A Scoping Review of Micro-Randomised Trials on Mobile Mental Health Interventions: Common Practices and Emerging Developments

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Abstract

Background: Mobile mental health interventions show promise in reducing barriers to mental healthcare, with micro-randomised trials (MRTs) increasingly used to support their development by evaluating intervention component effects in real-time. This scoping review examines empirical MRTs on mobile mental health interventions, highlighting common practices and emerging developments to inform future research and intervention development.

Methods: A systematic search was conducted across multiple databases, including Web of Science, PsycINFO, PubMed, and ClinicalTrial.gov. Data on study and sample characteristics, MRT design choices, and study outcomes were extracted. Descriptive and narrative synthesis techniques were used to summarise the results.

Results: The literature search identified 13 studies targeting diverse populations and mental health outcomes, with most interventions delivered via smartphone applications. In most studies, intervention options were randomised at daily decision points using equal probabilities, with observations of context collected for exploratory moderation analyses. Some studies additionally used observations of context to personalise intervention content, assess participant availability for randomisation, or align intervention options with individual needs. Study outcomes showed immediate intervention effects that varied substantially depending on contextual factors.

Conclusion: MRTs have been applied to a range of early-stage mobile mental health interventions, primarily for exploratory purposes to map out effective intervention strategies. The adoption of more contextually adaptive MRT designs marks progress toward more precise intervention optimisation. Future research is expected to see greater integration of just-in-time adaptive interventions within MRTs.

Keywords: micro-randomised trial, mobile mental health interventions, MRT design choices, mental health outcomes.

A Scoping Review of Micro-Randomised Trials on Mobile Mental Health Interventions: Common Practices and Emerging Developments

Mental health refers to a state of well-being that enables individuals to cope with daily challenges, think critically, grow personally, and build meaningful connections. It is an essential component of overall health (WHO, 2022). However, achieving and maintaining good mental health remains a global challenge. One in eight people worldwide lives with a mental disorder, and this number is rapidly increasing (WHO, 2022). Mental disorders affect both individuals and societies, accounting for 16% of the global disease burden and an estimated annual economic cost of approximately US$ 5 trillion (Arias et al., 2022). Despite this substantial burden, mental healthcare remains inaccessible to many due to overwhelmed health systems. The treatment gap is significant, with 67% of individuals with depression in high-income countries and 92% in low-to-middle-income countries going untreated (Moitra et al. 2022). In addition to the limited availability of health services, barriers such as geographical and time constraints, high costs, and social stigma further exacerbate the treatment gap (Carbonell et al., 2020). Scalable and accessible mental healthcare solutions are therefore urgently needed to meet the growing demand for care and close the treatment gap.

Mobile Mental Health Interventions

The widespread use of mobile devices has created opportunities for expanding mental health services, with mobile mental health interventions (MMHIs) emerging as a particularly promising innovation. MMHIs are defined as interventions that utilise mobile technologies to deliver mental health support (Goldberg et al., 2022). They have several advantages such as minimising travel time and costs, offering flexibility to accommodate daily routines, and mitigating stigma through anonymity, thereby overcoming barriers inherent in traditional treatments (Carbonell et al., 2020; Koh et al., 2022; WHO, 2022). In recent years, a growing number of MMHIs have been developed to address diverse mental health needs, aiming for

both the prevention and treatment of mental health conditions. These interventions can be used as standalone treatments or together with traditional face-to-face therapy as part of blended care (Fairburn & Patel, 2017; Marshall et al., 2019; Weisel et al., 2019).

Advancing Research on MMHIs

The randomised controlled trial (RCT) is the established research design for evaluating the efficacy of MMHIs. In an RCT, individuals are randomised once at the start of the trial to either an intervention group or a control group, allowing researchers to assess the overall causal impact of an intervention package on outcomes (Hariton & Locascio, 2018). Meta-analyses of RCTs have shown that MMHIs yield small to moderate reductions in symptoms like depression, anxiety, and stress compared to active and inactive control groups (Goldberg et al., 2022; Lecomte et al., 2020; Linardon et al., 2020, Weisel et al., 2019; Zheng et al. 2023). Although these findings underscore the potential of MMHIs, their effects remain modest.

Researchers have therefore emphasised the need to explore more nuanced processes within MMHIs, such as how underlying intervention components like dose, timing, and delivery methods influence effectiveness (Weisel et al., 2019; Zheng et al., 2023). Meanwhile, advancements in mobile and sensor technology have enabled the development of increasingly sophisticated MMHIs, capable of dynamically adjusting interventions to real-time user data (Dugas et al., 2020; Huckvale et al., 2020; Leong & Chakraborty, 2023). While RCTs remain the gold standard for evaluating MMHIs, they have notable limitations in capturing the dynamic processes of these interventions, providing limited insights into the momentary effects of individual components and how these effects may vary across different contexts and user-specific characteristics (Klasnja et al., 2015; Walton et al., 2018).

Micro-Randomised Trial

The micro-randomised trial (MRT) is an innovative experimental design originating in behavioural science that overcomes the shortcomings of RCTs and supports both the development and optimisation of MMHIs (Qian et al., 2022). MRTs employ a factorial, within-subject design that repeatedly randomises each participant to different intervention options. This can also include the option of receiving no intervention. By assessing variables of interest shortly before and/or after each randomisation, MRTs enable researchers to examine (1) the immediate effects of intervention components, (2) how these effects change over the intervention period, and (3) how user-specific and contextual influence an intervention component's efficacy (Klasnja et al., 2015; Qian et al., 2022). MRTs contribute to theoretical understanding by systematically exploring which strategies work best and under what conditions (Carpenter et al., 2020; Klasnja et al., 2015). Their ability to capture real-time intervention effects in dynamic settings makes them particularly valuable for informing the construction of Just-in-Time Adaptive Interventions (JITAIs), which aim to provide "the right type/amount of support, at the right time, by adapting to an individual's changing internal and contextual state" (Nahum-Shani et al., 2017, p. 446).

Growth of MRT Research

MRTs have gained increasing attention in the field of MMHIs, with researchers examining its design principles, statistical considerations, and potential applications in methodological reviews, conceptual discussions, and case studies (Bidargaddi et al., 2020; Carpenter et al., 2020; Klasnja et al., 2015; Liu et al., 2023; Qian et al., 2022; Walton et al., 2018). The transition from conceptual exploration to empirical application is currently underway, with an increasing number of empirical MRT studies emerging in the field of MMHIs (e.g., Laure et al., 2023; Militello et al., 2022; Thomas et al., 2023). Despite increasing uptake of MRTs, the current status of their application to MMHIs remains unclear. A scoping review by Leong and Chakraborty (2023) represents the only available paper to date that has assessed the scope of

empirical MRT research in mobile health. However, its focus was limited to the measurement of participant engagement in MRTs, thereby excluding those studies that examined only health outcomes (Leong & Chakraborty, 2023). Furthermore, the review did not provide insights into methodological design decisions, leaving a gap in understanding how the MRT design is applied in MMHI research. Consequently, no comprehensive overview of empirical MRT research on MMHIs currently exists.

Design Choices in MRT Studies

The design choices made in MRTs can significantly impact a trial's ability to generate insights that meaningfully inform the development and optimisation of MMHIs. As the empirical application of MRTs continues to expand, examining how these methodological decisions have been implemented in existing studies can therefore help guide future research and intervention development (Qian et al., 2022). The key design features as defined by Qian et al. (2022) provide a valuable reference for understanding how MRTs may be designed in practice and serve as a guiding reference for the present paper.

Broadly, these design features encompass intervention components and options, randomisation probabilities, decision points, observations of context, and proximal and distal outcomes. *Intervention components* refer to distinct aspects of an intervention that are studied separately in an MRT, such as delivery, content, or timing of an intervention (Qian et al., 2022). *Intervention options* are different types of support within a given component. Each participant is repeatedly randomised to one of these options based on *randomisation probabilities*, which can either be equal or unequal (Qian et al., 2022). Randomisation to intervention options occurs at *decision points*, which are the moments in time at which an intervention decision can be made. The frequency and timing of decision points are determined by considerations of when intervention delivery is likely to be meaningful. Each intervention component can have its own set of decision points (Qian et al., 2022).

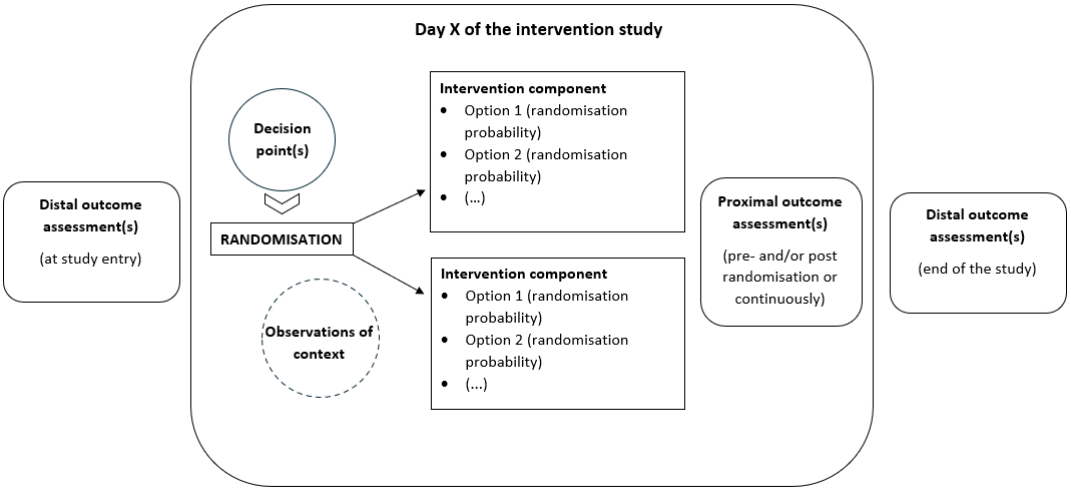
Next, *observations of context* refer to data gathered on an individual's current mood, activity levels, environmental conditions, or other behavioural indicators. These data can be used in multiple ways to support intervention adaptation. Firstly, observations of context can inform the personalisation of intervention content. For instance, personalised sleep feedback may be provided based on physiological data reflecting a participant's sleep patterns (Hornstein et al., 2023). Secondly, observations of context can be used in an exploratory manner to identify potential moderators of intervention effectiveness. Such moderators can help determine which intervention options are most effective and under what conditions. If moderation is found, the corresponding contextual variables may serve as tailoring variables in a future JITAI, meaning they are actively used to adapt the intervention. In the JITAI framework, decision rules refer to the specific set of rules that link tailoring variables to intervention options (Carpenter et al., 2020; Qian et al., 2022). Lastly, observations of context can also already be used as tailoring variables during the MRT itself to restrict randomisation times or the set of intervention options available in a given context (Qian et al., 2022).

Furthermore, *proximal outcomes* refer to the short-term effects an intervention option is intended to have. They serve as early indicators of whether the delivered option is having its desired effect. Common proximal assessment methods are ecological momentary assessments (EMA), which involve brief surveys completed by individuals in real-time (e.g., reporting their current mood), passive sensing methods, which monitor physiological or behavioural parameters (e.g., step count), and system-logged data, which track engagement-related behaviours (e.g., opening an app) (Klasnja et al., 2015). In contrast, *distal outcomes* represent the long-term goals of the intervention, commonly assessed with self-report questionnaires. By linking proximal outcomes as mediators to distal outcomes, MRTs enable researchers to understand not only the immediate impact of different intervention options but also how these short-term changes contribute to long-term improvement (Liu et al., 2023; Qian et al., 2022).

The interplay among the MRT features is further depicted in an analytical framework designed for this paper (Figure 1).

Figure 1

Analytical Framework of the MRT Design



Note. Observations of context are shown inside a *dashed* circle to reflect that they can be used in different ways within the MRT design. They may support exploratory analyses, such as identifying potential moderators without influencing other design features, or they may be directly embedded into the design to inform and shape elements such as intervention components, available options, or the randomisation scheme.

The Present Study

MRTs present a promising method for developing and optimising MMHIs. Yet, despite their growing empirical use, current implementation practices remain unclear. This scoping review aims to fill this gap by providing a comprehensive overview of empirical MRTs on MMHIs with three key objectives. Firstly, it will outline the studies based on publication and study details, target populations, and intervention characteristics. Secondly, it will systematically examine methodological design choices using the features outlined by Qian et al. (2022) and illustrated in the analytical framework (Figure 1). Lastly, it will explore the outcomes reported in these studies. Collectively, these objectives will provide an overview of

the current state and common practices in MRT research on MMHIs, highlight emerging developments, and offer insights to guide future research in this evolving field.

The research questions are as follows:

1. What are the study and sample characteristics of MRTs on MMHIs?
2. What design choices have been made in MRT studies on MMHIs?
3. What outcomes have been reported in MRT studies on MMHIs?

Methods

This scoping review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (Tricco et al., 2018).

Eligibility Criteria

Studies were included if they (1) used an MRT study design and (2) focused on MMHIs, defined as interventions that make use of mobile technologies (e.g., smartphones, wearables) to deliver mental health support. To obtain a complete overview of existing MRTs on MMHIs, both studies employing an MRT as the sole methodological approach and those incorporating an MRT within a broader research framework (e.g., as part of an RCT arm or combined with qualitative methods) were eligible. Pilot studies, secondary analyses, and both peer-reviewed and grey literature (e.g., dissertations, trial registers, preprints) were also considered to capture emerging research and mitigate publication bias (Aromataris & Riitano, 2014). Furthermore, studies examining MMHIs delivered either as standalone interventions or as blended treatments were eligible, whether provided entirely through technology or supplemented by human support. No restrictions were placed on participant demographics. Studies including clinical, sub-clinical, and non-clinical populations were eligible. Records written in English, regardless of publication year or country of origin, were included. Interventions targeting lifestyle-related health conditions (e.g., weight management, physical

activity) and addiction were excluded to maintain a manageable scope for comparison across studies. However, studies were included if mental health was the primary focus, even if they also addressed one of these conditions.

Information Sources and Search Strategy

To find relevant literature, the following databases were selected: Web of Science for its broad, interdisciplinary coverage, and PsycINFO and PubMed for their specific focus on psychology and biomedicine. The search was performed on July 28, 2024, using a search string that covered synonyms and terms associated with MRT and MMHI. The search strategy is based on a previous scoping review by Leong & Chakraborty (2023) and was further refined in accordance with this review's objectives. The search string was adjusted to match the formatting requirements of each database, and includes respective operators to search in titles, abstracts, and keywords. The final search strings for all databases can be found in Appendix A.

In addition to database searches, ClinicalTrials.gov was searched to identify unpublished studies relevant to the present research. The search was conducted on July 29, 2024 and the key terms "microrandomized", "microrandomised", "micro-randomised", "micro-randomized", "micro randomised", "micro randomized" were used. Furthermore, hand and citation searching were performed to identify other relevant sources. This included scanning the reference list from Leong & Chakraborty's (2023) review on MRTs for mHealth interventions, as well as reviewing the university's research repository.

Selection of Sources of Evidence

The final search results were exported into Covidence, a systematic review software supporting the screening process. After removing duplicates, the titles and abstracts of sources were screened for eligibility. In the next step, those meeting the criteria underwent a full-text screening, resulting in the final set of studies included in the scoping review. Although it is

suggested that at least two reviewers participate in the screening process, this was not manageable within the scope of this review (Smith et al., 2011). The screening process is illustrated in the PRISMA flow diagram (Figure 2).

Data Charting Process and Data Items

The data charting process began after identifying the final set of studies. To systematically gather and record information that corresponds with the review's questions, a data charting form was created in Microsoft Excel. A preliminary data charting form was first piloted with a small subset of the identified sources (~15%), to identify any issues or gaps and refine data items accordingly. This approach ensured that all relevant data required to answer the review questions was captured from the beginning (Tricco et al., 2018). Thereafter, the full data charting process was carried out by the author of this paper. The data charting form was continuously updated in an iterative process.

Data on study and sample characteristics (author, year, country of origin, primary/secondary analysis, document type, study status, study design, study aim, intervention target, type of mobile technology, delivery platform, population, clinical classification, age, gender), MRT design choices (MRT duration, sample size, frequency and timing of decision points, intervention components and options, randomisation probabilities, observations of context, proximal outcome assessments, distal outcome assessments), and study outcomes were extracted. An overview of all data items, along with a description of each item and details on how they were coded, can be found in Appendix B.

Synthesis of Results

The extracted data were summarised in tabular formats and supplemented by narrative text. The design features defined by Qian et al. (2022), along with the analytical framework presented in Figure 1, were used to synthesise MRT design choices. Descriptive analyses were conducted to illustrate frequency distributions.

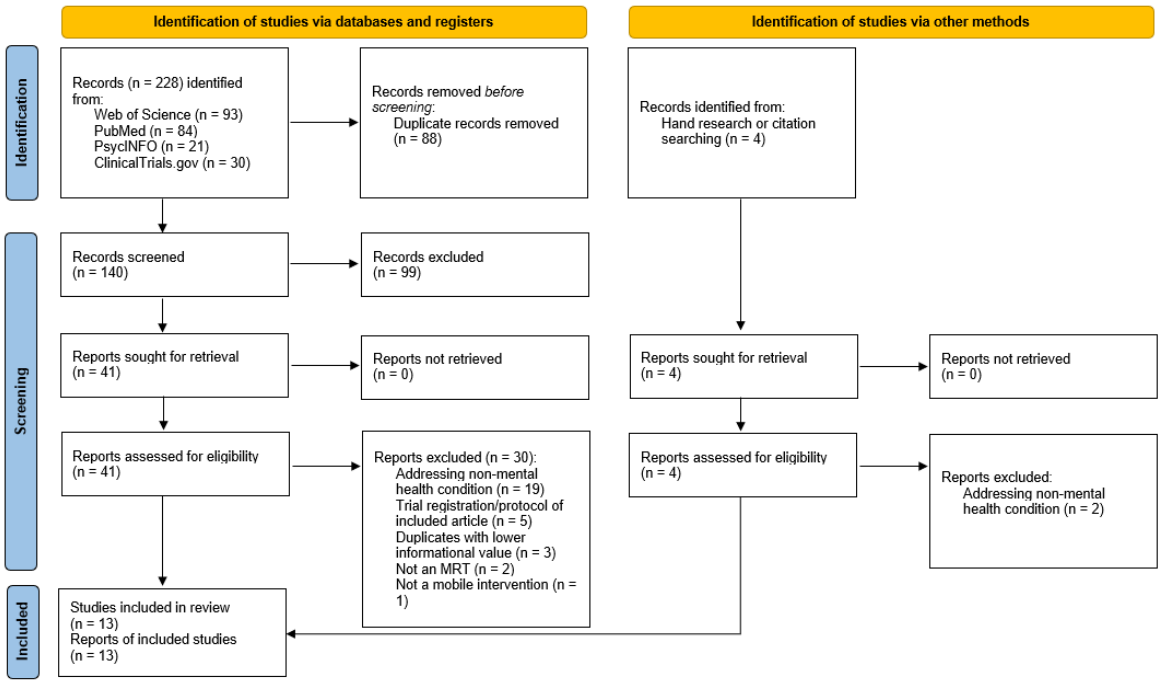
Results

Selection of Sources of Evidence

The database and register search initially yielded 228 sources. After duplicate removal, 140 sources remained for further screening. Title and abstract screening excluded 99 sources, leaving 41 for full-text screening, where 30 additional sources were excluded. This resulted in 11 sources from the database and register search. The hand and citation search added four more sources, of which two were included. In total, 13 sources were included in the scoping review. Figure 2 illustrates the study selection process.

Figure 2

Flow Diagram of the Study Selection Process



Research Question 1: Study and Sample Characteristics

Of the 13 sources included in this review, 10 used the MRT as the sole methodological approach. Three studies combined MRTs with additional methods. Accordingly, Laure et al.

(2023) incorporated user experience interviews to gain deeper insights into user engagement and mechanisms of change in MMHIs. Takeuchi et al. (2023) conducted prior observational research to identify the target population for the intervention, and Wang et al. (2023b) embedded an MRT within an RCT arm to evaluate the effectiveness of different intervention doses while maintaining the rigour of an RCT. With regard to document type, the sources were predominantly published journal articles (n = 8), with the remaining sources being trial protocols (n = 2), a trial registration, a doctoral dissertation, and a preprint. Ten of the studies had been completed, while three studies were still ongoing. The majority of studies were conducted in the United States (n = 9), while the others were conducted in either the Netherlands, Australia, or Japan. All included sources were dated between 2018 and 2024.

The intervention targets across the studies were diverse, ranging from broader constructs like general mental health promotion, quality of life enhancement, purposeful living, and stress management to more specific targets including fostering psychological flexibility, improving emotion regulation and mood, enhancing sleep, and preventing suicide. While most studies focused on non-clinical or sub-clinical populations (n = 11), including students, employees, caregivers, parents, or the general population, two studies specifically targeted clinical populations. Accordingly, Chocran et al. (2023) addressed individuals diagnosed with bipolar disorder and Bentley & Dempsey (2024) focused on adults hospitalised for suicidal thoughts or behaviours. Among all studies, students represented the most common population group (n = 5). Mean age was reported in five studies, with an average of 35.8 years. 69.71% of participants were female, while four studies did not report gender. Smartphones were the primary mobile technology used in all 13 studies, with five studies additionally utilising wearable devices. For instance, Takeuchi et al. (2023) used a wristband activity monitor to track participants' sleep behaviours, leveraging the data to provide real-time feedback on sleep patterns. Most interventions (n = 11) were delivered via mobile applications, while one

study utilised text messaging, and another employed a combination of phone calls, text messaging, and an application. Table 1 displays a summary of the study and sample characteristics.

Table 1
Study and Sample Characteristics

Author(s) (year)	Study design	Document type	Study status	Country	Intervention target	Population	Clinical classification	Mean age	Female %	Technology	Delivery platform
Arévalo Avalos et al. (2024) [a]	MRT	Journal article	Completed	United States	Mood improvement	Adults during the COVID-19 pandemic	Non-clinical	35.70	80.5%	Smartphone	Text messaging
Bidargaddi et al. (2018)	MRT	Journal article	Completed	Australia	Purposeful living	Office workers	Non-clinical	N/A [b]	63.97%	Smartphone	Smartphone application
Bentley & Dempsey (2024)	MRT	Trial registration	Ongoing	United States	Suicide prevention	Adults hospitalised for suicidal thoughts/ behaviours	Clinical	N/A	N/A	Smartphone	Phone call, text message, smartphone application
Chocran et al. (2023)	MRT	Journal article	Completed	United States	Psychological flexibility	Individuals with bipolar disorder	Clinical	42.70	60%	Smartphone & wearable	Smartphone application
Kraiss et al. (2024)	MRT	Trial protocol	Ongoing	Netherlands	Mental health promotion	Mildly distressed adults	Sub-clinical	N/A	N/A	Smartphone	Smartphone application
Latham (2020)	MRT	Dissertation	Completed	United States	Sleep improvement	Students with irregular sleep	Non-clinical	N/A	57%	Smartphone	Smartphone application
Laure et al. (2023)	MRT and interviews	Trial protocol	Ongoing	Netherlands	Emotion regulation	Students with mild-to-moderate mental health symptoms	Sub-clinical	N/A	N/A	Smartphone	Smartphone application
Militello et al. (2022)	(Pilot) MRT	Journal article	Completed	United States	Stress management	Parents of minors	Non-clinical	N/A	87.5%	Smartphone	Smartphone application

Author(s) (year)	Study design	Document type	Study status	Country	Intervention target	Population	Clinical classification	Mean age	Female %	Technology	Delivery platform
NeCamp et al. (2020)	MRT	Journal article	Completed	United States	Stress management	First-year medical residents	Non-clinical	N/A	55.91%	Smartphone & wearable	Smartphone application
Takeuchi et al. (2023)	Observa-tional study and MRT	Preprint	Completed	Japan	Sleep improvement	Employees	Non-clinical	N/A	N/A	Smartphone & wearable	Smartphone application
Thomas et al. (2023)	MRT	Journal article	Completed	United States	Psychological flexibility	First-generation college students reporting distress	Sub-clinical	18.53	85%	Smartphone	Smartphone application
Wang et al. (2023a)	(Cluster) MRT	Journal article	Completed	United States	Stress management	First-year medical residents	Non-clinical	27.6	54.5%	Smartphone & wearable	Smartphone application
Wang et al. (2023b)	RCT (including MRT)	Journal article	Completed	United States	Quality of life promotion	Caregivers of individuals with chronic illnesses	Non-clinical	54.4	78%	Smartphone & wearable	Smartphone application

[a]Only the second trial was included from this study.

[b]N/A: not available.

Research Question 2: MRT Design Choices

Table 2 displays the extracted data items for the MRT design choices. The duration of the MRT studies ranged from 16 days to 168 days, with an average of 54.77 days (*SD* = 41.87 days). The MRT sample sizes ranged from 10 to 1,779 participants, with an average of 421.85 participants (*SD* = 646.61) and a median of 72.0, indicating a right-skewed distribution.

Intervention Components and Options

Distinct intervention components were examined across the MRT studies, with the most common being intervention delivery, content, and timing. Seven studies manipulated two or more of these components simultaneously. The majority of studies (*n* = 12) focused on *intervention delivery*, which refers to whether or not to deliver an intervention (e.g., an exercise, message). For example, Bidargaddi et al. (2018) repeatedly randomised participants to either receive a tailored health message or no message. Similarly, Chocran et al. (2023) randomised participants to either receive an Acceptance and Commitment Therapy (ACT) intervention or no intervention. In addition to intervention delivery, variations in *intervention content* were investigated in five studies, where participants were repeatedly randomised to different types of content. To illustrate, Laure et al. (2023) randomised participants to receive one of four intervention exercises: an exercise targeting the upregulation of positive affect, mindfulness, cognitive defusion, relaxation and breathing, or self-compassion. All studies examining intervention content also investigated intervention delivery. Two studies examined intervention delivery and content within the same randomisation block. For example, Arévalo Avalos et al. (2024) randomised participants to receive either a behavioural activation advice, a coping advice, a social support advice, or no advice at all. Three studies separated the two components by first randomising each participant to either receive or not receive an intervention (intervention delivery) and then, if assigned to receive an intervention, further randomising each participant to a content option.

Moreover, three studies investigated *intervention timing* by randomising the delivery of interventions to different time points or windows. For instance, in the study by Arévalo Avalos et al. (2024), participants were randomised to either receive or not receive an intervention within one of three timeframes: 9 am-12 pm, 12 pm-3 pm, or 3 pm-6 pm. Other intervention components examined across the studies included the *delivery platform* (e.g., phone call, text message) as explored by Bentley & Dempsey (2024), *intervention sequence* as investigated by Kraiss et al. (2024), and competition variations (*opponent type*, *competition type*) studied by Wang et al. (2023a).

Randomisation Probabilities

Regarding randomisation probabilities, most studies used equal randomisation for component options, with each option assigned a probability of *1/n* (with *n* = number of intervention options for one component). However, two studies also employed unequal probabilities. For instance, Laure et al. (2023) randomised participants to either receive an intervention exercise with a 0.6 probability or receive a control exercise with a 0.4 probability. They selected this 60:40 ratio to ensure participants received the intervention more often than the control condition (Laure et al., 2023). Bentley & Dempsey (2024) did not report randomisation probabilities.

Decision Points

All MRT studies had at least one daily decision point. Most studies had one or two decision points per day (*n* = 10), while two had four, and one had six. NeCamp et al. (2020) and Wang et al. (2023a) incorporated an additional weekly decision point alongside the daily decision point. While the timing of decision points was rarely reported, the timing of intervention delivery was more commonly documented. Since intervention delivery typically occurs shortly after the decision point, some inferences about decision point timing can be made based on this information. Accordingly, seven studies allowed participants to define

their own preferred timeframes or time points for intervention delivery. For example, in the study by Thomas et al. (2023), participants set their typical wake and bedtimes at the start of the study, which were then used to establish the timeframes for intervention delivery. Two studies employed fixed decision points, occurring at predefined time points. In another three studies, timing of intervention delivery was randomised across different time points or timeframes. For instance, in the study by Arévalo Avalos et al. (2024), intervention delivery was randomised daily to occur within one of three timeframes (9 am-12 pm, 12 pm-3 pm, or 3 pm-6 pm). Two studies did not specify timing at all.

Observations of context

Of the 13 studies included in this review, 12 conducted exploratory moderation analyses. Most moderation analyses focused on the influence of time-related variables (n = 10), examining how factors such as day in study, time of day, and weekday versus weekend influenced intervention effects. Moderation analyses focusing on individual differences were conducted in seven studies, investigating demographics (n = 5), personality type, caregiver status, depression history, and sleep stability. Next, moderation analyses examining psychological states and behaviours were performed in seven studies, with six focusing on momentary affect and others investigating factors such as previous step count, sleep patterns, and well-being scores. Moderation analyses related to intervention characteristics and engagement were conducted in six studies. Among these, five studies examined differences in intervention content, while other assessments included prior engagement and the number of interventions engaged with.

Moreover, four studies personalised the content of messages based on user data and context. For instance, in the study by Wang et al. (2023b), messages were selected from a pool of over 400 options, tailoring the message choice based on each user's momentary sensor data (step count and sleep duration) and self-reported health-related quality of life

scores. Takeuchi et al. (2023) developed a system that tailored feedback messages by dynamically incorporating each participant's recent sleep data. The system calculated the relative sleep sufficiency by comparing the sleep hours from the previous night with the individual's baseline average. The feedback messages were adjusted based on the participant's sleep duration, providing negative feedback when the sleep hours were longer than usual and serving as an alert when they were shorter (Takeuchi et al., 2023).

Furthermore, Bentley & Dempsey (2024) used observations of context to adapt intervention options based on participants' momentary suicidal urge and intent, as measured through EMAs. At each decision point, participants were categorised into three momentary risk levels, which determined the randomisation of intervention options. Those identified as being in high-risk moments were randomised to receive a phone call, text message, or automated smartphone tool message. Participants in medium/low-risk moments were randomised to receive the automated tool message, non-interactive pop-up messages, or no intervention. Participants in no-risk moments received no intervention (Bentley & Dempsey, 2024).

Lastly, Bidargaddi et a. (2018) used observations of context for identifying appropriate timing for intervention delivery. They implemented an automated availability assessment with six daily decision points to classify users as available or unavailable for intervention delivery. Three decision rules were applied to determine availability: 1) users could only receive one intervention per day, making them unavailable for subsequent decision points that day, 2) users were considered unavailable before noon on weekends, and 3) users' availability was influenced by their longitudinal application engagement, with less active users being unavailable on more days. If unavailable, users advanced to the next of the six decision points, where their availability was reassessed (Bidargaddi et al., 2018).

Proximal and Distal Outcome Assessments

To assess proximal outcomes, studies collected data using EMAs, wearable devices, and system logs. EMAs were the most frequently used method (*n* = 12) and captured a range of psychological and behavioural constructs. These including mood and depressive symptoms (*n* = 10), anxiety (*n* = 2), sleep (*n* = 2), stress (*n* = 2), ACT-related outcomes (*n* = 3), emotion regulation strategies (*n* = 1), and suicidal thoughts (*n* =1). Additionally, EMAs assessed as engagement-related constructs (*n* = 4), such as safety plan use and engagement in mindfulness exercises.

Additionally, six studies utilised log data to objectively measure participants' engagement with the interventions. Wearable devices were used in four studies to collect physiological and activity data, including sleep (*n* = 4), step count (*n* = 3), and heart rate (*n* = 1). Distal outcomes were assessed in eight studies, with self-report questionnaires being the most common method (*n* = 7). Additionally, one study manually reviewed electronic health records, and another conducted phone interviews. A wide range of distal outcomes were assessed across the studies, including mental health symptoms such as depression, anxiety, and stress (*n* = 7), cognitive and psychological processes like psychological flexibility, emotion regulation, and reappraisal (*n* = 3), sleep-related outcomes (*n* = 2), and suicidal behaviours (*n* = 1).

Study Outcomes

Ten of the 13 MRT studies in this review reported study results. Seven studies documented positive short-term effects on proximal outcomes. For example, Arévalo Avalos et al. (2024) observed significant improvements in mood following intervention delivery, and both Bidargaddi et al. (2018) and Militello et al. (2022) reported that engagement increased with message delivery. However, these positive effects were not uniform across all proximal measures. For instance, Thomas et al. (2023) found that while values-based behaviour improved and depressive symptoms were reduced, there were no significant changes in

avoidance behaviour or perceived stress. Similarly, Wang et al. (2023a) reported that the team competition intervention increased daily step count but did not affect daily sleep minutes. Furthermore, five studies noted that these short-term effects tended to diminish over time. For example, mood improvements were strongest in the first two to three weeks (Arévalo Avalos et al., 2024), and effects of message delivery on engagement declined in later weeks (Bidargaddi et al., 2018).

Next, the results from four studies also highlighted several moderating effects. NeCamp et al. (2020) observed that notifications had a stronger impact on enhancing mood, step count, and sleep duration when participants had lower scores on these measures in the previous week. Wang et al. (2023b) found that message effects varied by caregiver group and were further moderated by prior depression levels. Arévalo Avalos et al. (2024) reported that intervention effects were most pronounced on weekends compared to weekdays, and Wang et al. (2023a) noted that competing against teams within the same institution weakened the beneficial impact on step count compared to competing against teams of a different institution. Lastly, not all interventions worked as intended, with one study by Chocran et al. (2023) even reporting harmful effects, where intervention delivery was associated with increased manic and depressive symptoms in individuals with bipolar disorder. The study outcomes are displayed in Table 2.

Table 2

MRT Design Choices and Study Outcomes

Author (year)	MRT duration	MRT sample size [a]	Intervention components, options, and randomisation probabilities	Decision points	Observations of context	Proximal outcome assessments	Distal outcome assessments	Study outcomes
Arévalo Avalos et al. (2024)	60 days	266	Intervention delivery & content: behavioural activation (0.25) vs. coping skills (0.25) vs. social support (0.25) vs. no message (0.25) Intervention timing: 9 am-12 pm (0.33) vs. 12 pm-3 pm (0.33) vs. 3 pm-6 pm (0.33)	One daily decision point; randomisation of timing	Moderation analyses: time of day, intervention content, day in study	Mood (EMA)	Depression, anxiety (questionnaire)	Mood improved, but no differences by message type/timing. Effects strongest in first 2-3 weeks.
Bidargaddi et al. (2018)	89 days	1255	Intervention delivery: tailored health message (0.5) vs. no message (0.5)	Six daily decision points; at fixed time points throughout the day	Availability tailoring that ensures timely and eligible message delivery (e.g., during weekends, users are marked as unavailable before noon). Content tailoring that personalises	Engagement (system logs)	N/A	Engagement increased with tailored messages but declined over time. Strongest on weekends.

Author (year)	MRT duration	MRT sample size [a]	Intervention components, options, and randomisation probabilities	Decision points	Observations of context	Proximal outcome assessments	Distal outcome assessments	Study outcomes
					messages based on user data and context. Moderation analyses: day in study, weekday vs. weekend, time of day			
Bentley & Dempsey (2024)	28 days	175	<u>Intervention delivery & delivery platform:</u> Phone call vs. text message vs. automated interactive smartphone tool message vs. non-interactive pop-up message vs. no intervention (N/A[b] randomisation probabilities <u>Intervention content:</u> recommendation to use entire safety plan vs. recommendation to use a specific component of safety plan (N/A	Four daily decision points; timing not specified	Intervention option tailoring to individuals' current level of suicidal thoughts and intent. Moderation analyses: affect, social support	Safety plan and coping strategy use, momentary suicidal urges and intent (EMA) Engagement (system logs)	Suicide attempt, hospital visit for suicidal thoughts or suicide-related behaviour (questionnaire) Suicide attempt (manual review of electronic health records)	N/A

Author (year)	MRT duration	MRT sample size [a]	Intervention components, options, and randomisation probabilities	Decision points	Observations of context	Proximal outcome assessments	Distal outcome assessments	Study outcomes
			randomisation probabilities)					
Chocran et al. (2023)	42 days	30	Intervention delivery: ACT intervention (0.5) vs. no ACT intervention (0.5)	Two daily decision points; user-specified timing of intervention delivery	Moderation analyses: day in study, momentary affect, demographics, intervention content	Values-based behaviour, avoidance behaviour, mood (EMA) Sleep, step count, heart rate (wearable)	Mood and health (phone interview)	Intervention delivery increased manic and depressive symptoms and had no significant effect on toward or away energy.
Kraiss et al. (2024)	16 days	72	Intervention timing: 8:30 am-10:30 am (0.5) vs. 12 pm-2 pm (0.5) vs. 3:30 pm-5:30 pm (0.5) vs. 7 pm-9 pm (0.5) (two of four options randomised) Intervention sequence: Sequence group 1 (0.5) vs. sequence group 2 (0.5)	Four daily decision points; randomisation of timing	Moderation analyses: demographics, number of completed EMIs, occurrence of stressful events, momentary affect, activity type, social context, location	Mood, emotion regulation strategies (EMA)	General symptoms, well-being, acceptance, rumination, reappraisal, savoring, gratitude, social functioning (questionnaire)	N/A

Author (year)	MRT duration	MRT sample size [a]	Intervention components, options, and randomisation probabilities	Decision points	Observations of context	Proximal outcome assessments	Distal outcome assessments	Study outcomes
Latham (2020)	28 days	34	Intervention delivery: Reminder (0.75) vs. no reminder (0.25) If randomised to receive reminder: Intervention content: reminder to set alarm (0.5) vs. reminder to use wake-up routine (0.5) Intervention timing: one hour before usual bedtime (0.5) vs. four hours before usual bedtime (0.5)	One daily decision point; user-specified timing of intervention delivery and randomisation of timing	Moderation analyses: time of day, day in study, weekday vs. weekend	Wake time variability, use of sleep hygiene techniques (EMA) Engagement (system logs)	Sleep, depression and anxiety symptoms, stress, wake time variability (questionnaire)	Neither the delivery of reminders nor their timing or content affected the use of wake-up techniques or the regularity of wake times.
Laure et al. (2023)	21 days	161	Intervention delivery: intervention exercise (0.6) vs. control exercise (0.4) If randomised to receive exercise: Intervention content: upregulation of positive affect (0.2)	Two daily decision points; user-specified timing of intervention delivery	Moderation analyses: Time of day, momentary affect, personality type, intervention content	Mood, thought believability and discomfort, engagement (EMA)	Emotion regulation, depression and anxiety symptoms, stress (questionnaire)	N/A

Author (year)	MRT duration	MRT sample size [a]	Intervention components, options, and randomisation probabilities	Decision points	Observations of context	Proximal outcome assessments	Distal outcome assessments	Study outcomes
			vs. mindfulness (0.2) vs. cognitive defusion (0.2) vs. relaxation and breathing (0.2) vs. self-compassion (0.2)			Engagement (system logs)		
Militello et al. (2022)	30 days	10	Intervention delivery: prompt to engage in mindfulness activity (0.5) vs. no prompt (0.5)	One daily decision point; user-specified timing of intervention delivery	N/A	Engagement, mood (EMA) Engagement (system logs)	N/A	Prompt delivery increased engagement with the app. While app use decreased, self-reported mindfulness increased over time.
NeCamp et al. (2020)	168 days	1565	Weekly: Intervention delivery & content: mood notifications (0.25) vs. sleep notifications (0.25) vs. activity notifications (0.25) vs. no notifications (0.25) Daily:	One daily decision point and one weekly decision point; user-specified timing of intervention delivery	Moderation analyses: previous week's mood, step count, sleep, day in study, demographics, depression history Content tailoring that personalises messages based on user data and context.	Mood (EMA) Sleep, step count (wearable)	N/A	Previous week's mood, step count, and sleep duration each negatively moderated the effects of corresponding notifications on mood, activity, and sleep.

Author (year)	MRT duration	MRT sample size [a]	Intervention components, options, and randomisation probabilities	Decision points	Observations of context	Proximal outcome assessments	Distal outcome assessments	Study outcomes
			Intervention delivery: notification (0.5) vs. no notification (0.5)					
Takeuchi et al. (2023)	14 days	67	Intervention delivery: personalised sleep feedback message (0.5) vs. no message (0.5)	One daily decision point; at fixed time point	Content tailoring that personalises messages based on previous night's sleep data. Moderation analyses: day in study, demographics, sleep stability	Sleep, depressive mood, anxiety (EMA) Sleep (wearable)	Sleep and mood (questionnaire)	Sleep feedback delivery prolonged sleep hours in unstable sleepers, and this effect lasted for up to 7 days. Sleep stability improved in the long term, but mood did not.
Thomas et al. (2023)	42 days	34	Intervention delivery: ACT intervention (0.5) vs. no ACT intervention (0.5)	Two daily decision point; user-specified timing of intervention delivery	Moderation analyses: time of day, day in study, prior depressive symptoms, prior engagement, demographics, intervention content	Values-based behaviour, avoidance behaviour, depressive symptoms, perceived stress (EMA)	Depression, stress, functioning, psychological flexibility (questionnaire)	Intervention delivery increased values-based behaviour but did not reduce avoidance behaviour. There was a reduction in depressive

Author (year)	MRT duration	MRT sample size [a]	Intervention components, options, and randomisation probabilities	Decision points	Observations of context	Proximal outcome assessments	Distal outcome assessments	Study outcomes
								symptoms, but no reduction in perceived stress.
Wang et al (2023a)	84 days	1779	Weekly: <u>Intervention delivery:</u> competition (0.5) vs. not competition (0.5) If randomised to competition: <u>Opponent type:</u> Opponent team randomised totally (0.33) vs. opponent team randomised within the same institution (0.33) vs. opponent team randomised within the same specialty (0.33) <u>Competition type:</u> compete on average step count (0.5) vs. compete on average sleep hours (0.5) Daily:	One daily decision point and one weekly decision point; user-specified timing of intervention delivery	Moderation analyses: day in study, intra-institutional competition, intra-speciality competition, device type, speciality	Mood (EMA) Step count, sleep (wearable) Engagement (system logs)	N/A	Competing on step count increased daily step count compared to the non-competition arm, but the intervention had no effect on sleep duration. The positive effect on step count declined over time. Competition against teams within the same institution negatively influenced effect of competition on step count.

Author (year)	MRT duration	MRT sample size [a]	Intervention components, options, and randomisation probabilities	Decision points	Observations of context	Proximal outcome assessments	Distal outcome assessments	Study outcomes
			Intervention delivery: push notification (0.5) vs. no push notification (0.5)					
Wang et al. (2023b)	90 days	36	Intervention delivery: personalised message (0.5) vs. no message (0.5)	One daily decision point; timing not specified	Moderation analyses: caregiver group, previous HRQOL[c] scores, day in study, previous step count and sleep duration Content tailoring that personalises messages based on user data and context.	HRQOL[c]: Caregiver strain, anxiety, depression (EMA)	N/A	Higher message frequency was significantly linked to reduced caregiver strain. Effects on anxiety and depression were inconsistent. Effect was moderated by caregiver group and previous week depression levels.

[a] This is the planned sample size for studies that are still ongoing.

[b] N/A: not available.

[c] HRQOL = health-related quality of life

Discussion

This scoping review aimed to provide a comprehensive overview of empirical MRT studies on MMHIs. By systematically examining study and sample characteristics, design choices, and outcomes, it sought to capture the state of the art in this rapidly evolving field, allowing for the identification of common practices and emerging developments. The literature search identified 13 studies involving diverse populations and addressing various mental health targets, with most interventions delivered via smartphone applications. It became evident that most studies randomised intervention components at daily decision points using equal probabilities. Observations of context were primarily conducted for exploratory moderation analyses, though some studies also used them to adapt intervention content, assess participant availability for randomisation, or align intervention options to participant needs. Moreover, study outcomes revealed immediate intervention effects that were highly context-dependent.

Study and Sample Characteristics

Empirical MRT research on MMHIs is still emerging, shown by the earliest study in this review dating back to 2018 and a clear increase in research from 2023 onward. A strong preference for using the MRT as the sole methodological approach was evident. However, the inclusion of qualitative interviews (Laure et al., 2023), an observational study (Takeuchi et al., 2023), or the embedding of the MRT within an RCT (Wang et al., 2023b) highlight the possibility of integrating MRTs with other research designs. Such combinations may yield complementary perspectives, with qualitative interviews, for example, shedding light on underlying reasons and mechanisms behind component effects observed in MRTs (O'Cathain et al., 2014). Currently, research on MRTs on MMHIs is largely concentrated in high-income countries, particularly the United States, reflecting WHO findings that mobile health programmes are most prevalent in these regions (WHO, 2016). This limits the generalisability of MRT findings to low- and middle-income countries. However, MMHIs have the potential

for significant impact in these underserved settings (McCool et al., 2022), making the expansion of MRT research to low-and middle-income countries a crucial area for future investigation, as MRTs can help test and optimise MMHIs to better align with the needs of these populations.

The growing integration of advanced mobile technology in MMHIs (Balaskas et al., 2021; Dugas et al., 2020; Huckvale et al., 2020) is reflected in this review's findings. All interventions were smartphone-based, with most using mobile applications as the primary delivery platform, and five studies incorporating wearable devices for more responsive, context-aware support (Balaskas et al., 2021). This technological shift appears driven by the potential of smartphone applications to offer instant communication, real-time monitoring, and user-friendly, multifunctional interfaces (Baños et al., 2022). However, Weisel et al. (2019) caution that despite these advantages, mental health applications also face challenges, including the difficulty of maintaining user engagement and concerns about data security, which future intervention developers must carefully address to ensure sustained usability and trust.

The studies included in this review addressed a range of mental health targets and included diverse populations, though most studies focused on non-clinical or sub-clinical groups. This trend may stem from ethical concerns, as MRTs tend to prioritise data collection for future intervention optimisation over immediate participant benefit (Liu et al., 2023). In clinical populations, where individuals require stable and continuous care, randomising the delivery of support may be ethically problematic if it leads to withholding an intervention at a time when an individual is in acute need of help (Bidargaddi et al, 2020). Therefore, non-clinical and sub-clinical populations provide a safer and more ethical setting for exploring intervention strategies, which may explain why most MRT studies in this review focused on these groups before potentially extending interventions to clinical populations. To make the

MRT design more ethical for clinical populations, Bidargaddi et al. (2020) recommend implementing symptom severity cut-off points that trigger direct clinical contact, ensuring that high-risk participants receive urgent professional support. This recommendation is reflected in the MRT design by Bentley & Dempsey (2024), which, for example, did not allow the intervention to be withheld from individuals at moments of high risk of suicidal urges and intent.

MRT Design Choices

The systematic analysis of MRT design features identified common MRT design choices across the studies which are summarised in Table 3.

Table 3

Common MRT Design Choices

MRT Design Features	Common MRT Design Choices
Intervention components and options	• Exploration of intervention delivery, content, and/or timing
Proximal and distal outcome assessments	• Use of EMAs to assess proximal outcomes • Frequent integration of wearable data and system logs for passive measurement
Randomisation probabilities	• Predominant use of equal randomisation probabilities
Decision points	• At least one daily decision point • Decision point timing was user-specified, pre-defined, or randomised
Observations of context	• Exploratory moderation analyses • Often used to personalise the content of messages based on user data and context

Common Practices in MRT Design

Selecting intervention components and options is a key decision in MRT design, which is directly linked to a study's research objectives. This review identified three primary components examined across MRT studies on MMHIs: intervention delivery (whether an intervention should be delivered or not), intervention content (which type of intervention

should be delivered), and intervention timing (when an intervention should be delivered). Such intervention components are also commonly examined in MRTs targeting physical activity (Klasnja et al., 2018; Klasnja et al., 2020) and addiction (Carpenter et al., 2020), highlighting the applicability of MRTs in advancing scientific understanding of these intervention mechanisms. To investigate the proximal effects of intervention components, a wide range of psychological, behavioural, and engagement-related constructs were assessed. Consistent with findings by Balaskas et al. (2021) and Leong & Chakraborty (2023), this review found that proximal outcomes were assessed actively using EMAs (n = 12) and passively using system logs (n = 6) and wearable devices (n = 4).

Across the studies, participants were repeatedly randomised to different component options at least once per day, most often using equal probabilities. While equal probabilities simplify the statistical analysis of intervention effects and ensure balanced data collection across component options, unequal probabilities may sometimes be preferable to reduce participant burden or prevent habituation (Qian et al., 2022), as applied in two studies included in this review. Generally, the likelihood assigned to each intervention option and the frequency of randomisation (decision points) directly affect the number of interventions delivered to a participant on average. This is an important consideration for shaping the user experience, as a higher frequency or increased likelihood of receiving an intervention can enhance engagement but may also risk overwhelming participants, while lower frequencies may reduce burden but limit potential benefits and the insights gained from the data (Qian et al., 2022). Across the studies, NeCamp et al. (2020) illustrate how these considerations inform design choices. In their study, participants were randomised once daily with a 50% chance to receive a notification, resulting in an average of 3.5 notifications a week. They considered this frequency optimal for promoting engagement and behaviour change while minimising the risk of treatment fatigue (NeCamp et al., 2020). Regarding decision point timing, a common

approach across the studies was participant-defined timing, allowing individuals to specify their preferred times for intervention delivery. This alignment with daily routines generally increases the likelihood of delivering an intervention when participants were most receptive (Bidargaddi et al., 2020).

Observations of context were commonly used for post-hoc exploratory moderation analyses (n = 12), highlighting researchers' recognition of the importance of understanding how psychosocial and contextual factors influence the short-term effects of intervention components over time. This is particularly important for developing MMHIs, as individuals may receive interventions in diverse situations, and some intervention options may be more effective than others depending on the context (Klasnja et al., 2015). Identifying which intervention option to offer, for whom, and at what time provides valuable insights into adapting intervention delivery, which can be translated into concrete decision rules within the JITAI framework (Qian et al., 2022). In addition to moderation analyses, observations of context were often used to personalise intervention content based on user data and context, such as by providing tailored sleep feedback messages (Takeuchi et al., 2023). Such personalisation strategy has been linked to increased user engagement and improved treatment outcomes (Hornstein et al., 2023).

Bringing together these common MRT design choices reveals that empirical research on MMHIs has largely followed an exploratory approach, in which intervention options were randomised using predefined probabilities to assess proximal effects, and observations of context were used to explore the influence of contextual and user-specific factors. This approach is particularly valuable in the early stages of intervention development, as it ensures balanced data collection across component options when their efficacy is still uncertain (Qian et al., 2022). As Liu et al. (2023) note, such *classical MRTs* focus primarily on post-data-collection optimisation, yielding valuable insights that inform the development of effective

decision rules for future intervention designs, although they do not offer immediate benefits to participants during the trial itself. This aligns with the observation that most studies included in this review targeted non-clinical populations, likely to avoid ethical concerns associated with withholding support from individuals in acute need. Overall, these findings indicate that current MRT research on MMHIs largely employs a bottom-up, exploratory strategy to map the conditions under which interventions are effective, thereby laying the groundwork for more targeted intervention optimisation in subsequent research. At the same time, such MRT data more fundamentally reveals how theoretical constructs from behavioural science vary across time and contexts, thereby supporting the development of dynamic theories (Klasnja, 2015).

Emerging Advancements in MRT Design

While most MRT studies on MMHIs were entirely exploratory, two studies in this review employed more contextually adaptive designs, signalling the potential of the MRT framework for more precise and responsive intervention optimisation. Bidargaddi et al. (2018), for instance, designed their MRT so that randomisation to component options occurred only in prespecified contexts, defined by decision rules. Unlike other studies in this review, where decision points triggered randomisation directly, this study incorporated an initial assessment to determine whether the current context was appropriate for randomisation. Bentley & Dempsey (2024) designed the MRT so that intervention options were adapted to participants' momentary level of suicidal urges and intent, ensuring alignment with the momentary risk status of this clinical population.

In both cases, the MRT design, particularly the use of observations of context, was aligned with the prespecified decision rules embedded in the JITAI, facilitating more precise and targeted intervention optimisation. However, Qian et al. (2022) caution that when contextual observations are used to limit the delivery of intervention options under certain

circumstances, the resulting MRT data can only inform the development of JITAIs that operate under those same constraints. Researchers should therefore carefully justify the implementation of decision rules that determine when and how randomisation occurs, as these rules directly influence how informative the findings will be for guiding future intervention development.

Study Outcomes

The MRTs provided valuable insights into the immediate effects of different intervention components, as well as how these effects change over the intervention period and vary according to user-specific and contextual factors. Although the outcomes were specific to each respective MMHI, certain common findings emerged. While not all interventions worked as intended, most MRTs demonstrated positive short-term effects of intervention delivery, underscoring the overall potential of such interventions. These effects often declined over time and showed considerable variation depending on contextual and user-specific factors, reflecting the dynamic setting in which MMHIs operate (Balaskas et al., 2021).

The study by NeCamp et al. (2020) exemplifies how such findings can directly inform the optimisation of intervention strategies. The authors found that the previous week's mood, step count, and sleep duration each negatively moderated the effects of corresponding notifications on mood, activity, and sleep, indicating that higher levels of these variables were associated with reduced intervention effects. Based on these results, they proposed specific design refinements, such as sending mood-related notifications only when the user's previous week's daily mood is below a score of 7 and not sending any when the score is 7 or higher. The authors planned to conduct a follow-up study to test new hypotheses informed by the findings of this trial (NeCamp et al., 2020).

More generally, it is important to acknowledge that MMHIs are optimised through an iterative process of continuous testing and refinement (Murray et al., 2016). In this process, a

single MRT study, just as the studies examined in this review, provides a snapshot of intervention efficacy under specific conditions and represents just one phase in the broader development cycle. By building on these insights in subsequent trials, researchers can progressively build more adaptive, personalised, and effective MMHIs. The final intervention package may ultimately be evaluated in an RCT to confirm its effectiveness and readiness for real-world implementation (Broder-Fingert et al., 2019).

Strengths and Limitations

This scoping review explored a novel and diverse research field. The broad search strategy on MRTs on MMHIs, including both peer-reviewed and grey literature, was a significant strength of this study as it allowed for a comprehensive coverage and exploration of all existing empirical MRT studies on MMHIs available to date. However, to maintain a manageable scope for comparison, interventions targeting lifestyle-related health conditions and addiction were excluded. It is important to acknowledge that MRTs have also been applied in these domains, and their exclusion omits valuable insights that could have contributed to a more nuanced understanding of MRT design and application. As no review on MRTs for lifestyle-related health conditions or addictions has been conducted to date, this presents a potential focus for future research.

To examine methodological design choices across the included MRT studies, the paper by Qian et al. (2022) was used as guidance. While this paper shares notable overlaps with other works on MRT design considerations, relying on a single source to structure the analysis of MRT design choices may have introduced bias and limited the scope of methodological perspectives considered. Yet, the absence of an established framework did not allow for alternative approaches. Developing a standardised MRT framework will be an important aim for future research, as this will help pinpoint key methodological considerations and provide structured guidance for prospective empirical MRT studies in defining and building their

study design. Consequently, it will also facilitate standardisation and enhance comparability across empirical MRT studies.

Some methodological limitations of this scoping review must be addressed. The screening, charting, and synthesis process was conducted by the single author of this paper. Ideally, at least two reviewers should have been involved to reduce the risk of selection and interpretation bias (Smith et al., 2011). Additionally, as a scoping review, this study did not assess the methodological quality of included studies, affecting the reliability of the findings. Thus, the results of this review should be interpreted as providing an overview to inform future MRT research, rather than as evidence-based conclusions.

Future Research

A key design consideration for future MRT studies is the decision to adopt either an entirely exploratory or more contextually adaptive MRT design. A helpful question to guide this decision might be: *"Is there already sufficient evidence to set meaningful decision rules that can improve intervention outcomes?"*. If the answer is yes, adopting a contextually adaptive design may be particularly valuable. This approach allows researchers to collect more targeted data, helping to fine-tune intervention delivery and pinpoint the most effective strategies. Yet, if the answer is no, an entirely exploratory approach may be the better choice to understand the broader decision space before moving on to more tailored, adaptive designs in subsequent trials (Liu et al., 2023). This approach might also be valuable to build more foundational, theoretical understanding. As part of the broader intervention development process, and with the growing number of optimisation trials, the integration of JITAIs within MRTs is expected to become increasingly prevalent in future research (Qian et al., 2022).

Conclusion

MRTs have been applied to a range of early-stage MMHIs, primarily for exploratory purposes to map out effective intervention strategies. The adoption of more contextually

adaptive MRT designs marks progress toward more precise intervention optimisation. Future research is expected to see greater integration of JITAIs within MRT studies. Researchers should carefully align MRT design choices with the study's research objectives, as these decisions directly influence the trial's ability to generate meaningful insights that can inform further intervention development.

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Appendices

Appendix A

Table A

Search Strings per Database

Search Strings per Database	
PsycINFO	((TI("mobile health interven*" OR "mhealth interven*" OR "m health interven*" OR "electronic health interven*" OR "ehealth interven*" OR "e health interven*" OR "mhealth technology" OR "just in time adaptive interven*" OR "jitai" OR "jitais" OR "sms interven*" OR "text messag* interven*" OR "mobile health" OR "mhealth" OR "m health" OR "electronic health" OR "ehealth" OR "e health" OR "mobile health app" OR "mobile health apps" OR "health app" OR "health app*" OR "mobile health application" OR "mobile health applications" OR "mhealth app" OR "mhealth apps" OR "mhealth application" OR "mhealth applications" OR "m health app" OR "digital health interven*" OR "digital interven*" OR "smartphone health interven*" OR "smartphone interven*" OR "wearable health interven*" OR "smartphone*" OR "mobile phone" OR "cell phone" OR "mobile app*" OR "iphone" OR "android" OR "mhealth" OR "m-health" OR "cellular phone" OR "mobile device*" OR "mobile-based" OR "mobile health" OR "tablet-based" OR "just-in-time adaptive" OR "just in time adaptive") OR AB("mobile health interven*" OR "mhealth interven*" OR "m health interven*" OR "electronic health interven*" OR "ehealth interven*" OR "e health interven*" OR "mhealth technology" OR "just in time adaptive interven*" OR "jitai" OR "jitais" OR "sms interven*" OR "text messag* interven*" OR "mobile health" OR "mhealth" OR "m health" OR "electronic health" OR "ehealth" OR "e health" OR "mobile health app" OR "mobile health apps" OR "health app" OR "health app*" OR "mobile health application" OR "mobile health applications" OR "mhealth app" OR "mhealth apps" OR "mhealth application" OR "mhealth applications" OR "m health app" OR "digital health interven*" OR "digital interven*" OR "smartphone health interven*" OR "smartphone interven*" OR "wearable health interven*" OR "smartphone*" OR "mobile phone" OR "cell phone" OR "mobile app*" OR "iphone" OR "android" OR "mhealth" OR "m-health" OR "cellular phone" OR "mobile device*" OR "mobile-based" OR "mobile health" OR "tablet-based" OR "just-in-time adaptive" OR "just in time adaptive") OR KW("mobile health interven*" OR "mhealth interven*" OR "m health interven*" OR "electronic health interven*" OR "ehealth interven*" OR "e health interven*" OR "mhealth technology" OR "just in time adaptive interven*" OR "jitai" OR "jitais" OR "sms interven*" OR "text messag* interven*" OR "mobile health" OR "mhealth" OR "m health" OR "electronic health" OR "ehealth" OR "e health" OR "mobile health app" OR "mobile health apps" OR "health app" OR "health app*" OR "mobile health application" OR "mobile health applications" OR "mhealth app" OR "mhealth apps" OR "mhealth application" OR "mhealth applications" OR "m health app" OR "digital health interven*" OR "digital interven*" OR "smartphone health interven*" OR "smartphone interven*" OR "wearable health interven*"

	OR "smartphone*" OR "mobile phone" OR "cell phone" OR "mobile app*" OR "iphone" OR "android" OR "mhealth" OR "m-health" OR "cellular phone" OR "mobile device*" OR "mobile-based" OR "mobile health" OR "tablet-based" OR "just-in-time adaptive" OR "just in time adaptive")) AND ((TI("micro random*" OR "microrandom*" OR "micro-random*" OR "micro random* trial" OR "micro random* trials" OR "microrandom* trial" OR "microrandom* trials" OR "micro-random* trial" OR "micro-random* trials" OR "MRT") OR AB((("micro random*" OR "microrandom*" OR "micro-random*" OR "micro random* trial" OR "micro random* trials" OR "microrandom* trial" OR "microrandom* trials" OR "micro-random* trial" OR "micro-random* trials" OR "MRT") OR KW((("micro random*" OR "microrandom*" OR "micro-random*" OR "micro random* trial" OR "micro random* trials" OR "microrandom* trial" OR "microrandom* trials" OR "micro-random* trial" OR "micro-random* trials" OR "MRT")
Web of Science	(TI=("mobile health interven*" OR "mhealth interven*" OR "m health interven*" OR "electronic health interven*" OR "ehealth interven*" OR "e health interven*" OR "mhealth technology" OR "just in time adaptive interven*" OR "jitai" OR "jitais" OR "sms interven*" OR "text messag* interven*" OR "mobile health" OR "mhealth" OR "m health" OR "electronic health" OR "ehealth" OR "e health" OR "mobile health app" OR "mobile health apps" OR "health app" OR "health app*" OR "mobile health application" OR "mobile health applications" OR "mhealth app" OR "mhealth apps" OR "mhealth application" OR "mhealth applications" OR "m health app" OR "digital health interven*" OR "digital interven*" OR "smartphone health interven*" OR "smartphone interven*" OR "wearable health interven*" OR "smartphone*" OR "mobile phone" OR "cell phone" OR "mobile app*" OR "iphone" OR "android" OR "mhealth" OR "m-health" OR "cellular phone" OR "mobile device*" OR "mobile-based" OR "tablet-based" OR "just-in-time adaptive" OR "just in time adaptive") OR AB=("mobile health interven*" OR "mhealth interven*" OR "m health interven*" OR "electronic health interven*" OR "ehealth interven*" OR "e health interven*" OR "mhealth technology" OR "just in time adaptive interven*" OR "jitai" OR "jitais" OR "sms interven*" OR "text messag* interven*" OR "mobile health" OR "mhealth" OR "m health" OR "electronic health" OR "ehealth" OR "e health" OR "mobile health app" OR "mobile health apps" OR "health app" OR "health app*" OR "mobile health application" OR "mobile health applications" OR "mhealth app" OR "mhealth apps" OR "mhealth application" OR "mhealth applications" OR "m health app" OR "digital health interven*" OR "digital interven*" OR "smartphone health interven*" OR "smartphone interven*" OR "wearable health interven*" OR "smartphone*" OR "mobile phone" OR "cell phone" OR "mobile app*" OR "iphone" OR "android" OR "mhealth" OR "m-health" OR "cellular phone" OR "mobile device*" OR "mobile-based" OR "tablet-based" OR "just-in-time adaptive" OR "just in time adaptive") OR AK=("mobile health interven*" OR "mhealth interven*" OR "m health interven*" OR "electronic health interven*" OR "ehealth interven*" OR "e health interven*" OR "mhealth technology" OR "just in time adaptive interven*" OR "jitai" OR "jitais" OR "sms interven*" OR "text messag*

	interven*" OR "mobile health" OR "mhealth" OR "m health" OR "electronic health" OR "ehealth" OR "e health" OR "mobile health app" OR "mobile health apps" OR "health app" OR "health app*" OR "mobile health application" OR "mobile health applications" OR "mhealth app" OR "mhealth apps" OR "mhealth application" OR "mhealth applications" OR "m health app" OR "digital health interven*" OR "digital interven*" OR "smartphone health interven*" OR "smartphone interven*" OR "wearable health interven*" OR "smartphone*" OR "mobile phone" OR "cell phone" OR "mobile app*" OR "iphone" OR "android" OR "mhealth" OR "m-health" OR "cellular phone" OR "mobile device*" OR "mobile-based" OR "tablet-based" OR "just-in-time adaptive" OR "just in time adaptive")) AND (TI=("micro random*" OR "microrandom*" OR "micro-random*" OR "micro random* trial" OR "micro random* trials" OR "microrandom* trial" OR "microrandom* trials" OR "micro-random* trial" OR "micro-random* trials" OR "MRT") OR AB=("micro random*" OR "microrandom*" OR "micro-random*" OR "micro random* trial" OR "micro random* trials" OR "microrandom* trial" OR "microrandom* trials" OR "micro-random* trial" OR "micro-random* trials" OR "MRT") OR AK=("micro random*" OR "microrandom*" OR "micro-random*" OR "micro random* trial" OR "micro random* trials" OR "microrandom* trial" OR "microrandom* trials" OR "micro-random* trial" OR "micro-random* trials" OR "MRT"))
Pubmed	("mobile health interven*"[Title/Abstract] OR "mhealth interven*"[Title/Abstract] OR "m health interven*"[Title/Abstract] OR "electronic health interven*"[Title/Abstract] OR "ehealth interven*"[Title/Abstract] OR "e health interven*"[Title/Abstract] OR "mhealth technology"[Title/Abstract] OR "just in time adaptive interven*"[Title/Abstract] OR "jitai"[Title/Abstract] OR "jitais"[Title/Abstract] OR "sms interven*"[Title/Abstract] OR "text messag* interven*"[Title/Abstract] OR "mobile health"[Title/Abstract] OR "mhealth"[Title/Abstract] OR "m health"[Title/Abstract] OR "electronic health"[Title/Abstract] OR "ehealth"[Title/Abstract] OR "e health"[Title/Abstract] OR "mobile health app"[Title/Abstract] OR "mobile health apps"[Title/Abstract] OR "health app"[Title/Abstract] OR "health app*"[Title/Abstract] OR "mobile health application"[Title/Abstract] OR "mobile health applications"[Title/Abstract] OR "mhealth app"[Title/Abstract] OR "mhealth apps"[Title/Abstract] OR "mhealth application"[Title/Abstract] OR "mhealth applications"[Title/Abstract] OR "m health app"[Title/Abstract] OR "digital health interven*"[Title/Abstract] OR "digital interven*"[Title/Abstract] OR "smartphone health interven*"[Title/Abstract] OR "smartphone interven*"[Title/Abstract] OR "wearable health interven*"[Title/Abstract] OR "smartphone*"[Title/Abstract] OR "mobile phone"[Title/Abstract] OR "cell phone"[Title/Abstract] OR "mobile app*"[Title/Abstract] OR "iphone"[Title/Abstract] OR "android"[Title/Abstract] OR "m-health"[Title/Abstract] OR "cellular phone"[Title/Abstract] OR "mobile device*"[Title/Abstract] OR "mobile-

	based"[Title/Abstract] OR "tablet-based"[Title/Abstract] OR "just-in-time adaptive"[Title/Abstract] OR "just in time adaptive"[Title/Abstract]) AND ("micro random*"[Title/Abstract] OR "microrandom*"[Title/Abstract] OR "micro-random*"[Title/Abstract] OR "micro random* trial"[Title/Abstract] OR "micro random* trials"[Title/Abstract] OR "microrandom* trial"[Title/Abstract] OR "microrandom* trials"[Title/Abstract] OR "micro-random* trial"[Title/Abstract] OR "micro-random* trials"[Title/Abstract] OR "MRT"[Title/Abstract])

Appendix B

Data Items and Description

Table B

Data Items and Description

Research Question	Data Item	Description
Study and sample characteristics	Author	The primary author of the paper
	Year	Year the study was published (for unpublished studies, the year of most recent updates)
	Study design	Type of study design
	Study aim	Primary reason for conducting the MRT
	Document type	The format in which the study is published (e.g., journal article, trial registration)
	Study status	Current phase of the study's process (ongoing, completed)
	Primary/secondary	Whether the study is a primary or secondary analysis
	Country	Country where the study was conducted
	Intervention target	Mental health area the intervention targets (e.g., stress management, mood improvement)
	Type of mobile technology	Mobile technology used to deliver the intervention (smartphone, wearable)
	Delivery platform	Platform on which intervention was delivered (e.g., application, text messaging)
	Population	Characteristic of participants included in the MRT study
	Clinical classification	Whether the sample was clinical (diagnosis), sub-clinical (elevated symptoms) or non-clinical
	Age (mean)	The average age of participants in the MRT study
	Gender	Gender distribution in percentages of female participants
MRT design choices	MRT sample size	The number of participants (intended to be) included in the MRT study
	MRT duration	The total length of time over which the MRT was conducted (in days)
	Frequency of decision point(s)	The regularity of moments of randomisation

	Timing of decision point(s)	The time points/windows at which randomisation occurs within the MRT
	Intervention components, options and randomisation	The distinct intervention components investigated, the options available for each component, and the randomisation probabilities assigned to these options at each decision point
	Randomisation probabilities	Whether randomisation probabilities are equal or unequal
	Observations of context	The aim of observing contextual data (moderation analyses and/or tailoring) and the contextual data gathered
	Proximal outcome assessments	The construct assessed to evaluate the short-term effect of an intervention component and the method/technology used to gather data
	Distal outcome assessments	The construct assessed to evaluate the long-term effects of an intervention and the method/technology used to gather data
Study outcomes	Outcomes	The primary results of the MRT study (linking to what is reported in the abstract)