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Digital Health Interventions for Mental Health Improvement in Older Adults with Mild Cognitive Impairment: A Systematic Review and Meta-Analysis

An Gu, An Huang, Bei Wu, Xueqi Liu, Cheng Huang, Xichenhui Qiu, Lina Wang

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Abstract

Background: Mental health issues are common among older adults with mild cognitive impairment. However, despite the growing use of digital health interventions to improve cognitive function, their impact on mental health remains largely underexplored.

Objective: To evaluate the effectiveness of digital health interventions on mental health outcomes in older adults with mild cognitive impairment, both overall and subgroup-specific effectiveness.

Methods: A systematic review and meta-analysis of randomized controlled trials was conducted, with searches in 7 databases from inception to March 2024. The primary outcomes were mental health outcomes. Quality assessment was used the Cochrane Collaboration's tool. Subgroup analysis examined variations based on specific intervention characteristics, with sensitivity and meta-regression analysis exploring other potential sources of heterogeneity.

Results: A total of 11 studies with 610 participants met the selection criteria. The meta-analysis demonstrated that digital health interventions reduced depressive symptoms (SMD -0.55, 95% CI -0.92 to -0.19) and anxiety symptoms (SMD -0.47, -0.76 to -0.18); however, no significant effect on positive (SMD 0.74, -0.46 to 1.94) and negative affect (SMD -0.23, -0.60 to 0.14). Subgroup analysis indicated that hospital or nursing home settings with non-portable modality were optimal. Furthermore, interventions over 6 weeks, with sessions exceeding 30 minutes and occurring up to 2 per week, were more effective for depressive symptoms.

Conclusions: This review indicates that digital health interventions hold promise for improving mental health in older adults with mild cognitive impairment. Future research should focus on integrating digital therapeutic technologies to develop more comprehensive and effective interventions. Clinical Trial: CRD42024522342

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Registry Number: CRD42024522342.

Keywords: Mild Cognitive Impairment; Digital Health Intervention; Mental Health

Introduction

Dementia is recognized as a major global public health concern, with its preclinical stage, mild cognitive impairment (MCI), considered a critical target for dementia prevention efforts [1]. MCI represents an intermediate phase between normal cognitive aging and dementia [2]. Increasing evidence indicates a high prevalence of mental health issues in older adults with MCI. Depressive, anxiety, and apathy symptoms are the most common, affecting approximately 42.0%, 31.2%, and 39.5% [3-5] of individuals with MCI, respectively. Severe depressive symptoms in older adults with MCI may disrupt homeostasis and increase the risk of falls [6]. Meanwhile, sleep disorders, prevalent in 14 to 60% of older adults with MCI [7, 8], are also associated with negative emotions, which may exacerbate cognitive decline [9, 10]. Negative emotions, are recognized contributors to cognitive decline and progression to dementia, with odds ratios of 1.28, 1.18, and 1.80 [11-13], respectively. Notably, older adults with MCI and depressive symptoms have a higher conversion rate to dementia (31%) compared to those without depressive symptoms (13.5%) [14], underscoring the synergistic effect of mental health and MCI on cognitive decline and dementia development [15].

Despite the high prevalence of mental health issues in individuals with MCI, these concerns have often been overlooked, with limited access to psychotherapy [5, 16]. Currently, the rapid integration of internet technologies into healthcare is transforming cognitive and psychological interventions for older adults, marking a new era of digital therapy [17]. Digital Health Interventions (DHIs) involve the use of technological platforms, such as mobile applications, email, wearable devices, and virtual reality, to deliver cognitive and psychological interventions and support for physical or mental health conditions [18, 19]. Emerging evidences suggest that DHIs can offer more flexible, effective, and personalized approaches that may improve cognitive function in individuals with cognitive impairment [20-22]. These interventions often include computer-based or virtual scenario-based exercises and games designed to challenge cognitive processes. Additionally, a recent study showing that personalized teleconversational interactions for older adults with MCI reduced dementia risk by preventing social isolation [23]. Furthermore, the acceptability and feasibility of DHIs among older adults with MCI have been positive, with both individuals and their caregivers reporting high satisfaction and usability with digital health platforms [24].

However, the effectiveness of DHIs in ameliorating negative emotions in individuals with cognitive impairments remains uncertain. A systematic review and meta-analysis showed that various digital interactive devices effectively reduced depressive and anxiety symptoms in older adults, including those with neurocognitive disorders [25]. However, other studies on older adults have yielded inconsistent results [26-28], indicating that DHIs' effectiveness may be influenced by intervention type, individual variability, short-term and long-term effects, etc. More notably, most research on DHIs in the context of MCI has primarily focused on cognitive function, with less emphasis on mental health outcomes. Therefore, a comprehensive approach is needed to evaluate the broader impact of DHIs on mental function in individuals with MCI.

This study aimed to examine the effectiveness of DHIs on mental health outcomes in older adults with MCI, focusing on: (1) investigate the overall effectiveness of DHIs compared to non-DHIs approaches; (2) explore the impacts of intervention characteristics (e.g., device, type and modality of DHIs, intervention setting, etc.) on specific mental health outcomes; and (3) summarize the advantages of DHIs in improving mental health, aiming to enrich health management strategies for older adults with MCI.

Methods

Study Design and Ethical Considerations

This systematic review and meta-analysis was registered in PROSPERO (CRD42024522342) and followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [29]. Ethical approval was not required as only previously published data were used. Rigorous ethical standards were maintained, including transparent reporting, bias minimization, and the inclusion of ethically approved studies.

Search Strategy

The search process and data extraction followed the Cochrane Handbook of Evaluation. A comprehensive search strategy was developed by our multidisciplinary research team and tailored to each electronic database. Relevant studies in English and Chinese were searched across seven databases, including PubMed, Web of Science, Cochrane Library, Embase, CINAHL, and Chinese database (i.e., CNKI and WanFang), from database inception to March 7, 2024. Search terms were designed to identify relevant studies based on population (older adults with MCI), DHIs (mHealth, eHealth, mobile phone, application, wearables, virtual reality, artificial intelligence, tablet, robot and email, etc.), and mental health outcomes (anxiety, depressive symptoms, apathy, loneliness, stress, psychological distress, and suicidal ideation, etc.), with details provided in **Supplementary eTable 1**.

Eligibility Criteria

The inclusion criteria, encompassing both English and Chinese randomized controlled trials (RCTs), were determined based on the principle of the Population, Intervention, Comparison, Outcome, and Study design (PICOS) framework, as outlined in **Table 1**.

Table 1. Selection criteria of studies in PICOS format

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PICOS	Inclusion	Exclusion
Population (P)	Age 60 years or older who met any one of the following formal diagnostic criteria for MCI: ● Petersen's MCI criteria [2] ● Revised Petersen's MCI criteria [30] ● MCI criteria established by the National Institute on Aging and the Alzheimer's Association (NIA-AA) [31] ● International Working Group (IWG)-MCI criteria [32] ● MCI criteria constructed by the Diagnostic and the Statistical Manual of Mental Disorder (DSM-V) [33, 34]	Dementia and healthy adults, as well as individuals with other diseases not related to MCI
Intervention (I)	At least one type of DHIs, such as mHealth, mobile apps, eHealth, wearable, or virtual reality, etc.	Non-DHIs
Comparison (C)	Where applicable, a placebo group, usual care group, or any other alternative intervention devoid of DHIs	No exclusion criteria applied
Outcome (O)	Any quantitative outcome measuring mental health that assesses changes by comparing post-intervention data with baseline measurements	Qualitative assessment of mental health outcomes
Study Design (S)	RCTs that assess DHIs applied to older adults with MCI	Non-RCTs like qualitative studies, study protocols, observational cohort studies, conference abstracts, narrative reviews, and other non-experimental designs

Study Selection and Data Extraction

The identified studies were imported into EndNote 20 for de-duplication and independently screened for inclusion by two reviewers. Data from the included studies were extracted into a standardized table, with discrepancies resolved through consensus with a third reviewer. Extracted data encompassed: (1) study characteristics (first author, year, country); (2) population characteristics (participant numbers, age); (3) DHI characteristics (device, type, modality, setting, session frequency, dose, duration, short- and long-term effects, and content); (4) comparators (intervention types); and (5) mental health outcomes.

Quality Assessment

Two reviewers used the Cochrane Collaboration's tool to independently assess the risk of bias for seven entries, which encompass randomized sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective outcome reporting, and other bias [35]. Each entry was categorized as low, high, or unclear risk. Discrepancies were resolved by consensus with the third reviewer. Additionally, when 10 or more studies were included, publication bias was assessed using funnel plots and the Egger test [36].

Data Synthesis

Meta-analysis was performed using R4.4.1 and STATA 17.0 software. The standardized mean difference (SMD) and 95% confidence interval (CI) were applied for continuous data to synthesize the pooled effect of DHIs on mental health outcomes, classified as small (0.2-0.5), moderate (0.5-0.8), and large (>0.80) [37]. When the mean and standard deviation (SD) were unavailable, estimates were derived from the sample size, median, range, and/or interquartile range [38]. When the heterogeneity test indicated $P > .10$, studies were considered homogeneous, and a fixed effects model was applied; when $P \leq .10$, sensitivity analysis, subgroup analysis, and meta-regression analysis were conducted to identify sources of heterogeneity. Heterogeneity (I^2) was categorized as unimportant (0%-40%), moderate (30%-60%), substantial (50%-90%), or considerable

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(75%-100%) [39]. Statistical significance was set at $P < .05$.

Results

Study Selection

The initial search across seven databases identified 1686 studies, with 272 duplicates subsequently removed, leaving 1414 potentially eligible studies. These were screened by titles and abstracts, resulting in 52 studies for full-text review. After detailed screening, 41 studies were excluded and did not meet the inclusion criteria. Finally, 11 studies were included in the analysis and quantitative synthesis (**Figure 1**).

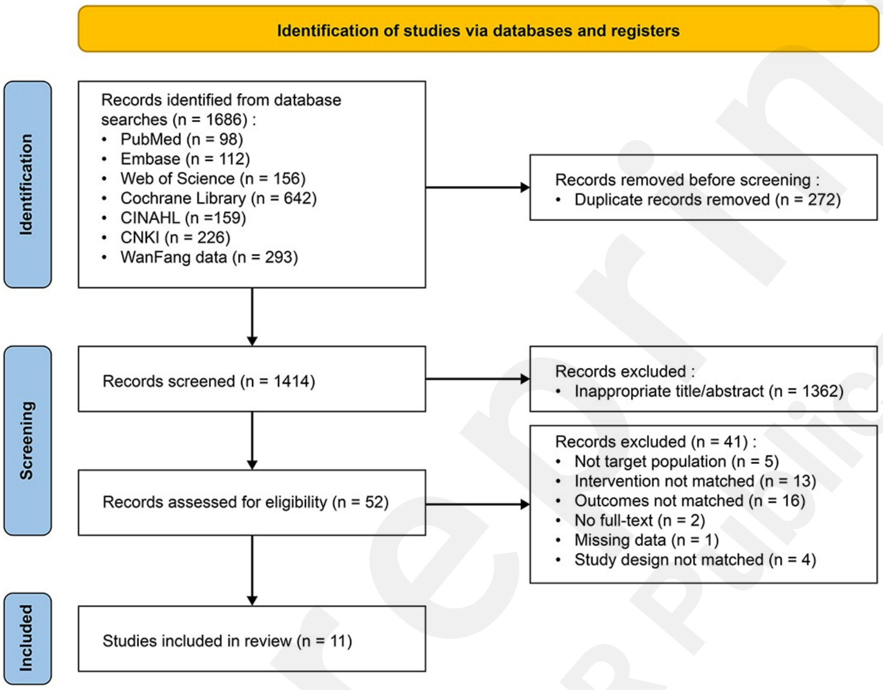

Figure 1. PRISMA flowchart of the study selection process

Characteristics of the Included Studies

Eleven RCTs published between 2017 and 2024 were included, involving 610 older adults with MCI (aged 62-92 years). Four studies were conducted in China [40-43], five in Korea [44-48], and two in Greece [49] and Iran [50]. Most participants came from hospitals (54.5%), followed by nursing homes (18.2%) and community or home settings (18.2%). Depressive symptoms were the most frequently assessed outcome [40-50], measured using the 15-item or 30-item Geriatric Depression Scale (GDS) [40-43, 46, 49, 50], or the Geriatric Depression Scale Short Form: Korean Version (GDSSF-K) [44, 45, 47, 48]. Anxiety symptoms, assessed in 4 studies [42-44, 50], were measured by Self-Rating Anxiety Scale (SAS) or Geriatric Anxiety Inventory (GAI). In two studies, positive and negative affect were measured using the Positive and Negative Affect Schedule (PANAS) [46] and the Memorial University of Newfoundland Scale of Happiness (MUNSH) [42]. Another study used the 18-item Apathy Evaluation Scale (AES) for apathy [46]. Self-esteem was measured by the Self-Esteem Scale (SES) in one study [42], while subjective feelings were measured in another study through the Mental Component Scale (MCS) of the 12-item Short-Form Health Survey (SF-12) [43]. All included studies had pre- and post-intervention assessments, with only one study conducting a 3-month follow-up [50]. The details are in **Supplemental eTable 2**.

Characteristics of the DHIs

Characteristics of DHIs varied by study, with sessions lasting 20 to 90 minutes, held 1 to 5 times per week, over a period of 4 weeks to 6 months, and were classified into five types: **(1) Tablet-based interventions:** these include tablet-based serious games that adjust difficulty to cognitive abilities, provide positive feedback, and promote a positive attitude [40]. Another approach adapts the Ubiquitous Spaced Retrieval-based Memory Advancement and Rehabilitation Training program into iPad application, featuring progressive retrieval intervals, difficulty adjustments, and automated verbal guidance [48]. **(2) Intervention robots:** including robot designed for cognitive training, equipped with sensors to monitor participants' signals, adjust difficulty, and assess mood, interest, and engagement [44]. Another type involves humanoid robots with Human-Robot Interaction technology that display facial expressions, recognize participants' intentions and emotions, and guide them through activities like problem-solving and physical exercises to enhance motivation and reduce depressive symptoms [47]. **(3) Virtual Reality (VR) interventions:** five studies used VR technology for multi-component cognitive training with headset displays and computer interfaces, where participants engaged in tailored games, received feedback, faced increasing task difficulty, and were motivated by visual or vocal cues to achieve high scores and promote social interaction [43, 45, 46, 49, 50]. **(4) Computer-assisted interventions:** computerized intervention, guided by psychotherapists, targeted multiple cognitive domains with 3 to 7 programs aligned with daily living and progressively increasing task difficulty [41]. **(5) Web-based remote interventions:** involving online platforms where participants engage in activities such as music, dance, visual art, with task difficulty adjusted to individual abilities to reduce negative emotions, stimulate creativity and social interaction, and enhance self-esteem [42]. The characteristics of the DHIs are detailed in **Supplemental eTable 3**.

Quality Assessment

All included studies exhibited a low risk of attrition and reporting bias. Five studies employed appropriate random allocation methods, indicating a low risk of bias in sequence generation [42, 43, 45, 46, 48]. Allocation concealment was reported in six studies [40-42, 45, 47, 50], and four described blinding of participants and personnel [42, 44, 47, 48], with seven studies blinding outcome assessment [40-43, 47, 49, 50]. Eight studies were assessed as having a low risk of other biases [40-44, 46, 48, 49]. Overall, the main bias were selection, performance, and detection, with detection bias contributing to the highest risk (**Supplemental eFigure 1**). Although the funnel plot exhibited an asymmetrical pattern (**Supplemental eFigure 2**), no publication bias was detected in this study, as confirmed by the Egger test (P= .930).

Overall Effects of DHIs on Mental Health Outcomes

As depicted in **Figure 2**, the effectiveness of DHIs compared with control groups was assessed across 11 studies: 11 for depressive symptoms [40-50], 4 for anxiety symptoms [42-44, 50], and 2 each for negative and positive affect [42, 46]. The pooled SMD was -0.55 (-0.92 to -0.19) for depressive symptoms and -0.47 (-0.76 to -0.18) for anxiety symptoms, indicating DHIs group had lower post-intervention symptoms than the control group. However, the effect size was more pronounced for depressive than anxiety symptoms. Additionally, considerable heterogeneity was found (I^2 = 79% for depressive symptoms), leading to the adoption of a random effects model for the analysis. The results showed no significant SMD favoring DHIs over the control group for negative affect (SMD -0.23, -0.60 to 0.14, I^2= 0.0%) and positive affect (SMD 0.74, -0.46 to 1.94, I^2= 88%, **Figure 2**). Due to the assessment of subjective feelings, self-esteem, and apathy by only one study, a meta-analysis was not possible, and a narrative summary was provided instead.

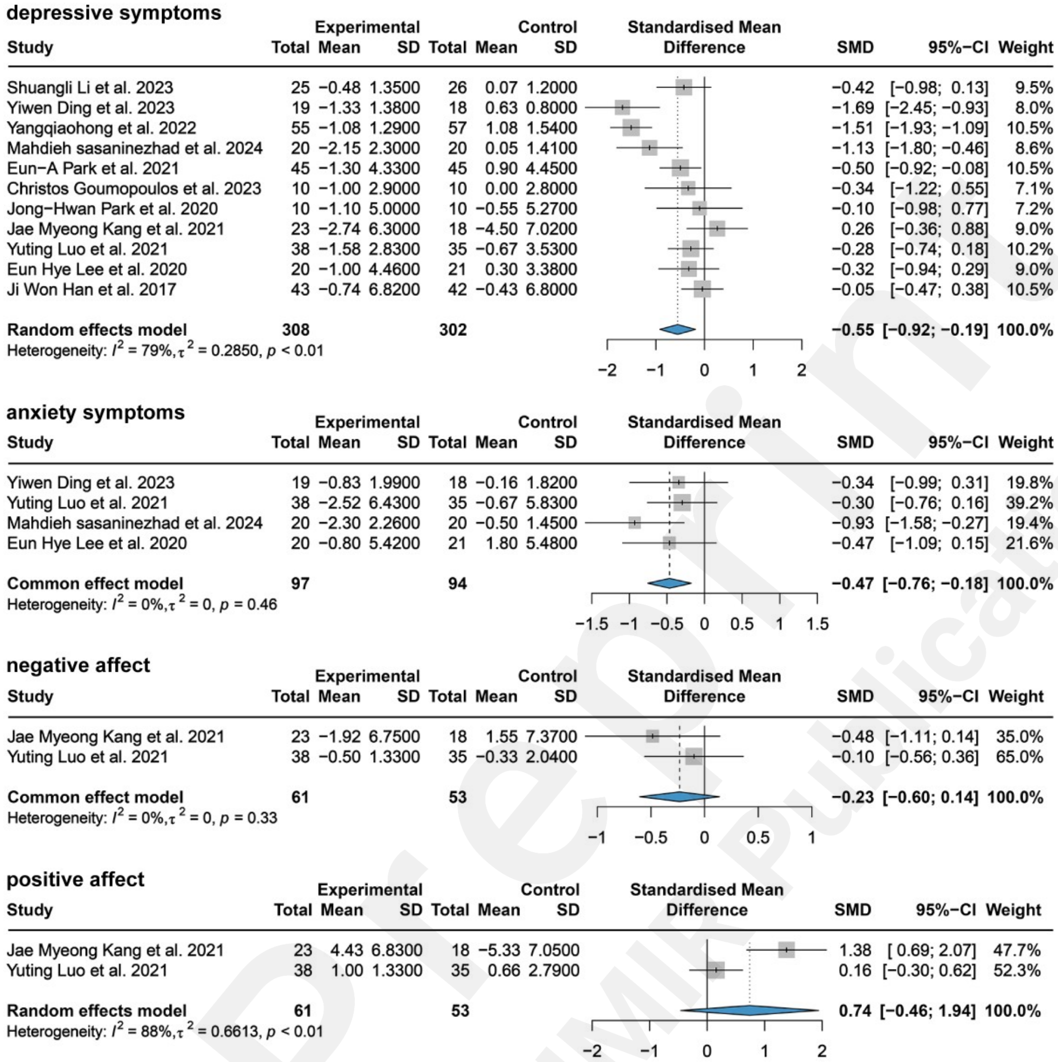

Figure 2. Forest plot of the effectiveness of DHIs on depressive[40-50]**, anxiety symptoms**[42-44, 50]**, negative and positive affect**[42, 46]

Subgroup Analyses of Intervention Scheduling

Subgroup analyses were performed to explore potential sources of heterogeneity in the effectiveness of DHIs on depressive symptoms (Figure 3-5). **(1) Intervention duration:** interventions over 6 weeks (N = 4) showed a statistically significant medium effect size (SMD -0.67, -1.29 to -0.05, I^2 = 84%), whereas those lasting 6 weeks or less (N = 7) did not demonstrate a statistically significant effect (SMD -0.48, -0.96 to 0.00, I^2 = 74%, Figure 3). **(2) Intervention dose per session:** sessions exceeding 30 minutes (N = 5) had a statistically significant medium effect (SMD -0.62, -1.12 to -0.13, I^2 = 80%) in reducing depressive symptoms, while sessions of 30 minutes or less (N = 6) showed no significant difference (SMD -0.50, -1.08 to 0.08, I^2 = 78%, Figure 3). **(3) Intervention frequency:** interventions conducted up to 2 per week (SMD -0.52, -0.94 to -0.09, I^2 = 81%, N = 9) reduced depressive symptoms. In contrast, interventions more than 2 per week (N = 2) showed no significant difference compared to the control group (SMD -0.72, -1.51 to 0.08, I^2 =

67%, **Figure 3**).

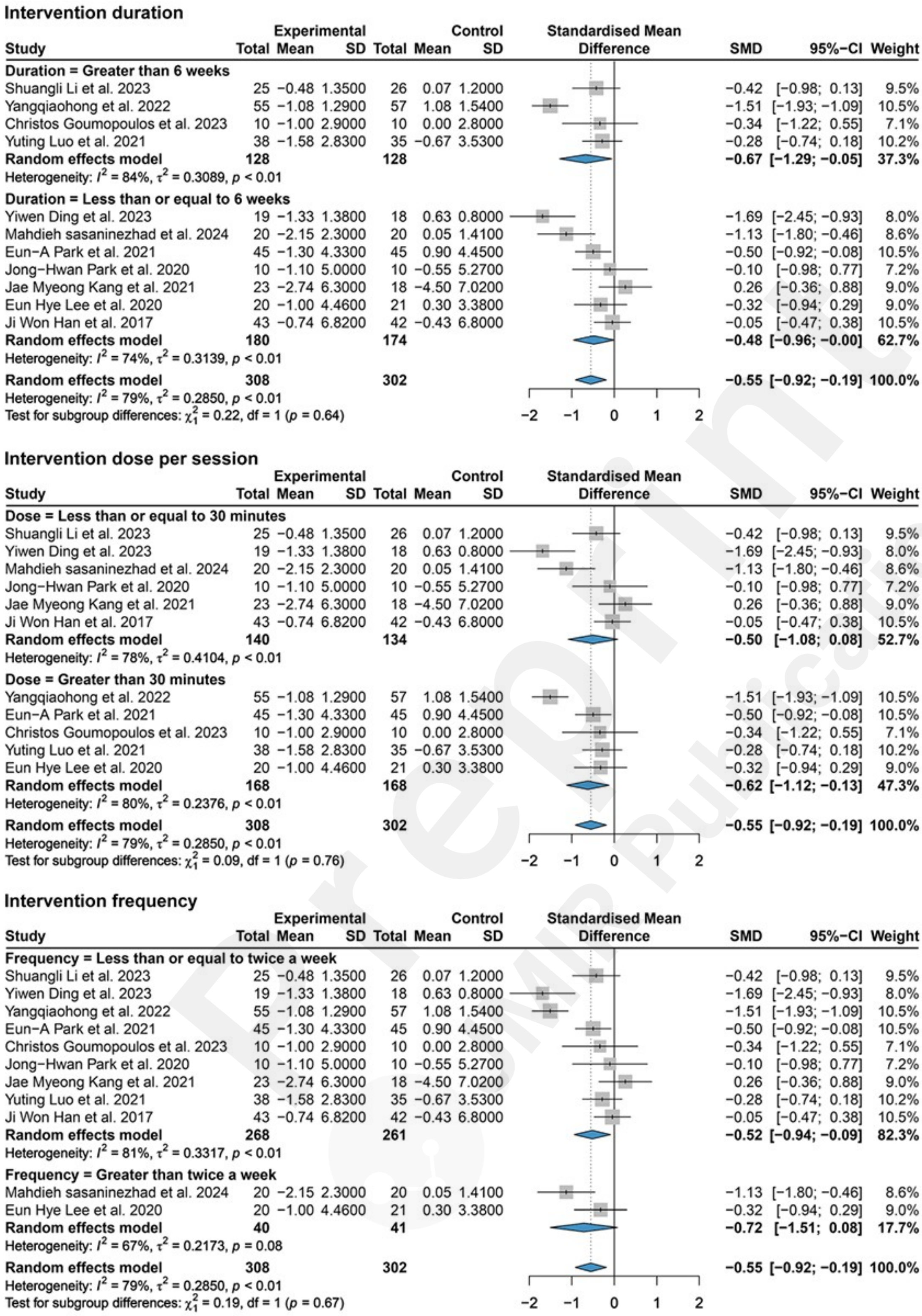

Figure 3. Forest plot of Subgroup analysis on intervention scheduling for depressive symptoms

Subgroup Analyses of Intervention Setting and Modality

(1) **Intervention setting:** DHIs implemented in hospitals or nursing homes (N = 8) demonstrated a small effect size of -0.48 (-0.90 to -0.06), suggesting a reduction in depressive symptoms among older adults with MCI compared to the control group. However, interventions conducted at community or home settings (N =

2) showed no significant difference (SMD -0.94, -2.10 to 0.22, I² = 90%, Figure 4). **(2) Intervention modality:** non-portable modalities of DHIs (N = 5) showed a large effect size in reducing depressive symptoms (SMD -0.88, -1.46 to -0.30, I² = 81%). However, portable modalities (N = 5) did not demonstrate a significant difference (SMD -0.28, -0.73 to 0.17, I² = 62%, Figure 4).

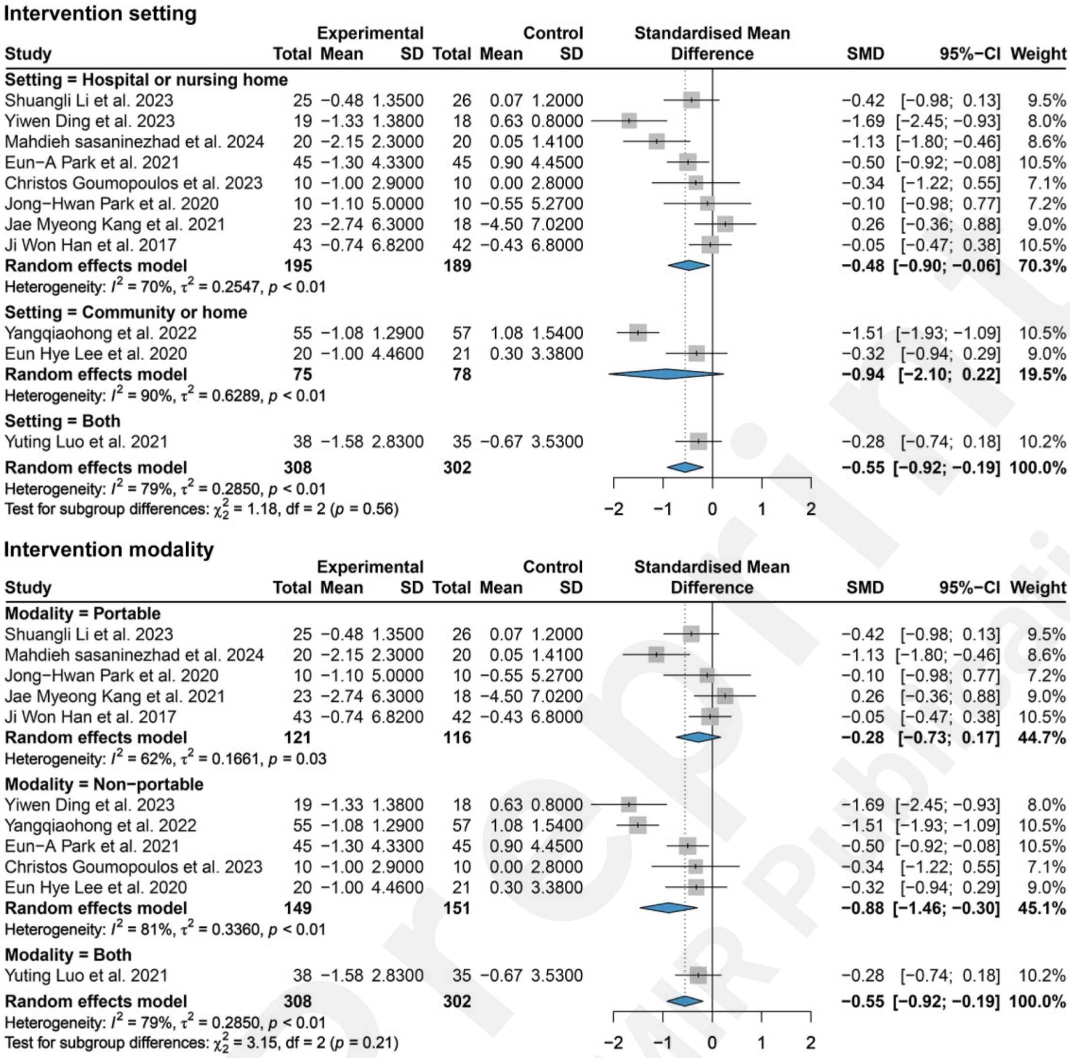

Figure 4. Forest plot of Subgroup analysis on intervention setting/modality for depressive symptoms

Subgroup Analyses of Intervention Device and Type

(1) Intervention device: both computer (N = 3) and robot (N = 2) significantly reduced depressive symptoms, with a larger effect size for computer (SMD -1.23, -1.98 to -0.48, I² = 68%) compared with robot (SMD -0.44, -0.79 to -0.09, I² = 0.0%). No significant difference was observed between tablet (SMD -0.19, -0.52 to 0.15, I² = 11%, N = 2) or headset display (SMD -0.33, -1.18 to 0.52, I² = 78%, N = 3, Figure 5) and the control group. **(2) Intervention type:** only the robotic intervention (SMD -0.44, -0.79 to -0.09, I² = 0.0%, N = 2) significantly reduced depressive symptoms. In contrast, tablet-based (SMD -0.19, -0.52 to 0.15, I² = 11%, N = 2) and VR intervention (SMD -0.60, -1.31 to 0.11, I² = 79%, N = 5, Figure 5) did not show significant effects.

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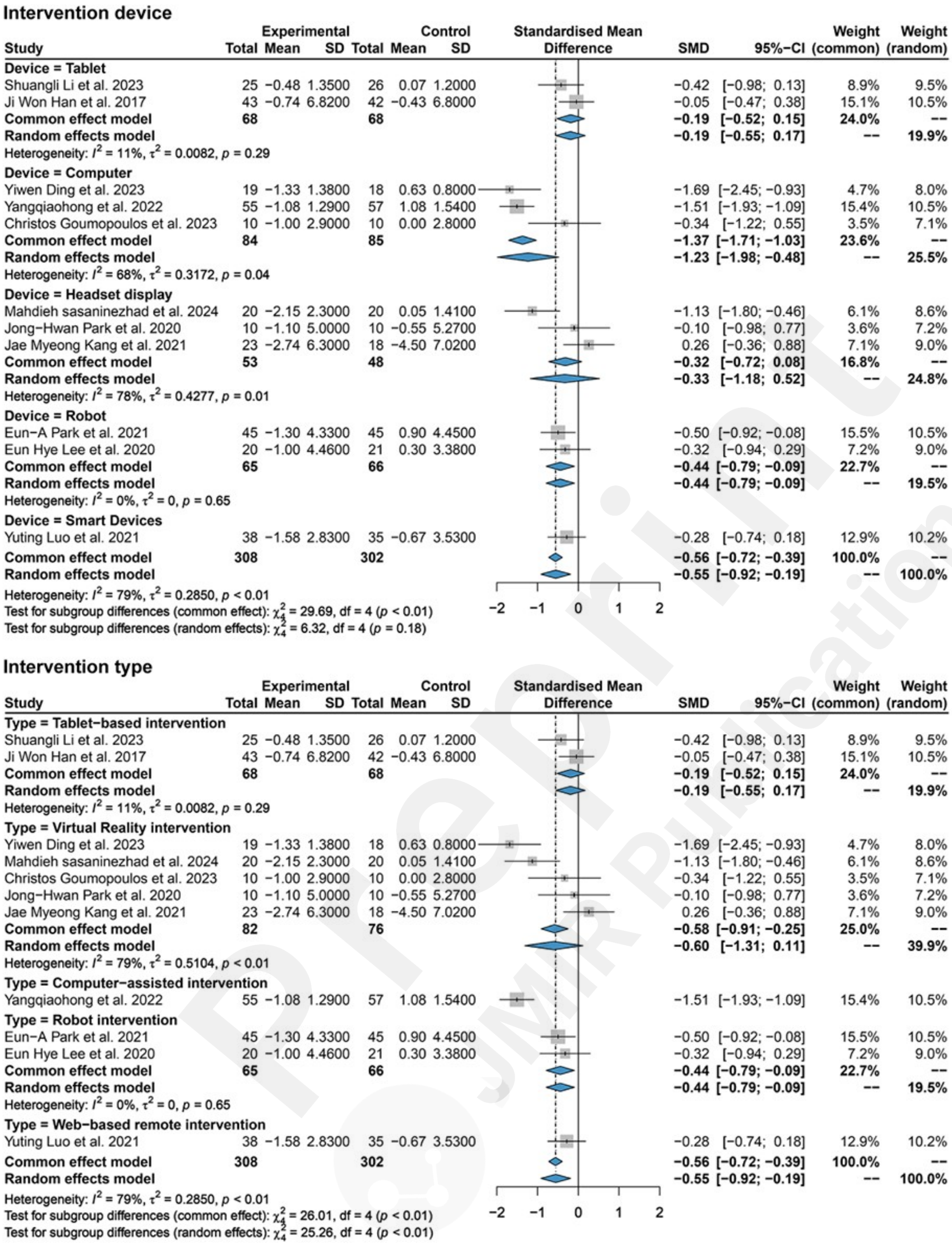

Figure 5. Forest plot of Subgroup analysis on intervention device/type for depressive symptoms

Narrative Summary

Only one study assessed subjective feelings [43], self-esteem [42], and apathy [46], showing that DHIs resulted in greater improvements in these mental health outcomes.

Meta-regression and sensitivity analysis

Meta-regression (**Table 2**) was conducted to identify sources of heterogeneity, with intervention devices (*P*= .048) emerging as a significant factor. No studies were excluded after sensitivity analysis (**Figure 6**), which revealed no disruptive changes in the combined results, indicating robustness in the study's findings.

Table 2. Meta-regression of DHIs on depressive symptoms among individuals with MCI

Variable	Coefficient	Std. err	t	*p*	95% CI
Year	-0.256	0.111	-2.31	.147	-0.734, 0.220
Setting	-1.129	0.521	-2.16	.163	-3.374, 1.116
Duration	-1.176	0.556	-2.11	.169	-3.572, 1.219
Dose	0.124	0.413	0.30	.791	-1.653, 1.903
Frequency	0.865	0.433	2.00	.184	-1.000, 2.731
Modality	0.218	0.448	0.49	.674	-1.712, 2.150
Device	0.563	0.127	4.42	.048	0.014, 1.112
Type	-0.115	0.169	-0.68	.565	-0.845, 0.614
_cons	519.448	224.760	2.31	.147	-447.619, 1486.516

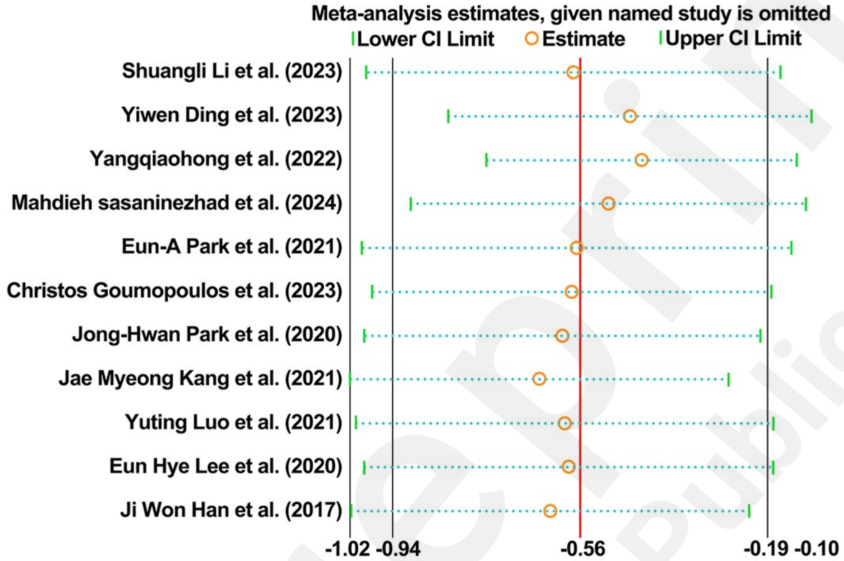

Figure 6. Sensitivity analysis of DHIs on depressive symptoms

Discussion

Summary of Findings

This meta-analysis assessed the effectiveness of DHIs on mental health outcomes in older adults with MCI. Significant improvements were found in depressive and anxiety symptoms, though no effects on negative or positive affect. Interventions over six weeks, with session exceeding 30 minutes and occurring up to 2 per week, were more effective in reducing depressive symptoms. Hospital or nursing home settings were the optimal environments, and non-portable DHIs, such as computer- and robot-based intervention, proved to be more effective modalities.

Overall Effects of DHIs on Mental Health Outcomes

Prior research has consistently demonstrated the positive impact of DHIs on mental health outcomes [51, 52], with a recent meta-analysis further confirmed their effectiveness as an alternative to traditional face-to-face therapy [53]. Our study supports these findings. Despite evidence supporting DHIs, older adults often favor traditional in-person treatments. However, stigma and cost barriers associated with face-to-face therapies can discourage treatment-seeking behavior and reduce adherence [54]. In contrast, DHIs could provide flexibility and accessibility alternatives. These digital platforms are scalable and adjustable, catering to the specific needs of diverse populations while overcoming barriers like geographic location, limited access to trained clinicians, and time constraints [51, 55].

Furthermore, contrary to our initial hypotheses and previous studies [42, 46], our findings suggest DHIs did not yield significant improvements in negative and positive affect. The discrepancies may be partly attributed to the relatively low baseline symptom severity among participants, though this hypothesis could not be fully tested due to the limited number of included studies. Additionally, intervention effectiveness may vary based on guidance level, participant or intervention characteristics, adherence, and variations in affect measurement across studies [51, 56, 57]. Consistent with a prior review [58], which highlighted limited evidence on non-pharmacological treatments for apathy due to the limited methodological quality and small number of studies, further rigorous trials are needed.

Intervention Characteristics Impacts DHIs Effectiveness on Mental Health Outcomes

Subgroup analysis revealed that interventions over six weeks, with sessions exceeding 30 minutes and occurring up to 2 per week, were more effective in reducing depressive symptoms. It is suggested that older adults with MCI, limited by physical and cognitive impairments, may show reduced engagement with DHIs [59]. Longer intervention duration and higher doses may provide a sustained impact and be crucial for adaptation behavior, as they offer the brain more time and stimulation to undergo changes, reinforce new neural connections, and help individuals integrate learned behaviors into daily routines, resulting in long-term adaptations [60]. A systematic review found that interventions over six weeks using information and communication technology were effective for individuals with MCI [61]. Another review demonstrated that computerized cognitive training sessions exceeding 30 minutes were most effective [62], likely due to synaptic plasticity after 30 to 50 minutes of training activities [63]. On the other hand, a frequency of up to 2 per week may better suit participants' limitations, as over three sessions could lead to cognitive fatigue and resistance [62]. These findings suggest that a well-structured DHI schedule could promote practical implementation and optimize effectiveness by aligning with cognitive and physical capacities.

This study found hospital or nursing home settings demonstrated greater effects for DHIs. However, Kim et al. reported better outcomes for VR interventions in community setting [64], potentially due to reduced commuting burdens and individual preferences. Furthermore, home or community settings also present challenges, including delays in technical support and unstable internet connections, which may compromise adherence and efficacy. In contrast, hospital or nursing home often provide supervision and coaching, fostering higher trust and adherence, which ensures that interventions are administered consistently and correctly. Additionally, hospital or nursing home settings may help mitigate social isolation through positive interactions [65], potentially contributing to the enhanced effectiveness of DHIs.

In subgroup analyses of intervention modality, device and type, both computer- and robot-based DHIs were associated with significant effects on depressive symptoms when using non-portable devices. Although portable devices, such as wearable technologies, have advanced in medical applications, their complexity and operational challenges can impose cognitive burdens on older adults [66]. Furthermore, age-related declines in vision, hearing, and dexterity, along with concerns about comfort, privacy, and lack of support, reduce adherence and limit their effectiveness in improving mental health outcomes [59, 66, 67]. Additionally, non-portable devices may allow for regular scheduling of intervention in fixed settings, providing a stable environment that enhances the quality of the intervention. This study also found that computer-based DHIs had greater effects on depressive symptoms than robot-based interventions, likely due to the more advanced software technologies and lower implementation and maintenance costs [68], allowing for personalized and diverse content. VR interventions showed no significant effect on depressive symptoms in this study, possibly due to the types of devices used. Non-immersive VR employs computer-based methods, while immersive VR uses headset displays. Moreover, immersive technologies currently face challenges such as security and privacy concerns, cost issues, connectivity problems, usability challenges, and design- related technical difficulties, which may explain the lack of statistical significance in the impact of headset displays [69].

Notably, studies on DHIs for mental health among older adults with MCI have been primarily conducted in East Asia and the Middle East, driven by several factors. Increased mental health awareness has led many countries to prioritize mental health in public health policies. The shortage of mental health professionals and the uneven distribution of healthcare resources, can render traditional face-to-face services insufficient for large populations. DHIs could offer remote care at lower costs and expanding access to a wider population, especially in resource-limited settings. Additionally, technological advancements in these regions, coupled with government-led digital transformation initiatives, may further facilitate the infrastructure needed to implement and expand digital health solutions.

Advantages of DHIs for Mental Health Outcomes and Recommendations

Current DHIs for MCI, primarily focusing on cognitive training, enhance mental health by combining adaptive tasks and interactive elements. These interventions adjust difficulty based on cognitive abilities, provide positive feedback, and promote engagement through real-time guidance. Robot-assisted and VR-based therapies monitor mood and motivation, offering personalized encouragement [43, 47], while creative programs delivered online stimulate mental health through activities like music and storytelling [42]. From a technological advancement perspective, DHIs that combine cognitive training with psychological techniques, including mindfulness and cognitive-behavioral therapy, hold potential for further improvement. Integrating adaptive algorithms, real-time data analysis, and machine learning would allow these platforms to dynamically tailor intervention strategies based on individual progress and responses. This optimization could significantly enhance cognitive function and alleviate depressive and anxiety by creating a more efficient synergistic effect.

Furthermore, DHIs offer accessibility, adjustability, and extensibility, overcoming time and space constraints [70]. They are particularly beneficial in resources-limited area by addressing physician shortages and providing timely, high-quality services [71]. However, overly complex interfaces may distract individuals with MCI, causing disorientation due to cognitive decline. Interfaces should be simplified and adapted to users' abilities, minimizing distractions and reducing cognitive load [72]. As Castilla et al. Suggest, key usability improvements include linear navigation, expanding interaction areas beyond the visual buttons to enhance the user's direction sense, and employing natural interfaces, such as audio interfaces, to match the user's cognitive abilities, ensuring usability and effectiveness [73].

Personalization is another key advantage of DHIs, as interventions can be tailored to individual needs. Participants can be matched to appropriate difficulty levels based on cognitive abilities. Real-time emotion recognition through sensor technology enables responsive adjustments, while smartphone apps allow users to select preferred stimuli (images, faces, or words) and track personalized data (location and physical activity) through their built-in sensors, providing real-time feedback [74]. Additionally, younger age, higher education, male gender, urban residency, and employment are associated with better internet access and digital skills, potentially enhancing DHIs outcomes [18]. Therefore, DHIs designs should consider these factors and incorporate users' values, preferences, history, and treatments to deliver the most personalized intervention.

Limitations and Future Directions

The findings of this study should be interpreted in the context of several limitations: (1) The exclusion of non-English or Chinese language studies, limits the comprehensiveness of our findings. Moreover, primary outcomes were based on self-reported symptoms, and the use of different measurement tools may explain the heterogeneity observed across the included studies. (2) Although sensitivity analysis confirmed the reliability of our findings, considerable heterogeneity was observed in depressive outcome. This variability may be attributed to individual differences, as well as in devices, types, modalities, and other intervention characteristics. Additionally, no subgroup analyses were conducted based on population characteristics or specific subtypes of MCI. Therefore, caution is warranted when generalizing the effectiveness of DHIs to individuals with specific pathologies. Future development on DHIs should emphasize the need for personalized interventions, with features tailored to accommodate variations in demographics, cognitive, emotional, and physical abilities. (3) Effect sizes for outcomes beyond depressive symptoms were based on a limited number of studies, resulting in low precision in estimating these effects. It is essential to broaden the scope of research to encompass a broader range of study populations and mental health outcomes. (4) The short follow-up periods in the included studies limit the ability to assess the long-term sustainability and potential risks of DHIs for mental health. Continuous monitoring and outcome tracking are essential for improving long-term sustainability and understanding user dynamics. Future research should use these technologies to evaluate the long-term effectiveness and safety of DHIs.

Conclusions

Given the potential of DHIs in managing mental health among individuals with MCI, this study provides the first comprehensive analysis of the existing evidence, suggesting that DHIs may offer a cost-effective solution. Future research should identify treatment moderators to develop personalized interventions for older adults with MCI, with collaboration between healthcare providers and researchers being key to successful implementation. Additionally, increased government support is essential for the sustainable integration of DHIs into healthcare systems, expanding mental healthcare options for older adults with MCI.

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Conflict of Interest

None declared.

Data Availability

All data relevant to this study are included in the article and its supplementary information files. This systematic review and meta-analysis was registered in PROSPERO (CRD42024522342).

Author Contributions

An Gu: Conceptualization, Methodology, Writing-original draft. **An Huang:** Conceptualization, Methodology, Data curation. **Bei Wu:** Writing-review & editing. **Xueqi Liu:** Conceptualization, Methodology, Data curation. **Cheng Huang:** Supervision, Validation. **Xichenhui Qiu:** Supervision, Validation. **Lina Wang:** Conceptualization, Methodology, Validation, Writing-review & editing, Funding acquisition. All authors read and approved the final version of the manuscript.

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Abbreviations

MCI: mild cognitive impairment
DHIs: Digital Health Interventions
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses
RCTs: randomized controlled trials
SMD: standardized mean difference
CI: confidence interval
GDS: Geriatric Depression Scale
GDSSF-K: Geriatric Depression Scale Short Form: Korean Version
SAS: Self-Rating Anxiety Scale
GAI: Geriatric Anxiety Inventory
PANAS: Positive and Negative Affect Schedule
MUNSH: Memorial University of Newfoundland Scale of Happiness
AES: Apathy Evaluation Scale
SES: Self-Esteem Scale
MCS: Mental Component Scale
SF-12: 12-item Short-Form Health Survey
VR: Virtual Reality

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Supplementary Files

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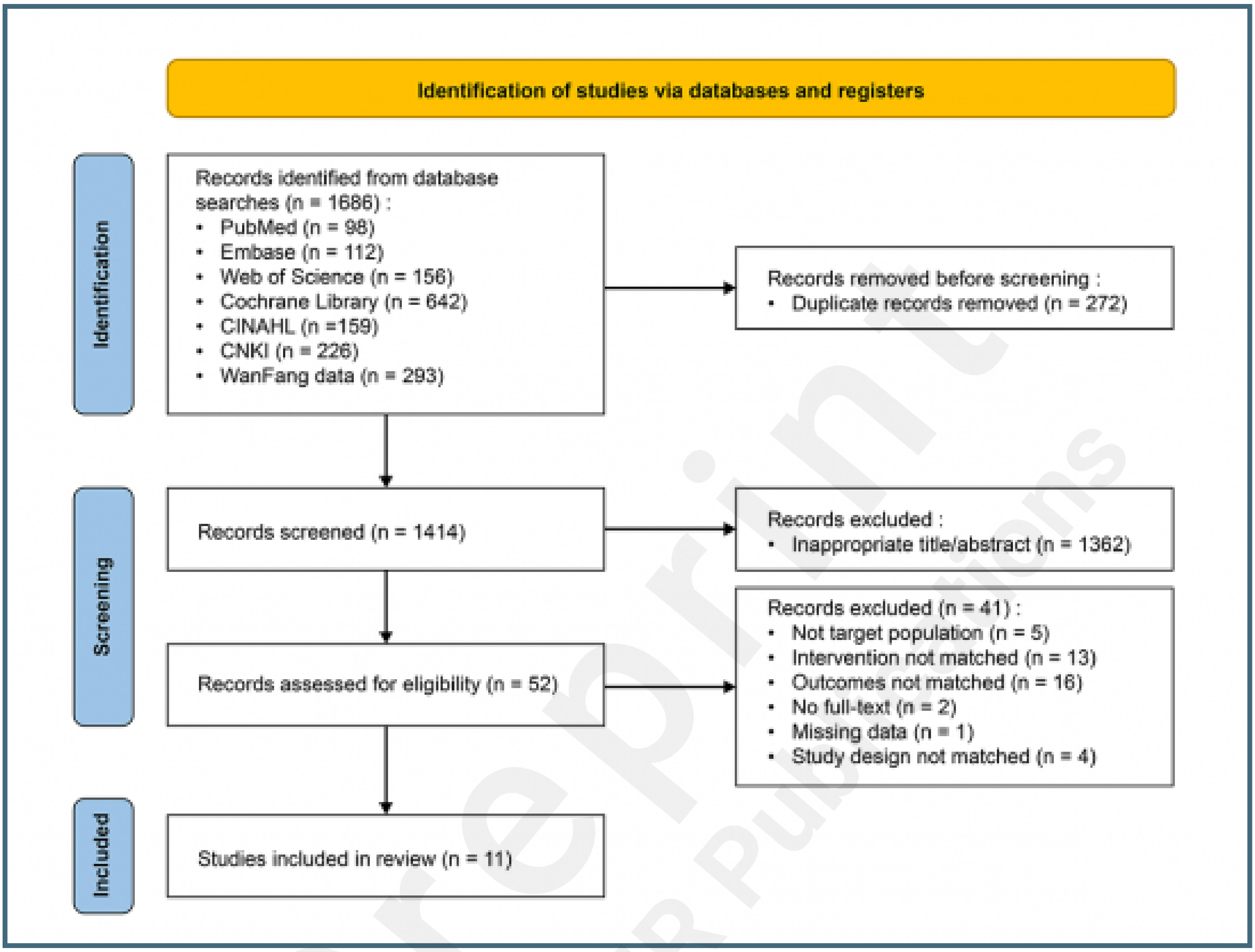
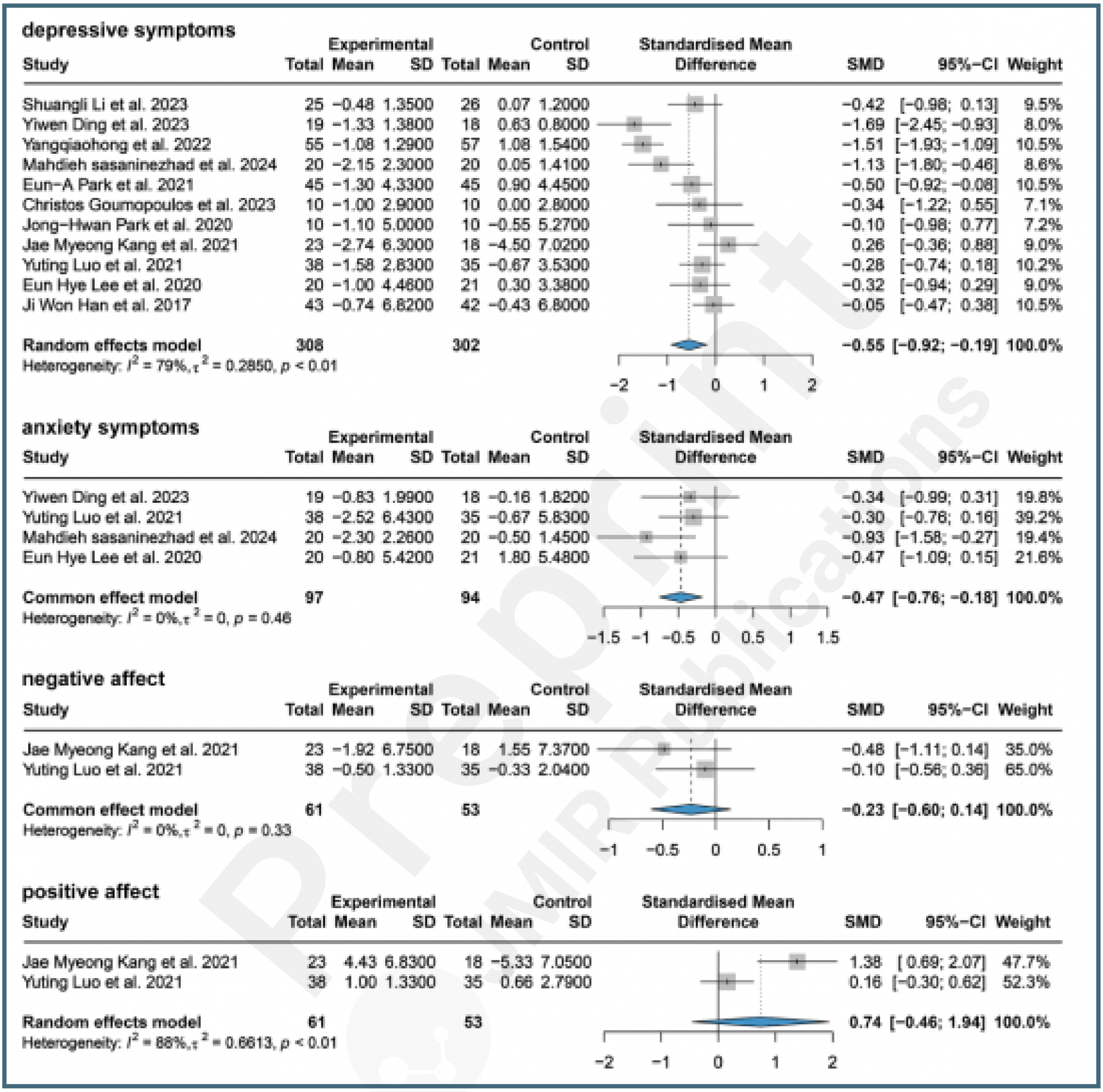
Figures

PRISMA flowchart of the study selection process.



Forest plot of the effectiveness of DHIs on depressive, anxiety symptoms, negative and positive affect.



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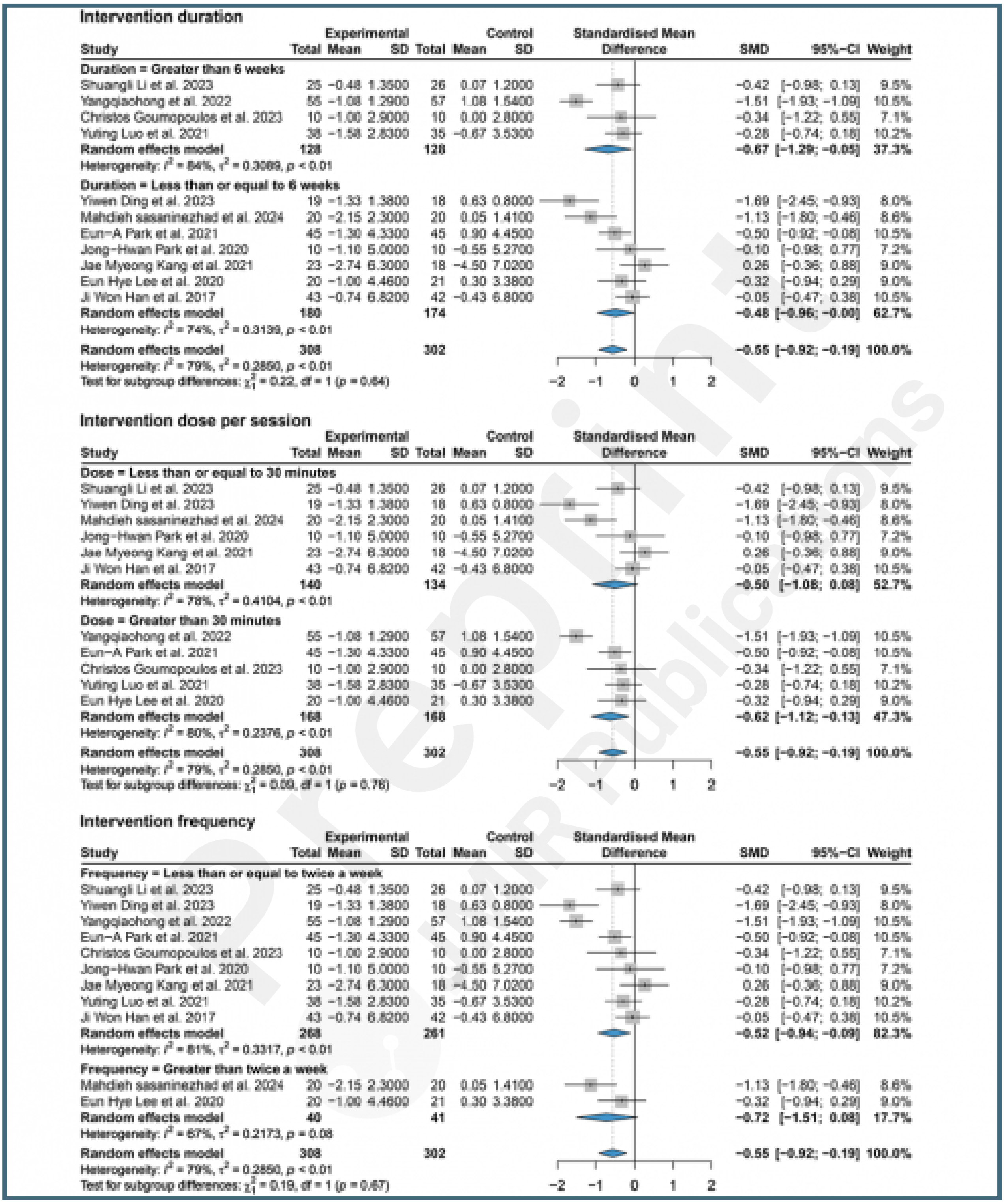
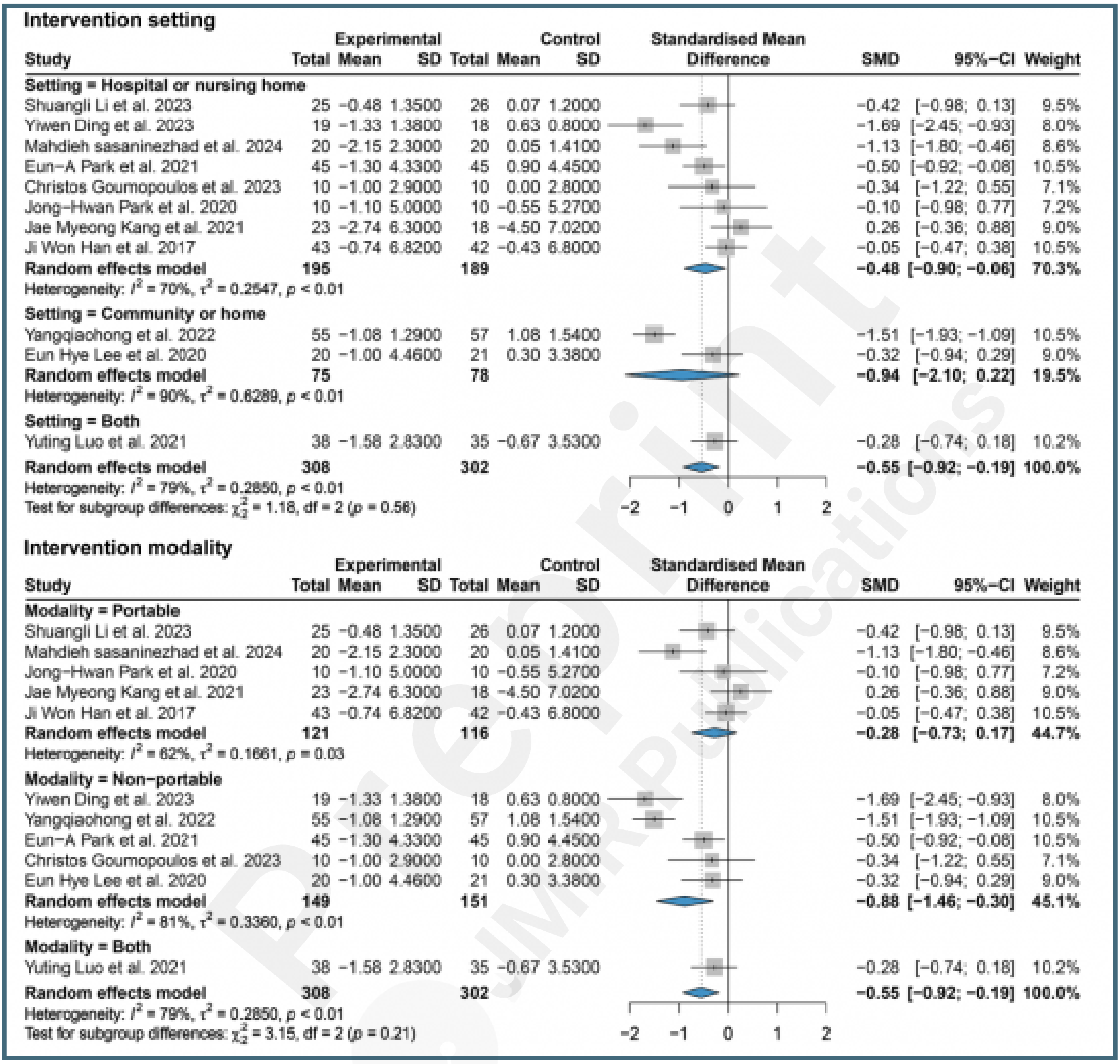
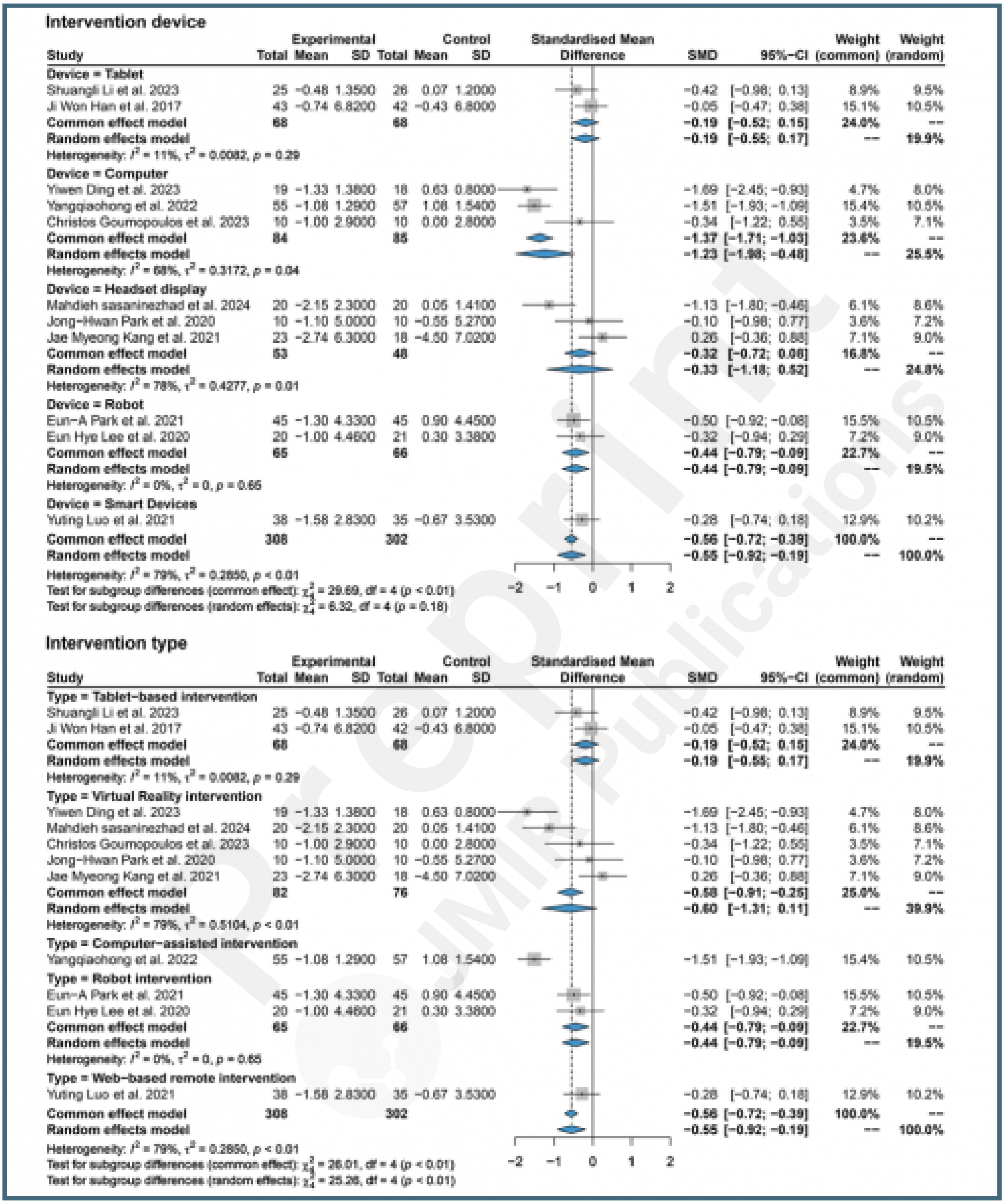
Forest plot of Subgroup analysis on intervention scheduling for depressive symptoms.



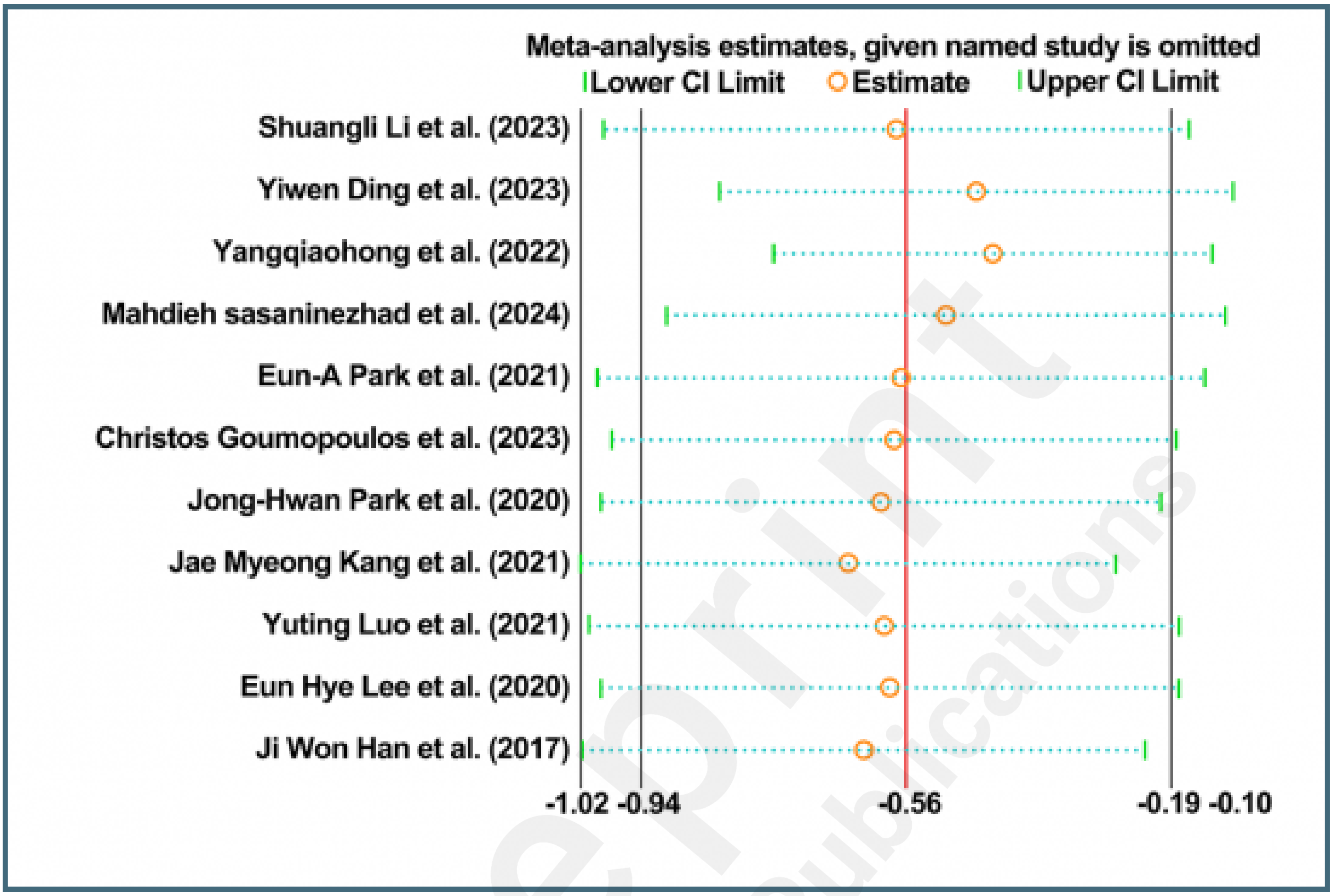
Forest plot of Subgroup analysis on intervention setting/modality for depressive symptoms.



Forest plot of Subgroup analysis on intervention device/type for depressive symptoms.



Sensitivity analysis of DHIs on depressive symptoms.



Multimedia Appendixes

Preprint JMIR Publications

Supplementary Material.
URL: http://asset.jmir.pub/assets/5dc03f4d83a423848ba98e3c8d2a43aa.docx

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