RESEARCH PAPER

# mHealth Interventions for Stroke Recovery: A Systematic Review and Meta-Analysis of Motor and Functional Improvements

***Running title:*** *mHealth Interventions for Stroke Recovery*

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**ABSTRACT**

**Background:** Stroke remains a major contributor to long-term disability globally, often impairing motor function and limiting physical independence. Emerging technologies, particularly mobile health (mHealth) applications, offer potential support for post-stroke rehabilitation in both clinical and home settings.

**Objectives:** To systematically evaluate the effectiveness of mHealth interventions in improving motor recovery and functional outcomes among adults with stroke survivors.

**Search Strategy:** A comprehensive electronic search was conducted across PubMed, Scopus, CINAHL, and PEDro databases up to March 2022. The strategy adhered to PRISMA guidelines to ensure transparency and reproducibility.

**Selection Criteria:** Randomized controlled trials (RCTs) evaluating mHealth applications for stroke rehabilitation were included. Studies focused solely on telerehabilitation, non-randomized designs, and conference abstracts were excluded.

**Data Collection and Analysis:** From an initial pool of 209 studies, six RCTs conducted between 2016 and 2022 (n = 308 participants) met the inclusion criteria. A narrative synthesis was performed, and meta-analysis was conducted for comparable outcomes. Standardized mean differences (SMDs) were computed, and heterogeneity assessed using the $I^2$ statistic.

**Results:** mHealth interventions yielded a statistically significant improvement in motor recovery (pooled SMD = 0.464, SE = 0.132, $p < 0.001$), with individual SMDs ranging from 0.11 to 1.00. Considerable heterogeneity ($I^2$ = 75.4%) was noted, attributed to intervention variability. Risk of bias was moderate to high, but Egger's test indicated no publication bias.

**Conclusions:** mHealth solutions demonstrate moderate efficacy in supporting motor and functional outcomes post-stroke. Further standardized, high-quality trials are needed to guide clinical integration.

**Keywords:** mHealth, Stroke Rehabilitation, Motor Recovery, Physical Function, Systematic Review, Meta-Analysis.

**Key Messages:** Clinical Relevance: mHealth tools can extend rehabilitation beyond hospital settings, offering continuity of care for stroke survivors with limited access to in-person therapy. Practice Gap: Despite promising results, inconsistent intervention designs and outcome metrics limit integration into current clinical protocols. Future Direction: Rehabilitation professionals should collaborate in designing standardized, evidence-based mHealth protocols tailored to post-stroke motor recovery.

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**Introduction:**

Stroke is one of the leading causes of long-term disability, profoundly affecting motor recovery and the ability to perform activities of daily living (ADLs).[1] Despite significant advances in stroke rehabilitation, access to multidisciplinary rehabilitation services, such as physical and occupational therapy, remains limited, particularly in low- and middle-income countries.[2,3] Barriers such as economic constraints, accessibility issues, and lack of continuity in care contribute to suboptimal recovery outcomes and increased caregiver burden.[4]

The rapid adoption of mobile health (mHealth) technologies offers potential solutions to these barriers by providing scalable, cost-effective rehabilitation interventions remotely.[5] mHealth applications can facilitate motor recovery and physical function improvements in stroke survivors by providing real-time feedback, progress tracking, and personalized rehabilitation programs. [6,7]

Game-based mobile applications have also been explored as innovative tools to improve patient engagement and neuroplasticity in post-stroke rehabilitation, with encouraging preliminary results.[8] While previous systematic reviews have examined the general role of mHealth technologies in healthcare, there remains a gap in understanding the specific impact of these interventions on motor recovery and functional independence in stroke survivors. [7, 9]

**Objectives:**

The objective of this review was to evaluate the effectiveness of mobile health (mHealth) applications in enhancing motor recovery and physical function among adult stroke survivors. We further aimed to synthesize findings from eligible randomized controlled trials through meta-analysis, and to explore sources of heterogeneity across studies in terms of intervention design, outcome measures, and methodological quality.

**Methods**

**Types of Studies**

This review included only randomized controlled trials (RCTs) that assessed the effectiveness of mobile health (mHealth) interventions in stroke rehabilitation.[9] Studies that were non- randomized, observational, pilot without full methodology, or conference abstracts lacking data were excluded to maintain methodological rigor.

**Types of Participants**

Eligible participants were adults aged 18 years and above with a clinical diagnosis of stroke. [10] No restrictions were applied regarding stroke type or chronicity, provided the study aimed to improve motor recovery or physical function. [8]

**Types of Interventions**

Included studies utilized mHealth applications delivered through smartphones or tablets. [11, 12] These apps supported rehabilitation by providing guided exercises, task-specific motor training, performance tracking, or interactive feedback. Studies using only videoconferencing or telephone-based interventions without an app-based platform were excluded.[5]

**Types of Outcome Measures**

Studies were eligible if they reported on at least one validated motor recovery or functional outcome post-intervention.[13]

**Primary Outcomes**

Motor recovery outcomes were the primary focus and included tools such as the Fugl-Meyer Assessment (FMA), Manual Muscle Testing (MMT), and Brunnstrom stages of stroke recovery. [14,15]

**Secondary Outcomes**

Secondary outcomes included measures of functional mobility and independence, such as the Timed Up and Go Test (TUG), 10-Meter Walk Test (10mWT), Functional Independence Measure (FIM), Modified Barthel Index (MBI), step counts, and stroke-specific quality of life scales (e.g., SS-QOL). [7,9]

**Search Strategy**

A comprehensive search strategy was employed to identify relevant RCTs. Search terms were framed around the population, intervention, and outcomes of interest and developed in line with PRISMA 2020 guidelines. [10]

**Electronic searches**

Electronic databases searched included PubMed, Scopus, CINAHL, and PEDro, covering all records up to March 2022. The search strategy incorporated both Medical Subject Headings (MeSH) and free-text keywords such as “stroke,” “mHealth,” “mobile health,” “motor recovery,” and “physical function.” Boolean operators ‘AND’ and ‘OR’ were used to refine the results.[16]

**Searching Other Resources**

Reference lists of included articles and previous systematic reviews were hand-searched to identify additional studies. [17, 18] No unpublished or gray literature was included.

**Data Collection and Analysis Selection of Studies**

After removing duplicates, two independent reviewers screened 178 records based on titles and abstracts. Thirteen articles were reviewed in full text, and six studies met the eligibility criteria.[9] Disagreements were resolved through consensus discussions involving a third reviewer. A PRISMA flow diagram (Figure 1) illustrates the selection process.

**Data Extraction and Management**

Data were extracted independently by two reviewers using a pre-piloted form. Extracted items included author, year, country, sample size, participant characteristics, intervention details, outcome measures, time points, and results. Inconsistencies were resolved through discussion with the review team.

**Assessment of Risk of Bias in Included Studies**

Risk of bias was assessed using two tools: the PEDro scale and the Cochrane Risk of Bias Tool (RoB 2). [19] The PEDro scale graded studies from poor to excellent based on methodological criteria. The RoB 2 tool evaluated bias across five domains: selection, performance, detection, attrition, and reporting. Results were presented in tabular and graphical formats (Table 2, Figures 2A and 2B).

**Measures of Treatment Effect**

For continuous outcomes, standardized mean differences (SMDs) with 95% confidence intervals were calculated to compare the effect sizes across studies using different scales.[19]

**Assessment of Heterogeneity**

Statistical heterogeneity was evaluated using the $I^2$ statistic. An $I^2$ value above 50% was interpreted as substantial heterogeneity.[13] Differences in participant characteristics, intervention protocols, and outcome measures were considered likely contributors.

**Assessment of Reporting Biases**

Publication bias was assessed through Egger’s regression test and visual inspection of funnel plot symmetry (Figure 4). [20]

**Data Synthesis Meta-analysis**

Where outcome data were sufficiently homogenous, results were pooled using a random- effects meta-analysis model.[19] The pooled SMDs were reported to reflect the standardized effect of mHealth interventions on motor recovery and functional outcomes.

**Summary Table**

Characteristics and findings of included studies were summarized in a structured table (Table 1), detailing sample size, intervention type, outcome measures, and results. [7,9]

**Report on Practical Significance**

Beyond statistical significance, findings were interpreted for their clinical relevance, particularly the feasibility and utility of mHealth applications in enhancing stroke rehabilitation, especially in resource-limited settings.[3, 14, 21]

**Report on Equity**

Most included studies originated from high-income countries, which limits the direct applicability of findings to low- and middle-income contexts. The equity implications were acknowledged, and future research is encouraged to address this gap. [4, 5]

**Subgroup Analysis and Investigation of Heterogeneity**

Due to limited study numbers, formal subgroup analysis could not be conducted. However, narrative interpretation identified variation in intervention intensity, supervision levels, and technology types as potential sources of heterogeneity. [9, 22]

**Sensitivity Analysis**

Sensitivity analyses were not performed due to the small number of studies included and variability in intervention protocols and outcome measures.[15]

**Results**

From an initial pool of 209 records retrieved through electronic database searches, 31 articles were excluded during the deduplication and preliminary screening phase, leaving 178 records for further evaluation. Two reviewers independently screened titles and abstracts, resulting in 13 studies selected for full-text review. After applying eligibility criteria, six randomized controlled trials were included in the final synthesis. The excluded studies consisted of four non-RCTs, three focused solely on tele-rehabilitation without a mobile application component, and one conference abstract lacking sufficient outcome data.

The six included trials, published between 2016 and 2022, collectively involved 308 adult stroke survivors across diverse geographic regions. All studies investigated mobile health (mHealth) applications aimed at improving motor or functional outcomes during stroke rehabilitation. The duration of interventions ranged from 2 to 8 weeks and featured app-based programs for home-based exercise, real-time feedback, interactive motor training, or daily activity tracking.

Regarding primary outcomes, all six trials reported improvements in motor function, including gains in upper limb recovery, muscle strength, or coordination. Standardized assessments such as the Fugl-Meyer Assessment for Upper Extremity (FMA- UE), Manual Muscle Testing, and functional mobility scores showed consistent within-group improvements. The meta-analysis yielded a pooled standardized mean difference (SMD) of
0.464 (SE = 0.132, $p < 0.001$), indicating a moderate effect size in favor of mHealth interventions.
The findings of this systematic review and meta-analysis suggest that mobile health (mHealth) interventions significantly improve motor recovery in stroke survivors. The pooled effect size (SMD = 0.464, SE = 0.132, $p < 0.001$) reflects a moderate impact, with improvements observed across upper and lower limb

Secondary outcomes addressed broader aspects of physical function and independence. Measures such as the 10-Meter Walk Test, Timed Up and Go Test, and Modified Barthel Index showed improvements across both groups, although between-group differences were more variable. [7,9] The use of mHealth apps contributed to increased step counts, enhanced adherence to exercise programs, and perceived improvements in quality of
life. [9,23]

Risk of bias was assessed using the PEDro scale and the Cochrane RoB 2 tool. The methodological quality was rated from fair to good, with PEDro scores ranging from 6 to
9. Common sources of bias included lack of blinding among participants and therapists, and inadequate allocation concealment in a few studies.

No major adverse effects or unintended consequences of mHealth interventions were reported. However, two studies noted minor issues such as reduced motivation over time or technical difficulties with app use.[13,19]

Although subgroup analysis could not be statistically conducted due to the limited number of included studies, descriptive comparisons suggested that interventions with therapist oversight or gamified interfaces may be associated with greater engagement and functional gains.[8,12]

Substantial heterogeneity was identified across studies ($I^2$ = 75.4%), likely influenced by variations in intervention design, participant characteristics, and outcome measurement tools.

Sensitivity analysis was not feasible in this review due to the small number of included studies and variability in reported outcomes. Nonetheless, the consistency of findings supports the potential value of mHealth interventions in stroke rehabilitation while underscoring the need for more standardized and longer-duration trials.

**Discussion**

motor function. These outcomes are consistent with prior studies that reported functional gains through app-based
Rehabilitation. [4, 19] Interventions offering real-time feedback, progressive difficulty levels, and task-specific training appear to be particularly beneficial in

promoting neuroplastic recovery.[18]

Although the evidence supports mHealth as a promising adjunct to stroke rehabilitation, its completeness is limited by several factors. Most included trials were conducted in high- income countries with relatively small sample sizes and short durations (2–8 weeks). These characteristics constrain the ability to assess long-term benefits and restrict generalizability to low- and middle-income settings where access to mobile technology and digital literacy may vary considerably. Furthermore, outcome reporting varied across trials, and not all studies measured both motor recovery and functional performance, limiting comprehensive synthesis. [1, 3, 6, 13]

The included studies exhibited several methodological strengths, including the use of validated outcome measures and randomization. However, common weaknesses included a lack of blinding and limited follow-up. Some studies combined mHealth with
In terms of equity, most of the current evidence base originates from resource-rich settings, which presents challenges when applying these findings globally. Stroke survivors in low- resource settings may face barriers such as lack of smartphone access, limited network infrastructure, or language and literacy constraints. Future trials must aim to test culturally adapted mHealth programs in underrepresented regions to reduce disparities in stroke care access. [3,6]

Overall, the quality of evidence was fair to good. PEDro scores ranged from 6 to 9, and most trials employed randomized designs. Nonetheless, performance and selection biases were evident in several studies due to the absence of blinding and unclear allocation concealment procedures. [7,16] The heterogeneity observed may also reflect differences in app interfaces, therapist engagement, and baseline functional status of participants. [8,9, 19]

To minimize bias in this review, a structured protocol adhering to PRISMA guidelines was followed, and the study was registered with the Open Science Framework. Dual independent screening, data extraction, and risk of bias assessments were performed, reducing subjective bias. [1,15] However, limitations include exclusion of non-English publications and potential underreporting of negative or

therapist-led sessions, while others were entirely self-administered, contributing to heterogeneity ($I^2$ = 75.4%). [14,16,17] Few studies provided detailed adherence data or long-term outcome follow-up, leaving gaps in understanding sustained use and real-world effectiveness. This review contributes to the existing literature by focusing specifically on stroke-related motor and functional outcomes, addressing a narrower scope than broader digital health reviews. [15, 21]

Clinically, the moderate effect size reported has meaningful implications. mHealth tools can complement conventional rehabilitation by providing structured, flexible, and often home-based support, which may improve therapy adherence. The ability to remotely monitor progress and personalize exercises makes these interventions practical in both urban and remote settings. [4,5,11] However, clear guidelines on dosage, progression, and therapist involvement are lacking and must be established to optimize their integration into physiotherapy practice. [14,24]
null results, which may affect the comprehensiveness of included evidence. [20,25]

The findings are in agreement with previous systematic reviews such as those by Cao et al. (2024) and Rintala et al. (2023), which reported moderate benefits of mHealth interventions on stroke recovery. [7, 9] While the effect sizes in our analysis align with those reported by Cao et al. (0.5–0.6), heterogeneity remains a consistent concern across studies. These results also echo meta-analytic findings in related domains, such as Zhou et al. (2023), which identified similar levels of variability in mHealth effects on blood pressure control.[26]

**Conclusion**

mHealth interventions appear to be a feasible and moderately effective adjunct to conventional stroke rehabilitation, particularly in improving motor function and supporting home-based care. While the overall evidence is encouraging, variation in study design, intervention protocols, and short follow-up durations limits generalizability. Integrating therapist feedback, ensuring equitable access, and conducting longer, methodologically sound trials will be key to realizing the full potential of mHealth in diverse clinical settings.

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**FIGURE 1** PRISMA flow diagram illustrating the process of study selection, from initial search to the inclusion of studies in the systematic review and meta-analysis.

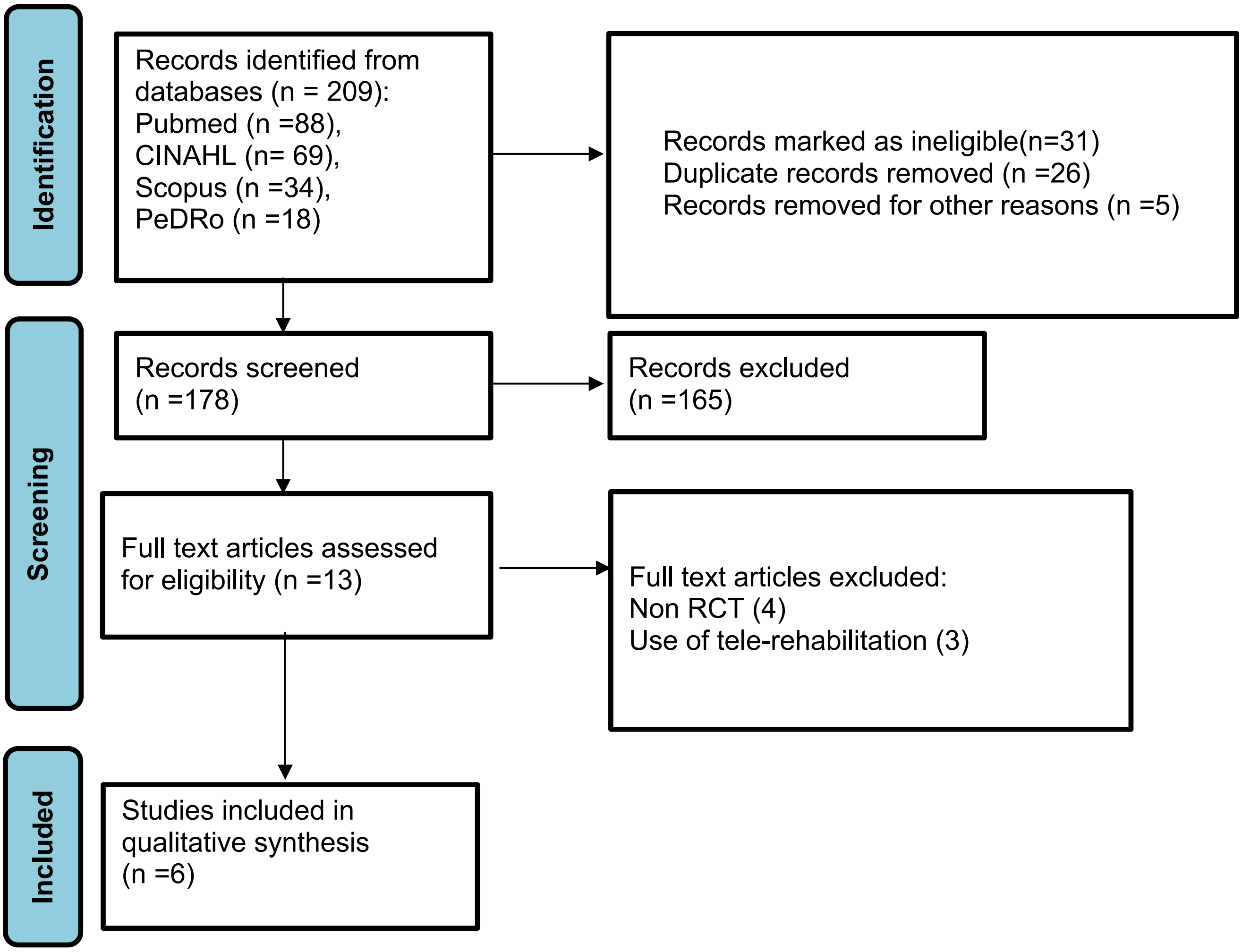


**TABLE 1** Characteristics of Included Studies on mHealth Interventions for Stroke Rehabilitation.

| Study | PEDro Score | Participants & Inclusion Criteria | Sample Size | Intervention | Dosage & Protocol | Outcome Measures | Key Findings |
|---|---|---|---|---|---|---|---|
| **Choi et al.** (2016) South Korea | 8 | Ischemic stroke, upper extremity impairment, B- stage 1-5 | N=24 (C=12 I=12) | Conventional therapy + MoU-Rehab app (4 game applications for UE moto improvement) | C: 1 hr/day. I: 30 mir conventional + 30 min intervention. 10 sessions over 2 weeks | FMA-UE, B- stage, MMT, MBI EQ-5D, BDI | Both groups improved ir UE recovery. Greater improvement in the intervention group. |
| **Jang & Jang** (2016), South Korea | 7 | Age 18-70, 6 months post-stroke, MMRC ≥2 | N=21 (C=11 I=10) | App with registration evaluation, and training (stretching, flexion extension) | 31 min/session, 6 days/week for 4 weeks | MMT, MFT, Purdue Pegboard Test | Significant improvement ir UE function in the intervention group compared to control. |
| **Paul et al**. (2016) UK | 6 | Unilateral stroke, independen ambulation, discharged from rehabilitation | N=24 (C=8 I=16) | STARFISH app (walking activates app to engage participants) | 30-min sessions for 6 weeks | 10 mWT, Steps/day, IADL, FSS SS- QOL, PGWBI | Increased steps/day and walking time in the intervention group Sedentary time reduced. |
| **Grau-Pellicer et al** (2019), Spain | 6 | Ischemic/hemorrhagic stroke, FAC ≥3, BI ≥45 | N=41 (C=17 I=24) | MMRP: FitLab Training and FitLab Test apps | 8 weeks, 2 days/week, 1 hr/session | 10 mWT, 6 MWT TUG, BI, EQ-5D-5L | Greater community ambulation and ADL independence in the intervention group. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Chung et al.** (2020), Hong Kong | 11 | Stroke, smartphone access, able to read Chinese | N=56 (C=29 I=27) | Exercise videos (QR code) + pamphlet | Daily to 3 times/day, 10-30 minutes | MFAC, MBI-C, SEE-C | Significant improvement in SEE and MFAC in the intervention group at 3 months. |
| **Li et al**. (2020), Australia | 9 | Age >18, rehabilitation participants, MMSE >24 | N=140 (C=69 I=71) | PT Pal app (California, USA) | Not reported | 10 mWT, 6 MWT, TUG, FIM | Significant improvements within both groups, but no between-group difference post-intervention |

C group = Control group; I group = Intervention group; FMA-UE = Fugl-Meyer Assessment for Upper Extremity; B-stage = Brunnstrom Stages of Stroke Recovery; MMT = Manual Muscle Testing; MBI = Modified Barthel Index; EQ-5D = EuroQol-5 Dimensions; BDI = Beck Depression Inventory; MoU- Rehab = Mobile application for Occupational and Rehabilitation Therapy; MFT = Manual Function Test; PPT = Purdue Pegboard Test.

**TABLE 2** PEDro Scale Assessment of Methodological Quality for Included Studies.

| | Choi et al. 2016 | Jang et al. 2016 | Paul et al. 2016 | Grau- Pellicer et al. 2020 | Chung et al. 2020 | Li et al. 2020 |
|---|---|---|---|---|---|---|
| **Eligibility Criteria** | Yes | Yes | Yes | Yes | Yes | Yes |
| **Random Allocation** | No | Yes | No | Yes | Yes | Yes |
| **Concealed Allocation** | Yes | No | No | No | Yes | Yes |
| **Baseline Similarity** | Yes | Yes | Yes | Yes | Yes | Yes |
| **Blinding Of Subjects** | Yes | No | No | No | No | No |
| **Blinding Of Therapists** | Yes | No | No | No | Yes | No |
| **Blinding Of Assessors** | Yes | No | No | No | Yes | Yes |
| **Outcome Measures** | Yes | Yes | Yes | Yes | Yes | Yes |
| **Statistical Reporting** | Yes | No | Yes | Yes | Yes | Yes |
| **Dropout Reporting** | No | Yes | Yes | Yes | Yes | Yes |

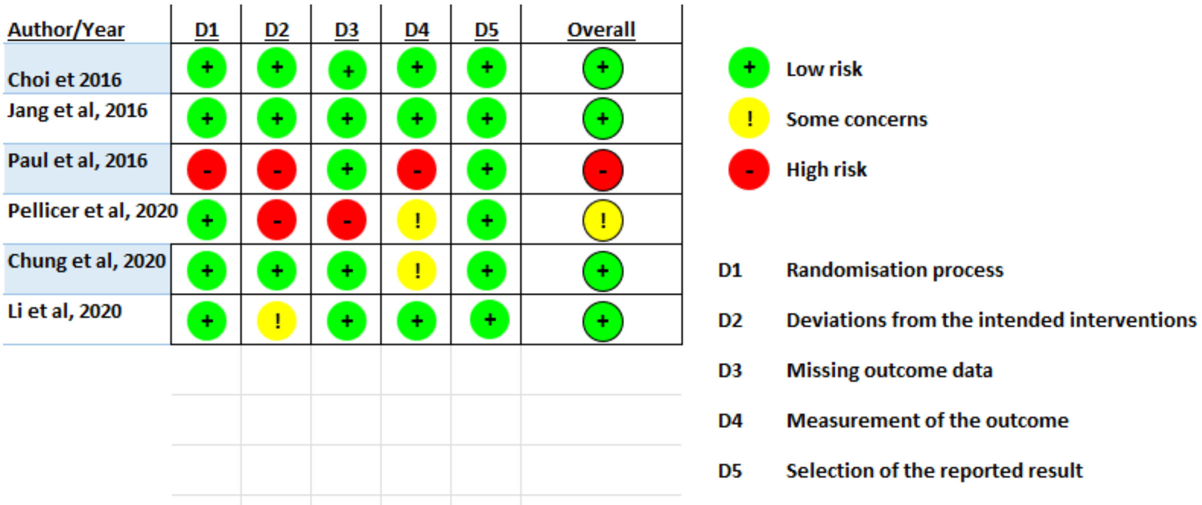
**TABLE 3** Meta-Analysis Results: Standardized Mean Differences (SMD) for Motor Recovery and Physical Function**.**

| **Study** | **Outcome Measure** | **SMD(95% CI)** | **p-value** |
|---|---|---|---|
| **Choi et al. 2016** | FMA-UE (Post-test) | 0.56 [-0.25, 1.37] | *P < 0.05** |
| | FMA-UE (1-Month Follow-Up) | 0.86 [0.03, 1.69] | *P < 0.05* |
| **Jang et al. 2016** | Wrist Extension | 1.00 [0.14, 1.86] | *P < 0.05* |
| **Paul et al. 2016** | Step Count | 0.94 [0.10, 1.78] | *P* = 0.021* |
| | Stroke Specific Quality of Life Scale (SS-QOL) | 0.20 [-0.66, 1.06] | *P* = 0.002* |
| **Grau-Pellicer et al., 2020** | Walking Speed | 0.96 [0.65, 1.27] | *P* = 0.034* |
| | Community Ambulation Scores | 0.71 [0.17, 0.95] | *P* = 0.034* |
| **Chung et al. 2020** | MFAC (Community Ambulation) | 0.64 [0.45, 0.83] | *P* = 0.036* |
| | Modified Barthel Index | 0.11 [-0.41, 0.64] | *P* = 0.808 |
| **Li et al. 2020** | Functional Mobility (TUG) | 0.22 [-0.35, 0.79] | *P* = 0.40 |
| | Functional Independence (FIM) | -0.09 [-0.42, 0.24] | *P* = 0.50 |
| | Walking Speed (10-Meter Walk) | -0.10 [-0.35, 0.15] | *P* = 0.20 |

| | |
|---|---|
| **Heterogeneity Statistics ($I^2$)** | **75.425% (overall meta-analysis)** |

*p < 0.05 indicates statistical significance. SMD = Standardized Mean Difference; CI = Confidence Interval; SS-QOL = Stroke Specific Quality of Life Scale; FMA-UE = Fugl-Meyer Assessment of Upper Extremity; TUG = Timed Up and Go Test; MFAC = Modified Functional Ambulation Classification; FIM = Functional Independence Measure.

A




B

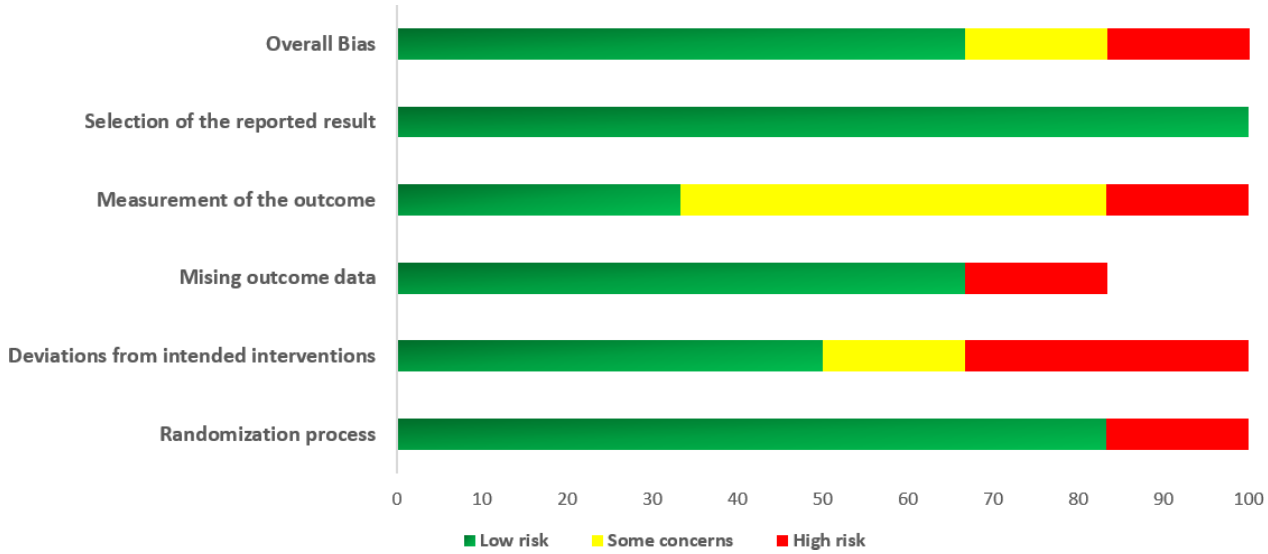



**FIGURE 2A)** Risk of bias summary for the included studies, showing judgments across five domains. **Figure 2B)** Risk of bias graph displaying the overall proportion of judgments across all included studies, indicating the level of bias in each domain (low, risk some concern, or high risk).

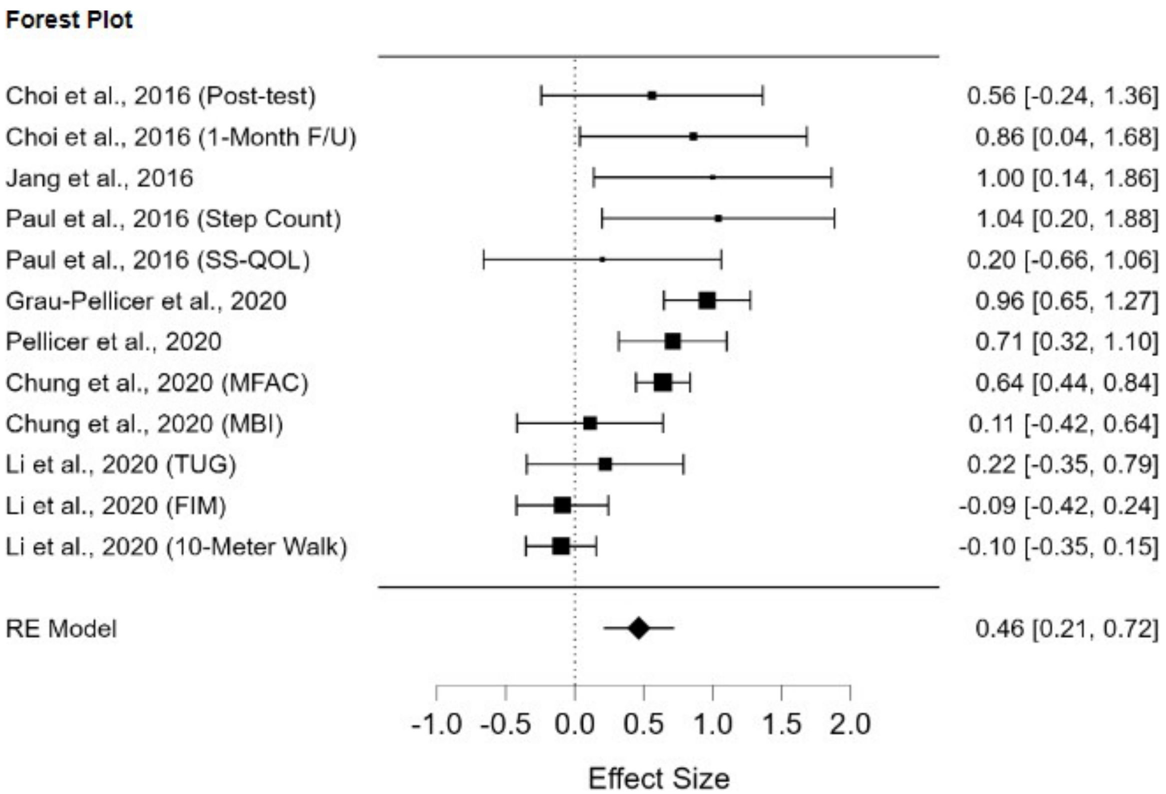



**FIGURE 3** Forest plot depicting the standardized mean difference (SMD) and 95% confidence intervals for the effect of mHealth interventions on motor recovery and physical function in stroke survivors across all included studies.

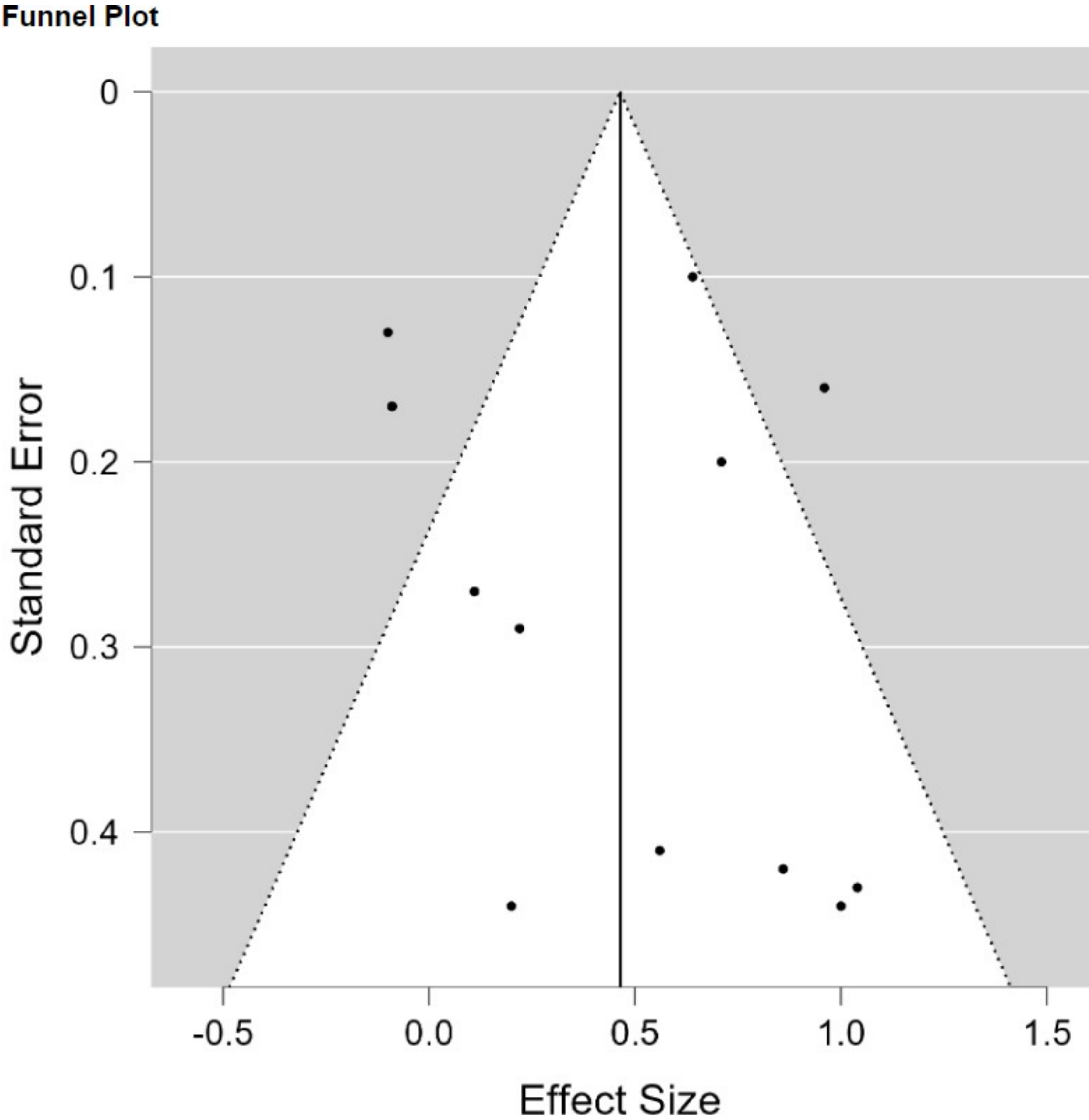



**FIGURE 4** Funnel plot assessing the potential for publication bias in the meta-analysis. The plot shows the symmetry of effect sizes for mHealth interventions in stroke rehabilitation, with no significant evidence of publication bias.