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# Effectiveness of just-in-time adaptive interventions for improving mental health and psychological well-being: a systematic review and meta-analysis

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## ABSTRACT

**Question** The rising prevalence of mental health conditions and a global treatment gap demand new solutions that address symptoms and foster psychological well-being. Just-in-time adaptive interventions (JITAIs) and ecological momentary interventions (EMIs) are emerging mobile health approaches, providing real-time, personalised support. However, the effectiveness of current JITAIs/EMIs and the longevity of effects remain uncertain.

**Study selection and analysis** Studies investigating the effectiveness of JITAIs/EMIs for depression, anxiety and indicators of psychological well-being, published between 2018 and May 2025, were eligible. Following the standards for reporting (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PRISMA) and quality assessment (Risk of Bias; RoB), a total of K=23 studies and N=2563 individuals (71.7% female) were included.

**Findings** JITAIs/EMIs showed a small between-group effect (g=0.15, 95% CI 0.05 to 0.26, p=0.003). Nine studies reported follow-up effects (mean follow-up time M=3.06 months, SD=2.21) with significant results at 1 and 3–6 months. Interventions shorter than 6 weeks yielded greater longevity of effects (g=0.71, 95% CI 0.18 to 1.24, p=0.008). Funnel plots and sensitivity analyses confirmed robustness of findings. Risk of bias was moderate to high for intervention adherence and missing outcome data.

**Conclusions** Currently existing JITAIs and EMIs slightly improve mental health, particularly mental illness, with long-term effects up to 6 months. A clear definition of JITAIs and decision rules, research on long-term effects and careful selection of control conditions are needed.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Existing evidence indicates that just-in-time adaptive interventions (JITAIs) yield short-term improvements in mental health symptoms and psychological well-being (PWB).
⇒ While dual enhancement of PWB and mental illness treatment is a key goal of these interventions, prior reviews lack mechanistic insights into how interventions sustain benefits at follow-up time points.
⇒ No meta-analysis to date has systematically compared the effects of current in-the-moment JITAIs/EMIs on reducing mental health symptoms vs enhancing PWB.

### WHAT THIS STUDY ADDS

⇒ JITAIs/EMIs sustain benefits for up to 6 months beyond the period of use. Even short intervention periods of less than 6 weeks increase the longevity of the effects.
⇒ JITAIs/EMIs are probably more effective in symptom reduction than in increasing positive PWB.
⇒ Control group selection (eg, waitlist vs alternative intervention comparator) significantly influences effect sizes, urging adherence to frameworks like the Pragmatic Model for Comparator Selection or Purpose-Guided Trial Design to standardise definitions and reduce trial heterogeneity.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Decision rules for interventions were systematically coded in this review. Future systematic reviews should build on this to clarify which types of support influence the effectiveness of interventions.
⇒ The findings support the further development of JITAIs/EMIs, suggesting that these technologies could complement therapeutic measures in the treatment of mental health conditions.
⇒ JITAI/EMI components for improving PWB should be explored and refined.

## BACKGROUND

Currently, half the world's population is projected to experience at least one mental disorder by the age of 75,[1] with depressive and anxiety disorders being the most prevalent.[2] To address the dynamic nature of mental health comprehensively, there has been a growing shift from focusing solely on treating illness to promoting *flourishing*[3]—a state of high psychological well-being (PWB). While most research still focuses on the detrimental aspects of mental health, the awareness of positive psychology and measurement of PWB is emerging.[4] PWB centres on the individual, subjective experiences of mental well-being, marked by positive feelings and the ability to function effectively.[5] In recent years, mobile health (mHealth) interventions aimed at reducing mental illness and enhancing well-being have emerged as a significant health tool, delivered within individuals' natural daily environments.[6] As found by a recent meta-analysis, remotely delivered mindfulness-based interventions

achieve effectiveness comparable to in-person formats such as workshops and classes,[7] underscoring their promise as accessible therapeutic options.

Yet, diverse terminology and frameworks are employed across the various disciplines involved in mHealth research. Frameworks such as 'Just-in-Time Adaptive Intervention'[8] (JITAI) and 'Ecological Momentary Intervention'[9] (EMI) provide app-based, adaptive, real-time support grounded in ecological momentary assessment (EMA). Advances in smartphone-based sensing, AI algorithms and wearable sensors now enable these interventions to adapt more effectively.[8] While both JITAIs and EMIs offer contextualised assistance, JITAIs dynamically adjust based on real-time data, whereas EMIs deliver in-the-moment support that is less adaptive, using simple triggers rather than continuous data analysis.[6 8 9] They are theorised to improve outcomes by delivering support at moments of heightened vulnerability and receptivity to facilitate habit formation through repeated timely assistance, state assessment and feedback.[8] In light of the considerable overlap between JITAIs and EMIs, this systematic review and meta-analysis examined the impact of both intervention types.

Although prior reviews have examined JITAIs/EMIs or have employed broad definitions of smartphone-based interventions,[10] there is still a lack of meta-analytical evidence on JITAI/EMI long-term effectiveness,[6] and a holistic approach that includes both ends of the mental health spectrum, examining JITAI/EMI effects on mental illness while also considering positive aspects beyond symptom relief.[11 12] JITAIs are designed to adapt dynamically to individual states, yet many studies rely on fixed tailoring mechanisms, diluting the 'just-in-time' advantage: nearly one-third of the included studies in a previous meta-analysis failed to specify how interventions were triggered.[12] Therefore, given the fast-paced developments in this field of research, an update is due.

Our review advances prior meta-analyses by (1) coding interventions as JITAIs or EMIs, (2) modelling duration-dependent outcome decay to quantify intervention longevity and (3) systematically comparing effects by control group type—each representing a novel contribution to the digital mental health literature. Following the PICO (population, intervention, comparator, outcome) framework for research questions in systematic reviews,[13] we ask:

RQ1 (effectiveness at post-intervention): In adults with or at risk for mental health concerns [P], what is the effectiveness of JITAIs and EMIs [I] compared with various control conditions [C] in improving mental illness symptoms and psychological well-being [O]?

RQ2 (longevity and duration-dependent effects): Among adults [P] receiving JITAI/EMI [I], what is the longevity and duration-dependent effect of these interventions on mental illness and psychological well-being outcomes [O] at various follow-up time points?

RQ3 (differential effects on outcomes): Among adults [P] receiving JITAI/EMI [I], do these interventions differentially affect mental illness symptoms versus psychological well-being [O]?

## STUDY SELECTION AND ANALYSIS

### Search strategy and selection criteria

This systematic review and meta-analysis is registered with the Open Science Framework and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[14] The following deviations from the preregistered protocol should be noted: First, we deleted the within-subject perspective from RQ1 and RQ3. Second, one quasi-experimental study[15] was included alongside randomised controlled trials (RCTs); and third, when studies reported multiple eligible outcomes, only one was extracted per study, choosing the primary or secondary mental health outcome that was either (1) designated as the study's primary outcome, or (2) best reflects the intervention target (if secondary outcome). In May 2025, a database search was conducted in PubMed, Web of Science and ScienceDirect using terms related to (1) JITAIs and EMIs, (2) mHealth and (3) mental health (online supplemental table 1). Full strings for each database are provided in the online supplemental appendix 3.

In line with the PICO framework,[13] we applied predefined inclusion criteria through a three-stage screening process: duplicate removal and title screening, abstract screening and full-text review. Two trained coders independently conducted all screening and eligibility assessments, resolving any disagreements through discussion until consensus was reached. Studies were included if they evaluated app-based mHealth interventions that were momentarily delivered and included an ecological momentary assessment (EMA) component (coded as 'EMI'). If the intervention was dynamically tailored or adapted to the user's momentary state, it was coded as 'JITAI'. Eligible studies had to target depression, anxiety or PWB as either a primary outcome or a secondary outcome that aligned most closely with the intervention's aims. The search was restricted to studies published between January 2018 and May 2025 to reflect recent technological advancements.[6 8] Eligible studies were RCTs or quasi-experimental designs, included adults aged at least 18 years, and were published in English. Interventions had to be implemented in real-world settings, either as stand-alone treatments or combined with other therapeutic elements and must have measured outcomes at baseline and post-intervention, with follow-up data preferred.

### Coding and data collection

Data extraction followed a structured protocol, collecting information on (1) study characteristics (first author, publication year and design); (2) sample characteristics (clinical characteristics, age, gender, total sample size (N), type of control condition, and sample sizes at post-intervention in both the intervention and control groups); (3) outcome characteristics (primary/ secondary outcome, selected mental health outcome and outcome measure); and (4) intervention characteristics (intervention technique, training type (JITAI or EMI; with or without treatment as usual (TAU)), decision rule, intervention period, and time point of a follow-up measurement if present). We extracted pre-post and intervention-control measures for the meta-analysis. For each study, we included one outcome to avoid double-counting participants.[16] When a mental illness outcome (depression, anxiety) or PWB was the primary outcome, it was selected. If mental health was only a secondary outcome, we chose the secondary outcome that best aligned with the intervention's target. All primary and secondary outcomes are listed in online supplemental table 2.

### Quality assessment

The Revised Cochrane Risk-of-Bias Tool for Randomised Trials (RoB 2)[17] was used to evaluate study quality across five domains, including (1) randomisation process, (2) deviations from intended interventions (effect of assignment to

intervention, effect of adhering to intervention), (3) missing outcome data, (4) measurement of the outcome and (5) selection of the reported result. UVL and NLN rated each domain per study as 'low', 'some concerns' or 'high' risk of bias, which provided an overall risk of bias judgement for each study that was determined by the highest risk of bias level in any of the five domains.[17]

### Data analysis

The standardised mean difference, defined as the adjusted Hedges' g, was used as an estimate of the effect size.[18] It measures the strength and direction of an intervention's effect. Hedges' g was calculated using the M, SD and sample size (n) for between-group comparisons at each relevant time point. When only SEs were reported, SD was calculated as SD=SE×N.[18] Hedges' g follows Cohen's d interpretation, with 0.8 indicating a large effect, 0.5 a moderate effect and 0.2 a small effect.[19] ReviewManager (RevMan) V.5.3 was used for the analysis. Random-effects models were applied to account for heterogeneity, assessed using $\chi^2$ and $I^2$ statistics. Heterogeneity reflects the variability in observed effects across different studies beyond chance. A large $\chi^2$/df ratio is indicative of some effects heterogeneity. The $I^2$ statistic describes the percentage of between-study variation in the observed effects that cannot be attributed to chance alone.[20] Publication bias was evaluated via funnel plots, and sensitivity analyses (re-evaluating the main results after systematically excluding outliers to confirm the stability of findings) were conducted to test the robustness of findings. Subgroup analyses explored potential moderators, such as intervention period and type of control group.

### Patient and public involvement

Patients and members of the public were not directly involved in the planning, conduct or analysis stages of this systematic review and meta-analysis.

## FINDINGS

The search identified a total of 989 publications, which were downloaded and entered into a literature management program (Zotero, V.6.0.37). If the full text was not accessible, only the abstract was initially saved. Of the total 989 publications, 44 duplicates were removed, and the number of studies was reduced to 100 by reviewing titles and abstracts. In the last step of study selection, full texts have been screened of the remaining 100 publications, whereby a further 77 studies were excluded due to the exclusion criteria outlined in the PRISMA flow chart (figure 1, online supplemental appendix 5). A total of 33 publications were considered relevant. 10 more publications were excluded because of missing data, which could not be obtained after contacting the authors. Therefore, a final 23 studies are included in this systematic review and meta-analysis.

Online supplemental table 2 provides a summary of the characteristics of the included studies. A total of n=2563 participants were recruited in the 23 studies. The studies were published between 2018 and 2025, with 12 studies (k=12, 52.2%)[21–32] published in or after 2024. Most studies (k=22, 95.7%) employed a RCT design and one study (k=1, 4.4%)[15] used a quasi-experimental design with random allocation, which was also included in the meta-analysis.

The samples were adults with different clinical and non-clinical characteristics. Five studies included samples with different forms of anxiety disorders (k=5, 21.7%).[22 23 33–35] Participants aged 19.8–58.1 years (M=34.12 years, SD=13.39), and the majority were female 71.7% (SD=19.1%). Three studies included a woman-only sample (k=3, 13.0%).[29 36 37]

For each study, one intervention and one control group were included. In two cases, multiple eligible intervention groups were reported (k=2, 8.7%),[38 39] which were pooled into one composite intervention group for the meta-analysis. Specifically, the 'do module' and the 'think module' in Bastiaansen *et al*[38] and the 'instructor-framed' and 'peer-framed messages' in Murphy *et al*[39] were merged. Control conditions included waitlist (k=6, 26.1%),[22 32 34 36 39 40] alternative interventions (k=9, 39.1%),[15 21 23 24 26 28 31 33 41] treatment as usual (TAU) (k=7, 30.4%)[25 27 29 30 37 38 42] and no-treatment (k=1, 4.3%).[35] Primary or secondary outcomes were extracted. Mental ill-being outcomes (depression, anxiety) were included from 15 studies (k=15, 65.2%),[4 21–24 26 31–38 40] and PWB outcomes from eight studies (k=8, 34.8%).[15 25 27–30 39 41]

A range of intervention techniques was used across the studies, with most app-based JITAIs and EMIs relying on cognitive behavioural therapy (CBT) (k=12, 52.2%).[21 22 24 28 31 32 34–37 40 42] Other interventions focused solely on mindfulness (k=4, 17.4%),[23 30 33 39] hope (k=1, 4.3%),[15] gratitude (k=1, 4.3%),[26] acceptance and commitment therapy (k=1, 6.7%),[41] or other self-management and feedback techniques (k=4, 17.4%).[25 27 29 38] The intervention period ranged from 1 week[21 24] to 6 months[27] (M=6.52 weeks, SD=5.93). Furthermore, interventions were categorised as JITAIs (k=8, 34.8%)[21 28 31 32 34 37 40 41] or EMIs, depending on their decision rules, which were central to determining study eligibility for the meta-analysis and ranged from simple EMI delivered at fixed time points[27] to highly adaptive interventions using AI algorithms to identify decision points based on real-time symptom tracking and user engagement data.[32] While most studies were classified as EMIs, the type of intervention and the underlying decision rules likely influenced the observed pooled effect sizes. Follow-up measurements were reported in nine studies (k=9, 39.1%)[22 23 29 31 33 35 36 38 40] and occurred between 1-month and 6-month follow-up (M=3.06 months, SD=2.21).

Potential sources of bias were systematically evaluated using the Cochrane RoB 2 tool, with detailed information provided in the online supplementary appendix 4. A summary is shown in table 1. 18 studies were rated as having 'some concerns' for bias (k=18, 73.3%),[21–24 26 27 29–33 35–39 41 42] four studies as having 'high risk' (k=4, 17.4%)[15 25 34 40] and one as having 'low risk' (k=1, 4.3%)[28] of bias. Most studies had a low risk of bias arising from the randomisation process; however, one study (k=1, 4.3%)[15] used a quasi-experimental design, resulting in high risk due to the absence of true randomisation at the individual level and increased susceptibility to confounding. Bias due to deviations from intended interventions was identified in all but four studies,[24 28 31 38] primarily related to adherence issues (k=19, 82.6%). High dropout rates were observed in three studies (k=3, 13.0%),[15 34 40] with many participants not completing post-intervention and follow-up assessments. Outcome measurement bias was low across all studies (k=23, 100%) because validated tools were used, despite the inability to blind self-reported outcomes. No evidence of selective reporting was found in any of the included studies. For all outcomes, funnel plots were visually inspected and found to be relatively symmetrical. With most studies centred at the top, this indicates no bias due to significant variability in smaller studies (online supplemental figure 4).

The between-subject analysis of 22 studies, one was excluded due to incomplete control group data,[22] found a small significant effect favouring interventions over controls (g=0.15, 95%

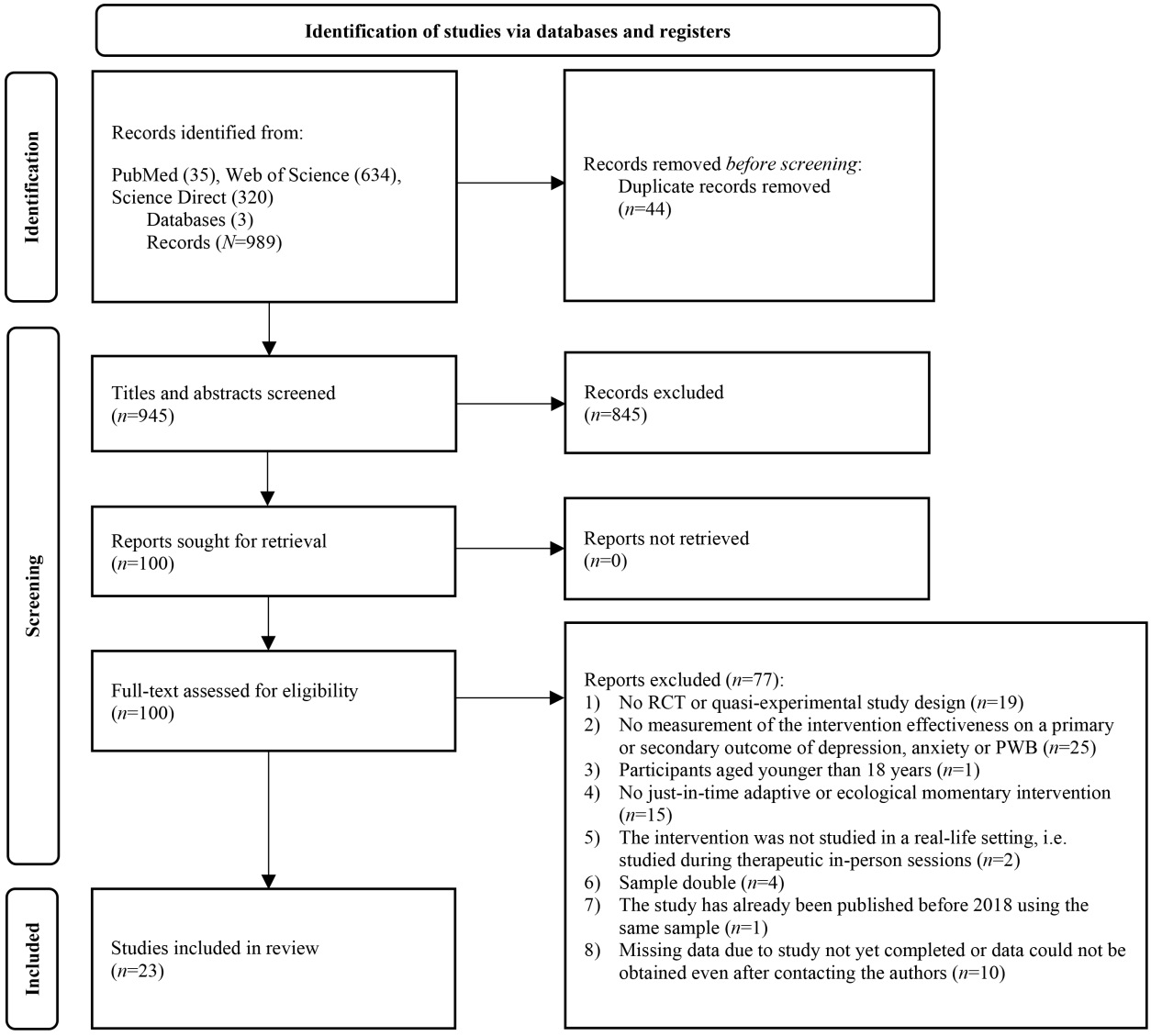


**Figure 1** PRISMA flow diagram for study inclusion Note: Preferred Reporting Items for Systematic Review and Meta-Analyses flow diagram of study selection and inclusion. PWB, psychological well-being; RCT, randomised controlled trial.

CI 0.05 to 0.26, p=0.003) with low variability among these studies ($\chi^2$=26.35, df=21, p=0.19; $I^2$=20%) (online supplemental figure 1). Sensitivity analysis excluding one outlier[34] still demonstrated a small but significant effect favouring the intervention groups (g=0.16, 95% CI 0.06 to 0.26, p=0.002) and little evidence of heterogeneity ($\chi^2$=24.60, df=20, p=0.22; $I^2$=19%) (online supplemental figure 2). Moderator analysis based on sensitivity-adjusted data showed significant effects only when comparing intervention groups to alternative intervention controls (g=0.16, 95% CI 0.03 to 0.29, p=0.01),[15 21 23 24 26 28 31 33 41] but not when comparing to TAU,[25 27 29 30 37 38 42] waitlist[32 36 39 40] and no treatment control groups.[35] However, no significant subgroup differences were found between the four control types ($\chi^2$=1.02, df=3, p=0.80; $I^2$=0%) (online supplemental figure 3). (RQ1)

Nine studies with follow-up assessments were analysed.[22 23 29 31 33 35 36 38 40] Only one study reported follow-up data at multiple time points, and we included the longest follow-up, which was at 6 months.[38] Four studies yielded a significant high pooled 1-month follow-up effect (g=0.92, 95% CI 0.30 to 1.53, p=0.003).[22 23 33 40] A moderate significant effect size was found at 3–6 month follow-up assessments from five studies (g=0.45, 95% CI 0.08 to 0.83, p=0.02).[29 31 35 36 38] Although the subgroup analysis showed moderate heterogeneity between the 1 month and 3–6 month follow-up periods ($\chi^2$=1.57, df=1, p=0.21; $I^2$=36.5%), the difference was not statistically significant, indicating no reliable variation in effect sizes across follow-up durations. The overall pooled follow-up effect was found to be moderate and significant (g=0.65, 95% CI 0.29 to 1.01, p<0.001), and indicates substantial heterogeneity ($\chi^2$=55.81, df=8, p<0.001; $I^2$=86%) (figure 2).

Moderator analysis showed that intervention periods lasting less than 6 weeks yielded a larger follow-up effect (g=0.71, 95% CI 0.18 to 1.24, p=0.008)[22 23 29 33 38 40] than those longer than 6 weeks (g=0.52, 95% CI 0.23 to 0.81, p<0.001).[31 35 36] Immediately at the end of the interventions, both shorter (g=0.35, 95% CI 0.09 to 0.61, p=0.008)[15 21–24 26 28–30 33 34 38 40] and longer intervention periods (g=0.41, 95% CI 0.25 to 0.56, p<0.001)[25 27 31 32 35–37 39 42] showed small-to-moderate effects (online supplemental table 3). (RQ2) To answer RQ3, subgroup analysis was performed to see whether JITAIs/EMIs differ in their effects on improving symptoms of mental illness

**Table 1** Summary of the risk-of-bias evaluation using the RoB 2 tool

| | D1* | D2† | D3‡ | D4§ | D5¶ | Overall |
|---|---|---|---|---|---|---|
| 01 Amo and Lieder, 2025[24] | L | L | S | L | L | S |
| 02 Bastiaansen *et al*, 2022[38] | L | L | S | L | L | S |
| 03 Bell *et al*, 2018[42] | L | S | S | L | L | S |
| 04 Dang *et al*, 2025[25] | L | H | L | L | L | H |
| 05 Daugherty *et al*, 2018[15] | H | S | H | L | L | H |
| 06 Everitt *et al*, 2021[40] | L | S | H | L | L | H |
| 07 Fuller *et al*, 2025[26] | L | S | S | L | L | S |
| 08 Kwon *et al*, 2024[27] | L | S | L | L | L | S |
| 09 Lee *et al*, 2025[28] | L | L | L | L | L | L |
| 10 Levin *et al*, 2019[41] | L | S | S | L | L | S |
| 11 Loo Gee *et al*, 2021[34] | L | S | H | L | L | H |
| 12 Marciniak *et al*, 2024[21] | L | S | L | L | L | S |
| 13 Merckaert *et al*, 2023[36] | L | S | S | L | L | S |
| 14 Murphy *et al*, 2021[39] | L | S | L | L | L | S |
| 15 Newman *et al*, 2021[35] | L | S | S | L | L | S |
| 16 Pang *et al*, 2025[29] | L | S | L | L | L | S |
| 17 Remskar *et al*, 2025[30] | L | S | L | L | L | S |
| 18 Saulnier *et al*, 2024[22] | L | S | L | L | L | S |
| 19 Shin *et al*, 2024[31] | L | L | S | L | L | S |
| 20 Springer *et al*, 2024[32] | L | S | S | L | L | S |
| 21 Suharwardy *et al*, 2023[37] | L | S | L | L | L | S |
| 22 Zainal & Newman, 2023[33] | L | S | S | L | L | S |
| 23 Zainal *et al*, 2024[23] | L | S | S | L | L | S |

Note: Summary table of risk of bias assessment per domain and per study. The judgement 'L'=low risk of bias indicates minimal risk; 'S'=some concerns for bias indicates potential but non-severe weaknesses; and 'H'=high risk of bias indicates serious methodological flaws likely to bias results. A study was rated 'low risk' if it was well designed and conducted, with no or minimal evidence of bias. 'Some concerns' indicate potential but not serious weaknesses in one or more domains. 'High risk' was assigned when serious methodological flaws were present that could materially bias results. These include major deviations from research standards such as lack of randomisation or unconcealed allocation.
*D1: Bias arising from the randomisation process.
†D2: Bias due to deviations from intended interventions.
‡D3: Bias due to missing outcome data.
§D4: Bias in measurement of the outcome.
¶D5: Bias in selection of the reported result.

compared with PWB. This analysis was conducted based on the between-group analysis with one outlier[34] excluded. The interventions' pooled effect was not significant on PWB (g=0.03, 95% CI −0.19 to 0.25, p=0.80),[15 25 27–30 39 41] but significant for improving mental illness (g=0.21, 95% CI 0.10 to 0.31, p<0.001)[21 23 24 26 31–33 35–38 40 42] (figure 3). The test for subgroup differences indicated moderate heterogeneity between PWB and mental illness outcomes, although this difference was not statistically significant ($\chi^2$=2.10, df=1, p=0.15; $I^2$=52.4%). (RQ3)

## CONCLUSIONS AND CLINICAL IMPLICATIONS

This systematic review and meta-analysis evaluates the short-term and long-term effectiveness of JITAIs and EMIs for improving mental health and PWB across 23 studies (2018–May 2025). Findings show small benefits compared with control conditions (g=0.15), supporting their potential as accessible mental health tools. The effects varied by control group, with significant effects only for comparisons to alternative interventions (g=0.16), emphasising the need for careful selection of control conditions to ensure robust conclusions and mitigate placebo effects.[4 11 43] Follow-up analyses showed strong effects at intervals of 1 month (g=0.92) and moderate benefits at 3–6 months (g=0.45). Although both short (<6 weeks) and longer (≥6 weeks) intervention periods produced comparable post-intervention effects, the shorter interventions seemed to produce the strongest pooled follow-up effect (g=0.71). These findings point to the potential of brief, well-timed JITAIs/EMIs to yield durable outcomes. However, extended engagement may be critical for embedding coping strategies and promoting durable behavioural change—supporting calls for gradual disengagement models[44] that facilitate habit formation.[45] While previous reviews (eg, Lu and colleagues[10]) reported diminishing effects over time, our findings suggest that current JITAIs/EMIs—particularly those with complex, adaptive decision rules—may offer greater ecological validity and longer-lasting impact. Subgroup analysis revealed significant improvements only for symptom reduction (ie, depression, anxiety) and not for PWB. This trend reflects

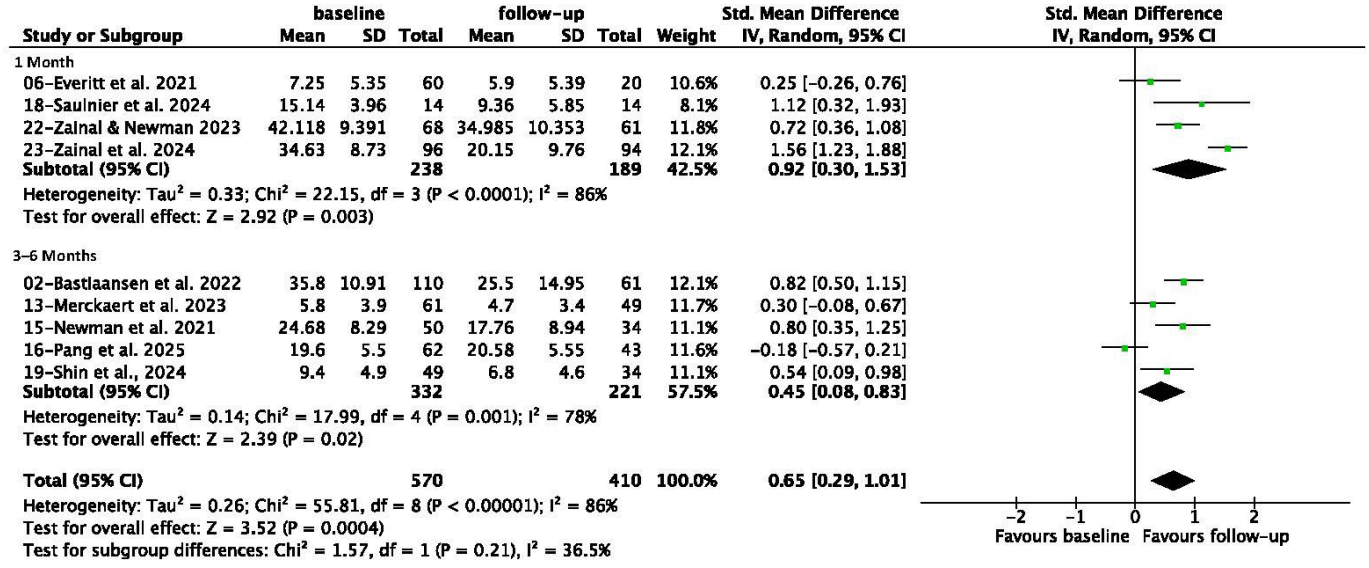


**Figure 2** Follow-up effects at 1 month vs 3–6 months. Note: Forest plot for baseline to follow-up comparison in the intervention group. A subgroup analysis compared effects at 1 month follow-up and 3–6 month follow-up, k=9.

earlier meta-analyses and suggests a need for refined components that more directly enhance positive PWB.[12] A continued lack of standardised PWB measures remains a concern,[4 12] potentially limiting effect detection. Importantly, decision rules were central to implementing the degree of adaptation within the interventions, determining when and what kind of support to deliver. As such, they may constitute a critical mechanism driving intervention effectiveness and should be a focus in future research to guide the optimisation of digital mental health designs. Beyond decision rules, JITIAs/EMIs operate through diverse mechanisms such as prompting self-regulatory strategies, mood tracking to enhance emotional awareness and reinforcement learning via contingent feedback. Future trials and meta-analyses should clarify which design features (eg, timing, tailoring and intensity) are subject to these mechanisms. A detailed summary of the findings is presented in table 2.

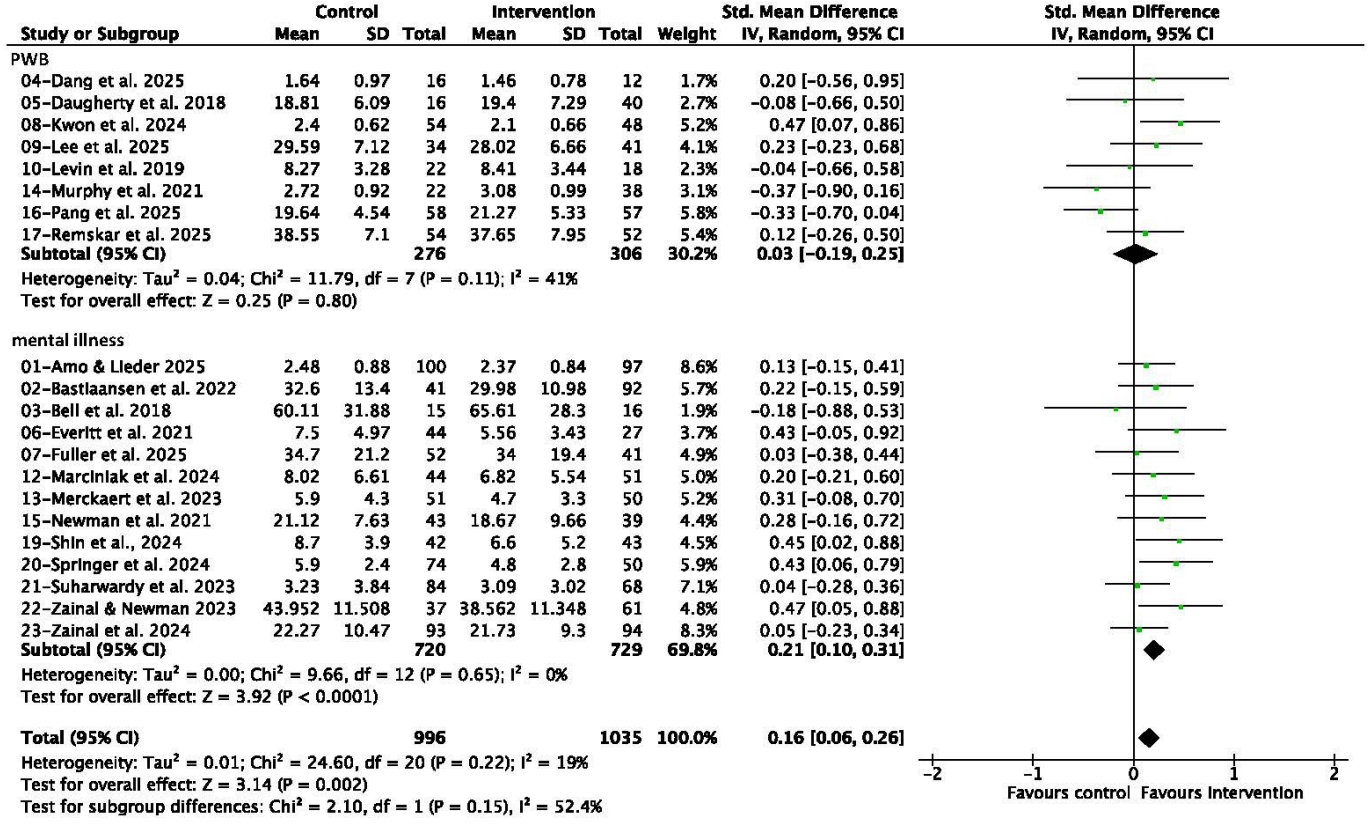


**Figure 3** Effectiveness for psychological well-being (PWB) versus symptoms of mental illness (between-group). Note: Forest plot for a subgroup analysis comparing between-group effect sizes on PWB and symptoms of mental illness at post-intervention time; based on the sensitivity analysis with one outlier excluded, k=21.

**Table 2** GRADE certainty of the evidence summary

| Outcomes | Anticipated absolute effects* (95% CI) Difference | Number of participants(studies) | Certainty of the evidence (GRADE) | Comments |
|---|---|---|---|---|
| Effect of JITAIs/EMIs on mental health | SMD **0.15 higher** (0.05 higher to 0.26 higher) | 2045 (22 RCTs) | ⊕⊕◯◯Low*† | App-based JITAIs/EMIs probably improve mental health slightly. |
| Longevity of JITAI/EMI effects on mental health follow-up: range 1–6 months | SMD **0.65 higher** (0.29 higher to 1.01 higher) | 980 (9 RCTs) | ⊕⊕⊕◯Moderate*†‡§ | The positive effects of JITAIs/EMIs on mental health probably persist throughout follow-up periods up to 6 months. |
| Duration-dependent follow-up effect, <6 weeks intervention period | SMD **0.71 higher** (0.18 higher to 1.24 higher) | 703 (6 RCTs) | ⊕⊕◯◯Low*‡§ | The evidence suggests that short intervention periods of less than 6 weeks can improve mental health in the long term. |
| Duration-dependent follow-up effect, ≥6 weeks intervention period | SMD **0.52 higher** (0.23 higher to 0.81 higher) | 277 (3 RCTs) | ⊕⊕⊕◯Moderate* | The evidence suggests that long intervention periods of 6 weeks or more can improve mental health in the long term. |
| Effect of JITAIs/EMIs on improving psychological well-being | SMD **0.03 higher** (0.19 lower to 0.25 higher) | 582 (8 RCTs) | ⊕◯◯◯Very low*†¶ | App-based JITAIs/EMIs probably do not improve psychological well-being. |
| Effect of JITAIs/EMIs on improving symptoms of mental illness | SMD **0.21 higher** (0.1 higher to 0.31 higher) | 1449 (13 RCTs) | ⊕⊕⊕◯Moderate* | App-based JITAIs/EMIs probably improve symptoms of mental illness slightly. |

Note: Summary of the certainty of evidence for all main outcomes. The Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach was followed using GRADEpro GDT software.
*Most of the studies showed some concerns for bias, with four studies being at high risk of bias, due to deviations from the intended interventions and missing outcome data.
†Wide confidence interval might not be due to heterogeneity.
‡Visual inconsistency and statistical analyses also showing heterogeneity.
§Wide confidence interval likely due to high heterogeneity.
¶Wide confidence interval likely due to heterogeneity. There was heterogeneity in outcome measurement, a range of different scales were used across the studies to measure different dimensions of psychological well-being.
EMIs, ecological momentary interventions; JITAIs, just-in-time adaptive interventions; RCT, randomised controlled trial.

To advance understanding of digital mental health interventions, we adopted a holistic approach, targeting both mental illness and PWB—an approach previously employed by only one other meta-analysis.[12] The analysis of potential moderators, including intervention period and control condition type, offers valuable information for optimising intervention design and implementation. Incorporating diverse samples and real-world settings enhances the generalisability of findings, making them more applicable across populations. We also sought to address the paucity of meta-analytic evidence on the benefits of JITAIs in producing long-lasting behavioural change. Despite these strengths, some limitations remain. First, unclear terminology between JITAIs and EMIs made it difficult to identify eligible studies, as EMIs were included despite the more advanced nature and clear framework of JITAIs. This highlights the need for clearer definitions and more focused research. Hence, the JITAIs/EMIs synthesised in this meta-analysis vary in their goals, targets and adaptive designs, limiting the interpretability of pooled effects. Accordingly, our findings reflect the effectiveness of current implementations rather than their full potential if optimised, for example, through clinical co-design. Second, study biases arose from high dropout rates and deviations from intended interventions, potentially affecting true effect sizes. Although funnel plot analysis found no publication bias, excluding grey literature may have underestimated less favourable results. Third, self-report bias remains an inherent limitation in mental health research; however, the use of validated measures across all studies likely mitigated this risk. Still, heterogeneity in outcome measures for PWB, depression and anxiety may have reduced consistency and affected comparability, especially in subgroup analyses. Fourth, included studies insufficiently reported how JITAIs were operationalised, particularly the decision rules for intervention delivery, reflecting broader challenges in standardising descriptions of these highly adaptive, increasingly AI-driven interventions. Although guiding frameworks exist for JITAI development,[8] many studies lack such specificity; for concrete examples of decision points and rules, we recommend the qualitative review by van Genugten *et al*.[46] Finally, five interventions included TAU alongside smartphone-based approaches, potentially influencing effects, though no major distortions were observed.

JITAIs and EMIs are scalable tools for mental health, with sustained benefits emerging from interventions lasting up to 6 weeks, particularly for anxiety and depression. However, modest differential effects on PWB versus mental illness outcomes—and variability in control group responses—suggest underexplored mechanisms as implied by similar meta-analyses.[4 11 47] To reduce trial heterogeneity and improve methodological robustness, future studies should implement standardised frameworks such as the Pragmatic Model for Comparator Selection[48] or Purpose-Guided Trial Design (PGTD).[49] Greater use of such frameworks can enhance conceptual clarity (eg, distinguishing JITAIs from EMIs) and reduce bias in future trials. A priori specification of intervention goals, mechanisms and comparators can help minimise bias introduced by deviations from intended interventions or missing outcome data, thereby improving the quality of pooled estimates in meta-analyses. Researchers should also systematically select active (eg, waitlist controls, alternative interventions) or passive controls (eg, TAU, no-treatment conditions) tailored to their hypotheses.[11] Next-generation mHealth interventions

could enhance long-term behaviour change by focusing on gradual disengagement and habit formation. Interventions might progressively reduce their frequency and intensity, encouraging users to adopt self-regulatory strategies and fostering sustainable PWB without creating dependency on the system. Embedding machine learning[50] and AI to predict long-term adherence decay—and deploying booster interventions during predicted 'critical inflection points'—holds transformative potential for prolonging therapeutic gains beyond the 6-month threshold, thereby bridging the gap between acute efficacy and long-term mental health resilience.

**Correction notice** This paper has been corrected since it was first published. A circle was missing in table 2, from the line '08 Kwon et al, 2024'.

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## REFERENCES

1 McGrath JJ, Al-Hamzawi A, Alonso J, *et al*. Age of onset and cumulative risk of mental disorders: a cross-national analysis of population surveys from 29 countries. *Lancet Psychiatry* 2023;10:668–81.
2 World health organization. World mental health report: transforming mental health for all [online]. 2022. Available: https://www.who.int/publications/i/item/9789240049338 [Accessed 9 Jun 2024].
3 VanderWeele TJ, McNeely E, Koh HK. Reimagining Health-Flourishing. *JAMA* 2019;321:1667–8.
4 Carr A, Cullen K, Keeney C, *et al*. Effectiveness of positive psychology interventions: a systematic review and meta-analysis. *J Posit Psychol* 2021;16:749–69.
5 Ryff CD, Singer B. Psychological well-being: meaning, measurement, and implications for psychotherapy research. *Psychother Psychosom* 1996;65:14–23.
6 Wang L, Miller LC. Just-in-the-Moment Adaptive Interventions (JITAI): A Meta-Analytical Review. *Health Commun* 2020;35:1531–44.
7 Ong NY, Teo FJJ, Ee JZY, *et al*. Effectiveness of mindfulness-based interventions on the well-being of healthcare workers: a systematic review and meta-analysis. *Gen Psych* 2024;37:e101115.
8 Nahum-Shani I, Smith SN, Spring BJ, *et al*. Just-in-Time Adaptive Interventions (JITAIs) in Mobile Health: Key Components and Design Principles for Ongoing Health Behavior Support. *Ann Behav Med* 2018;52:446–62.
9 Heron KE, Smyth JM. Ecological momentary interventions: incorporating mobile technology into psychosocial and health behaviour treatments. *Br J Health Psychol* 2010;15:1–39.
10 Lu S-C, Xu M, Wang M, *et al*. Effectiveness and Minimum Effective Dose of App-Based Mobile Health Interventions for Anxiety and Depression Symptom Reduction: Systematic Review and Meta-Analysis. *JMIR Ment Health* 2022;9:e39454.
11 Kraiss J, Redelinghuys K, Weiss LA. The effects of psychological interventions on well-being measured with the Mental Health Continuum: a meta-analysis. *J Happiness Stud* 2022;23:3655–89.
12 Versluis A, Verkuil B, Spinhoven P, *et al*. Changing Mental Health and Positive Psychological Well-Being Using Ecological Momentary Interventions: A Systematic Review and Meta-analysis. *J Med Internet Res* 2016;18:e152.
13 Stern C, Jordan Z, McArthur A. Developing the review question and inclusion criteria. *Am J Nurs* 2014;114:53–6.
14 Page MJ, Moher D, Bossuyt PM, *et al*. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ* 2021;372:n160.
15 Daugherty DA, Runyan JD, Steenbergh TA, *et al*. Smartphone delivery of a hope intervention: Another way to flourish. *PLoS ONE* 2018;13:e0197930.
16 Borenstein M, Hedges LV, Higgins JPT, *et al*. *Introduction to Meta-analysis*. 1st edn. Chichester: Wiley, 2009.
17 Sterne JAC, Savović J, Page MJ, *et al*. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ* 2019;366:l4898.
18 Higgins JPT, Li T, Deeks JJ, *et al*. Choosing effect measures and computing estimates of effect. In: Higgins JPT, Chandler J, Thomas J, eds. *Cochrane handbook for systematic reviews of interventions*. 2nd edn. Hoboken, NJ: Wiley, 2019: 143–76.
19 Cohen J. A power primer. *Psychol Bull* 1992;112:155–9.
20 Higgins JPT, Thompson SG, Deeks JJ, *et al*. Measuring inconsistency in meta-analyses. *BMJ* 2003;327:557–60.
21 Marciniak MA, Shanahan L, Myin-Germeys I, *et al*. Imager-A mobile health mental imagery-based ecological momentary intervention targeting reward sensitivity: A randomized controlled trial. *Appl Psychol Health Well Being* 2024;16:576–96.
22 Saulnier KG, Koscinski B, Flynt S, *et al*. Brief observable anxiety sensitivity treatment: intervention development and a pilot randomized-controlled acceptability and feasibility trial to evaluate a brief intervention for anxiety sensitivity social concerns. *Cogn Behav Ther* 2024;53:190–206.
23 Zainal NH, Tan HH, Hong RY, *et al*. Is a brief mindfulness ecological momentary intervention more efficacious than a self-monitoring app for social anxiety disorder? A randomized controlled trial. *J Anxiety Disord* 2024;104:102858.
24 Amo V, Lieder F. Evaluating the Effectiveness of InsightApp for Anxiety, Valued Action, and Psychological Resilience: Longitudinal Randomized Controlled Trial. *JMIR Ment Health* 2025;12:e57201.
25 Dang TH, Wickramasinghe N, Jayaraman PP, *et al*. Digital Solution to Support Medication Adherence and Self-Management in Patients with Cancer (SAMSON): Pilot Randomized Controlled Trial. *JMIR Form Res* 2025;9:e65302.
26 Fuller C, Marin-Dragu S, Iyer RS, *et al*. A Mobile App-Based Gratitude Intervention's Effect on Mental Well-Being in University Students: Randomized Controlled Trial. *JMIR Mhealth Uhealth* 2025;13:e53850.
27 Kwon OY, Lee MK, Lee HW, *et al*. Mobile App-Based Lifestyle Coaching Intervention for Patients With Nonalcoholic Fatty Liver Disease: Randomized Controlled Trial. *J Med Internet Res* 2024;26:e49839.
28 Lee S, Jeong J, Kim M, *et al*. Development of a Mobile Intervention for Procrastination Augmented With a Semigenerative Chatbot for University Students: Pilot Randomized Controlled Trial. *JMIR Mhealth Uhealth* 2025;13:e53133.
29 Pang Y, He H, Ng R-P, *et al*. Effectiveness of an Innovative Mobile-Based Perioperative Care Program for Women Undergoing Breast Cancer Surgery (iCareBreast): Randomized Controlled Trial. *J Med Internet Res* 2025;27:e71684.
30 Remskar M, Ainsworth B, Maynard OM, *et al*. Getting active through mindfulness: Randomised controlled trial of a digital mindfulness-based intervention promoting physical activity engagement and enjoyment. *Ment Health Phys Act* 2025;28:100680.

31 Shin J, Kim S, Lee J, *et al*. Efficacy of Mobile App-Based Cognitive Behavioral Therapy for Insomnia: Multicenter, Single-Blind Randomized Clinical Trial. *J Med Internet Res* 2024;26:e50555.
32 Springer F, Maier A, Friedrich M, *et al*. Digital Therapeutic (Mika) Targeting Distress in Patients With Cancer: Results From a Nationwide Waitlist Randomized Controlled Trial. *J Med Internet Res* 2024;26:e51949.
33 Zainal NH, Newman MG. A randomized controlled trial of a 14-day mindfulness ecological momentary intervention (MEMI) for generalized anxiety disorder. *Eur Psychiatry* 2023;66:e12.
34 Loo Gee B, Batterham PJ, Gulliver A, *et al*. An Ecological Momentary Intervention for people with social anxiety: A descriptive case study. *Inform Health Soc Care* 2021;46:370–98.
35 Newman MG, Jacobson NC, Rackoff GN, *et al*. A randomized controlled trial of a smartphone-based application for the treatment of anxiety. *Psychother Res* 2021;31:443–54.
36 Merckaert I, Waroquier P, Caillier M, *et al*. Improving emotion regulation in breast cancer patients in the early survivorship period: Efficacy of a brief ecologically boosted group intervention. *Psychooncology* 2023;32:597–609.
37 Suharwardy S, Ramachandran M, Leonard SA, *et al*. Feasibility and impact of a mental health chatbot on postpartum mental health: a randomized controlled trial. *AJOG Glob Rep* 2023;3:100165.
38 Bastiaansen JA, Ornée DA, Meurs M, *et al*. An evaluation of the efficacy of two add-on ecological momentary intervention modules for depression in a pragmatic randomized controlled trial (ZELF-i). *Psychol Med* 2022;52:2731–40.
39 Murphy KM, Burns J, Victorson D. Consider the Source: Examining Attrition Rates, Response Rates, and Preliminary Effects of eHealth Mindfulness Messages and Delivery Framing in a Randomized Trial with Young Adult Cancer Survivors. *J Adolesc Young Adult Oncol* 2021;10:272–81.
40 Everitt N, Broadbent J, Richardson B, *et al*. Exploring the features of an app-based just-in-time intervention for depression. *J Affect Disord* 2021;291:279–87.
41 Levin ME, Haeger J, Cruz RA. Tailoring Acceptance and Commitment Therapy Skill Coaching in the Moment Through Smartphones: Results from a Randomized Controlled Trial. *Mindfulness (N Y)* 2019;10:689–99.
42 Bell IH, Fielding-Smith SF, Hayward M, *et al*. Smartphone-based ecological momentary assessment and intervention in a coping-focused intervention for hearing voices (SAVVy): study protocol for a pilot randomised controlled trial. *Trials* 2018;19:262.
43 Linardon J, Cuijpers P, Carlbring P, *et al*. The efficacy of app-supported smartphone interventions for mental health problems: a meta-analysis of randomized controlled trials. *World Psychiatry* 2019;18:325–36.
44 Park J, Lee U. Understanding Disengagement in Just-in-Time Mobile Health Interventions. *Proc ACM Interact Mob Wearable Ubiquitous Technol* 2023;7:1–27.
45 Lally P, van Jaarsveld CHM, Potts HWW, *et al*. How are habits formed: Modelling habit formation in the real world. *Euro J Social Psych* 2010;40:998–1009.
46 van Genugten CR, Thong MSY, van Ballegooijen W, *et al*. Beyond the current state of just-in-time adaptive interventions in mental health: a qualitative systematic review. *Front Digit Health* 2025;7:1460167.
47 Chakhssi F, Kraiss JT, Sommers-Spijkerman M, *et al*. The effect of positive psychology interventions on well-being and distress in clinical samples with psychiatric or somatic disorders: a systematic review and meta-analysis. *BMC Psychiatry* 2018;18:211.
48 Freedland KE, King AC, Ambrosius WT, *et al*. The selection of comparators for randomized controlled trials of health-related behavioral interventions: recommendations of an NIH expert panel. *J Clin Epidemiol* 2019;110:74–81.
49 Freedland KE. Purpose-guided trial design in health-related behavioral intervention research. *Health Psychol* 2020;39:539–48.
50 Kelly J, Gooding P, Pratt D, *et al*. Intelligent real-time therapy: harnessing the power of machine learning to optimise the delivery of momentary cognitive-behavioural interventions. *J Ment Health* 2012;21:404–14.