Mobile health interventions for active aging: a systematic review and meta-analysis on the effectiveness of physical activity promotion

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Background: With increasing evidence supporting the benefits of physical activity (PA) for older adults, there is a critical need for effective interventions to promote activity in this population. Mobile health (mHealth) technologies offer innovative approaches to enhance engagement in PA, yet evidence of their effectiveness remains varied and insufficiently synthesized. This systematic review and meta-analysis aims to evaluate the effectiveness of mHealth interventions in improving physical health, quality of life, cognitive function, and mental well-being among community-dwelling older adults aged 65 years and over.

Methods: This systematic review and meta-analysis followed the PRISMA guidelines, focusing on studies that utilized mHealth interventions to promote PA among community-dwelling older adults aged 65 years and older. The literature search included electronic databases like PubMed, Web of Science and CENTRAL, with studies published from 2014 onwards. Eligible studies were randomized controlled trials (RCTs), non-RCTs, and single-group studies that provided quantitative and qualitative data on physical health outcomes.

Results: The search yielded 4,453 studies, with 22 meeting the inclusion criteria. These studies involved a total of 3,055 participants, primarily from high-income countries. The interventions included the use of an application (n=5), websites (n=7), wearable device (n=3), website + wearable device (n=3), and application + wearable device (n=3). Meta-analysis of 11 RCTs, representing 2,204 participants, showed an overall significant effect of the mHealth intervention [standardized mean difference =0.23; 95% confidence interval: 0.08–0.38], subgroup analysis shows varied effects on PA levels, with some studies reporting significant improvements in PA metrics, while others showed minimal impact.

Conclusions: mHealth interventions have the potential to promote PA among older adults, but the effectiveness is highly variable. This variability may be influenced by intervention design, technology used, and participant engagement. Future research should focus on personalized, adaptable mHealth solutions that address the specific needs and preferences of older adults to enhance sustained engagement and effectiveness.

Keywords: Mobile health (mHealth); older adults; physical activity (PA); systematic review; meta-analysis

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Introduction

Background

Regular physical activity (PA) offers substantial health benefits for individuals, regardless of their ages (1). Interestingly the importance of PA does not decrease over age as increasing evidence suggests that engaging in PA can not only prolong active, independent living but also decrease disability, and enhance the quality of life for older adults (2). Additionally, inactivity in individuals over 65 years old is linked to increased frailty and adverse health outcomes. Furthermore, mortality is twice as high in this group compared to those who lead an active lifestyle (3). This is particularly worrying as we have seen that inactivity in this group is linked to increased frailty and adverse health outcomes (4).

Despite the benefits of PA, older adults tend to exercise less often than younger individuals, and their participation diminishes progressively with age (5-7). Actually, age is one of the most consistent risk factors linked to reduced PA levels. Studies have documented a widespread decline in PA across lifespan, with significant drops during early childhood; adolescence and older age (8,9).

Considering these findings, the World Health Organization (WHO) endorses tailored PA guidelines for those aged 65 years and older (10). These guidelines recommend a combination of moderate-intensity aerobic exercises, muscle-strengthening activities, flexibility, and balance training. Despite compelling evidence supporting these guidelines, recent research published in the *Lancet* (7) provided a comprehensive assessment of PA levels worldwide. This study synthesized data from 507 population-based surveys encompassing 5.7 million participants, revealing that the global age-standardized prevalence of insufficient PA was 31.3%. This marks an increase from 23.4% (range, 21.1–26.0%) in 2000 and 26.4% (range, 24.8–27.9%) in 2010 (11-13). To effectively address the gap in PA participation among older adults, it is, therefore, essential to develop innovative and sustainable interventions as the conventional approaches (i.e., guidelines, booklets, information given by the doctors) does not seem to work given the low level of PA activity level in this group (14). The advent of mobile technology (i.e., smartphone, tablet) provides potential new opportunities to promote PA and foster healthier lifestyle choices (15-17).

Digital Health encompasses the use of digital technologies in healthcare, including electronic health (eHealth) and mobile health (mHealth). It extends to areas such as big data, and artificial intelligence. The WHO defines eHealth as the utilization of information and communication technologies (ICT) for health. On the other hand, mHealth is specifically defined as the use of mobile wireless technologies for health purposes (18,19). Telehealth and telemedicine use electronic communications to deliver healthcare services remotely, with telehealth covering both clinical and non-clinical services and telemedicine focusing specifically on clinical services (20-22). Telerehabilitation, a part of telemedicine, provides rehabilitation services remotely via telecommunication technologies (23-25). Thus, eHealth is a broader concept that encompasses telemedicine and telehealth, including mHealth, which is specifically related to mobile phone technology (26-28). mHealth in particular is defined by the WHO as '*a medical and public health practice supported by mobile devices*, *such as mobile phones*, *patient monitoring devices*, *personal digital assistants and other wireless devices*' (29,30).

Leveraging the widespread adoption of smartphones

Highlight box

Key findings

- The review found that mobile health (mHealth) interventions can potentially enhance physical outcomes among older adults. However, the effectiveness of these interventions varies significantly depending on the specific design and implementation of the mHealth technology.

What is known and what is new?

- Existing research highlights that mHealth technologies have been utilized to enhance physical activity (PA) among older adults, with various tools being employed. However, the effectiveness of these technologies has been inconsistent, with studies reporting mixed results on their impact on sustaining both short and long-term PA among this demographic.
- This manuscript adds a comprehensive synthesis of recent mHealth interventions, demonstrating a broader range of technologies and approaches used to promote PA among older adults. It highlights the need for interventions that are both personalized and adaptable.

What is the implication, and what should change now?

- The inconsistent effectiveness of mHealth interventions suggests a need for not only more personalized approaches but also for a re-evaluation of the methods used to study these interventions. Traditional randomized controlled trials may not fully capture the dynamic and personalized nature of mHealth technologies. Therefore, there is a need to explore novel study designs such as adaptive trials, and real-world data analyses that can provide more flexible and contextually relevant insights into how these interventions work in everyday settings.

and tablets, these apps have the potential to implement PA promotion among older adults. These applications introduce novel solutions for guidance and support, training and motivation, and regular reminders to engage in PA or exercise (31,32). The scope of mHealth spans from basic text messaging to sophisticated software and apps combined with external wearable sensors, providing valuable instruments for goal-setting, coaching, monitoring, and self-evaluation of exercise and activity (33,34). mHealth offers numerous advantages, including accessibility and flexible timing. Users can begin exercising anytime and anywhere, without the need for a therapist or an in-person guide (35).

Rationale and knowledge gap

The rapid evolution of technology often outpaces the slower robust pace of research, resulting in a significant gap where findings may quickly become outdated (36). This is particularly evident in the field of mHealth technologies aimed at older adults. Most systematic reviews and meta-analyses tend to focus on younger segments of the older population, typically those aged 50 to 55 years, leaving those aged 65 years and older underrepresented (32,37-41). This gap highlights a crucial need for targeted research that specifically addresses the effectiveness of mHealth interventions in enhancing PA among the older adult population above 65 years of age.

Furthermore, while many studies focus on short-term usability and initial acceptance of mHealth technologies, there is a profound lack of long-term efficacy studies (31,40,42). Such studies are essential to determine whether initial acceptance of mHealth tools leads to sustained behavioural changes, particularly in terms of PA and associated health outcomes in older adults. The absence of long-term data makes it difficult to assess whether these interventions can consistently provide benefits, such as improved health and quality of life, over time (39).

Moreover, comparative studies that evaluate the effectiveness of mHealth interventions against traditional methods and other eHealth strategies are sparse. These comparative analyses are vital to understanding the relative advantages and disadvantages of mHealth technologies (41). Without them, healthcare providers, policymakers, and end-users are deprived of the evidence needed to make informed decisions regarding the most appropriate and effective interventions for promoting PA among the older demographic (43,44).

Objective

This systematic review and meta-analysis aim to assess and evaluate the effectiveness of mHealth interventions in improving physical health outcomes or a combination of physical health outcomes with quality of life, cognitive function, and mental well-being/health across community-dwelling older adults aged 65 years and over. We present this article in accordance with the PRISMA reporting checklist (available at https://mhealth.amegroups.com/article/view/10.21037/mhealth-24-41/rc) (45).

Methods

Study registration

This systematic review was registered at PROSPERO (registration number: 545591).

Search strategy

A systematic literature search was conducted using three different electronic reference databases (PubMed, Web of Science, and CENTRAL). The following search strategy was used in PubMed and adapted to other databases (Appendix 1): ((Aged[Mesh] OR Aging[Mesh] OR Aged[Text Word] OR aging[Text Word] OR elder*[Text Word] OR "old adult*"[Text Word] OR "older adult*"[Text Word] OR "old person*"[Text Word] OR "older person*"[Text Word] OR "old individual*"[Text Word] OR "older individual*"[Text Word] OR "old people"[Text Word] OR geriatr*[Text Word] OR "independent living"[Mesh Terms] OR "independent living"[Text Word] OR "healthy aging"[Mesh] OR "healthy aging"[Text Word] OR healthy[Text Word]) AND (Exercise[Mesh] OR Exercise[Text Word] OR "physical activity"[Text Word] OR "physical exertion"[MeSH] OR "physical exertion"[Text Word] OR "physical fitness"[Mesh] OR "Physical Education and Training"[Mesh] OR "Physical Education and Training"[Text Word] OR "Physical Education"[Text Word] OR "Physical Training"[Text Word] OR "physical fitness"[Mesh] OR "physical fitness"[Text Word]) AND (mhealth[Text Word] OR "m-health"[Text Word] OR "mobile health"[Text Word] OR "wearable technolog*"[Text Word] OR "Smartphone*"[Text Word] OR "mobile app*"[Text Word] OR app*[Text Word] OR webapp*[Text Word] OR ehealth[Text Word] OR "e-health"[Text Word] OR Telemedicine[Text Word])). On September 10th, 2024, the search was re-run and subjected to a final analysis, in adherence to good practice and to ascertain whether interventions that met the inclusion criteria had been added since the initial search on May 13th, 2024. The search was restricted to studies published in English in peer-reviewed journals, focusing on articles published from 2014 onward, reflecting the rapid evolution of technology and the need to focus on current, relevant mHealth applications in the paper.

Inclusion and exclusion criteria

The following Participants, Interventions, Comparisons, Outcomes (PICOs) criteria were used to select the relevant individual studies.

Study designs

Both randomized controlled trials (RCTs), non-RCTs, and single-group studies were used in the review, focusing on mHealth PA interventions for community-dwelling older adults aged 65 years and above. However, only RCTs were included in the meta-analysis for quantitative synthesis, while other studies were described qualitatively. These studies compared mHealth PA interventions either to non-mHealth PA interventions or to control groups that did not receive any intervention.

Participants

Studies focusing on participants aged 65 years or older, who did not present with severe preexisting chronic medical conditions such as cancer, or active neurological, cardiovascular, respiratory, severe metabolic, or cognitive disorders, were included. Moreover, studies targeting specific subsets of the older population, such as patients in rehabilitation settings, were systematically excluded from the review.

Interventions

Studies evaluating the utilization of mHealth interventions focusing on PA and examining the effectiveness of these interventions on physical health outcomes were included in the analysis. Eligible mHealth interventions were those involving mobile phones, smartphones, tablets, or activity trackers in combination with an application or website specifically designed to promote PA. These interventions could be standalone or part of broader programs. Exclusion criteria included studies focused solely on interventions utilizing telephone calls, video calls, or personal digital assistants, particularly when the integration of mobile phones or tablets in the interventions remained unclear.

Comparison

Comparative analyses included participation in (I) a non-mHealth intervention, such as traditional methods, paper-pencil interventions, or exercise programs conducted in group or individual settings; or (II) no intervention; or (III) another mHealth intervention.

Outcomes

Outcome measures pertaining to intervention effectiveness included physical health outcomes, either alone or in combination with other factors such as quality of life, cognitive function, and mental well-being/health. In the reviewed studies, these outcome variables were assessed through objective methods (accelerometers, pedometers, wearables, objective clinical assessment), subjective methods (self-reporting assessments, PA diaries), or a combination of both. When mixed interventions were present, careful consideration was given to how the non-PA component, such as nutrition or cognitive training could influence the results. For example, when PA was paired with other interventions, the analysis focused on specific physical health outcomes, such as improvements in PA levels, balance, mobility, endurance, and strength, to isolate the direct impact of the PA component. Studies that failed to report data on the effectiveness of interventions in promoting PA were excluded, particularly those that only provided data on usability, feasibility, or acceptability.

Selection of studies

All results were initially uploaded to Rayyan to eliminate duplicates (46). Subsequently, two independent reviewers screened the results by title and abstract. Full-text articles of potentially relevant studies were then examined. Additionally, the reference lists of these articles, as well as related review articles on mHealth, were searched for further relevant studies. In instances of disagreement, the reviewers engaged in discussions to reach a consensus. If consensus could not be achieved, the matter was escalated to a third reviewer for resolution.

Study quality

The Physiotherapy Evidence Database (PEDro) scale, an 11-item validated and reliable tool for evaluating RCTs, was employed to assess the quality of the studies (47,48). This scale is widely recognized in the field of rehabilitation and clinical research, providing a structured approach to assess study quality based on key factors such as randomization, allocation concealment, blinding, and adequacy of follow-up. The first item, related to the eligibility criteria, is not scored, resulting in a total PEDro scale score ranging between 0 and 10 (49). A higher score indicates a study with fewer risks of bias. The methodological quality of the RCTs was independently evaluated by two reviewers, blinded to each other's assessments, to further reduce potential bias. They checked for any inconsistencies during this process. Final decisions regarding the quality of each RCT were reached by consensus. In cases of disagreement, a third author was consulted to resolve the issue. To rate the overall quality of evidence of each outcome, the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach was used (50). GRADE provides a comprehensive framework for assessing the certainty of the evidence-based on factors such as study limitations, consistency of results, precision, and potential publication bias.

Data extraction

The following information was extracted from the included studies: year of publication, country of research, aim of the study, participant demographics, descriptions of interventions, research design, outcome measures and main conclusion.

Statistical analysis

Data related to the interventions delivered in the included studies, and effectiveness of non-RCTs and single-group studies have been summarized narratively. Meta-analyses were performed to evaluate the effectiveness of RCTs. The measure of treatment effect was the effect size [standardized mean difference (SMD)], defined as the between-group difference in mean values divided by the pooled standard deviation (SD) computed using the Hedge's g method. Since RCTs reported mostly physical outcomes, only physical outcomes were included in the meta-analysis. Outcome measures included PA, balance, mobility, endurance, and strength.

When several tests are used to evaluate one particular function, the results of the different tests were combined, using weighted means, to produce a single SMD according to Cochrane's recommendation (51). A positive SMD indicates higher effect in the mHealth group compared to the control group.

To assess heterogeneity between trials, we calculated the variance estimate tau^2 as a measure of between-trial heterogeneity (52). To account for high or moderate heterogeneity, we utilized random-effect models and presented forest plots. To assess the risk of publication bias, funnel plots were checked for asymmetry and Egger's test for the intercept was applied for the different conditions evaluated (53,54). To assess the potential effect of the type of mHealth and the effect on different outcomes, sub-group analysis was performed.

Finally, random-effects meta-regression analysis quantified the association of changes in physical function, the duration of the intervention and the age of the participants. Studies were weighted by the inverse of the sum of the within- and between-study variance (55). Statistical analyses were performed at an overall significance level of 0.05, carried out in RStudio (version 2023.12.1), using R version 4.3.2.

Results

Identified studies and characteristics

The systematic search strategy yielded 4,453 results. According to the study protocol, 22 studies were retained after full-text screening. The compete flow-chart of study selection is presented in *Figure 1*.

Study quality

Of the 22 studies included 11 were RCTs assessing physical health outcomes. The quality of the 11 included RCTs varied, as indicated by PEDro scores ranging from 4 to 8, with an average score of 6 (SD 1.4) (*Table 1*). All RCTs specified eligibility criteria and utilized adequate random allocation; however, concealed allocation was problematic in 73% of the trials. Baseline comparability was achieved in 100% of the trials. None of the studies blinded subjects or therapists, and only 36% blinded the assessors. Participant follow-up was robust, with measures obtained from over 85% of subjects in 55% of the trials. Intention-to-treat analysis was conducted in 73% of the trials. All RCTs reported between-group statistical comparisons and provided point estimates and measures of variability for at least one key outcome.

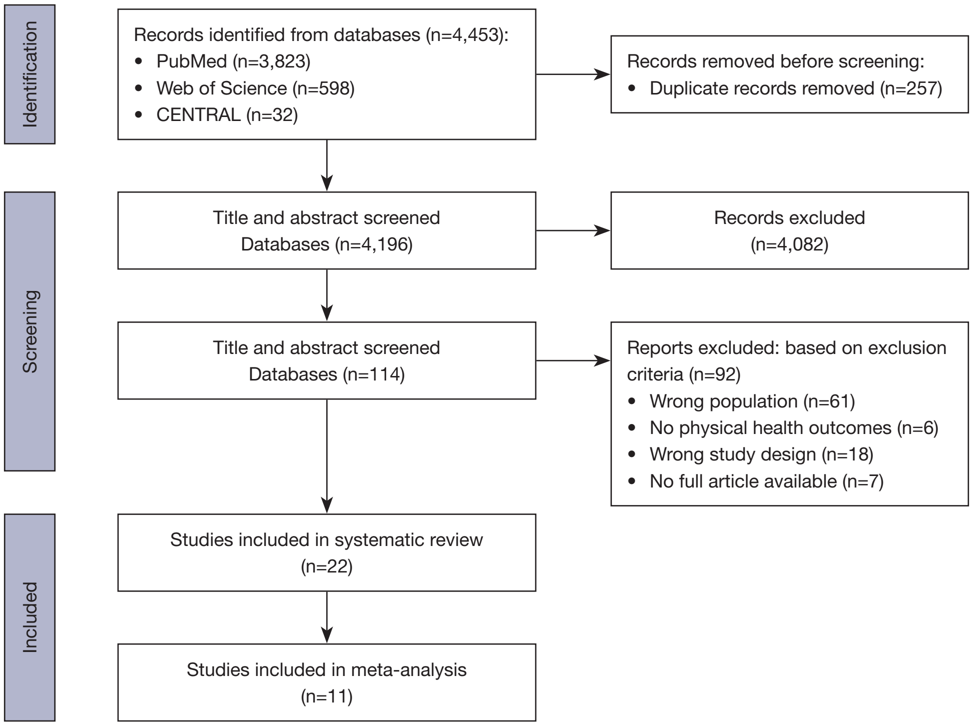

Figure 1 PRISMA flowchart for study selection. This flowchart outlines the process of study identification, screening, and inclusion in the systematic review and meta-analysis.

Table 1 Quality assessment of randomized controlled trials—PEDro scale

Study	Eligibility criteria*	Random allocation	Concealed allocation	Baseline comparability	Blind subjects	Blind therapists	Blind assessors	Adequate follow-up	Intention-to-treat analysis	Between-group comparisons	Point estimates and variability	Total
Delbaere *et al.*, 2021 (56)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	8
Pischke *et al.*, 2022 (57)	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	5
van den Helder *et al.*, 2020 (58)	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	5
Jungreitmayer *et al.*, 2022 (59)	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	4
Van Dyck *et al.*, 2019 (60)	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5
Tuominen *et al.*, 2021 (61)	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6
Brickwood *et al.*, 2021 (62)	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	6
Rowley *et al.*, 2019 (63)	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	4
Cai *et al.*, 2022 (64)	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7
Roberts *et al.*, 2019 (65)	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7
Recio-Rodríguez *et al.*, 2022 (66)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	8

Average score (mean ± standard deviation): 6±1. *, this item does not contribute to the total PEDro score. PEDro, Physiotherapy Evidence Database.

Study and intervention characteristics

Of the 22 studies analyzed, 11 were RCTs (56-66), 8 were single group studies (67-74) and 3 were non-RCTs (75-77). Complete description of the included individual study is provided in Table S1.

In the initial analysis, the 22 studies collectively enrolled a total of 3,055 participants. The sample sizes varied widely among these studies, with the smallest having 10 participants (69) and the largest including 503 participants (56). On average, 64.7% of participants across all studies were female, though this proportion fluctuated significantly, ranging from 33.2% (57) to 100% (59). The average age of participants was 71.15 years, with average ages spanning from 65 (59,61) to 82.56 years (67).

All 22 studies analysed, 33 (97%) utilized technology associated with PA interventions (56-67,69-78). Respectively, 10 studies also focused on monitoring PA (57,58,61-63, 65,67,69,70,73), 4 studies integrated PA with health promotion content (56,63,64,77), 1 study was dedicated to fall prevention strategies (56), 1 study combined PA with a nutrition intervention (66), and another investigated the combination of cognitive training and PA (75).

Most PA interventions (n=7) utilized websites or online platforms as the primary technology (56,60,67,71,72,74,75). Six interventions were delivered through native mobile apps (58,59,64,68,76,77), while others incorporated wearable devices either alone (n=3) (61,62,65) or in combination with websites (n=3) (57,63,73) or mobile apps (n=3) (66,69,70).

All 22 studies assessed the effectiveness of mHealth technologies in terms of physical health outcomes, with seven of these studies additionally evaluating their acceptability (57-59,68,70,75,76) and two respectively assessing usability (68,75) and feasibility (68,70).

Effectiveness was measured through a variety of metrics across the studies. In all of the studies, physical health parameters were assessed, including measurements of balance (n=14) (56,58,59,62,65,67-69,71,72,74-77), endurance (n=13) (56,58,62,64,65,67-69,71,72,75-77), strength (n=12) (56,58,59,64,65,67-69,72,75-77), mobility (n=10) (56,58,59,65,68,72,74-77), and overall PA levels (n=15) (56-58,60-64,66,68-70,72-74). Mental functioning was evaluated in three studies (56,70,71), and cognitive functioning in four (56-58,66). Quality of Life (QoL) was assessed in three studies (56,64,75) and 13 studies incorporated various other measures (such as technology commitment, adherence, perceptions) to evaluate the impact of the mHealth interventions (56,57,59,64,66,68-71,74-77).

Results of the non-RCTs

The reported physical health outcomes can be categorized into five areas: PA levels, balance, mobility, strength, and endurance. Among the 11 non-RCTs included (67-71,73-77,79), only three (75-77) featured a control or comparison group. Notably, only three studies (70,73,76) demonstrated statistically significant improvements in physical health outcomes, and two of these (70,73) utilized wearable devices to monitor real-time PA levels. Significant improvements were seen in single and dual-task walking (76), with significant increases in gait velocity and cadence, daily moderate to vigorous physical activity (MVPA) (70,71), and the daily number of steps (71). Other physical health outcomes in other studies showed positive trends, but were not statistically significant.

Six interventions focused exclusively on PA (67,68,70,73-75), while five others (69,71,73,77,79) combined PA with additional therapeutic modalities to enhance physical health outcomes. These included PA monitoring found in three studies (69,77,79), cognitive training (73) and health literacy interventions (71) both found in one single study.

The 11 interventions reviewed employed diverse digital platforms to promote PA and improve physical health outcomes among older adults. Vivo delivered interactive fitness classes via Zoom, focusing on cardiovascular, strength, balance, and agility exercises (67). Physitrack used a tablet app for muscle strengthening and balance exercises (68), while "Bingocize" combined a game-centered app with health education (77). Platforms like FitForAll (75) and ActiLifestyle (76) engaged participants with gamified exercise programs or tablet-based training for strength and balance. The PACE app tracked PA adherence by syncing with a wearable device (69), while a specifically developed mHealth app supported group walks and provided step-counting features (70). Other interventions included personalized phone coaching, a PA tracker app with detailed reports (71), and the "Make Movement Your Mission" platform (74), which promoted daily movement through short sessions shared on social media. During the coronavirus disease 2019 (COVID-19) pandemic, Google Classroom delivered PA materials and videos, helping participants maintain healthy behaviours (72).

The interventions employed a wide variety of measures to assess physical, psychological, and social outcomes. Physical health outcomes were commonly evaluated across studies, with outcomes including the Short Physical Performance Battery (SPPB) (67,68,76,77), 30-second chair stand test (67), 6-minute walk test (6MWT) (64,67,69,76),

Table 2 Quality of evidence—GRADE approach

Outcome	No. of RCTs (no. of participants)	Results, SMD (95% CI)	Study limitations (0, −1, −2)	Imprecision (0, −1, −2)	Inconsistency of results (0, −1, −2)	Indirectness of evidence (0, −1, −2)	Publication bias (0, −1)	Certainty of the evidence
Physical activity[1]	9 (n=2,054)	0.37 (0.01 to 0.74)	Some concerns (−1)	Some concerns (−1)	Serious concerns (−2)	No concerns (0)	No concerns (0)	Very low[1]
Balance[2]	2 (n=616)	0.03 (−0.06 to 0.13)	Some concerns (−1)	No concerns (0)	No concerns (0)	No concerns (0)	No concerns (0)	Moderate[2]
Mobility[3]	6 (n=1,087)	0.14 (−0.02 to 0.29)	Some concerns (−1)	No concerns (0)	Serious concerns (−2)	No concerns (0)	No concerns (0)	Low[3]
Endurance[4]	2 (n=362)	0.15 (−0.13 to 0.42)	Some concerns (−1)	No concerns (0)	No concerns (0)	No concerns (0)	No concerns (0)	Moderate[4]
Strength[5]	3 (n=222)	0.26 (0.04 to 0.48)	Some concerns (−1)	Some concerns (−1)	Serious concerns (−2)	No concerns (0)	No concerns (0)	Very low[5]

Reasons for downgrading: [1], downgraded by one level due to some concerns about risk of bias (average score on the PEDro scale is 6). Downgraded by one level for some concerns about imprecision. 95% CI is the possibility for no benefit and possibility for appreciable benefit. Downgraded by two levels for inconsistency of results due to high heterogeneity (I^2=90%, P<0.01). [2], downgraded by one level due to some concerns about risk of bias (average score on the PEDro scale is 6). [3], downgraded by one level due to some concerns about risk of bias (average score on the PEDro scale is 6). Downgraded by two levels for inconsistency of results due to high heterogeneity (I^2=62%, P<0.01). [4], downgraded by one level due to some concerns about risk of bias (average score on the PEDro scale is 6). [5], downgraded by one level due to some concerns about risk of bias (average score on the PEDro scale is 6). Downgraded by one level for some concerns about imprecision. 95% CI is the possibility for no benefit and possibility for appreciable benefit and sample size is <400. Downgraded by two levels for inconsistency of results due to high heterogeneity (I^2=82%, P<0.01). SMD, standardized mean difference; CI, confidence interval; PEDro, Physiotherapy Evidence Database; GRADE, Grading of Recommendations, Assessment, Development and Evaluation; RCT, randomized controlled trial.

daily steps (70), PA levels (68,70,72,73) and various tests of strength, balance, and mobility (67,69,74-77). Adherence and usability were assessed frequently, with tools like the System Usability Scale (SUS), Software Usability Measurement Inventory (SUMI), and subjective questionnaires, reflecting the feasibility and acceptability of the interventions (68,70,71,75,76). Psychological well-being and quality of life were evaluated using instruments such as the WHOQoL-BREF (WHO quality of life questionnaire), SF-12, EQ-5D-5L, the Feeling Thermometer, and the Hospital Anxiety and Depression Scale (HADS) (69-71,74,75). Cognitive outcomes were explored through examiner-based cognitive batteries and health knowledge questionnaires (71,77), while PA enjoyment and adherence to prescribed exercise regimens were also measured (68,71,75,76). Additionally, some interventions examined health-related behaviour's, such as pacing strategies (69) and exercise self-efficacy (69), demonstrating the broad scope of measures used to capture the multifaceted impact of the interventions on participants' physical and mental health.

This diversity in both the interventions and the outcome measures poses a challenge for direct comparison between studies. The duration of interventions varied widely, ranging from 6 (70) to 120 weeks (72), with the majority lasting around 8 weeks (68,73,75,77).

Effectiveness of interventions

The outcomes of the interventions are detailed in *Table 1*, while *Table 2* presents an overview of the certainty of evidence, assessed using the GRADE approach (50). Overall, the quality of evidence from the RCTs ranged from very low to moderate. Risk of bias, imprecision and inconsistency of results were the main causes to downgrade the score.

Results of meta-analysis

Out of the 22 studies included in the systematic review, 11 were included in the meta-analysis, representing 1,498 participants, to quantify the impact of mHealth on physical outcomes. To assess publication bias, we examined the funnel plot, which revealed no significant asymmetry (Egger's intercept =0.31, P=0.76, see *Figure 2*).

First, we assessed the overall effect of mHealth. Out of the eleven included studies participants experienced

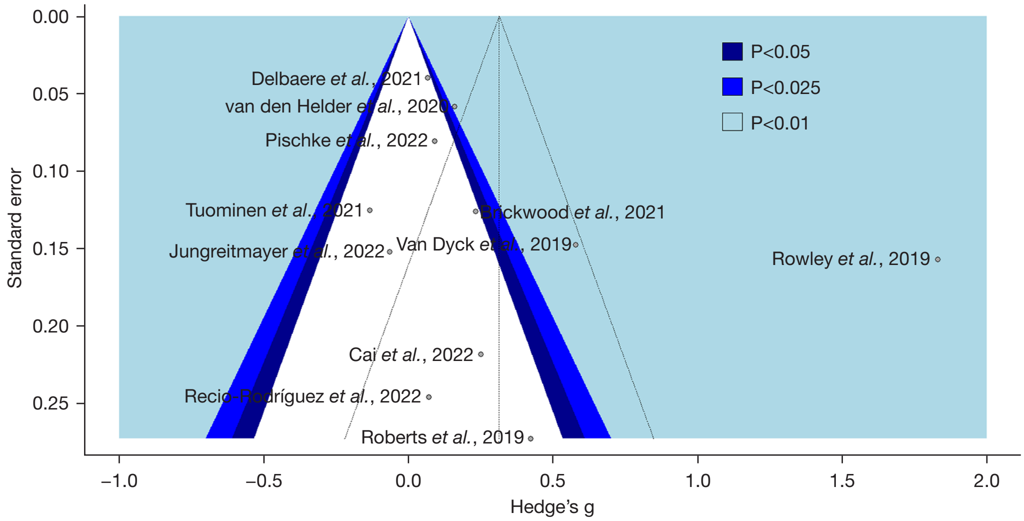

Figure 2 Funnel plot of standard error and Hedge's g. The funnel plot presents the relationship between the standard error and Hedge's g effect size for the studies included in the meta-analysis. The shading indicates significance levels (P<0.05, P<0.025, and P<0.01), with lighter areas showing higher levels of significance. Studies clustered symmetrically within the funnel indicate less publication bias, while asymmetric distribution suggests potential bias.

on average, an overall increase in SMD of 0.23 [95% confidence interval (CI): 0.08–0.38] (using random effect model due to high heterogeneity (I^2=88%, P<0.01).

We then performed subgroup analysis to determine if different effects could be found for the different outcome measures (*Figure 3*). Nine studies assessed PA as an outcome variable (56-58,60-64,66). The effect of the intervention on PA was small but significant with a SMD of 0.37 (95% CI: 0.01–0.74; I^2=90%, 2,054 participants, very low certainty of evidence). Mobility outcomes were analysed in six studies (56,58,59,62,64,65). An uncertain effect of the intervention on mobility was found (SMD =0.15; 95% CI: −0.03 to 0.32; I^2=62%, 1,087 participants, low certainty of evidence). Three studies assessed strength (59,64,65). A positive a statistically significant effect of the intervention on strength was found (SMD =0.26; 95% CI: 0.04–0.48; I^2=82%, 222 participants, very low certainty of evidence). Balance was reported in two studies (56,59). The effect of interventions on balance is not significant with a SMD of 0.03 (95% CI: −0.06 to 0.13; I^2=0%, 616 participants, moderate certainty of evidence). Only two studies reported results on endurance (58,62). An uncertain effect of the intervention on endurance was found (SMD =0.15; 95% CI: −0.13 to 0.42; I^2=0%, 362 participants, moderate certainty of evidence). A complete overview of the certainty of evidence, assessed with GRADE is presented in *Table 2*.

Finally, we performed meta-regression to determine if the amount of training or the age of the participants influences the outcomes. We did not find any significant association between the duration of the intervention (in weeks) and the outcomes [β=−0.0087, standard error (SE) =0.0067, P=0.19] nor the age of the participant (β=−0.0174, SE =0.0498, P=0.73), see *Figure 4*.

Discussion

This systematic review and meta-analysis offer significant insights into the evolving landscape of mHealth interventions aimed at promoting PA among older adults. Our findings are essentially aligned with existing literature (37,39,40), demonstrating a potential positive effect of mHealth to increase PA in older adults. However, the variability in effectiveness, sample size, methodology, duration of studies and adoption across studies presents a complex picture. Moreover, interventions themselves varied widely, from simple mHealth applications to complex, multi-component strategies.

Key findings

The review included 22 studies encompassing various research designs, such as RCTs, single group studies and feasibility studies. The quality of the RCTs was variable, with PEDro scores ranging from 4 to 8, and significant issues were identified in areas like allocation concealment,

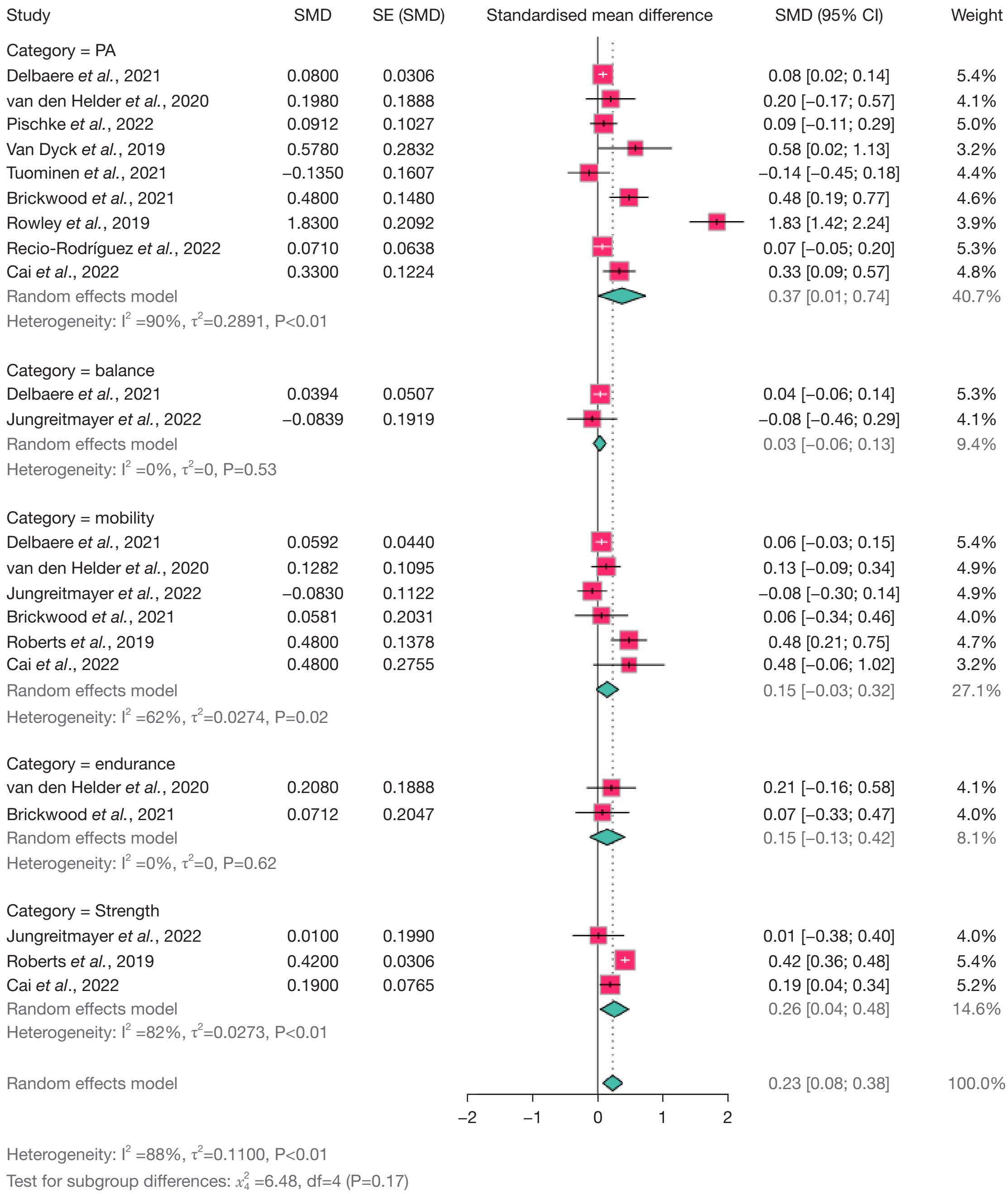

Figure 3 Forest plot of standardized mean differences. This forest plot displays the SMDs and their 95% confidence intervals for multiple health outcomes: PA, balance, mobility, endurance, and strength. The plot includes subgroup analyses for each outcome, with diamonds representing the pooled effect sizes using random effects models. The size of each square reflects the study's weight, while horizontal lines show confidence intervals. Heterogeneity statistics (I^2) are presented for each outcome category, with the overall pooled effect size at the bottom. SMD, standardized mean difference; PA, physical activity; CI, confidence interval; SE, standard error.

which was lacking in 73% of cases. This reflects a broader challenge within mHealth interventions, where blinding participants and assessors is difficult due to the nature of the treatments. For example, control groups often receive no app or a conventional method, making it evident which participants are receiving the intervention. This

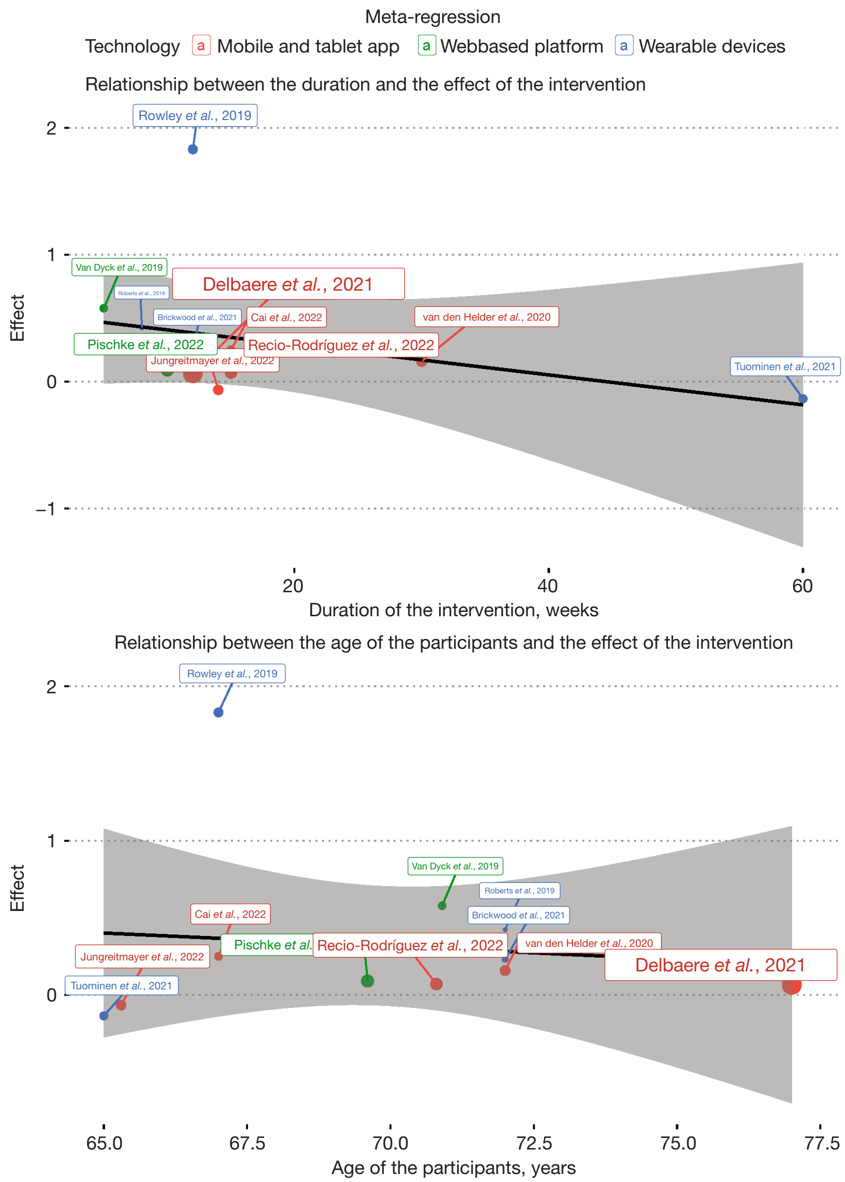

Figure 4 Meta regression on intervention duration and participant age. The meta-regression figure examines the relationship between training duration (weeks) and participant age on intervention effectiveness. The top plot shows the effect of intervention duration on outcomes, with studies using mobile apps (orange), web-based platforms (green), and wearable devices (blue) differentiated by color. The bottom plot evaluates how the age of participants impacts the effect of the intervention. The dark solid line represents the meta-regression line. This line shows the general trend/relationship between the independent variable (either the duration of the intervention in the top plot or the age of the participants in the bottom plot) and the dependent variable, which is the effect size of the intervention in both plots. The shading around the line indicates the confidence interval, giving a sense of the uncertainty or variability around the trend.

visibility undermines the potential for a true placebo effect, introducing biases that could affect both participant behavior and assessor judgments. As a result, the lack of blinding may contribute to overestimated effects in some of the studies (80-86).

The diversity of mHealth interventions in the review highlights the rapid evolution of digital health technologies. Interventions utilized combinations of native apps, websites, and wearable devices. Notably, wearable technology rarely functioned as a standalone intervention but was integrated with apps or websites to provide users with real-time feedback on their PA levels. This integration of wearable technology with feedback systems enhances user engagement by making activity tracking more interactive and personalized (87). However, this user-driven nature of mHealth tools presents a unique challenge: outcomes are often closely tied to the level of user engagement, which varies greatly between individuals.

Within this review, there was significant diversity in terms of technology, intervention types, and outcome measures. This diversity aligns with findings from previous works (37,39,40,88,89). The effectiveness of these technologies is extensively evaluated using a scale of metrics that span PA levels, mental health, quality of life, and cognitive function, employing both subjective and objective assessment methods. Although results generally indicate positive trends towards effectiveness, demonstrating this effectiveness within mHealth contexts presents significant challenges. This complexity arises not merely from the technological products themselves but significantly from their user-driven interaction dynamics. Unlike medical devices, which are influenced by healthcare professionals' operational proficiency, mHealth apps are directly managed by the users, introducing a variable interplay between user engagement and outcomes (90). This interaction is non-linear, as evidenced by the variability in user experiences and outcomes based on individual engagement levels (91). Moreover, while the importance of user engagement in influencing outcomes is undisputed, it complicates the process of evidence generation, making it hard to maintain engagement over time (44,92,93).

Furthermore, while many interventions showed promise in short-term effectiveness, maintaining long-term user engagement and achieving sustainable health outcomes remains a significant challenge. Although user-centered design principles are frequently employed during the development phase, there is often limited ongoing involvement from end users throughout the intervention period (44). This disconnect can limit the long-term impact of mHealth tools, as sustained engagement is crucial for lasting behavior change (94). The review also suggests that deeper integration of end-user feedback throughout the design and implementation stages could lead to improved adherence and more substantial health outcomes, particularly in promoting PA (95). Ultimately, the success of mHealth interventions lies not only in technological innovation but also in fostering continuous, meaningful engagement from users over time (96,97).

The review identified studies using automatic tracking via wearable devices as a prevalent strategy for monitoring and promoting PA among older adults. Interventions incorporating wearable devices for real-time PA monitoring yielded for example significant improvements in activity levels and associated physical health outcomes (98). Thus, the integration of wearable technology should be prioritized in the design of future mHealth interventions aimed at enhancing PA engagement in this population. These devices not only facilitate the promotion of PA but also enable individuals to objectively track their movements and exercise routines in everyday environments, providing richer behavioral insights than traditional self-report methods (99,100). By offering real-time data, wearable technologies address limitations associated with conventional clinical assessments, capturing subtle changes in PA levels and delivering personalized feedback (101,102). This continuous feedback loop fosters sustained engagement with PA goals while allowing health professionals to deliver more accurate and tailored interventions.

In the development of an effective mHealth apps for older adults, several critical factors must be addressed. First, a user-centered design is paramount (44,96,103,104), ensuring that the needs, preferences, and limitations of the end user are central throughout the design and implementation process. Additionally, the integration of behavior change techniques (BCTs), aimed at facilitating behavior modification, and personalization is fundamental to fostering long-term adherence to health interventions (94,105). For older adults, integrating PA goals into routine activities of daily living (ADLs) makes the interventions more relevant and practical, as they align with functional, rather than performance-oriented, objectives (106). Additionally, fostering social networks within these platforms helps to reduce isolation and build a sense of community, which can further motivate users to maintain healthy behaviors (107). Finally, incorporating gamification elements like virtual rewards and progress tracking sustains motivation, ensuring long-term adherence to the intervention (108). The theoretical framework underpinning these design elements is grounded in literature on the motivators and barriers associated with PA and digital health technologies (40,109,110). In this review, the examined mHealth apps were mapped to these key features to provide insight into their respective mechanisms of action. The variability in implementation approaches is presented in the accompanying *Table 3*, illustrating the diverse methodologies employed across different platforms.

The reviewed mHealth technologies display varying levels of integration across key features, including user-centered design, behavioral change techniques, and personalized interventions. While behavioral change techniques are widely incorporated, elements such as interactivity, ADL, and social cohesion are less consistently addressed. Integration with wearable devices and the use of rewards or incentives are also limited in many technologies. Overall, there is a strong focus on personalization, but greater emphasis on interactivity and social engagement could further enhance user outcomes.

Strengths and limitations

This review possesses several strengths and limitations that are crucial to understanding its impact and scope. One of the principal strengths is the inclusion of a diverse array of study designs and intervention types, providing a comprehensive overview of the field. However, this diversity also introduces significant challenges. The methodological heterogeneity across studies complicates the aggregation of data and synthesis of findings, which is a notable limitation. To tackle these challenges, we carried out a meta-analysis to quantify the impact of various interventions, specifically focusing on their effects on physical wellbeing. However, the subgroup analysis, aiming to evaluate the effect of mHealth on different PA components may be underpowered due to the low number of included studies. The current study offers several key strengths in comparison to previously reported reviews. Firstly, it broadens the scope by assessing not only physical health outcomes but also their combination with quality of life, cognitive function, and mental well-being, thus providing a more comprehensive evaluation of mHealth interventions. In contrast, earlier reviews often limited their focus to PA alone. Secondly, by exclusively including participants aged 65 years and older, this study mitigates the potential bias present in previous reviews that used a lower age cutoff of 55 years, which may have favored younger participants more adept at using technology. This higher age threshold ensures a more accurate representation of older adults, particularly those who may face greater challenges in adopting mHealth technologies.

Despite the systematic nature of our review and our efforts to ensure quality, there are inherent limitations that must be acknowledged. Our focus was on measures of effectiveness with physical, mental and cognitive health outcomes. However, as previously noted, the effectiveness of an mHealth app in promoting PA is influenced not just by the app itself, but also by user interaction, feasibility, and usability. Therefore, it is advisable for future reviews to integrate and combine both feasibility and usability outcomes with effectiveness measures. Furthermore, the scope of our review was limited to the use of mHealth in primary prevention. Nevertheless, the application of these tools is equally significant in secondary and tertiary prevention, as well as in treatment.

Lastly, the rapid evolution of technology in mHealth apps often makes traditional RCTs inadequate for demonstrating their efficacy, leading to the advocacy for alternative research designs that include real-world evidence in an ecological way (81). Moreover, mHealth apps involve complex interventions with multiple components and outcomes, often employing dynamic and evolving BCTs (82-84). This complexity challenges the traditional RCT framework, which is based on direct causal relationships, as outcomes may be influenced by various mediators and moderators and linked to the broader social environment (82). In response, new methodologies more suited to digital technology have been proposed, such as adaptive research models, factorial designs for component effectiveness, and predictive modelling. These methods aim to improve the understanding of individual differences and enhance RCT efficiency (85). However, despite these advancements, RCTs remain the predominant method for evaluating mHealth apps in peer-reviewed research (86).

Implications and actions needed

To enhance the effectiveness of mHealth apps for older adults, it is crucial to address barriers such as technology apprehension and limited digital literacy (110,111). These challenges significantly hinder their adoption and utilization of mHealth solutions. Additionally, these digital health tools should offer personalized exercise programs that cater to the specific health conditions and fitness levels of older adults (95). Such customization not only boosts user engagement but also helps reduce risks linked to physical inactivity and age-related conditions such as falls and sarcopenia (112). Effective mHealth interventions should also integrate seamlessly into existing healthcare frameworks to facilitate better monitoring, management, and support from healthcare professionals, thus improving the continuity and quality of care for older adults (43). The systematic review reveals a diverse array of study designs and methodologies in mHealth research, presenting a complex picture of effectiveness, sample sizes, durations, and rates of adoption.

Table 3 Key features of mHealth technologies included in the review

Study	mHealth technology included	User centred design[1]	Behavioral change techniques[2]	Personalized intervention[3]	Interactivity[4]	Activities daily living[5]	Intergration with wearable devices[6]	Social cohesion[7]	Education and information[8]	Rewards and incentives[9]
Delbaere *et al.*, 2021 (56)	Standing tall			×	×					
van den Helder *et al.*, 2020 (58)	HBex	×	×	×	×	×			×	×
Thompson *et al.*, 2023 (67)	Vivo	×			×					
Jungreitmayer *et al.*, 2022 (59)	App based exercise program			×		×			×	
Daly *et al.*, 2021 (78)	Physitrack			×	×					
Van Dyck *et al.*, 2019 (60)	My plan 2.0	×	×	×	×				×	×
Shake *et al.*, 2018 (77)	Bingocize				×			×	×	×
Konstantinidis *et al.*, 2016 (75)	Fit for all platform			×	×					×
van Het Reve *et al.*, 2014 (76)	ActiveLifestyle		×	×					×	
Albergoni *et al.*, 2020 (69)	PACE app			×		×	×			×
Nikitina *et al.*, 2018 (71)	Gymcentral	×	×	×	×			×		×
Johnson *et al.*, 2021 (72)	Telehealth intervention			×	×			×		
Bosco *et al.*, 2022 (74)	Make Movement Your Mission		×		×	×		×	×	×
Recio-Rodríguez *et al.*, 2022 (66)	Evident		×	×	×		×		×	×
Pischke *et al.*, 2022 (57)	Fit im Northwesten	×	×		×					
Tuominen *et al.*, 2021 (61)	REACT tracker			×	×		×			×
Brickwood *et al.*, 2021 (62)	PA tracker		×	×	×		×			
Rowley *et al.*, 2019 (63)	Ti Ped			×			×			×
Cai *et al*., 2022 (64)	WeChat		×		×	×		×	×	
Roberts *et al.*, 2019 (65)	EX+NEPA				×		×			
Frei *et al.*, 2019 (70)	Stepcounter app			×	×	×	×	×	×	

[1], this design prioritizes the end-user's needs, preferences, and limitations throughout the development process. [2], these are systematic strategies derived from behavioral science theories to influence and sustain behavior modification. [3], personalized interventions involve tailoring health-related strategies and communications to individual users based on specific data gathered about their behaviors, preferences, and environmental contexts. [4], refers to the dynamic capability of the application to engage users through direct and responsive interactions. [5], integrates physical activity into routine daily tasks to reduce perceived barriers and enhance the practicality of exercises. [6], this component involves the app's capability to synchronize with wearable technology to gather continuous physiological data, which can be used for monitoring health conditions in real-time. [7], encourages the formation of supportive social networks within the app, enhancing user engagement through community building. [8], delivers evidence-based health information and instructional content to improve knowledge and skills related to PA. [9], utilizes motivational elements such as virtual badges, achievement unlocking, and progress tracking to enhance motivation and encourage continual app engagement. PA, physical activity.

Approaches such as real-world evidence, ecological momentary assessment, and adaptive research models could better navigate the intricacies of digital health technologies and offer more precise effectiveness evaluations (91,113).

Conclusions

The systematic review underscores the potential of mHealth interventions to improve PA among older adults but also highlights the challenges in achieving consistent and sustainable outcomes. Moving forward, a focus on personalized, interactive, and user-friendly technology solutions, combined with robust methodological approaches, will be essential in harnessing the full potential of mHealth in public health strategies for managing the quickly growing aging populations.

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Footnote

Reporting Checklist: The authors have completed the PRISMA reporting checklist. Available at https://mhealth.amegroups.com/article/view/10.21037/mhealth-24-41/rc

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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