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The Meditation App Revolution

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Abstract

Smartphone-based meditation training has jumped onto the world stage, shifting how millions of people learn and practice meditation. This review examines the rapid proliferation of meditation apps and synthesizes current scientific findings on their usage patterns, efficacy, mechanisms of action, and safety. Though research lags well behind public adoption, recent randomized controlled trials and meta-analyses reveal that app-based meditation interventions produce modest but consistent reductions in depression and anxiety. Initial mechanistic studies further suggest that improvements in worry, repetitive negative thinking, and self-reported mindfulness skills may underpin these effects, alongside early findings on blood pressure reduction and pro-inflammatory gene expression. This review describes some of the similarities and differences between meditation apps and traditional, in-person mindfulness programs. Meditation apps often differ in the relative absence of interpersonal support, briefer practice sessions, lower sustained engagement rates, and greater opportunities for personalization and large-scale data capture. We discuss opportunities based on these issues, including hybrid models that combine app-based content with human support, just-in-time interventions, and advanced trial designs that harness app analytics. With thoughtful development and rigorous evaluation, meditation apps have potential to expand the reach of evidence-based meditation training, offering a unique platform for advancing translational research on meditative practices.

Keywords

meditation; digital health; mindfulness; smartphone app; mental health

Over the past 50 years, significant scientific work has focused on understanding in-person meditation training interventions (Creswell, 2017; Goldberg, Riordan, et al., 2022). However, the past decade has witnessed the emergence of a new class of digital smartphone meditation training apps that have transformed both public engagement and scientific efforts. There are now thousands of meditation apps available worldwide, with millions of new users each year (data.ai, 2024; Singh, 2020). This app revolution offers a broad range of meditation techniques, most commonly mindfulness meditation training, but also focused

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attention, compassion, loving kindness, and other attention and emotion regulation training approaches. An emerging scientific literature on digital meditation apps is striving to catch up with these broader patterns. As shown in Figure 1, there's been significant growth in published meditation app intervention studies. This digital meditation app revolution presents both opportunities and challenges. Notably, significant differences exist between these digital tools and their in-person, group-based counterparts (Wasil et al., 2020), although important similarities exist as well. Here, we describe the landscape of meditation apps, discuss empirical evidence, explore challenges and opportunities for scientists, and suggest ways to advance a science of meditation interventions using these tools.

Meditation Apps Have Gone Mainstream

Meditation apps, such as Headspace and Calm, first entered the commercial market in 2011. These initial apps were not overnight successes; it took at least five years before they attracted large numbers of users, revenue, and investment. Between 2015 and 2020, over 2,500 meditation apps were launched, with many more health and fitness apps integrating mindfulness training elements into their platforms (Singh, 2020). This growth coincided with the expansion of other mental health-focused apps on the commercial market (e.g., apps for sleep, cognitive restructuring, exposure therapy). Within this broader mental health app space, meditation apps loom large. For example, a review found that while mindfulness meditation training was present in 37% of mental health apps, meditation apps—most notably Calm and Headspace—accounted for 96% of total active monthly users (Wasil et al., 2020).

For decades, meditation intervention science has utilized the in-person Transcendental Meditation (TM) program, the 8-week Mindfulness-Based Stress Reduction (MBSR), or Mindfulness Based Cognitive Therapy (MBCT) programs. While precise uptake within the general population is difficult to estimate, hundreds of thousands of individuals have enrolled in these programs worldwide since their inception. In contrast, the top 10 meditation apps have collectively reached over 300 million downloads (data.ai, 2024). To put this in context, participants who have signed up for these in-person programs over several decades is a fraction of who have downloaded meditation apps *in the past year*.

It's not just the sheer volume of users downloading digital meditation apps that is striking; there has also been a significant shift in how users practice meditation. While 8-week MBSR and MBCT participants practice on average about 30 minutes each day six days per week (Parsons et al., 2017), the average use of meditation apps among active users is 10–21 minutes of training 3 days per week (Baumel et al., 2019; Linardon, Messer, et al., 2024). This difference in practice frequency and duration has important implications for both the effectiveness of the interventions and the design of future research studies; it may also signal that individuals are using and being impacted by these digital tools in different ways than traditional in-person meditation interventions. While the dramatic number of people downloading meditation apps is noteworthy, equally significant are the statistics around sustained engagement. Only 4.7% of initial users continue to use digital meditation apps after 30 days, with some estimates suggesting that the average lifetime use of a meditation app is between 1–4 sessions (Baumel et al., 2019; Lam et al., 2023). Although

this 30-day engagement rate may seem low, analysis of objective usage data has highlighted that meditation apps are actually outperforming many other mental health apps in terms of sustained user engagement (Baumel et al., 2019). As we will discuss further, one of the principal goals of building a translational science of meditation apps is to better understand digital app engagement and to develop strategies to improve sustained engagement over time (Nahum-Shani et al., 2022).

Initial Randomized Controlled Trials of Meditation Apps: Efficacy, Mechanisms, and Safety

Efficacy

Worldwide adoption of meditation apps has certainly outpaced the available scientific evaluation of them, but there is nonetheless a rapidly growing body of research examining the efficacy, mechanisms of action, and safety. A recent meta-analysis identified 45 randomized controlled trials (RCTs) testing the effects of various meditation apps on depression and anxiety (Linardon, Messer, et al., 2024). Like some previous reviews (e.g., Gál et al., 2021), results indicated that meditation apps modestly reduce depression (Hedges' $g = 0.24$) and anxiety ($g = 0.28$) relative to control conditions, with fairly consistent results across studies (I^2s = 32% and 44%, respectively). Effects were similar when restricting to lower risk of bias studies and larger sample trials. Benefits of meditation apps were observed relative to active control conditions that were not necessarily intended to be therapeutic (e.g., listening to music, information resources). Meditation apps performed on par with other interventions that were intended to be therapeutic (e.g., behavioral activation app) in the small number of RCTs that included this comparison (ks = 3 and 4, for depression and anxiety, respectively). Results from the Linardon et al. (2023) meta-analysis are somewhat encouraging, showing that meditation apps modestly reduce depression (Hedges' g = 0.24) and anxiety (g = 0.28) relative to control conditions. These effects were consistent across studies and robust in analyses that limited to larger sample sizes and lower risk of bias trials. However, these findings should be considered in light of concerns that meta-analyses of RCTs may overestimate population-level effects (Nelson et al., 2018).

A growing number of large-scale RCTs (e.g., ns > 500) have begun to appear in the literature, made possible in part due to the ease with which digital meditation training can be delivered. Results from these studies suggest that apps can be scaled up to larger samples and still improve outcomes. For example, a study examining Headspace (n = 994) found reductions in distress relative to a waitlist control (d = 0.61) and a relaxation control group (d = 0.32) among participants with compulsive internet use (Quinones & Griffiths, 2019). In a study using the Calm app (n = 1029) (Huberty et al., 2022), those receiving the app showed significantly reduced depressive and anxiety symptoms (ds = 0.32 to 0.23, respectively) and improved insomnia symptoms (d = 0.94), relative to a waitlist control group. Likewise, the Healthy Minds Program (HMP) app (n = 662) showed moderate reductions (d = 0.53) in psychological distress (composite of depression, anxiety, and stress) at post-treatment, and small magnitude reductions at 3-month follow-up (d = 0.33) relative to a waitlist control in public school employees (Hirshberg et al., 2022). Similarly promising results supporting the benefits of meditation app training were found in

a recent large-scale, multi-site trial (n = 2239 participants, n = 37 sites) that compared four brief meditation practices to an audiobook active control condition (Sparacio et al., 2024). In preregistered analyses, brief meditation practices produced moderate magnitude reductions in state anxiety (ds = 0.45 to 0.56) relative to the attention-matched control condition.

Mechanisms

Meditation apps offer significant advantages for advancing a mechanistic understanding of meditation training: they afford significant experimental control over and measurement of intervention content, dosage, intervention engagement patterns, real-time feedback, informal daily practice, and putative mechanisms of change. While meditation app interventions likely share core mechanisms with traditional, in-person meditation programs, emerging research suggests they may also engage some unique psychosocial pathways. For instance, as described below, initial studies have shown that meditation apps can reduce loneliness and strengthen a sense of digital therapeutic alliance—factors that may be less prominent in in-person formats. Still, the field is in its early days, and it remains unclear whether these mechanisms are truly distinct. Further research is needed to systematically evaluate whether these psychosocial pathways are unique to app-based formats and to directly compare them with mechanisms observed in traditional in-person interventions.

A growing body of research is examining the psychological mechanisms that drive the benefits of digital meditation interventions (for a review, see Macrynikola et al., 2024). Using statistical mediation analysis, several studies indicate that reductions in worry and repetitive negative thinking may be a mechanism of change in digital meditation programs. For instance, Gao et al. (2022) and Roy et al. (2021) found that app-based meditation training significantly reduced worry, which in turn mediated improvements in anxiety symptoms. These findings align with prior research on in-person meditation interventions, where reductions in worry and rumination are key drivers of clinical improvements (Querstret & Cropley, 2013). A recent review examined whether meditation apps improve psychological mechanisms of change across 28 RCTs and concluded that there was a relative advantage of meditation app groups relative to control groups on repetitive negative thinking, attention regulation, and decentering (Macrynikola et al., 2024). The overall effect was moderate in magnitude and gains seemed to persist in follow-up assessments 2–6 months later.

Initial studies have also tested how app-based mindfulness meditation interventions influence mindfulness skill development over time. In a recent ecological momentary assessment study, Gavrilova and Zawadzki (2023) found that daily app-based meditation training led to linear increases in self-reported mindfulness skills over an 8-week training period with the Headspace app, including attention regulation, acceptance, and nonreactivity. Interestingly, their findings suggest a delayed effect for self-reported decentering skills, which did not significantly increase until the fifth week of training, highlighting potential distinctions in how different mindfulness subcomponents may develop in app-based programs. It is still hard to say whether these self-reported mindfulness skills may be key mechanisms for meditation interventions more broadly, as there is mixed evidence on whether meditation interventions reliably increase these self-report mindfulness measures

relative to well-matched active treatment comparator programs without a mindfulness meditation training component (Tran et al., 2022). Nonetheless, one potential possibility is that meditation apps may have common mechanisms of change with in-person mindfulness meditation programs like MBSR or MBCT. For example, the mechanisms of reduced worry and self-reported mindfulness observed with digital meditation apps look similar to these same mechanisms of change observed in these 8-week group-based in-person mindfulness meditation programs (for a review, see Gu et al., 2015).

Meditation apps may work, in part, through unique psychosocial mechanisms. Hirshberg et al. (2025) found that reductions in psychological distress following a smartphone-based well-being program were significantly mediated by decreased loneliness, increased mindful awareness, increased purpose, and increased cognitive defusion. Interestingly, mediation analyses suggested that app reductions in loneliness accounted for the largest amount (62%) of the distress reduction effect (Hirshberg et al., 2025). Notably, this finding was consistent with an earlier trial showing that a mindfulness meditation app significantly reduced daily loneliness and increased the frequency of meaningful social connections among stressed community adults (Lindsay et al., 2019). Likewise, there is also some initial evidence that meditation app training can increase more compassionate behavior toward others (Lim et al., 2015). These findings suggest that even though meditation apps often lack the face-to-face interaction found in traditional in-person meditation groups, they may still foster increased emotion regulation and sense of social connection as potential mechanisms of change.

While initial studies have primarily evaluated self-reported psychological mechanisms of change (Macrynikola et al., 2024), several studies have begun investigating whether meditation apps change bio-behavioral mechanisms. An initial study showed that the Headspace meditation app reduced pro-inflammatory gene expression in immune cells (Dutcher et al., 2022), and two initial studies suggest that meditation apps may alter blood pressure. In the case of blood pressure, we showed that a 14-day mindfulness meditation app program reduced systolic blood pressure (and salivary cortisol) reactivity to an acute laboratory stress challenge relative to two active 14 day comparator programs (Lindsay, Young, et al., 2018). Adams et al. (2018) manipulated a twice-daily dose of digital meditation training (5, 10, or 15 minutes of daily app practice) for six months in a sample of prehypertensive adults. There were significant reductions in laboratory-measured systolic blood pressure over time, with greater reductions observed at higher practice dosages. However, digital app adherence declined over time, particularly in the higher-dose condition, suggesting a potential tradeoff between app intervention engagement and blood pressure reduction. This finding highlights a critical challenge: while greater practice duration may produce stronger effects, increasing practice requirements may reduce user retention. It will be important for future studies to examine whether meditation app effects on biomarkers in turn drive improvements in clinically relevant health outcomes (Creswell & Lindsay, 2014).

One strength of the meditation app approach is that it affords opportunities to relatively easily dismantle meditation training into its putative active components in order to mechanistically evaluate their relative contributions to outcomes of interest. We conducted an initial dismantling trial of our 14-day digital meditation app, testing whether removing the equanimity/acceptance skills training component from a mindfulness program would

eliminate its beneficial effects (Lindsay, Young, et al., 2018). Participants were randomly assigned to one of three conditions: monitor and accept, which trained both attention-monitoring and equanimity/acceptance skills; monitor only, which trained attention-monitoring without equanimity skills instruction; and an active coping effectiveness training control, which included non-mindfulness focused stress management techniques. Results showed that removing the equanimity training components eliminated many of the benefits of mindfulness training relative to the attention monitoring only mindfulness condition, including reductions in stress reactivity (Lindsay, Young, et al., 2018), increases in daily-life positive emotions (Lindsay, Chin, et al., 2018) and stressor evoked positive emotions (Lindsay et al., 2025), and improvements in daily loneliness and social connection (Lindsay et al., 2019). Consistent with theorizing on the important role of learning an attentional stance of non-reactivity in mindfulness meditation interventions (Creswell, 2017; Hadash et al., 2016; Lindsay & Creswell, 2017), these findings provide initial experimental evidence that learning equanimity (i.e., being open and non-reactive to experience) skills may be an important mechanism of action. This finding has important implications for app design, as interventions that explicitly train users in equanimity skills could be more effective at driving benefits.

Safety

There has been increasing investigation of potential unusual or adverse effects associated with in-person meditation programs and intensive retreats (Goldberg, Lam, et al., 2022; Lindahl et al., 2017; Van Dam et al., 2025), and it is likewise important to evaluate whether meditation apps carry their own risks. Mental health apps, after all, are being offered up to millions of users without the live coaching support that is commonly available with in-person meditation programs, and meditation apps often fail to pre-screen users who are presenting with significant acute mental health concerns. Meditation app users are also consuming a smaller and more periodic dose of meditation training relative to their in-person meditation programs (Parsons et al., 2017). The unsupervised and unstructured nature of meditation apps is a challenge we will discuss later as an opportunity that the next generation of digital meditation apps can address. These characteristics raise an important safety question now particularly since meditation is, by design, intended to be a skill building training program that challenges users to change how they relate to their own moment-to-moment experiences (Creswell, 2017; Creswell et al., 2019). No studies (to our knowledge) have reported any serious adverse events with meditation app use, although there has not been careful evaluation and assessment of adverse effects, and adverse effects are unexplored within mental health apps more generally (Linardon et al., 2024). As reported previously, initial studies show that digital meditation apps at the sample level reduce anxiety and depressive symptoms (Gál et al., 2021; Linardon et al., 2024). And initial results from RCTs suggest that meditation apps reduce the likelihood of psychological symptoms worsening over time relative to waitlist controls (Goldberg, Imhoff-Smith, et al., 2020; Hirshberg et al., 2022). Yet, a subset of individuals may well still experience challenges that could be minimized. This might include, for example, content that is responsive to user-provided risk factors (e.g., trauma history) (Canby et al., 2025) and the provision of human support through coaching or referrals to clinical care.

Comparing Digital to Traditional In-Person Meditation Training Programs

The rise of digital meditation apps has sparked growing interest in how these tools compare to well-known in-person mindfulness training programs such as MBSR and MBCT. While, to our knowledge, no large-scale studies have directly compared these approaches in RCTs, theoretical considerations and emerging empirical data suggest important differences, as well as many points of convergence. Here, we first review some of the key differences between digital and in-person meditation training formats, and then we highlight several similarities that might be less obvious at first glance.

Differences

One prominent difference lies in the loss of robust interpersonal and group dynamics that typically characterize in-person mindfulness programs. MBSR and MBCT are typically delivered to groups by a trained instructor, creating a space for real-time feedback, group cohesion, and emotional support. Most meditation apps, by contrast, rely on guided audio or text-based lessons with minimal direct human interaction (Wasil et al., 2020). Although some apps are beginning to incorporate live coaching elements or text-based feedback, these remain relatively limited. Consequently, participants may miss out on the sense of interpersonal support and associated therapeutic alliance. These factors are often cited as a critical mechanism in clinical interventions including meditation-based interventions (Creswell, 2017; Goldberg, Riordan, et al., 2022). The lack of real-time, customized instructor guidance may be a particularly important difference. Within mental health interventions broadly, there is clear evidence that incorporating human guidance and support into digital interventions improve both clinical outcomes as well as engagement (Domhardt et al., 2019). Instructor support may be especially helpful and important for certain individuals, such as those with more severe clinical symptoms that may not be adequately managed and may even worsen in the context of an app (Goldberg, Lam, et al., 2022).

There are also important differences in dosage, engagement, and accountability. As discussed earlier, meditation practice dosage appears to be much lower in meditation apps than in-person meditation interventions (Baumel et al., 2019; Parsons et al., 2017). Further, while meditation apps are often celebrated for their scalability and convenience, they also have low sustained engagement (Baumel et al., 2019). By contrast, in-person meditation create engagement through weekly class meetings and direct contact with an instructor and peers; this setting provides a form of supportive accountability that can motivate sustained practice (Mohr et al., 2011; Nahum-Shani et al., 2022). In addition to these structural and engagement differences, it is important to consider how user characteristics may shape the perceived effectiveness of digital versus in-person meditation programs. Individuals who pursue in-person mindfulness training may differ systematically from those who opt for meditation apps—for example, in their time availability, symptom severity, motivation levels, or comfort with digital platforms. These self-selection factors could influence engagement and outcomes, making direct comparisons between formats complex. Rather than focusing on which delivery method is universally “better,” future research may benefit from adopting a person-centered approach—matching individuals to the intervention

format that best fits their needs, preferences, and context. These different delivery formats may also serve distinct purposes. While in-person programs like MBSR typically aim to cultivate long-term mindfulness skills through intensive practice, app-based interventions may be better suited to offering brief, just-in-time support during moments of acute stress or emotional need. These approaches are not mutually exclusive—both skill development and short-term symptom relief may be possible within either format—but recognizing these distinct functional roles could help guide intervention design and research priorities. Future studies could explicitly test whether apps and in-person training yield different outcomes depending on user intent or context. Likewise, one possible explanation for stronger effects observed in traditional in-person programs is that they may attract individuals with more severe symptoms, who are actively seeking intensive support. In contrast, many app users may engage with these tools for general wellness, contributing to smaller overall effects. Future research can better characterize baseline severity, and consider stratified or moderated analyses to clarify how symptom severity influences intervention outcomes.

Another key difference involves new opportunities for personalization and data capture afforded by digital technology. Meditation apps can in theory incorporate wearable sensors, ecological momentary assessments (EMA), and personalized practice reminders, features that do not have obvious non-digital corollaries in traditional programs (Chien et al., 2020; Nahum-Shani et al., 2022). Digital platforms can collect fine-grained data about engagement patterns, user preferences, and biomarkers (e.g., heart rate variability), that might offer a unique opportunities for intervention and customization. However, these capabilities raise data security and privacy concerns, which, although not exclusive to the digital domain, can be amplified by the scale and reach of apps (Torous et al., 2019). Personalization can also involve both structural features—such as tailoring practice duration, delivery timing, or app reminders—and content features, including the specific type of meditation offered or how that content is offered (e.g., tailoring to specific chronic disease challenges). While this flexibility is a strength, it also introduces complexity relative to in-person programs that often follow more standardized protocols.

Digital meditation apps also frequently omit or abbreviate elements of traditional meditation interventions, such as psychoeducational training around stress in MBSR and cognitive therapy elements in MBCT. Though the newer generation of apps is increasingly expanding beyond simple guided audio files, many still lack the comprehensive curriculum design that went into traditional, in-person meditation interventions. This gap could be especially critical for individuals with heightened mental health needs who might benefit from some of the meditation-adjacent content (e.g., recognizing depressive relapse signs) (Segal et al., 2012). It is also helpful to consider the historical development context of these tools. Most meditation apps were initially designed and marketed as general wellness products, not clinical interventions. This origin helps explain why many apps lack features common to in-person programs, such as psychoeducational components, diagnostic screening, or structured therapeutic content. These distinctions in purpose may carry important implications—for example, whether some apps could or should be evaluated as medical devices under FDA pathways in the future.

Finally, one obvious difference is that digital meditation apps are, in theory, much easier to access and lower in cost than in-person delivery formats. This is, of course, a major driver of their widespread use in the general public. There are formidable barriers facing participation in in-person meditation interventions such as associated costs, lack of trained providers, and logistical challenges related to scheduling and travel, as well as stigma associated with participating in treatment. These factors contribute to the fact that approximately half of those with mental health disorders in the US do not access care in a given year (Substance Abuse and Mental Health Services Administration, 2020). There are substantial demographic disparities in engagement with mental health care generally (Goldberg et al., 2019) as well as engagement with meditation (Cramer et al., 2016). Meditation apps can be accessed at a fraction of the cost and reduce or eliminate other barriers associated with in-person interventions (e.g., lack of providers, logistical challenges, etc.). These encouraging possibilities aside, whether or not meditation apps can in fact reduce treatment engagement disparities across demographic groups remains to be rigorously tested. Indeed, there is some evidence suggesting that disparities seen for traditional mental health care (e.g., lower engagement among men and racial/ethnic minorities) (Goldberg, Fortney, et al., 2020; Wang et al., 2007) appear even in the context of a freely available meditation app (Jiwani et al., 2023). Clearly more work is needed to clarify barriers that persist for engagement with meditation apps as well as strategies that may be helpful for reducing these barriers (e.g., personalization, cultural adaptation) (Borghouts et al., 2021).

Similarities

These differences aside, digital meditation training may have more in common with traditional in-person delivery formats than may meet the eye. Meditation instructions have been passed down through the oral tradition for several thousand years. The earliest Buddhist doctrine (i.e., the Pali canon) offer core instructions on mindfulness meditation such as the *Satipatthana Sutta* (Anālayo, 2003), and were traditionally learned and memorized by listening to a teacher, much like what one might do on a meditation app. Second, core meditation practices such as mindful breathing, body scans, and encouragement to engage in informal meditation practice in daily life (e.g., attending to sensory experiences while walking or eating) are central to both in-person and digital delivery formats (Creswell, 2017; Linardon et al., 2024). Popular meditation apps typically guide users through many of the same exercises that have formed the backbone of in-person meditation program for decades. At a basic level, the key ingredients within the practice instructions themselves are similar across these formats. Moreover, both traditional meditation interventions and meditation apps tend to hold the view that home practice and integration of these practices in daily life are key drivers of success. And, whether one may be learning these techniques through a live instructor or a self-guided app, ultimately it is one’s own practice that will yield long-term benefits.

Third, remote and self-guided components have long existed within traditional in-person evidence-based meditation programs. Early mindfulness research leveraged audio-guided instruction for participants (e.g., the body scan in MBSR), with some early landmark mindfulness meditation studies delivering training for individuals with psoriasis (Kabat-Zinn et al., 1998) or stimulated pain (Zeidan et al., 2011) almost exclusively through

audio guidance. These approaches foreshadowed the current explosion in meditation apps, suggesting that the notion of non–face-to-face mindfulness guidance is hardly new. In each case, the underlying assumption is that guided audio or written instructions can effectively teach meditation, even without a continuous in-person presence.

Fourth, as discussed above, overlapping mechanisms of action appear to drive benefits across both digital and in-person formats. Emerging research suggests that app-based interventions yield reductions in worry, repetitive negative thinking, and stress reactivity —mechanisms that have been widely studied in traditional in-person programs (Gao et al., 2022; Roy et al., 2021). Although the digital context may open new pathways (e.g., real-time behavioral tracking and adaptive feedback), the foundational emphasis on attention monitoring and acceptance/equanimity skills and the mechanisms purportedly linked to these skills remains the same (Lindsay & Creswell, 2017; Macrynikola et al., 2024). There is also some emerging evidence that a digital corollary to therapeutic alliance exists and is associated with psychological benefits (Goldberg, Baldwin, et al., 2022).

In sum, while digital meditation apps differ from traditional in-person mindfulness interventions in critical ways—most notably around interpersonal support, practice, and the integration of novel technology—they also share many of the same practices and theoretical mechanisms of change. From a historical perspective, recorded and remotely delivered meditation instructions have been part of mindfulness training for decades, and many of the fundamental principles underlying in-person programs are similarly implemented in modern app-based programs. Understanding these points of divergence and convergence will be crucial for developing a translational science of meditation apps and guiding future research on how best to maximize user engagement, clinical efficacy, and well-being.

Challenges and Opportunities with this New Class of Meditation Apps

Over the past decade, digital meditation apps have entered the public and scientific mainstream at a remarkable pace. Yet, even with the promising outcomes reported in RCTs (Linardon, Messer, et al., 2024), it is clear that the wide adoption of digital meditation apps outstrips our current scientific understanding of how best to design, deliver, assess, and disseminate them. Here we focus on the major challenges facing digital meditation interventions, as well as the key opportunities and future directions for scientists. Figure 2 offers an organizational depiction of the new meditation app ecosystem.

One of the most persistent challenges is sustained digital app engagement (Nahum-Shani et al., 2022). While meditation app download numbers run in the millions each year, objective usage data often tells a sobering story: only a small fraction of users remain active beyond the first month (Baumel et al., 2019). The modal individual likely engages in sessions much shorter or less frequent than the daily 30- to 45-minute practices traditionally prescribed in programs like TM, MBSR, or MBCT. This gap between historically recommended and actual usage patterns raises important questions about how we conceptualize an effective dose-response in a digital setting. Although longer practice durations have sometimes been linked to better outcomes (Parsons et al., 2017; Strohmaier, 2020), it may also be that consistency of short, structured “mindful moments” throughout the week could yield

significant benefits (Manigault et al., 2021; Xie et al., 2024). Recent work on adaptive interventions and just-in-time interventions (Smyth & Heron, 2016; Xu & Smit, 2023) suggests that highly personalized reminders or brief "micro-practices" might help sustain engagement and help address ways for users to better translate formal meditation into daily life when they might need it the most (Manigault et al., 2021). Moreover, integrating social or gamified features (Sardi et al., 2017)—such as group leaderboards or team meditation challenges—could help replicate some of the accountability typically found in in-person meditation programs. Likewise, apps provide a lot of flexibility and can be easily accessed during periods of high stress or acute mental health needs. It is possible, although not yet formally tested, that many users of meditation apps are accessing the apps when they need them, and that some subset of users don't really have a sustained engagement problem—instead their engagement reflects usage that is actually meeting their app goals and desired outcomes. In tandem with concerns about engagement, there is a growing need to assess the safety of unsupervised, app-based meditation (Van Dam et al., 2025). A potential way forward involves embedding screening tools within the apps themselves to flag users who may need additional features or supports (e.g., Roberts et al., 2021). For instance, apps could routinely prompt check-ins and measures of meditation-related challenges and adverse events (Britton et al., 2021; Van Dam et al., 2025), then direct higher-risk users toward support.

Another pressing issue is the variability in app content. With thousands of meditation apps on the market and hundreds of different schools of meditation – the depth, style, and fidelity of instruction can vary dramatically. Some apps include only simple breath awareness practices. Others incorporate acceptance training, cognitive-behavioral strategies, or entirely distinct psychoeducational modules. Some of the apps' content is based on established meditation training lineages, pedagogy, or evidence-based studies, other meditation apps might be from individuals without formal teacher training. This can create complexity for both users and clinicians, and raises the question of whether some apps could be "watering down" meditation training in ways that limit its effectiveness. These concerns have been previously discussed with the secularization and spread of in-person mindfulness meditation training programs to the West (Van Dam et al., 2018), but the current meditation app revolution now raises new questions around how these practices are being tailored, altered, and now disseminated to millions of people across the world. Scientists and experienced meditation teachers play an important role in the development of meditation app curricular content—and there is a pressing need not only for scientists and teachers to develop guidelines for evidence-based scientific meditation apps, but also to accelerate our scientific studies of these apps to evaluate their safety, efficacy, and effectiveness.

Digital apps also offer a distinctive strength: the ability to deliver personalized, context-sensitive meditation training. Unlike in-person courses, which often adhere to a more fixed and manualized curriculum, apps have the potential to additionally incorporate sophisticated algorithms that track user habits, preferred session lengths, or symptom severity. Through ecological momentary assessments, an app might detect times of heightened stress and proactively suggest specific practices, or send reminders at precisely the moments a user is most likely to be receptive (Xu & Smit, 2023). Ecological momentary assessments could also capture candidate mechanisms, such as affect experienced during meditation (Goldberg

et al., 2024), that can also guide intervention delivery. These opportunities that are more unique to digital apps present new opportunities for a tailored or personalized medicine approach to meditation training, but can also create challenges for scientists who are now straying away from highly structured and repeatable manualized interventions. While there is some real scientific control over comparing a highly structured MBSR intervention and a well-matched intervention like the Health Education Program (HEP) (MacCoon et al., 2011) for example, there is a significant shift in how scientists conceptualize experimental control when comparing personalized meditation app programs.

The tension between personalization in medicine and experimental control in research is a well-recognized challenge and there have been extensive discussions of ways to leverage various trial designs approaches to optimize treatment development (Collins et al., 2024). Examples include the use of factorial designs that can evaluate multiple components in a single RCT (e.g., Cox et al., 2024) and adaptive designs such as sequential multiple assignment randomized trials (SMART) that can evaluate the impact of modifying the intervention received based on treatment response approaches (e.g., Fröhlich et al., 2018). Customization extends further into cultural adaptation. Meditation techniques that resonate with one demographic may be less relevant to another. There is significant potential with apps to be able to fine tune meditation app guidance to specific patient groups, demographic groups, and to support a more effective approach to intervention delivery. With large language models now capable of immediate translation and dialect support, apps can be tailored to different linguistic and cultural contexts. This opens the door for a much broader global reach, provided that developers and researchers remain sensitive to the nuanced ways in which meditation training can intersect with cultural beliefs and traditions. Furthermore, “freemium” or lower-cost apps have the potential to reduce financial barriers, ensuring that a broader cross-section of users can access evidence-based meditation training.

One of the most exciting scientific frontiers is using a new generation of meditation apps to conduct pragmatic trials that evaluate the effectiveness and implementation of meditation training among very large samples of users out in the world. While we have described some initial published studies of meditation apps that have engaged 500–2000 participants in this review (Hirshberg et al., 2022; Huberty et al., 2021; Kranenburg et al., 2022; Quinones & Griffiths, 2019; Sparacio et al., 2024), it is certainly possible to imagine even larger samples in RCTs of meditation apps in the coming years. These larger trials are useful not only for evaluating the efficacy of meditation app training among large samples of people in the wild, but they enable better powered moderation and mediation analyses of when and how these interventions work. Previous critical reviews of the meditation literature have highlighted how there are very few effectiveness trials in this space (Dimidjian & Segal, 2015), and the low cost scalable nature of meditation apps can help begin to close these implementation science gaps.

While traditional in-person meditation studies often rely on a few self-report, behavioral or biomarker measures, digital apps can generate a continuous stream of user data, from practice session logs to respiration tracking or heart rate variability captured through wearable devices. These app-based features offer new opportunities for important mechanistic research. As one example, we have been using machine learning techniques

to explore how guided mindfulness meditation app training alters respiratory dynamics, finding that respiratory signals tell us a lot about who is going deep with their meditation practice (Khan et al., under review). Furthermore, we find that giving users feedback on how their respiration is changing during meditation increases their engagement on our Equa meditation app. One could imagine a future where the integration of biosensors and user inputs then shapes real-time adaptation of meditation practice guidance. Meditation training micro-dosing protocols could test whether multiple daily sessions of brief meditation outperform a single longer session per day. Additionally, researchers can conduct rapid, repeated trials to dismantle or compare interventions, potentially revealing which components—such as acceptance/equanimity instructions—yield the strongest effects (e.g., Lindsay, Young, et al., 2018).

Even as digital tools advance, there is much to be said for blended or hybrid scientific meditation training approaches that incorporate both technology-based and in-person elements. One might imagine MBSR or MBCT courses in which participants use an app for daily "homework" while attending weekly group sessions for deeper discussion and interpersonal support. Indeed, many meditation research programs seem to be shifting to these online or hybrid systems. In clinical settings, providers could recommend or "prescribe" specific app-based programs, monitor patients' usage data, and intervene when signs of non-adherence or heightened distress appear. There are also promising signs that virtual or telehealth counselors are starting to integrate with existing apps, blurring the line between self-guided and instructor-led meditation. Live meditation communities in virtual reality platforms are another frontier, for example, the TrippVR platform (www.tripp.com) offers live meditation groups in the Metaverse. For healthcare systems that grapple with limited access to mental health services, these types of app-based or hybrid meditation training models have the potential to expand care to more people at low cost. We do not expect these platforms to replace in-person treatments, but the low cost and accessible nature of these apps can provide an on-ramp toward wellness and mental health support.

A final area of challenge and opportunity facing digital mental health interventions is Food and Drug Administration (FDA) approval. A small number of mental health apps have received FDA approval, with the Rejoyn app appearing in 2024 as the first app approved for treating major depressive disorder (Richmond, 2024). It is too early to say how FDA approval may intersect with meditation apps. Meditation apps may be, intentionally or not, positioning themselves as wellness devices (which cannot be approved by FDA) versus medical devices (which can be approved by FDA) (Torous et al., 2024). If meditation apps were to seek FDA approval as medical devices, this shift could bring both benefits and drawbacks. On the one hand, FDA approval could enhance credibility and facilitate integration with healthcare systems. On the other, it could impose access barriers due to cost, prescription requirements, or regulatory limitations—and might also limit the ease with which researchers can study these tools in pragmatic trials. As meditation apps occupy a commercial space, it is important to acknowledge the potential for financial and professional conflicts of interest in app-based research. While some apps are developed by not-for-profit organizations, many others are affiliated with for-profit companies or investor-backed ventures. Even in nonprofit contexts, researchers may be incentivized to promote tools with which they are affiliated. As the field matures, transparency around funding sources, app

ownership, and researcher affiliations will be essential for maintaining trust and scientific rigor.

Conclusions and Future Directions

Presently we find ourselves in a real digital health revolution. There has been an acceleration of mobile apps, smart devices, and remote health care delivery systems. Meditation apps have played a central role in the rise of digital mental health apps (Wasil et al., 2020). Despite the initial studies we have described on the efficacy, mechanisms, and safety of these apps, many open questions remain. High-priority areas include conducting comparative trials where in-person mindfulness programs are tested head-to-head against app-based interventions, ideally across diverse populations and patient groups. More nuanced measurement of outcomes in daily life, along with objective markers of biological or behavioral change, would greatly strengthen the evidence base. Researchers also need to examine the ethical and regulatory frameworks surrounding digital data collection and the deployment of artificial intelligence in these apps. At a minimum, best practices for data privacy should be clearly outlined, and screening protocols must be developed for at-risk users. Broader policy and funding efforts could encourage the development of rigorously tested FDA-cleared meditation apps that could eventually be reimbursed as part of standard healthcare (Miao et al., 2022).

Ultimately, while the rise of meditation apps represents a major addition to how meditation training is delivered and studied, it simultaneously raises new and critical challenges. With so many millions of people turning to these apps across the globe, there is time urgency to scientific research in this area. These apps can be powerful tools for well-being, but arguably deserve to be studied with the same scientific rigor historically applied to our other evidence-based behavioral health interventions. By addressing engagement, safety, fidelity, personalization, and integration with existing systems, the field can accelerate our understanding of meditation training in our new technology enabled world.

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Public Significance Statement:

Smartphone meditation apps are widely used and while initial studies suggest they may be helpful for improving some markers of mental health, sustained engagement is low. This review describes the emergence and impact of this relatively new class of digital tools and explores challenges and opportunities for advancing a robust science of digital meditation apps.

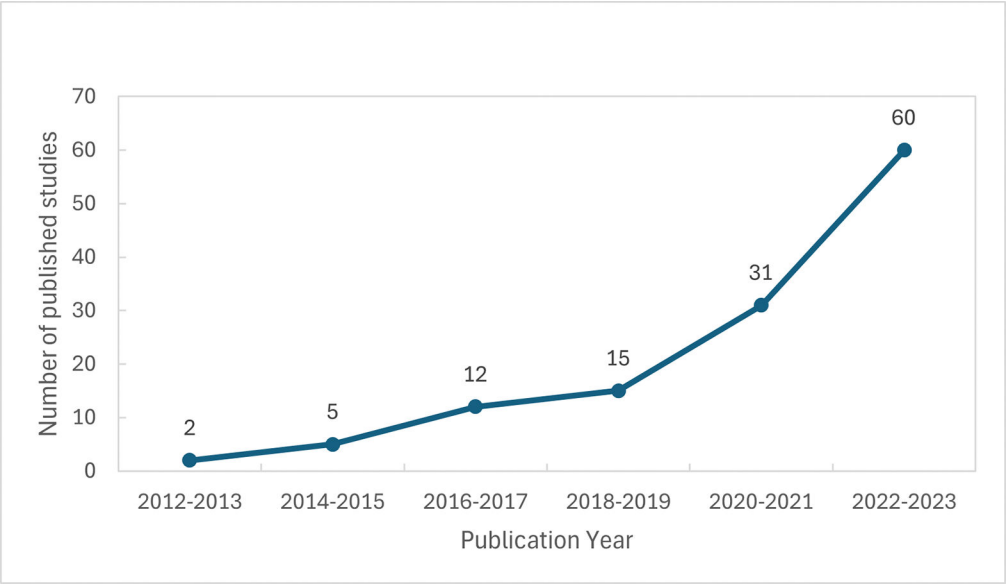

Figure 1.
Non-cumulative counts of published meditation app studies in two-year intervals

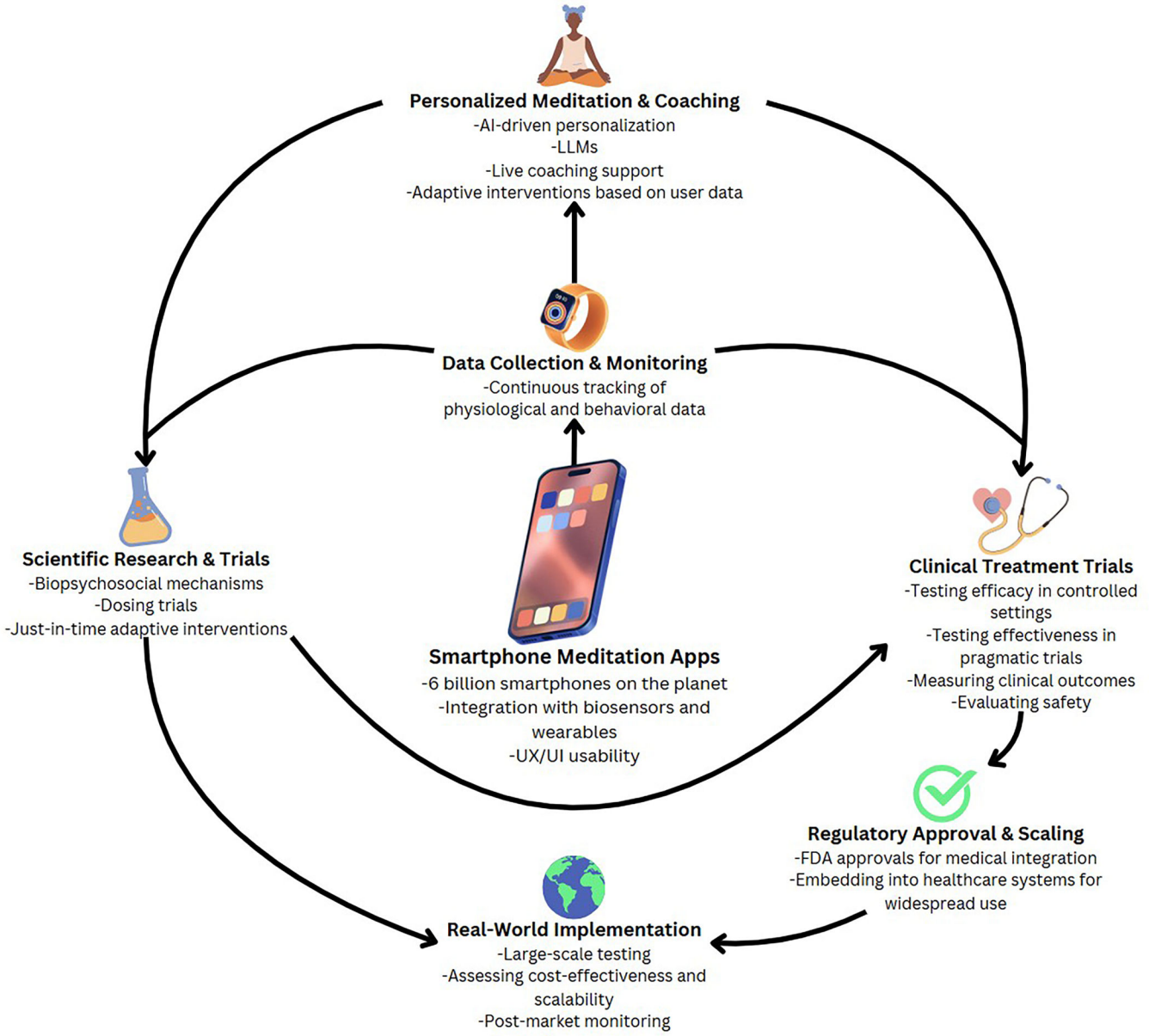

Figure 2.
Challenges and Opportunities in the New Meditation App Scientific Ecosystem