literature is considered good.

Overall effect of physical activity on physical health elderly

A total of 12 controlled studies were included in the meta-analysis to elucidate and compare the effects of PA on the PH of elderly. The SMD values and confidence intervals of the

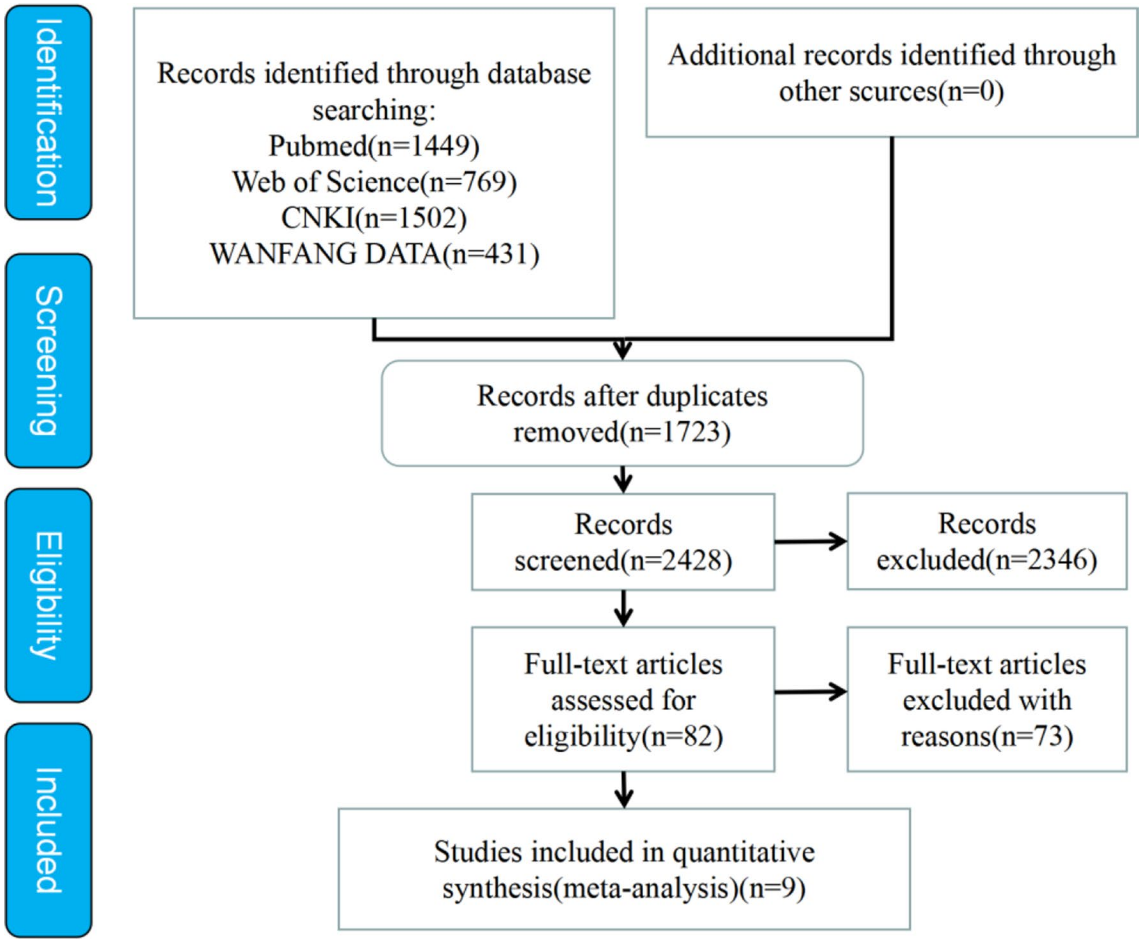


Fig. 1 The selection process for the meta-analysis

12 studies shown in Fig. 3 vary widely. Some studies (e.g., "Lai (2022)" with three studies and "Yang (2024)") reported positive and significant SMD values ranging from 1.92 to 3.21, indicating a positive effect. In contrast, "Sun (2024)" reported an SMD of -1.70, indicating a negative impact on the overall effect. The diamond at the bottom represents the overall effect estimate, approximately [SMD = 0.86, 95%CI(0.08, 1.64)]. The confidence interval does not cross zero, indicating that the overall effect is statistically significant, which suggests that the combined results generally show a positive effect. The I^2value is 93.8%, with a $p < 0.05$, indicating significant heterogeneity among the studies. Therefore, a random effects model was employed for analysis to address the high heterogeneity between studies.

Subgroup moderation effect test

Studies have found that PA can effectively improve the PH of elderly. As the forest plot showed a high level of heterogeneity, a subgroup analysis was applied to the incorporated articles and the outcomes are shown in Fig. 4. The observations are as follows:

Figure 4 shows that the overall combined effect is [SMD = 0.86, 95% CI (0.08, 1.64)], I^2=93.8%, $p < 0.05$, indicating some heterogeneity, but overall, PA interventions have a positive impact on the PH of elderly (as the SMD is negative and the confidence interval does not include 0).

The grouping based on intervention frequency indicates 1 for three interventions per week, 2 for fewer than three interventions per week, and 3 for more than three interventions per week. Subgroup analysis results indicate that the heterogeneity for interventions less than three times per week is low (I^2 = 25.6%), suggesting that the results in this subgroup are relatively consistent. This suggests that lower-frequency interventions may produce more consistent outcomes across studies, possibly due to better adherence and recovery time among elderly, which enhances the stability of effects. The overall effect estimate for this subgroup is 0.84 (CI: 0.08, 1.59), and the confidence interval does not include 0, indicating statistical significance.

Table 2 Included basic information

Study	Sample		design	sample size		Experimental					outcome symptom	Outcome indicator	outcome
	countary	age(Range)		Experi–mental	control	experimental group	control group	frequency	duration	cycle			
Sun(2024)	China	≥65	N-RCT	41	41	OMI	MNI	3times/week	30–40 min	12week	Lower limb muscle strength	FTSTS	OMI can improve lower limb muscle strength in the elderly
Lai(2022)	China	≥60	RCT	20	20	SMSR	MNI	3times/week	20 min	12week	Lower limb muscle strength	U.S MRAK-10, Series EKK	SMSR can improve lower limb muscle strength in the elderly
Lai(2022)	China	≥60	RCT	19	20	SHSR	MNI	3times/week	20 min	12week	Lower limb muscle strength	U.S MRAK-10, Series EKK	SHSR can improve lower limb muscle strength in the elderly
Lai(2022)	China	≥60	RCT	18	20	LHSR	MNI	3times/week	20 min	12week	Lower limb muscle strength	U.S MRAK-10, Series EKK	LHSR can improve lower limb muscle strength in the elderly
Yang(2024)	China	≥60	RCT	25	21	YOGA	MNI	3times/week	60 min	12week	Physical mental	Stop-watch, tape measure, wooden chair (43 cm), 8 lb dumbbell, 5 lb dumbbell, ruler, yoga mat and ioi353 body composition tester	Yoga can improve the body composition and physical fitness level of the elderly

Table 2 (continued)

Study	Sample		design	sample size		Experimental					outcome symptom	Outcome indicator	outcome
	countary	age(Range)		Experi–mental	control	experi-mental group	con-trol group	frequency	duration	cycle			
Yang(2024)	China	≥60	RCT	24	21	BUE	MNI	3times/week	60 min	12week	Physical mental	Stop-watch, tape measure, wooden chair (43 cm), 8 lb dumbbell, 5 lb dumbbell, ruler, yoga mat and ioi353 body composition tester	Body-building exercise can improve the body composition and physical fitness level of the elderly
Wang(2020)	China	> 60	N-RCT	25	25	MPE	MNI	5times/week	10 min	14month	Physical function, mental state	PEF, EFV1, FVC, SCL-90	MPE can improve the cardiopulmo-nary function and mental state of the elderly
Lai(2024)	China	≥60	RCT	36	36	MCT	GHE	2times/week	30 min	16week	Mental state, physical quality	TFI, POMA, TUGT	MCT can improve the mental state and physical fitness of the elderly
Amir(2021)	Iran	≥65	N-RCT	15	15	LIAB	MNI	2times/week	55 min	12week	Psychological Well-Being	Ryff's scales	LIAB can improve the psychological well-being of the elderly
Amir(2021)	Iran	≥65	N-RCT	15	15	MIAB	MNI	2times/week	55 min	12week	Psychological Well-Being	Ryff's scales	MIAB can improve the psychological well-being of the elderly
Yoon(2019)	Korea	≥60	RCT	10	10	RE	MNI	3times/week	60 min	12week	Physical health, cog-nitive psychology	ABM, BS-3,BS-3, etc., KDSQ-C	RE can improve physical health and cognition in the elderly

Table 2 (continued)

Study	Sample		design	sample size		Experimental					outcome symptom	Outcome indicator	outcome
	countary	age(Range)		Experi– mental	control	experi- mental group	con- trol group	frequency	duration	cycle			
Yoon(2019)	Korea	≥60	RCT	10	10	IT	MNI	3times/week	60 min	12week	Physical health, cog- nitive psychology	ABM, Biodex sys- tem-3, etc., KDSQ-C	IT can improve the physi- cal health and cognition of older people
Garry(2017)	UK	≥60	RCT	21	26	Yoga	MNI	1times/week	75 min	12week	physical health、psychological health	SPPB, WEMWBS	Yoga can improve the physical health and psy- chological health of older people
Giuseppe(2016)	Italy	≥60	RCT	17	13	APAP	MNI	2times/week	70 min	8week	physical health、psychological health	PCS-36, MCS-36	Apap can improve the phys- ical functioning and psychological health of older people

N-RCT: Non-randomized controlled trial; RCT: Randomized controlled trial; OMI: Otago Movement Intervention; MNI: Maintain a normal life; FTSTS: Five TimesSit-To-Stand; SMSR: Small amount of moderate strength resistance intervention; SHSR: Small amount of high strength resistance intervention; LHSRarge number of high strength resistance interventions; BUE: Body-building exercise; MPE: Moderate physical exercise; PEF: Peak expiratory flow; EFV1: 1 s forced expiratory volum; FVC: Forced expiratory volume; SCL-90: Symptom Checklist; MCT: Motor cognitive training; GHE: General health education; TFI: Tilburg frailty indicto; POMA: Tinetti gait and Performance Oriented Mobility Assesent; TUGT: Time up and go test; LIAB: Low IntensityAerobic-Based; MIAB: Moderate IntensityAerobic-Based; RE: Resistance exercise; IT: Interval training; APAP: Adapted physical activity program; KDSQ-C: Korean Dementia Screening Questionnaire-Cognition; ABM: Automatic body meter; BS-3: Biodex system-3; SPPB: Short Physical Performance Battery; WEMWBS: Warwick Edinburgh Mental Well-being Scale; PCS-36: Physical component summary; MCS-36: Mental component summary

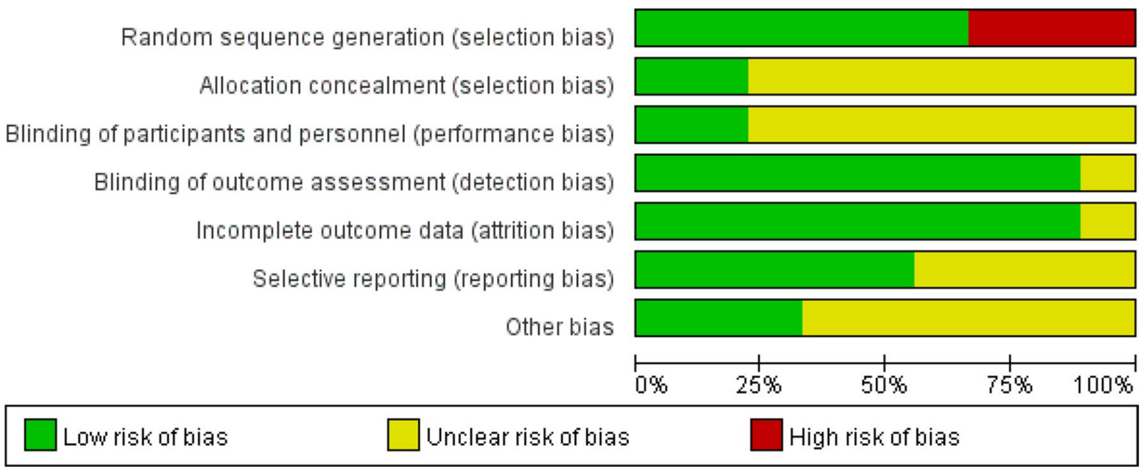


Fig. 2 The quality evaluation is shown

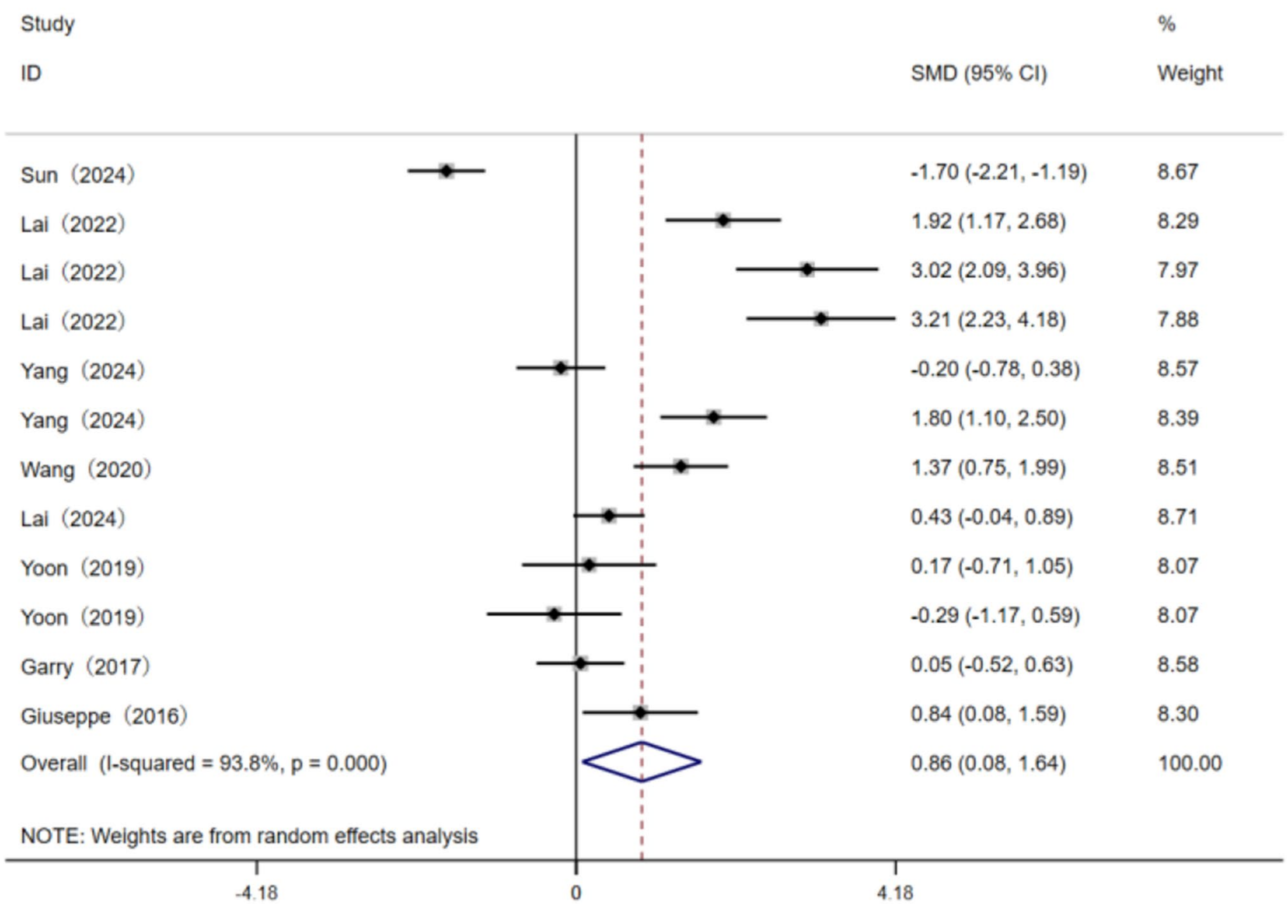


Fig. 3 A meta-analysis of the overall effects of PA on physical health in elderly

The grouping based on intervention duration indicates 1 for single intervention times of 30–40 min, 2 for less than 30 min, and 3 for more than 40 min. Subgroup analysis results indicate that while the heterogeneity for interventions lasting less than 30 min is relatively high, the direction of the study results is quite consistent. The overall effect size is 2.32 (CI: 1.45, 3.20), indicating statistical significance. Despite the significant effect, the high heterogeneity may stem from differences in exercise types (e.g., aerobic vs. resistance), methods (group vs. individual), or measurement tools used across studies.

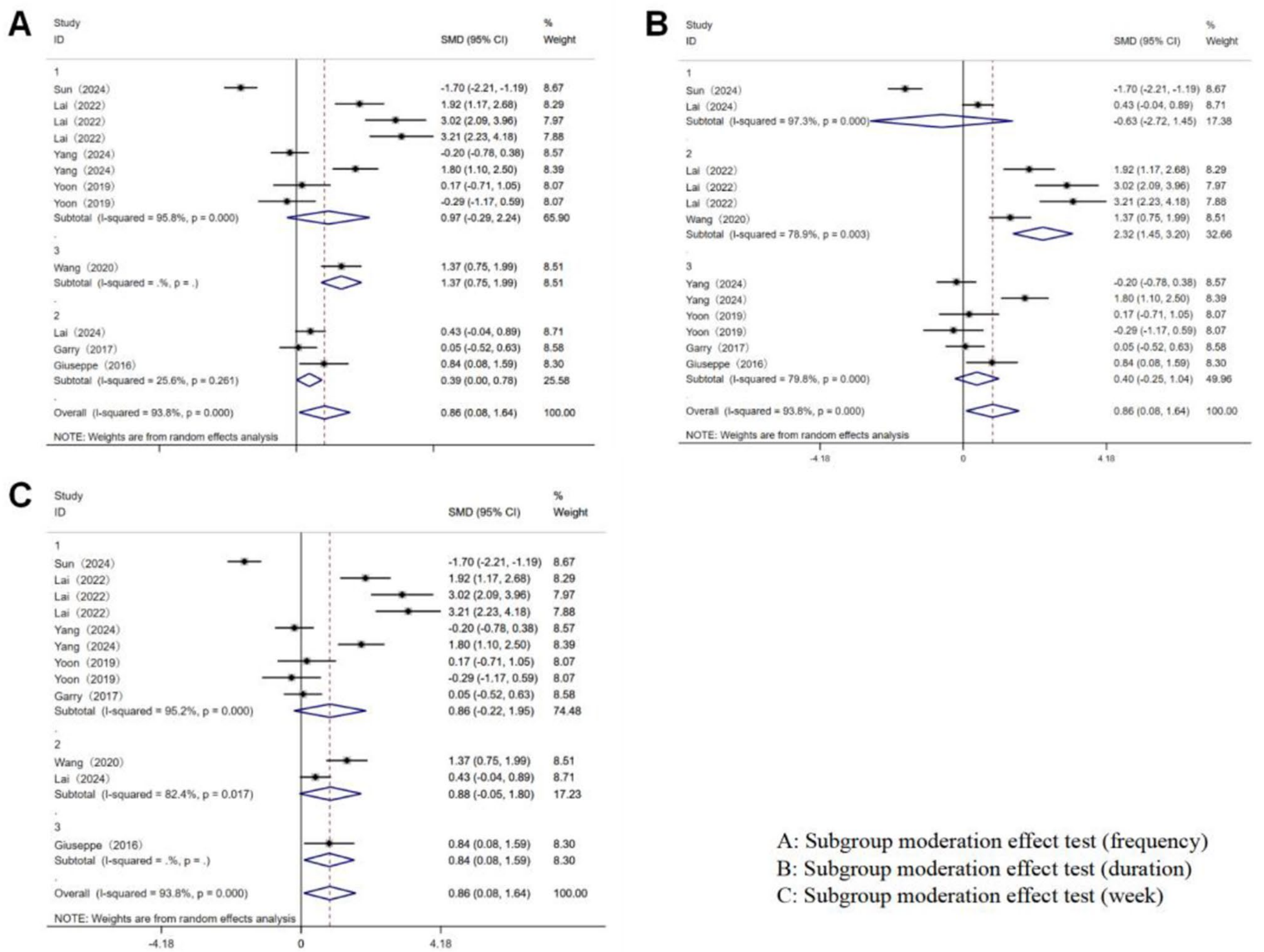


Fig. 4 A subgroup analysis of physical health in elderly

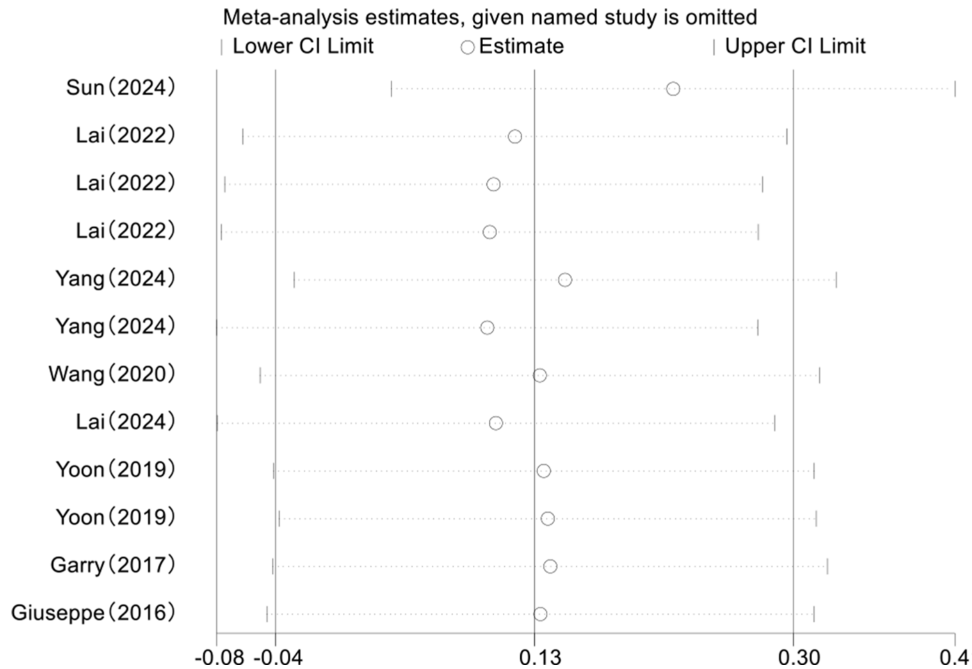
The grouping based on overall intervention duration indicates 1 for a duration of 12 weeks, 2 for more than 12 weeks, and 3 for less than 12 weeks. Subgroup analysis results show that the overall effect size for interventions lasting less than 12 weeks is (CI: 0.08, 1.59), while the effect sizes for the other two subgroups include 0, indicating non-significant results. Therefore, interventions lasting less than 12 weeks are relatively more effective, This may be due to higher adherence and lower dropout rates in shorter programs. In contrast, longer durations may introduce variability due to participant attrition and reduced engagement over time.

In summary, the subgroup analysis based on intervention frequency exhibits low heterogeneity, and the results are robust. The subgroup analysis based on intervention duration and period is statistically significant but shows high heterogeneity, which may require further analysis of the sources of heterogeneity. Overall, subgroup analysis helped clarify part of the observed heterogeneity, especially in terms of intervention frequency. However, residual variability may still result from differences in study design, population characteristics, and outcome measures, highlighting the need for standardized protocols in future research.

Sensitivity analysis

In Fig. 5, it can be seen that the overall effect estimate does not vary much when any individual study is removed, and most effect estimates are concentrated around 0.13. This indicates that the results of the analysis are robust and not significantly affected by any single study. Additionally, although the confidence intervals of different studies vary slightly, their effect estimates are near the central reference line (0.13) and show no extreme deviations, indicating high consistency among the results of different studies and low heterogeneity. While the confidence intervals of most studies encompass the overall effect estimate, individual studies (such as “Lai (2022)” and “Yang (2024)”) have somewhat higher effect estimates, suggesting that these studies slightly

Fig. 5 Sensitivity analysis(physical health)



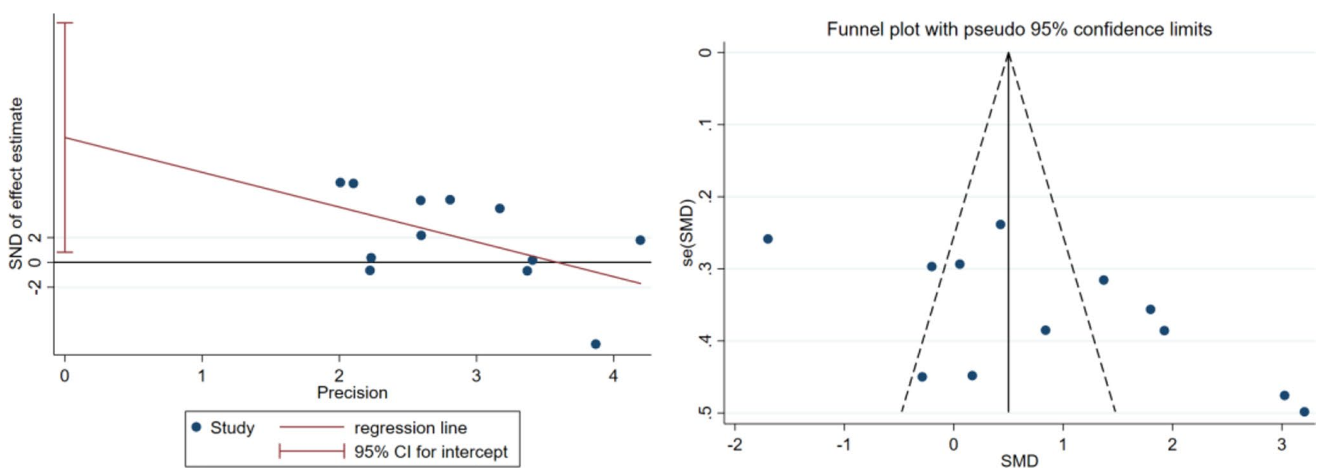


Fig. 6 Publication bias funnel plots of included studies and results of Egger's linear regression method

inflated the overall effect value, but their removal did not significantly alter the results.

Publication Bias test

Publication Bias

To formally assess potential publication bias, we constructed a funnel plot (Fig. 6). In the absence of publication bias, studies should be symmetrically distributed around the pooled effect size and lie within the pseudo 95% confidence limits. However, visual inspection of the funnel plot suggests noticeable asymmetry, with more studies concentrated on the right side of the plot. This pattern indicates a potential absence of studies reporting small or negative effect sizes.

Furthermore, Egger's linear regression test was conducted to quantitatively evaluate funnel plot asymmetry. The test yielded a statistically significant result (bias = 1.27, $p = 0.036$), providing additional evidence of potential publication bias. This finding suggests that smaller studies with nonsignificant or negative results may be underrepresented in the current literature.

Impact of publication Bias

The presence of publication bias may lead to an overestimation of the intervention effects in the pooled results. Since studies with null or negative findings are less likely to be published, the overall SMD may be upwardly biased. Therefore, the observed beneficial effects of physical activity on physical health outcomes in elderly should be interpreted with caution. To reduce publication bias in future research, prospective trial registration and comprehensive reporting of results—regardless of significance—are essential.

Meta-Regression analysis for heterogeneity

To further explore the potential sources of heterogeneity, we conducted a meta-regression analysis using exercise frequency, session duration, and intervention period as moderator variables. However, none of these factors significantly explained the between-study variability in effect sizes: (1) Exercise frequency (Effect size: −0.10, 95% CI: −2.54 to 2.32, $p=0.921$); (2) Exercise duration (Effect size: 0.05, 95% CI: −1.47 to 1.53, $p=0.961$); (3) Exercise period (Effect size: 0.07, 95% CI: −2.41 to 2.57, $p=0.943$).

These results indicate that the high heterogeneity observed in the overall analysis cannot be fully explained by differences in exercise frequency, session length, or intervention duration across studies. Other unmeasured factors such as participant characteristics, intervention fidelity, or outcome measurement methods may contribute to the observed variability.

Overall effect of physical activity on mental health elderly

A total of 8 controlled studies were included in the meta-analysis to elucidate and compare the effects of different PA on the MH of the elderly. Figure 7 lists the SMD values and their confidence intervals for the 8 studies, with the horizontal axis representing the effect size. Most effect sizes are concentrated around zero, but there are significant differences; for instance, the effect sizes of "Wang (2020)" and "Lai (2024)" are negative, at -3.85 and −2.15, respectively, indicating a substantial negative impact on the overall effect. In contrast, the effect sizes of "Amir (2021)" and "Giuseppe (2016)" are positive, at 1.15, 2.44, and 0.65, suggesting a positive influence on the overall effect. The diamond at the bottom represents the overall effect estimate, approximately [SMD=-0.22, 95%CI(-1.46, 1.03)]. The confidence interval crosses zero, indicating that the overall effect is not statistically significant, meaning there is no consistent effect direction across the different studies. I^2= 95.3%, and the $p=0.000$, indicating very high heterogeneity among the studies, suggesting considerable differences in the results. Therefore, a random-effects model was adopted to synthesize these results, attempting to balance the discrepancies among the studies.

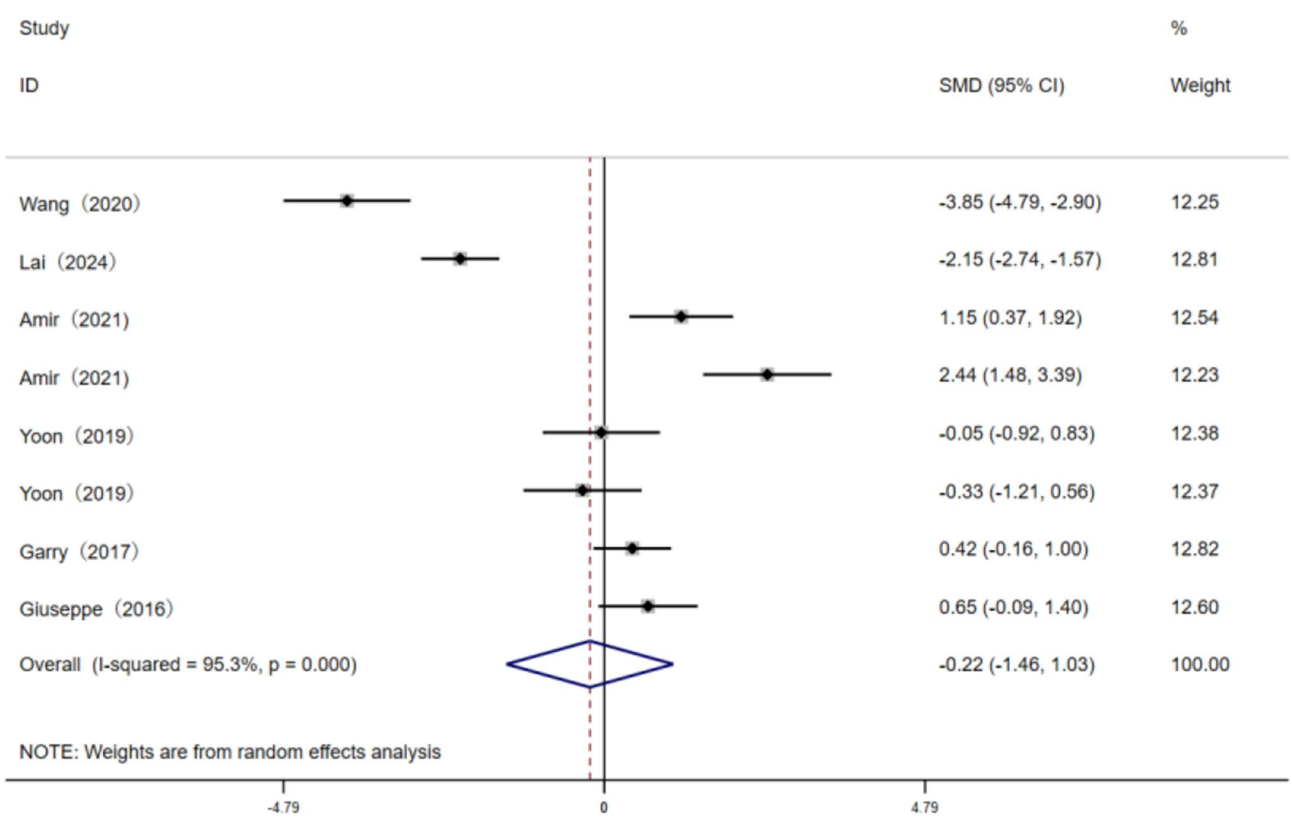


Fig. 7 A meta-analysis of the overall effects of PA on mental health in elderly

Subgroup moderation effect test

Studies have found that PA can effectively improve the mental health of elderly. As the forest plot showed a high level of heterogeneity, a subgroup analysis was applied to the incorporated articles and the outcomes are shown in Fig. 6. The observations are as follows:

Figure 8 shows that the overall combined effect is [SMD = -0.22, 95% CI (-1.46, 1.03)], I^2 = 95.3%, $p<0.05$, indicating some heterogeneity, but the overall PA intervention has a positive impact on the MH of the elderly. However, due to the high heterogeneity, we will further investigate the sources of this heterogeneity.

For grouping based on intervention frequency, 1 indicates more than three interventions per week, 2 indicates fewer than three interventions per week, and 3 indicates three interventions per week. Subgroup analysis results indicate that the heterogeneity for three interventions per week is low (I^2 = 0%), suggesting consistent results within this subgroup. The overall effect estimate for this subgroup is -0.18 (CI: -0.81, 0.44), indicating no significant difference between the two studies.

For grouping based on intervention duration, 1 indicates a single intervention duration of less than 40 min, and 2 indicates a single intervention duration of more than 40 min. Subgroup analysis results show that studies in subgroup 1 consistently display negative effects with substantial effect sizes, possibly indicating a consistent trend of negative impact within this subgroup variable. However, high heterogeneity suggests that the results of these two studies may be influenced by different sample characteristics, study designs, or methodological differences. The effect directions in studies of subgroup 2 are inconsistent; some studies (e.g., Amir 2021) show positive and significant effects, while others (e.g., Yoon 2019) show negative or non-significant effects. This discrepancy in effects may contribute to the high heterogeneity observed.

For grouping based on overall intervention period, 1 indicates a 12-week intervention period, 2 indicates more than 12 weeks, and 3 indicates less than 12 weeks. Subgroup analysis results indicate that, similar to the grouping based on intervention duration, high heterogeneity suggests that the results of the studies may be affected by different sample characteristics, study designs, or methodological differences. In summary, due to the high heterogeneity, we

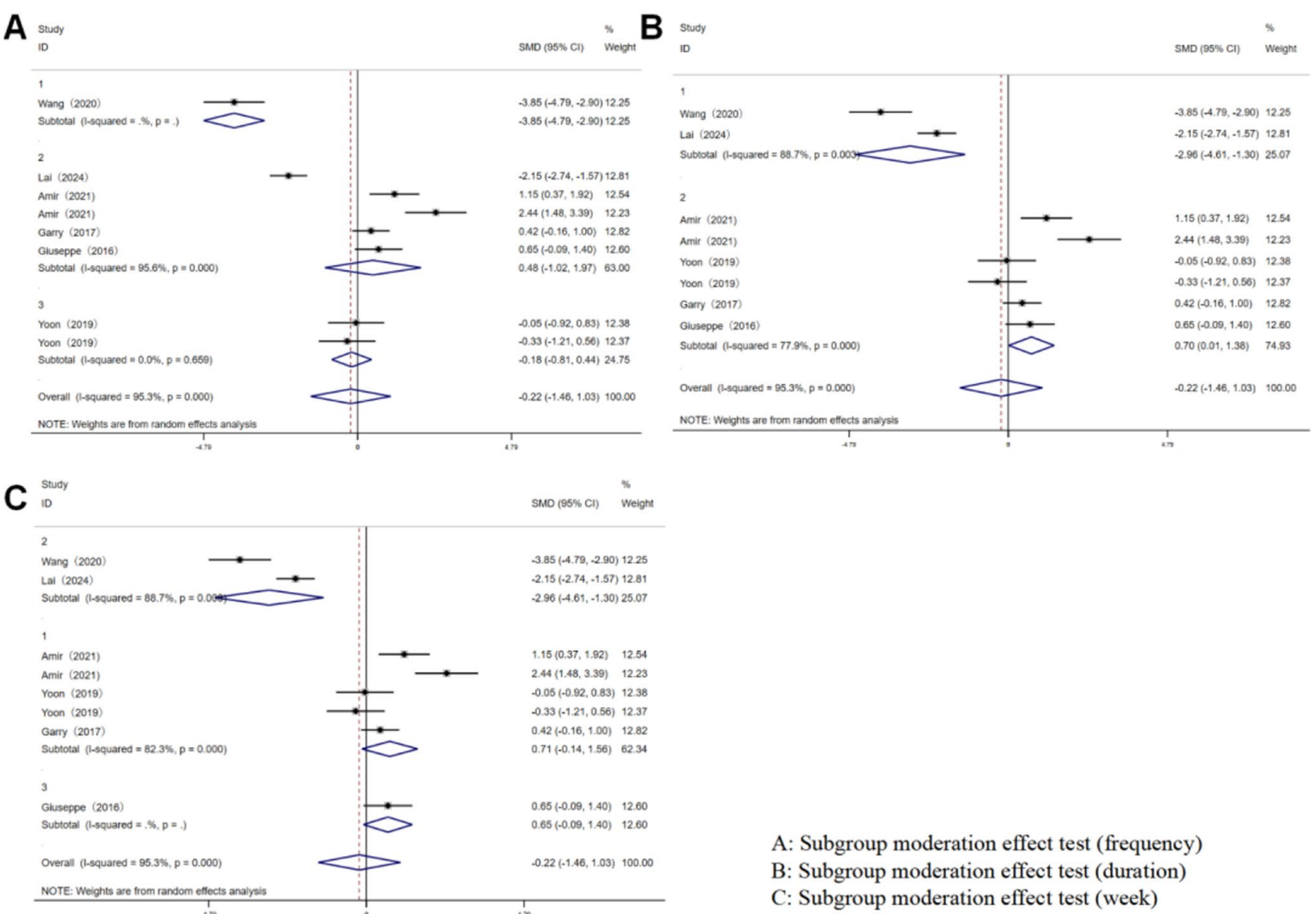


Fig. 8 A subgroup analysis of mental health in elderly

cannot determine the optimal dosage for PA to improve the mental health of the elderly through subgroup analysis. Based on this, our meta-regression analysis indicates that neither exercise frequency (ES: -0.59, 95% CI: -3.08, 2.01, $P=0.589$) nor exercise duration (ES: -0.20, 95% CI: -2.00, 1.73, $P=0.849$) is a source of heterogeneity, whereas the regression results show that exercise time (ES: 3.27, 95% CI: 0.60, 7.40, $P=0.031$) is a source of heterogeneity.

Sensitivity analysis

In Fig. 9, it can be seen that the overall effect estimate does not vary much when any individual study is removed, and most effect estimates are concentrated around −0.22. The overall effect estimate is approximately −0.22, and most studies' estimates and confidence intervals cluster around this range, indicating high consistency and reliability of the meta-analysis results. Additionally, individual studies (such as "Amir (2021)") show slightly elevated effect estimates after removal, but overall, these changes do not significantly affect the total estimate. The confidence intervals indicate low heterogeneity among the studies, suggesting a certain degree of consistency in the results. Overall, the figure demonstrates that the meta-analysis results are not significantly influenced by any single study and possess strong robustness.

Publication Bias test

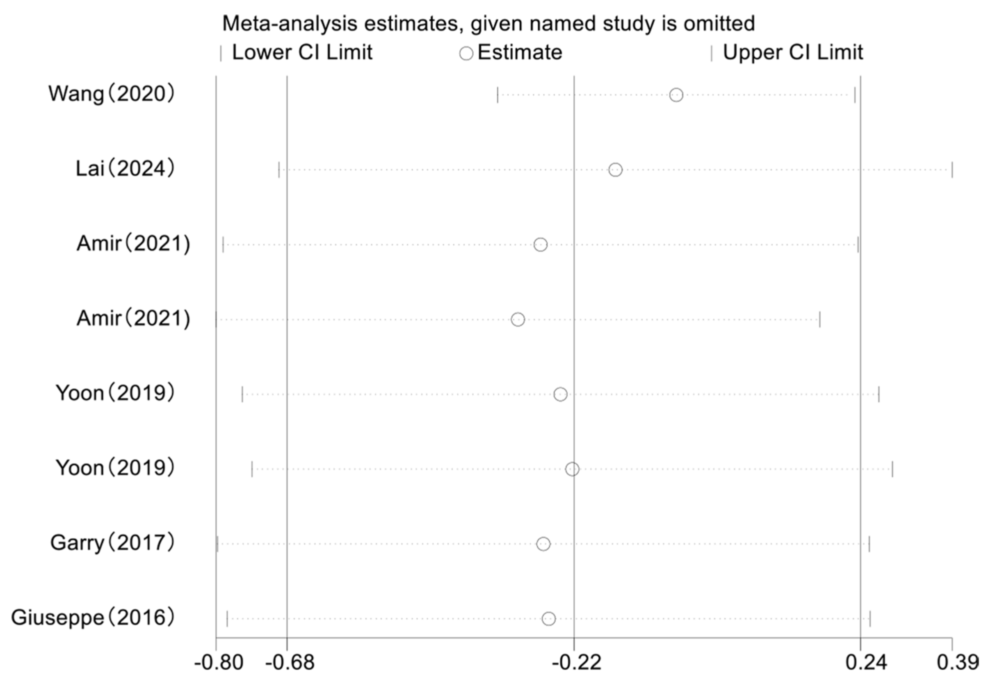
Publication Bias

To formally evaluate publication bias for the meta-analysis of mental health outcomes, a funnel plot was generated (Fig. 10). In the absence of publication bias, individual study estimates should be symmetrically distributed around the pooled effect size and fall within the pseudo 95% confidence intervals. Visual inspection of the funnel plot did not reveal substantial asymmetry, suggesting a relatively low risk of publication bias.

To further validate this observation, Egger's linear regression test was conducted. The test yielded a non-significant result ($p=0.742$), indicating that there is no statistically significant evidence of publication bias in the included studies related to mental health.

Although no publication bias was detected, it is important to interpret the findings with caution. The relatively small number of studies included and the variability in study designs, sample characteristics, and outcome measures may still influence the observed effects. Moreover, the absence of a consistent optimal exercise dose for improving mental health among elderly may stem from these methodological differences rather than a lack of effect. Nonetheless, the current evidence supports the positive role of physical activity in enhancing the mental well-being of elderly.

Fig. 9 Sensitivity analysis(mental health)



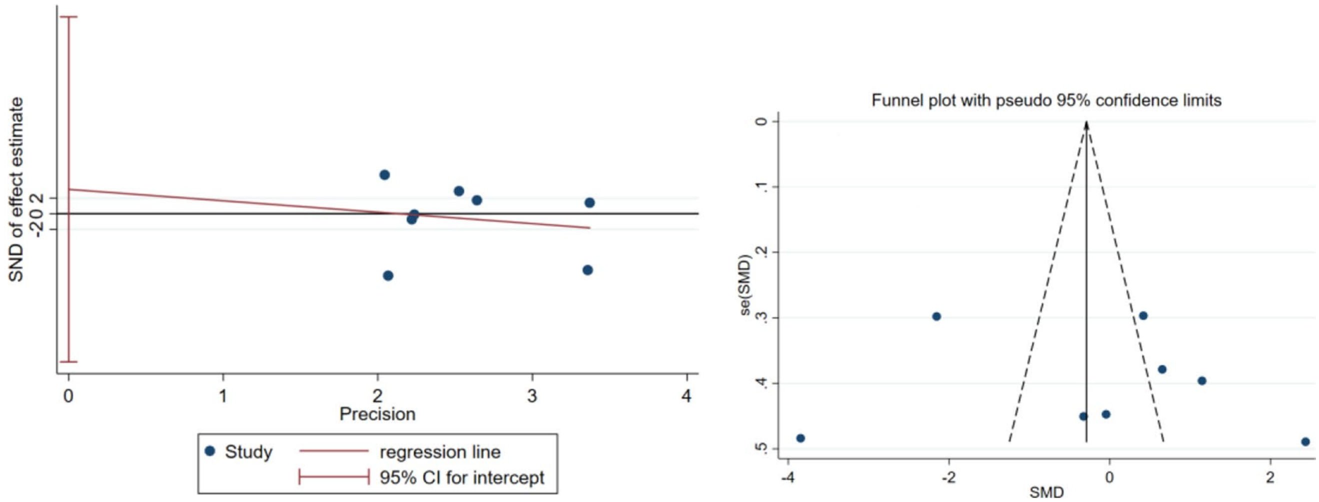


Fig. 10 Publication bias funnel plots of included studies and results of Egger's linear regression method

Discussion

This meta-analysis included nine studies published up to 2024, with an overall good methodological quality. It offers a timely and innovative contribution by evaluating the effects of PA on the PH and MH of elderly. Compared with pharmacological or psychological interventions, empirical research focusing specifically on PA interventions for older populations remains limited. Our findings contribute to closing this gap by synthesizing current evidence and highlighting the diversity of exercise types and their differential effects on health outcomes.

The application of PA interventions in the elderly population has received considerable attention and has shown positive effects [13–18]. The literature included in this study encompasses various types of physical exercises, including interval training [19], resistance training [20], yoga [21], and aerobic exercise [22], reflecting the diversity of PA. Our meta-analysis of PA interventions for the elderly indicates that the positive effects of PA on physical and mental health are related to the expected dose of PA, however, the effects differ for physical and mental health.

Discussion on the impact of PA on the PH of elderly

PH is of significant importance for the PH of elderly, helping them maintain and enhance physical function, prevent diseases, and improve quality of life in multiple ways. As people age, the muscle and bone mass of elderly gradually decline, which can lead to osteoporosis and muscle weakness [23–25]. Strength training and resistance exercises can help elderly maintain and increase muscle strength, reinforce bone structure, and prevent the risk of fractures and falls, aligning with the views presented in this study.

In addition, aerobic exercise plays a critical role [26]. Such exercises can enhance cardiopulmonary function of elderly, improve blood circulation, and help control blood pressure and blood sugar levels, thereby reducing the risk of chronic diseases such as cardiovascular diseases and diabetes [26–29]. Moreover, flexibility training positively impacts maintaining joint mobility, relieving muscle stiffness, and improving balance, which helps reduce the risk of falls [30–32], as indicated by the studies included in this analysis. Research shows that moderate exercise can also enhance immune function, enabling elderly to better resist diseases such as viruses [34]. Especially for those with limited mobility of elderly, the intensity and frequency of exercise should be adjusted appropriately, as suggested by the optimal exercise dosage in this meta-analysis (fewer than three times per week, each session lasting less than 30 min, and not exceeding 12 weeks), which can improve health effectively while avoiding excessive fatigue. Overall, a scientifically sound PA can help elderly maintain physical function, slow down the aging process, and improve quality of life, providing multiple benefits for both their physical and mental well-being.

Discussion on the impact of PA on the MH of elderly

PA has a significant positive impact on the MH of elderly, particularly in alleviating stress, enhancing mood, boosting self-confidence, and preventing cognitive decline [35'37]. Although this study did not determine the optimal exercise dosage for improving the MH of elderly, it cannot deny the positive role of PA in promoting their MH. Research indicates that moderate PA can effectively help elderly reduce psychological stress and release endorphins, known as the "happiness hormone," which can improve mood and lower anxiety levels [38, 39]. Additionally, exercise stimulates the release of neurotransmitters such as dopamine and serotonin in the brains of elderly, which have a positive effect on mood regulation [40, 41]. By participating in PA, elderly can maintain a more positive and pleasant mood in their daily lives, reducing symptoms of depression, while the sense of achievement and satisfaction from exercise enhances their overall well-being [42]. Not only that, numerous studies have shown that PA can help elderly maintain cognitive function and lower the risk of cognitive impairments such as Alzheimer's disease [43]. The impact of PA on the MH of olderly is comprehensive and profound, playing an important role in helping them maintain physical and mental health as well as a positive attitude toward life. Future research will focus on determining the optimal exercise dosage, rigorously screening more high-quality research literature to ensure the reliability and scientific validity of the results. At the same time, we will explore the specific mechanisms through which different types, intensities, and frequencies of exercise affect the MH of elderly, aiming to develop more precise exercise intervention programs tailored to their needs, thereby enhancing their MH levels.

Practical recommendations for Real-World implementation

Despite the proven benefits of PA, real-world implementation remains challenging. elderly often face barriers such as chronic illness, lack of motivation, fear of injury, limited transportation, and inaccessible facilities. Tailored exercise prescriptions—based on individual health status and preferences—are crucial for improving adherence.

Community-based programs should be strengthened by integrating PA into existing public health services, senior centers, and rehabilitation clinics. Trained instructors, social support groups, and structured schedules can improve participation rates. In particular, group-based activities may enhance motivation through social interaction.

Additionally, digital health technologies (e.g., wearable fitness trackers, mobile applications, virtual exercise classes) offer new opportunities. These tools can provide real-time feedback, track progress, and encourage engagement through gamification and remote coaching. However, to ensure inclusivity, training and technical support should be offered to elderly unfamiliar with digital platforms.

Post-pandemic recovery presents both a challenge and an opportunity. COVID-19 disrupted many in-person programs, but also accelerated the adoption of virtual interventions. Hybrid models that combine online and in-person activities could optimize accessibility and safety. Policymakers should prioritize equitable access to exercise resources and promote age-friendly environments that encourage safe and enjoyable PA in public spaces.

Limitation

Despite the results obtained from this study, there are limitations. First, there is considerable heterogeneity in the results; the regression analysis of mental health suggests that the duration of exercise intervention may be a source of this heterogeneity. Second, the number of studies included is relatively small, which is related to the limited amount of research on the health of normal elderly individuals concerning PA. Third, there is a significant variation in the doses used in the collected data. Fourth, this study only includes the latest research published in Chinese and English, which may have excluded studies published in other languages.

Conclusions

This meta-analysis explored the effects of PA on the PH and MH of elderly. We found that PA interventions involving fewer than three sessions per week, lasting less than 30 min each, and with a total duration of no more than 12 weeks, are most beneficial for improving PH. While we did not determine the optimal exercise dosage for MH, PA consistently showed positive effects. Given the observed heterogeneity, future research should further investigate the dose-response relationship for MH outcomes. Using the GRADE approach, we assessed the evidence quality, which enhances the credibility of our conclusions despite the high heterogeneity.

Author contributions W.Z. and K.Q. wrote the main manuscript text and W.Z. and K. Q. prepared figures 1–8. All authors reviewed the manuscript.

Funding There is no funding to report.

Data availability The data supporting the findings of this study are available within the article. Any additional data or materials can be requested from the corresponding author.

Declarations

Institutional review board statement Not applicable.

Informed consent Not applicable.

Competing interests The authors declare no competing interests.

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