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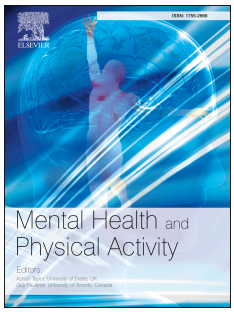

Getting Active through Mindfulness: Randomised controlled trial of a digital mindfulness-based intervention promoting physical activity engagement and enjoyment

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Getting Active through Mindfulness: Randomised controlled trial of a digital mindfulness-based intervention promoting physical activity engagement and enjoyment

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Project administration, Funding acquisition, Liaising with non-academic partner. **BA, OMM & MJW**—Conceptualisation, Methodology, Supervision, Writing – Review & editing, Funding acquisition. **OSM**—Formal analysis, Validation, Data curation, Writing – Review & editing. **AB, AKB, TCC, LEA, ACT & AM**—Investigation, Validation, Writing – Review & editing. **Medito Foundation**—Software.

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ETHICAL APPROVAL: University of Bath's Biomedical Research Ethics Committee approved this study (#0306-569). Site approvals were also given by Research Ethics Committees at Universities of Bristol (#17533) and Southampton (#89466).

DATA STATEMENT: Supplementary materials are available alongside the publication. Full study materials, data and code are available through the Open Science Framework at https://osf.io/jh9ge/.

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Abstract

Background: Physical inactivity and mental ill-health are common in university students. Physical activity (PA) interventions can improve health and wellbeing, yet resulting changes to behaviour are rarely maintained. Mindfulness training that develops psychological skills and PA cognitions may facilitate PA engagement. This preregistered trial explored the additive effects of a 30-day digital mindfulness-based intervention promoting PA engagement, compared to a simple PA intervention alone, in insufficiently active university students.

Methods: 109 participants from three sites in England were randomised to receive an activity monitor and daily step goal (8000 steps/day; PA-only group), or a 30-day digital mindfulness intervention plus activity monitor/step goal (MPA group). Primary outcomes were self-reported PA and sedentary time; secondary were wellbeing, mental health, PA motivation, enjoyment and self-efficacy, and theoretical predictors of PA. Data were collected through surveys (pre- and post-intervention) and daily ecological momentary assessments.

Results: Self-reported PA doubled, and sedentary time reduced, with greater but not significant improvements in the MPA group from baseline to post-intervention ($M_{diff of diff}$ = 305 MET-min/wk; -9.5 hrs/wk). Psychological health outcomes were mixed. The MPA group reported stronger increases in behavioural intentions to be active vs. PA group. State mindfulness during PA increased in both groups, whereas exercise self-efficacy was unchanged.

Conclusions: Adding digital mindfulness training to a wearable-based PA intervention helped participants increase their intentions for PA, but did not produce differences in PA behaviour or sedentary time. Further research should determine if mindfulness-induced changes in PA cognitions support sustained engagement in PA over longer time periods.

Keywords: physical activity, mindfulness, behaviour change, mental health, digital health, self-regulation

Original paper for re-submission to Mental Health and Physical Activity

Getting Active through Mindfulness: Randomised controlled trial of a digital mindfulness-based intervention promoting physical activity engagement and enjoyment

[AUTHOR INFORMATION, FUNDING AND CONTRIBUTION STATEMENTS REMOVED FOR BLIND PEER REVIEW]

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Introduction

Physical inactivity is a significant public health concern estimated to affect a third of the global adult population (Strain et al., 2024). It is associated with the onset and exacerbation of burdensome mental health conditions, such as depression and anxiety, which are themselves identified as a key area for intervention (World Health Organization, 2021). When individuals enter adulthood they are at an inflection point for both issues—engagement in physical activity (PA) declines between the ages of 15 and 25 (Strain et al., 2024), while mental health concerns often develop (Solmi et al., 2022). University students appear to be a particularly vulnerable group, reporting higher rates of physical inactivity (Kwan et al., 2012; Vella-Zarb & Elgar, 2009) and mental ill-health than their counterparts outside of higher education (Thorley, 2017). Research consistently endorses PA as a strategy for improving mental health outcomes, with a recent umbrella review concluding that PA interventions can achieve medium-sized effects (Singh et al., 2023), similar to those seen through 'gold-standard' psychotherapeutic and pharmacological treatments (Carpenter et al., 2018; Cipriani et al., 2018). Despite this, their long-term effects are frequently undermined by poor participant engagement (Rhodes & Sui, 2021). Understanding and targeting the psychological processes associated with sustained PA is therefore crucial. Enjoyment of PA, self-efficacy, and intrinsic motivation are some of the PA cognitions that have been identified as predictors of continued engagement in PA (Amireault et al., 2013; Kwasnicka et al., 2016).

Literature suggests that mindfulness training—the structured practice of non-judgementally paying attention to one's mental and physical experience, and surroundings (Shapero et al., 2018)—can facilitate the development of these crucial psychological skills (Ryan et al., 2021). Individuals with higher levels of mindfulness, whether by trait or training, tend to engage in more health-promoting behaviours and report better health outcomes (Sala et al., 2020; Tomlinson et al., 2018). Schuman-Olivier and colleagues' (2020) theoretical framework describes

the potential of mindfulness to facilitate behaviour change through self-regulatory processes, including better regulation of attention and emotion, more adaptive self-related processes, motivation and learning. Empirical evidence has demonstrated effects of mindfulness-based interventions (MBIs) on increased self-efficacy, motivation and discomfort tolerance, as they relate to health behaviour engagement (Kadziolka et al., 2016; Neace et al., 2022; Ruffault et al., 2016). While the potential of MBIs for supporting mental health is well-documented, including in young adult and student populations (Breedvelt et al., 2019), their application to facilitate behaviour change, such as increasing PA, is novel. Recently, our review of intervention studies combining PA and mindfulness training determined that the two can feasibly be delivered in combination and can work synergistically to benefit mental health (Remskar, Western, Osborne, et al., 2024) – although data were too scarce to determine precise effects on PA engagement or PA cognitions.

Behaviour change efforts are increasingly leveraging digital methods to improve scalability, reach and cost-effectiveness (König et al., 2024; Mrazek et al., 2019). Interventions using wearable activity monitors have shown good short term efficacy for changing PA behaviour in young and adult populations alike (Au et al., 2024; Laranjo et al., 2021). A recent meta-analysis of 75 randomised controlled trials (RCTs) with over 12 thousand participants concluded that PA interventions providing strategies in addition to self-monitoring of behaviour via a wearable (e.g., adding a smartphone app, goal-setting, or counselling) induce small but meaningful increases in PA beyond those observed in interventions only prescribing self-monitoring of PA (i.e., additional 926 steps/day; Vetrovsky et al., 2022). Adding psychological skills and self-regulation training through digital mindfulness may be one promising approach: in a recent pragmatic RCT with 300 participants, 30 days of 10-minute daily mindfulness training guided by a free mobile app led to favourable shifts in attitudes towards health maintenance and behavioural intentions to look after one's health (Remskar, Western, & Ainsworth, 2024). These effects were achieved

through 'generic' mindfulness training not tailored to PA and the authors measured general health maintenance cognitions, whereas the potential of PA-specific digital mindfulness is yet to be explored.

To our knowledge, the present work is the first to create a mindfulness training intervention specifically designed to incorporate behaviour change strategies and promote PA. This trial aimed to explore the additive effects and mechanisms of a 30-day self-delivered digital MBI promoting PA engagement and enjoyment, compared to a wearable-based PA intervention alone. Specifically, we predicted that the addition of mindfulness to a PA intervention (compared to PA without mindfulness) will lead to:

1. Increased PA levels and reduced sedentary time,
2. Increased mental wellbeing and reduced levels of depression, anxiety and stress, and
3. More adaptive PA cognitions (increased enjoyment, motivation, self-efficacy) and theoretical predictors of PA behaviour over time (attitudes, perceived behavioural control, behavioural intentions).

Our primary outcomes are validated questionnaire-based data. We include daily diary data as exploratory to start delineating the mechanisms of change underpinning our results and to generate future hypotheses.

Methods

Design

For this single-blind randomised controlled trial (RCT), we recruited participants between January and April 2024 from three higher education institutions in England. Participants were randomly assigned to intervention (MPA) or control conditions (PA only) in a 1:1 ratio, stratified by site and gender, using a computer-generated plan by a researcher not involved with data collection or analysis. Due to the nature of the intervention, it was impossible to blind participants and research assistants delivering study instructions. However, participants were

unaware that an alternative study condition existed, and research assistants were not involved in random sequence generation nor data analysis. All procedures complied with the Declaration of Helsinki and were approved by the University of [BLINDED] Biomedical Research Ethics Committee (#0306-569), with site approvals from Psychology Research Ethics Committees at [BLINDED] (#17533) and [BLINDED] (#89466). The study is reported according to the Consolidated Standards of Reporting Trials (CONSORT) guidelines and was prospectively registered [BLINDED].

Participants

Eligible participants were recruited from participating universities. Inclusion criteria were to be aged 18-65, to engage in less than 60 minutes of PA in an average week, and be fluent in English. Exclusion criteria were to currently use technology to track or change their PA behaviour and medical contraindications to light PA (such as injury or high-risk pregnancy).

Intervention and comparator

At baseline, all participants received a wrist-worn activity monitor that tracked steps, distance and calories burned that day. They were instructed to wear the monitor during waking time (except for water-based activities) and aim for at least 8000 steps per day—identified as an ambitious but achievable target for currently sedentary individuals (Pillay et al., 2014; Tudor-Locke et al., 2011)—for the 30-day study period.

After randomisation, the MPA group participants were also enrolled in a 30-day digital mindfulness intervention tailored to promote PA engagement and enjoyment. This was accessed via a free commercially available mobile application (Medito; https://meditofoundation.org/medito-app). Intervention content was designed by the research team and incorporated into the Medito app for the study. It was created using the Person-Based Approach to intervention design (Yardley et al., 2015), including stakeholder feedback to ensure the intervention was engaging and acceptable. The intervention aimed to enhance participants'

PA engagement and enjoyment by developing psychological skills associated with successful health behaviour change (e.g., self-regulation, self-efficacy, discomfort tolerance; see *Figure 1* for the intervention logic model). This was done through daily 10-minute audio recordings, which combined mindfulness training exercises (present-moment awareness, breathing exercises and body scans; 7 min/session) with psychoeducation and reflection on the day's session focus (such as goal setting, non-judgement towards the body, cultivating motivation; 3 min/session). Participants were instructed to follow one session per day while sat in a calm environment, preferably at the same time every day. The research team had access to app use metrics tracking participants' fidelity. See Supplementary materials for more details on intervention development and content, including the Template for Intervention Description and Replication (TIDieR; Hoffmann et al., 2014) checklist.

Procedure

Potential participants were recruited via flyers on campus, social media and undergraduate research participation schemes. Following an eligibility screening, participants gave digital informed consent and filled out baseline measures through a digital survey platform (*QuestionPro*, 2024; duration 20 minutes). They then attended an in-person setup appointment lasting 30 minutes, where they received the activity monitor, were set up on the ecological momentary assessment (EMA) mobile application platform (*M-Path*, 2024) and given instructions for the next 30 days. The study period commenced the day after the setup appointment. Every evening during study period, participants were prompted by a mobile push notification to complete a daily diary on the EMA platform (duration 2 minutes/day). On day 31, participants were emailed a personalised link to the post-intervention survey (duration 15 minutes). Once post-intervention measures were completed, participants kept the activity monitors as reimbursement. Intervention condition participants were invited to take part in an optional one-to-one interview about their experience of the study, which was conducted virtually (*MS Teams*, 2024; duration 30-60 minutes)

within two weeks of post-intervention measures. Interview participants were reimbursed an additional £20 retail voucher. Interview findings will be reported separately.

Measures

At baseline, online surveys collected demographics (age, gender, ethnicity), study site and mindfulness experience (1-5 Likert scale from "none" to "abundant"). In addition, the following questions were asked at both pre- and post-intervention timepoints:

Self-reported PA and sedentary time were measured with the short form of International Physical Activity Questionnaire (IPAQ-SF; Craig et al., 2003). IPAQ-SF is a valid and reliable measure of walking, moderate- and vigorous-intensity activities over the past 7 days, expressed in total metabolic equivalents per minute (MET-minutes) per week. It also measures sedentary time in hours per week.

Mental wellbeing was measured with the Warwick-Edinburgh Mental Wellbeing Scale (WEMWBS; Tennant et al., 2007), which consists of 14 statements describing positive mental states rated on a 5-point Likert scale ("None of the time" to "All of the time" over the past week). Higher scores indicate better wellbeing (range 14-70, Cronbach's $\alpha = 0.89$).

Mental health was measured using the 12-item mini version of Depression, Anxiety, Stress Scale (Mini-DASS; Monteiro et al., 2023), with subscales measuring depression, anxiety, and stress. Participants rated the frequency of symptoms over the past week on a 4-point scale from "Did not apply to me at all" to "Applied to me very much or most of the time" (range 0-12 for each; Cronbach's $\alpha = 0.84, 0.67, 0.82$, respectively).

Trait mindfulness was measured using the Philadelphia Mindfulness Scale (PMS; Cardaciotto et al., 2008), which assesses two dimensions of mindfulness: present-moment awareness and acceptance. Its 20 items are rated on a 5-point Likert scale ("Never" to "Very often") for subscale scores of 10-50 each (Cronbach's $\alpha = 0.82, 0.87$, respectively).

Mindfulness during PA was measured using the Mindfulness in Physical Activity scale (MFPA; Tsafou et al., 2016). It consists of 6 items rated on a 5-point Likert scale ("Not at all" to "Very much"), with higher scores indicating more mindful attention during PA (range 5-30; Cronbach's $\alpha = 0.78$).

Enjoyment of PA was measured using the Physical Activity Enjoyment Scale (PACES; Kendzierski & DeCarlo, 1991), which includes 18 items rated on a 7-point Likert scale ("Disagree a lot" to "Agree a lot"; range 18-126; Cronbach's $\alpha = 0.94$).

Exercise self-efficacy was measured using the Exercise Self-Efficacy Scale (ESES; Kroll et al., 2007), comprising 10 items about confidence in one's ability to engage in PA despite barriers (e.g., tiredness, lack of support). Items are rated on a 5-point Likert scale ("Not at all confident" to "Very confident"; range 10-50; Cronbach's $\alpha = 0.77$).

Motivation for PA was measured using the Behavioural Regulation in Exercise Questionnaire (BREQ-3; Wilson et al., 2006). Its 24 items assess six types of motivation for exercise based on the Self-Determination Theory (Ryan & Deci, 2000), rated on a 4-point Likert scale ("Not true for me" to "Very true for me"; range 4-16 for each; all Cronbach's $\alpha = 0.81$-0.88).

Behavioural predictors of PA were measured using the 12-item Theory of Planned Behaviour Questionnaire (TPBQ; Ajzen, 2019; Fishbein & Ajzen, 2009), which evaluates attitudes, subjective norms, perceived behavioural control (PBC) and behavioural intentions to be active. Ratings on a 7-point Likert scale (“Disagree” to “Agree”; range 3-24 for each) give subscale sums, where higher scores indicate more positive attitudes, stronger social norms, greater PBC and stronger behavioural intentions (Cronbach's $\alpha = 0.60$-0.75).

Daily diaries, filled out on the EMA mobile app before going to sleep, asked about participants’ *mood*, *depression*, *anxiety*, *stress* for the day (each single-item scored 0-100, where higher scores indicated better mood but worse feelings of depression, anxiety and stress). EMA prompts were included to explore changes in mechanisms and mental health outcomes over time with more

granularity than the pre-post comparisons. Therefore, we selected daily prompts as close as possible to the questionnaire-based measures, so that we could compare the trends in both types of data. Depression, anxiety and stress all exhibit state symptoms that can be detected through EMA (Hall et al., 2021; Targum et al., 2021). Next, participants were asked whether they wore their activity monitor today (multiple choice: Yes/No/Partly). If answered Yes, they were prompted to report the *step count* reading from the monitor. Participants were then asked whether they had been physically active that day (Yes/No). If Yes, they were asked how much they *enjoyed* the activity, how *confident* they felt in their ability to perform it, and how *motivated* they were for it (each single-item on a 1-7 Likert scale from "Not at all" to "Very much"). Finally, participants in the intervention condition were asked whether they had done the digital mindfulness session for the day (Yes/No/Still intend to). Full materials and further information on scoring are available in Supplementary materials.

Sample size

We aimed to recruit 100 participants, based on *a priori* power calculation estimates for our primary outcome (self-reported PA; 80% power, alpha 0.05) using a mixed-effects general linear model. In absence of previous comparable effect sizes, and commensurate with the resources for intervention monitors, we opted for a pragmatic target sample size between a large effect size (34 total participants, f = .50) and a medium effect size (128 participants, f = .25) with a recruitment minimum of 30 participants per randomised condition (Wilson et al., 2006). Our final sample size of 109 exceeded the recruitment goal, and *post hoc* power calculation revealed an achieved power of 93.1% (Faul et al., 2007).

Data analysis

All analyses were performed in R (v4.3.1; R Core Team, 2021) according to the pre-registered analysis plan. We conducted intention-to-treat analyses using all available data with no imputation. For each survey outcome, we ran a 2-level linear mixed model (observations nested

within persons) with random intercepts and fixed slopes, using the *lmer* function from 'lme4' package in R (Bates et al., 2015). Unadjusted models included one between-subjects factor (condition), one within-subjects factor (time) and their interaction (condition*time) as predictors. This was repeated with minimally adjusted models, where gender and age were added into the models as covariates. Model fit was compared on the Akaike Information Criterion (AIC), with lower AIC indicating a better fit to the data. In primary outcome analysis (IPAQ MET-min/week scores, which were log transformed to better meet the assumption of normality of residuals), adding demographics did not meaningfully change model fit. In secondary outcomes, adding age and gender into models improved model fit, so we report minimally adjusted models across all outcomes for consistency. Daily diary data were prepared and analysed similarly, albeit with 'time' as a continuous predictor. Daily step count data were also log transformed for normality of residuals. Details of data preparation, model fit parameters and full reproducible code are given in Supplementary materials.

Results

Sample characteristics & fidelity

Out of 240 people screened for eligibility, 109 were randomised and 106 provided complete valid data at post-intervention follow-up (95% retention rate). Participant flow is detailed in Figure 2. The sample predominantly self-described as women (78%), the most common ethnicity was white (62%), roughly a fifth (21%) reported a long-term health condition, and the mean age was 20.8 years. Most participants had no (20%) or limited (44%) experience of mindfulness meditation. Our sample reflected the demographic profile and mindfulness skills of the studied population (Higher Education Statistics Agency, 2023). Full demographics are given in Table 1. Participants in the intervention condition (MPA; $N = 54$) opened the mindfulness mobile app on average 16.9 times ($SD = 14.5$, range 0-68) in the 30 days. They completed a median of 9.5 mindfulness sessions out of prescribed 30 (range 0-61). Notably, 14 intervention participants (27%) completed zero mindfulness sessions, while 23 (44%) completed at least half (15 sessions), 8 (15%) completed all 30 sessions and 4 participants (8%) did more than 30 by repeating at least one session (see Supplementary materials for all mindfulness app user data).

Self-reported PA & sedentary time

Total weekly PA measured in MET-min/week by the IPAQ-SF doubled in both conditions over the course of the study period (Table 2). Participants who received MPA increased their PA by an average of 1492 MET-min/week and reduced sedentary time by 18.6 hours/week, whereas control participants increased their PA by 1187 MET-min/week and reduced sitting time by 9.1 hours/week. The interaction terms were, however, not statistically significant (PA condition*time $B = 0.19$, SE = 0.21, $t(102.45) = 0.91$, $p = 0.363$, *95% CI* [-0.21, 0.60]; sedentary time $B = -0.16$, $SE = 0.09$, $t(102.06) = -1.80$, $p = 0.074$, *95% CI* [-0.34, 0.01]).

Mental health & wellbeing

Mental wellbeing

The interaction term for WEMWBS scores approached statistical significance, favouring the MPA condition (interaction B = 3.20, SE = 1.67, t(101.62) = 1.92, p = 0.058, *95% CI* [-0.07, 6.46]).

Mental health

For both conditions, mean scores for stress, depression and anxiety were all in the 'normal' range. Stress levels (MiniDASS-Stress subscale) reduced from baseline to post-intervention by similar amounts in both groups (MPA M_{diff} = -1.12; PA only M_{diff} = -0.87). There was no evidence that the magnitude of change over time in the mixed-effects models for depression and anxiety subscales of MiniDASS varied according to condition (Table 3).

Mindfulness

Trait mindfulness

PMS subscale 'awareness' showed a slight increase over time, which was comparable between conditions (MPA M_{diff} = 1.10; PA only M_{diff} = 1.03). There was no statistically significant condition by time interaction for the PMS 'acceptance' subscale scores (interaction B = 2.10, SE = 1.18, t(101.16) = 1.78, p = 0.079, *95% CI* [-0.22, 4.42]).

Mindfulness during physical activity

Levels of mindfulness during PA (MFPA) rose over time in both conditions, with no significant differences between groups (Table 2).

PA cognitions and theoretical predictors

Enjoyment of PA

PACES scores increased over the study period in both groups (MPA M_{diff} = 8.26; PA only M_{diff} = 6.30), but the condition by time interaction was not statistically significant (p = 0.713).

Exercise self-efficacy

There was no statistically significant condition by time interaction for exercise self-efficacy (ESES) scores.

Motivation for PA

The MPA condition reported higher levels of intrinsic regulation at baseline (BREQ-3 Intrinsic subscale; condition B = 1.33, SE = 0.51, t(138.75) = 2.62, p = 0.010, *95% CI* [0.34, 2.32]), although increases over time were similar between the two conditions (both groups M_{diff} = 0.77).

Behavioural predictors of PA

Participants in the MPA condition reported a significantly greater increase in behavioural intentions to be active (TPBQ-Intentions) compared to PA only participants (interaction B = 1.15, SE = 0.54, t(99.76) = 2.13, p = 0.036, *95% CI* [0.09, 2.22]). There was no evidence of differences over time in attitudes towards PA, social norms and PBC over PA engagement according to condition.

Daily diary data

The median participant responded to 27 daily diary prompts during the 30-day window (M = 24.5, SD = 6.1, range 3-30 times). Across both conditions, the number of daily steps fell by an average of 500 steps over the study period (8900 to 8400/day). Mood ratings remained stable in both groups (interaction B = -0.10, SE = 0.06, t(4823.94) = -1.70, p = 0.089, *95% CI* [-0.22, 0.02]). Daily depression ratings increased in both conditions over the course of study period, although remained in the healthy range (<30/100). Daily anxiety and stress ratings remained stable in MPA condition but reduced by an average of 10 points (on 100 scale) in PA only condition, leading to significant time-condition interaction terms (anxiety B = -0.28, SE = 0.07, t(4827.61) = -4.26, p <0.001, *95% CI* [-0.41, -0.15]; stress B = -0.46, SE = 0.07, t(4828.13) = -6.56, p <0.001, *95% CI* [-0.59, -0.32]).

Single-item PA enjoyment, confidence and motivation measured via daily EMA all significantly increased over the course of study period in both groups (Figure 3). Confidence for PA improved significantly more for MPA participants compared to PA only (interaction B = -0.01, SE = 0.00, t(2115) = -2.52, p = 0.012, *95% CI* [-0.02, -0.00]), enjoyment of PA marginally, though not statistically significantly more for MPA (B = -0.01, SE = 0.01, t(2121.73) = -1.73, p = 0.084, *95% CI* [-0.02, 0.00]), whereas the increase in motivation for PA was comparable between groups (Table 3).

Exploratory sensitivity analyses: Engaged intervention vs. control

Considering poor fidelity to mindfulness training instructions in the intervention condition, we conducted exploratory sensitivity analyses in which we compared control group participants to intervention participants who completed at least one full mindfulness training session (N = 38; leaving out 14 non-engagers). Pre-post comparisons were largely all in agreement with intention-to-treat analyses (data not shown; see Supplementary materials).

Discussion

This RCT aimed to explore the additive effects of a digital MBI tailored to promote PA engagement and enjoyment over a simple activity tracker intervention in a sample of insufficiently active university students. Based on the pre-post intervention data, self-reported PA increased, and sedentary time reduced, to a similar degree in both groups, whilst daily diary data demonstrated steps per day decrease over time in both groups, offering no support for hypothesis one. Psychological health outcomes showed partial support for hypothesis two. We observed improvements in mental wellbeing and stress in both groups but no change in depression or anxiety levels; however, mean MiniDASS scores at baseline fell in the 'normal' range for both groups, likely creating floor effects. Support for hypothesis three was also mixed: The MPA group reported stronger increases in behavioural intentions to be active when

measured pre-post intervention. Enjoyment of PA and state mindfulness during PA increased in both groups, whereas exercise self-efficacy remained largely unchanged in pre-post analyses. Daily diary data likewise found greater PA enjoyment over time in both groups, however, it also indicated increases in PA confidence and motivation, such that the MPA group reported a higher increase in confidence for PA compared to PA only group.

Self-reported PA doubled over the course of the trial period, adding the equivalent of 373 minutes of moderate-intensity PA per week in the MPA condition and 297 minutes in the control (PA only) condition. Sedentary time displayed the same trend: both groups reported substantial reductions, with MPA participants reducing sedentary time by 18.5 hours/week on average and control participants reducing by 9 hours/week. These findings align with systematic review evidence, which finds wearable-based interventions effective for increasing PA engagement in insufficiently active populations (Laranjo et al., 2021; Vetrovsky et al., 2022) and early evidence on mechanisms of mindfulness for supporting predictors of behaviour change (Remskar, Western, & Ainsworth, 2024). We observed discrepancies between trends from pre-post survey data and daily diaries (e.g., increase in self-reported PA but decrease in device-guided daily steps over time, where the latter likely represents regression to the mean following an initial increase in steps; Arigo & König, 2024; König et al., 2022). Literature syntheses find that self-report questionnaires tend to overestimate PA and underestimate sedentary time, instead recommending methods with shorter recall spans (e.g., EMA) and device-based estimates (Prince et al., 2020). In our dataset, discrepancies may partially reflect different concepts (any self-reported PA in pre-post analyses vs. steps-only in EMA) and timeframes in measurement (retrospective estimates for the past week vs. daily device-guided value), yet also emphasise the value of frequent real-time assessment for documenting trend changes (Dunton, 2017).

The trial saw comparable effects on self-reported PA in both conditions, suggesting limited added value of a tailored MBI beyond a wearable intervention with a step goal. However, the

differential changes in behavioural intentions are promising, since they are associated with long-term behaviour change and more likely to predict maintenance of PA in absence of intervention instructions (Amireault et al., 2013). Behavioural intentions are a meaningful predictor of future behaviour (Rhodes & Dickau, 2012); while the intention-behaviour gap is well-evidenced and complex (Conner & Norman, 2022), they are an appropriate proxy measure in early exploratory work in lieu of costly longitudinal objective behavioural measures.

Other theoretical predictors of PA engagement from the TPB that precede intentions (i.e., attitudes, social norms, PBC; Ajzen, 1985) did not differentially change over time according to condition, suggesting that the change in behavioural intentions arose due to factors not accounted for in the TPB model. Hall and Fong's (2007, 2010) Temporal Self-Regulation Theory offers a potential theoretical explanation: It posits that intentions arise from a 'motivational sphere of influences' on a behaviour, including expectancies and subjective valuations, but emphasises the role of ambient temporal influences (i.e., the contrast between immediate perceived costs of engaging in PA and delayed benefits). These ambient temporal factors increase reliance on self-regulatory skills to make the 'right' behavioural choice. When applied to PA promotion, authors of Temporal Self-Regulation Theory suggest that interventions increase behavioural intentions through more positive valuations, correcting the temporal disjunction between perceived costs and benefits, and enhanced executive function (P. A. Hall & Fong, 2015)—all of which our MBI was designed to do (see *Figure 1*).

Effects on mental health and wellbeing from pre-post survey measures are also discordant with those from daily diary measures. This could be due to several factors. Firstly, the low baseline scores for depression, anxiety and stress on the MiniDASS render pre-post data on mental health inconclusive, since we likely observed floor effects. Secondly, and similarly to the PA data, different timeframes of measurement may have resulted in different concepts being captured despite the same name. While single-item measures of depression and anxiety have been found

to be valid and predictive in EMA-based research (Song et al., 2023), other work has found differences between pre-post questionnaires and EMA prompts, in that EMA data were more sensitive to change (Moore et al., 2016). This could help explain our finding of increased depression in daily diary data, compared to no changes in questionnaire-based primary analyses. We speculate that slight detriments in depression, anxiety and stress observed in the daily diary dataset (which remained in the healthy range, <30/100) may have been a consequence of common extraneous contextual factors experienced by our participants (e.g., exam periods). The MPA group reported a more pronounced detriment to mental health in the daily prompts than PA group. As the only difference between groups was the presence of mindfulness training, we might infer that one impact of the mindfulness training was to decrease acute adverse mood, depression and anxiety perceptions. However, given the poor adherence the mindfulness training (discussed below), we recommend further studies verify and investigate these mechanisms. Another possible explanation is the higher participant burden in the MPA condition, who were instructed to engage in daily mindfulness sessions in addition to reaching the daily step goal. Low engagement with the tailored MBI warrants attention: Most participants never received crucial intervention content and nearly a third of MPA group participants were non-engagers, despite the iterative and person-based intervention development. Poor engagement is an issue in digital health—where one meta-analysis estimates the average adherence to digital interventions at 40% (Groot et al., 2023)—and mindfulness research more broadly (Osborne et al., 2023). On one hand, our observed engagement reflects the pragmatic nature of the trial and patterns in which self-delivered digital interventions like apps are used (Ainsworth et al., 2022; Remskar, Western, & Ainsworth, 2024). However, poor engagement could also reflect lacking interest in mindfulness training or low perceived utility in trying to reach the specific goal of 8000 steps/day. Given how straightforward the goal was, participants may have perceived the support from the wearable device—monitoring and feedback on behaviour—sufficient for achieving it.

Pursuit of more complex behavioural goals (e.g., starting an exercise habit or changing one's diet) may be more conducive to the support provided by the MBI provided here, which could be explored in future work. Future research should also try to maximise motivation for engagement, such as by clearly describing the potential of mindfulness training for health behaviour change. This approach proved valuable in previous research on digital mindfulness interventions (Ainsworth et al., 2022). Improving engagement in the mindfulness portion of multi-component interventions will enable us to better investigate its impact and mechanism for augmenting behavioural interventions.

Strengths and limitations

This study is strengthened by adhering to its pre-registered protocol, ecologically-valid intervention using commercial digital tools that were free to the user, strong retention, minimal missing outcome data, and a sample representative of the target population of UK university students. However, the trial had limitations that should be noted. Fidelity to the MBI element was suboptimal, restricting our ability to draw firm conclusions on intervention effects. The MPA group had higher intervention burden than the control group, which could have contributed to poor adherence to instructions. Alternative explanations include low perceived utility of the MBI because its potential for promoting PA and psychological health was not explicitly verbalised at enrolment—a purposeful decision taken to standardise setup appointments and minimise demand characteristics. Lastly, the daily step count data we collected was device-based but ultimately self-reported because participants were asked to report the device reading through the EMA platform. This leaves the trial dependent on self-report PA measures, which have documented validity and overreporting concerns (Prince et al., 2020; Sember et al., 2020). It also limits the types of PA we were able to detect to repetitive, step-based activities, whereas activities with other types of movement (e.g., yoga, swimming) would have gone undetected.

Conclusion

Our research evaluated the first digital intervention combining mindfulness training and behaviour change principles to promote PA engagement and enjoyment. While no significant differences in short term PA behaviour were observed relative to the control group, there were promising changes in cognitions associated with successful sustained behaviour change, most notably behavioural intentions to be physically active. Daily diary data reporting within-intervention physical activity, mental health, and behavioural cognitions did not align with the pre-post findings, showing an inverse impact on depression and physical activity. This, along with the observed sub-optimal engagement in the mindfulness training, suggests more work is needed to develop engaging mindfulness interventions and understand the mechanisms by which it can support behaviour change and wellbeing. Nevertheless, the present work helps further our understanding of the mechanisms involved in successful PA promotion and contributes to the growing interest in innovative strategies for sustained health behaviour change.

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TABLE 1: RCT sample participant characteristics by condition.

Variable		**MPA condition (N = 54)**	**PA only condition (N = 54)**	**Total (N = 108)**
Age (years)	Mean (SD)	21.6 (6.3)	20.1 (2.2)	20.8 (4.7)
	Median	20	19.5	20
	Range	18-52	18-27	18-52
Gender (n, %)	Woman	42	43	85 (79%)
	Man	10	8	18 (17%)
	Other	2	3	5 (5%)
Ethnicity (n, %)	Asian	16	10	26 (24%)
	Black	2	4	6 (6%)
	White	32	36	68 (62%)
	Mixed	4	4	8 (7%)
	Other	-	1	1 (1%)
Disability (n, %)	No	39	38	77 (71%)
	Yes	11	12	23 (21%)
	Prefer not to say	4	4	8 (7%)
Mindfulness experience (n, %)	None	12	10	22 (20%)
	Limited	21	27	48 (44%)
	Some	11	12	23 (21%)
	Moderate	9	4	13 (12%)
	Abundant	1	1	2 (2%)

Note. N = 108 at T1, N = 106 at T2, valid complete survey data N = 104. Values may not add up to 100% due to rounding.

TABLE 2: Means and standard deviations of primary and secondary trial outcomes.

		MPA					PA only					Comparison	
		Baseline (*N* = 54)		Post-intervention (*N* = 52)			Baseline (*N* = 54)		Post-intervention (*N* = 54)				
Measure	**Outcome**	**M**	**SD**	**M**	**SD**	**M diff**	**M**	**SD**	**M**	**SD**	**M diff**	**Diff of diff**	**Cohen's *d***
IPAQ-SF	PA (METmin/wk)	1165	996	2657	2302	1492	1393	1138	2580	1688	1187	305	0.14
	Sitting (hrs/wk)	61.43	25.21	42.83	15.06	-18.60	62.87	50.58	53.77	39.52	-9.09	-9.51	-0.19
WEMWBS	Wellbeing	41.70	7.95	46.35	7.95	4.65	43.85	9.28	45.45	7.10	1.60	3.04	0.36
MiniDASS	Depression	3.20	2.73	2.57	2.35	-0.64	2.74	2.75	2.36	2.60	-0.38	-0.25	-0.11
	Anxiety	3.37	2.45	3.26	2.26	-0.12	3.20	2.48	3.04	2.44	-0.17	0.05	0.02
	Stress	5.57	2.73	4.45	2.72	-1.12	4.72	3.22	3.85	2.72	-0.87	-0.25	-0.10
PMS	Awareness	37.07	4.64	38.18	5.01	1.10	35.57	6.12	36.59	5.94	1.03	0.08	0.02
	Acceptance	25.08	6.22	27.22	7.18	2.14	27.02	7.10	27.59	7.34	0.57	1.57	0.25
MFPA	Mindfulness in PA	21.52	3.90	23.04	3.68	1.52	20.32	4.18	22.04	3.55	1.72	-0.20	-0.05
PACES	Enjoyment of PA	85.59	18.43	93.84	17.54	8.26	82.06	15.38	88.36	17.25	6.30	1.95	0.12
ESES	Self-efficacy for PA	34.39	6.21	37.10	6.08	2.71	34.85	6.68	36.19	6.35	1.34	1.37	0.22
BREQ-3	Amotivation	5.82	2.06	5.56	1.96	-0.26	5.42	1.65	5.21	1.97	-0.21	-0.05	-0.02
	External	7.17	2.99	6.58	2.55	-0.59	8.23	3.32	7.53	3.12	-0.70	0.11	0.05
	Introjected	10.46	3.57	9.72	3.25	-0.74	10.55	3.26	10.62	3.16	0.08	-0.82	-0.34
	Identified	11.70	2.18	12.18	2.00	0.48	11.49	1.80	12.23	1.99	0.74	-0.26	-0.16
	Integrated	8.94	2.92	9.42	2.64	0.48	8.36	2.47	8.94	2.78	0.58	-0.11	-0.05
	Intrinsic	11.41	2.45	12.18	2.55	0.77	10.19	2.69	10.96	2.66	0.77	0	0.00
TPBQ	Attitudes	17.44	2.61	17.86	2.78	0.42	17.37	2.44	17.59	2.54	0.22	0.20	0.08
	Social norms	12.69	4.53	12.24	3.99	-0.45	14.14	4.45	14.48	4.13	0.35	-0.79	-0.21
	PBC	16.43	2.52	17.46	2.67	1.03	15.96	3.60	16.26	3.08	0.30	0.73	0.25
	Beh. intention	16.43	2.79	17.38	2.66	0.95	16.83	2.64	16.62	3.71	-0.21	1.16	0.42

Note. Cohen's d effect sizes are given for difference of differences scores. IPAQ-SF—International Physical Activity Questionnaire short form. METmin/wk—Metabolic equivalent-minutes per week. WEMWBS—Warwick-Edinburgh Mental Well-Being Scale (range 0–70, where higher scores indicate better well-being). MiniDASS—Depression, Anxiety and Stress Scales mini form (range 0–12 for each subscale, where higher

scores indicate more severe symptoms). PMS—Philadelphia Mindfulness Scale (range 10-50 for each subscale, where higher scores indicate grater awareness or acceptance, respectively). MFPA—Mindfulness in Physical Activity scale (range 5-30, where higher scores indicate greater mindfulness during physical activity). PACES—Physical ACtivity Enjoyment Scale (range 18-126, where higher scores indicate more enjoyment). ESES—Exercise Self-Efficacy Scale (range 10-50, where higher scores indicate greater self-efficacy). BREQ-3—Behavioural Regulation in Exercise Questionnaire 3rd version (range 4-16 for each subscale, where higher scores indicate stronger presence of the respective subtype of motivation). TPBQ—Theory of Planned Behaviour Questionnaire (range 3-24 for each subscale, where higher score indicate stronger behavioural predictors). PBC—Perceived behavioural control.

TABLE 3: Model estimates for primary, secondary and daily diary outcomes.

Measure	Outcome	Effect	B Estimate	SE	df	t	P value	95% CI	Effect size (η^2)
Primary pre-post outcomes									
IPAQ-SF	Physical activity (MET-min/wk)[a]	Intercept	6.78	0.40	107.28	17.10	<0.001	6.01-7.55	
		Condition	-0.23	0.18	187.79	-1.32	0.189	-0.56-0.11	0.52
		Time	0.72	0.15	101.05	4.89	<0.001***	0.43-1.00	0.99
		Gender	0.03	0.19	100.14	0.16	0.872	-0.33-0.39	0.03
		Age	0.00	0.02	100.22	0.32	0.752	-0.02-0.03	0.11
		Condition*Time	0.19	0.21	102.45	0.91	0.363	-0.21-0.60	
IPAQ-SF	Sitting (hrs/wk)	Intercept	4.09	0.20	105.65	20.82	<0.001	3.70-4.47	
		Condition	0.03	0.08	173.97	0.33	0.741	-0.13-0.19	0.16
		Time	-0.17	0.06	101.66	-2.58	0.011*	-0.29- -0.04	0.90
		Gender	-0.06	0.09	102.10	-0.67	0.506	-0.24-0.12	0.12
		Age	-0.00	0.01	100.68	-0.15	0.879	-0.02-0.01	0.01
		Condition*Time	-0.16	0.09	102.06	-1.80	0.074	-0.34-0.01	
WEMWBS	Wellbeing	Intercept	49.40	3.90	106.00	12.66	<0.001	41.83-56.97	
		Condition	-1.86	1.59	164.89	-1.17	0.246	-4.94-1.23	0.01
		Time	1.54	1.17	100.86	1.32	0.191	-0.76-3.83	0.79
		Gender	-1.82	1.87	102.78	-0.97	0.332	-5.44-1.80	0.20
		Age	-0.20	0.15	100.82	-1.30	0.196	-0.49-0.10	0.32
		Condition*Time	3.20	1.67	101.62	1.92	0.058	-0.07-6.46	
MiniDASS	Depression	Intercept	2.20	1.30	104.55	1.69	0.094	-0.33-4.73	
		Condition	0.38	0.51	150.08	0.73	0.464	-0.62-1.37	0.24
		Time	-0.34	0.33	100.68	-1.02	0.310	-0.99-0.31	0.89
		Gender	0.18	0.62	101.30	0.29	0.772	-1.03-1.39	0.13
		Age	0.02	0.05	101.37	0.37	0.710	-0.08-0.12	0.20
		Condition*Time	-0.36	0.48	101.66	-0.76	0.452	-1.29-0.58	
MiniDASS	Anxiety	Intercept	2.57	1.21	103.05	2.14	0.035	0.24-4.91	
		Condition	0.28	0.47	146.63	0.58	0.561	-0.64-1.19	1.00
		Time	-0.13	0.29	99.25	-0.43	0.669	-0.71-0.46	1.00
		Gender	1.16	0.58	99.98	2.02	0.046*	0.05-2.28	1.00
		Age	-0.02	0.05	100.04	-0.38	0.708	-0.11-0.07	1.00
		Condition*Time	-0.01	0.43	100.20	-0.02	0.982	-0.85-0.83	

MiniDASS	Stress	Intercept	3.35	1.42	104.29	2.36	0.020	0.60-6.09	
		Condition	0.83	0.56	148.89	1.50	0.137	-0.25-1.91	0.71
		Time	-0.77	0.36	100.45	-2.15	0.034*	-1.47- -0.07	0.96
		Gender	0.98	0.68	101.12	1.46	0.149	-0.33-2.30	0.76
		Age	0.02	0.05	101.19	0.45	0.653	-0.08-0.13	0.24
		Condition*Time	-0.41	0.51	101.42	-0.81	0.422	-1.41-0.59	
Secondary pre-post outcomes									
PMS	Awareness	Intercept	31.72	2.81	103.79	11.29	<0.001	26.26-37.16	
		Condition	1.32	1.08	137.24	1.23	0.222	-0.77-3.41	0.98
		Time	1.01	0.60	100.29	1.69	0.095	-0.16-2.18	0.99
		Gender	2.11	1.35	101.49	1.57	0.119	-0.50-4.72	0.98
		Age	0.10	0.11	101.52	0.96	0.339	-0.11-0.32	0.96
		Condition*Time	0.17	0.86	101.06	0.20	0.846	-1.51-1.84	
PMS	Acceptance	Intercept	28.86	3.53	104.27	8.18	<0.001	22.02-35.71	
		Condition	-2.04	1.38	144.74	-1.49	0.140	-4.71-0.62	0.17
		Time	0.37	0.82	99.92	0.45	0.655	-1.24-1.98	0.65
		Gender	-1.32	1.69	101.49	-0.78	0.435	-4.60-1.95	0.16
		Age	-0.04	0.14	101.61	-0.26	0.795	-0.30-0.23	0.02
		Condition*Time	2.10	1.18	101.16	1.78	0.079	-0.22-4.42	
MFPA	Mindfulness in PA	Intercept	20.61	1.91	104.81	10.81	<0.001	16.91-24.31	
		Condition	1.19	0.77	158.23	1.56	0.122	-0.29-2.67	0.92
		Time	1.88	0.54	99.73	3.31	0.001**	0.72-2.82	0.99
		Gender	0.01	0.91	102.03	0.01	0.994	-1.77-1.78	0.00
		Age	-0.01	0.07	100.23	-0.20	0.843	-0.16-0.13	0.17
		Condition*Time	-0.34	0.77	100.83	-0.44	0.662	-1.83-1.17	
PACES	Enjoyment of PA	Intercept	84.66	8.68	103.20	9.76	<0.001	67.84-101.50	
		Condition	3.67	3.45	149.13	1.07	0.289	-3.01-10.36	0.93
		Time	6.15	2.26	98.18	2.72	0.008**	1.72-10.57	0.99
		Gender	1.34	4.16	99.97	0.32	0.749	-6.74-9.40	0.43
		Age	-0.17	0.33	98.29	-0.51	0.613	-0.82-0.48	0.65
		Condition*Time	1.19	3.22	98.51	0.37	0.713	-5.10-7.53	
ESES	Self-efficacy for PA	Intercept	39.80	3.11	105.79	12.81	<0.001	33.77-45.82	
		Condition	-0.39	1.24	156.26	-0.32	0.753	-2.79-2.01	0.06
		Time	1.19	0.85	100.85	1.40	0.165	-0.48-2.84	0.88
		Gender	-0.77	1.49	103.21	-0.52	0.606	-3.66-2.11	0.16
		Age	-0.20	0.12	101.46	-1.70	0.092	-0.44-0.03	0.68

		Condition*Time	1.43	1.21	101.91	1.18	0.241	-0.94-3.81	
BREQ-3	Amotivation	Intercept	7.42	0.89	105.72	8.34	<0.001	5.69-9.15	
		Condition	0.50	0.37	171.30	1.34	0.183	-0.22-1.21	0.91
		Time	-0.20	0.29	101.26	-0.68	0.495	-0.75-0.36	0.92
		Gender	-0.82	0.42	100.60	-1.94	0.055	-1.64-0.00	0.96
		Age	-0.07	0.03	100.62	-1.90	0.060	-0.13-0.00	0.95
		Condition*Time	-0.17	0.41	102.07	-0.42	0.678	-0.97-0.63	
BREQ-3	External	Intercept	10.66	1.55	102.94	6.88	<0.001	7.66-13.67	
		Condition	-0.82	0.59	135.88	-1.39	0.167	-1.97-0.33	1.00
		Time	-0.64	0.33	99.24	-1.96	0.053	-1.29-0.00	1.00
		Gender	-0.48	0.74	100.72	-0.65	0.517	-1.93-0.96	0.99
		Age	-0.11	0.06	100.73	-1.75	0.083	-0.22-0.01	1.00
		Condition*Time	-0.04	0.47	99.72	-0.08	0.939	-0.96-0.89	
BREQ-3	Introjected	Intercept	7.90	1.72	102.64	4.58	<0.001	4.55-11.25	
		Condition	-0.12	0.65	130.41	-0.18	0.854	-1.39-1.15	0.22
		Time	0.06	0.34	98.96	0.17	0.867	-0.60-0.71	0.41
		Gender	0.70	0.83	100.79	0.85	0.398	-0.90-2.31	0.25
		Age	0.10	0.07	100.80	1.47	0.144	-0.03-0.23	0.50
		Condition*Time	-0.71	0.48	99.38	-1.48	0.142	-1.65-0.23	
BREQ-3	Identified	Intercept	9.64	1.01	101.05	9.55	<0.001	7.68-11.60	
		Condition	0.13	0.39	139.83	0.33	0.742	-0.63-0.89	0.00
		Time	0.68	0.23	97.30	2.93	0.004**	0.23-1.14	0.94
		Gender	0.70	0.48	98.42	1.45	0.151	-0.24-1.64	0.75
		Age	0.06	0.04	98.43	1.57	0.119	-0.01-0.14	0.78
		Condition*Time	-0.27	0.33	97.85	-0.83	0.411	-0.93-0.38	
BREQ-3	Integrated	Intercept	8.38	1.44	102.20	5.84	<0.001	5.60-11.17	
		Condition	0.54	0.54	128.83	1.00	0.321	-0.51-1.59	0.92
		Time	0.57	0.27	98.51	2.09	0.039*	0.04-1.11	0.99
		Gender	-0.45	0.69	100.43	-0.66	0.511	-1.79-0.88	0.84
		Age	0.02	0.06	100.44	0.33	0.746	-0.09-0.13	0.57
		Condition*Time	-0.11	0.39	98.92	-0.28	0.778	-0.87-0.65	
BREQ-3	Intrinsic	Intercept	10.79	1.32	103.21	8.16	<0.001	8.23-13.36	
		Condition	1.33	0.51	138.75	2.62	0.010**	0.34-2.32	0.94
		Time	0.88	0.30	99.49	3.01	0.003**	0.31-1.46	0.97
		Gender	-0.16	0.63	100.80	-0.25	0.800	-1.39-1.07	0.14
		Age	-0.03	0.05	100.81	-0.54	0.589	-0.13-0.07	0.42

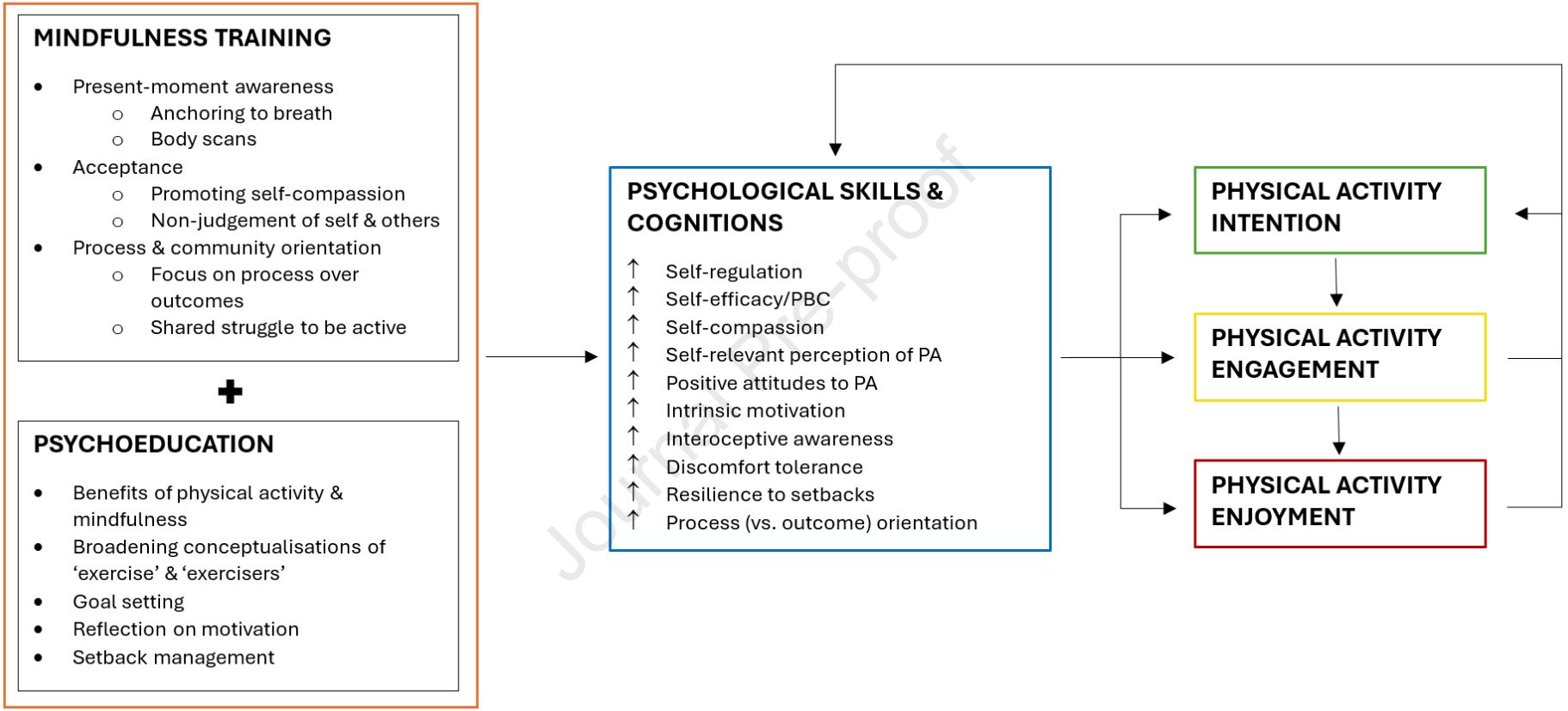
		Condition*Time	-0.27	0.42	100.00	-0.64	0.524	-1.08-0.55	
TPBQ	Attitudes	Intercept	15.33	1.26	103.56	12.18	<0.001	12.89-17.78	
		Condition	-0.07	0.51	161.90	-0.14	0.887	-1.06-0.92	0.08
		Time	0.21	0.37	98.23	0.57	0.573	-0.52-0.93	0.97
		Gender	0.32	0.60	100.43	0.54	0.593	-0.85-1.49	0.90
		Age	0.09	0.05	98.54	1.84	0.069	-0.01-0.18	0.99
		Condition*Time	0.10	0.53	99.39	0.18	0.856	-0.94-1.14	
TPBQ	Social norms	Intercept	14.38	2.20	102.48	6.52	<0.001	10.09-18.65	
		Condition	-1.34	0.86	143.08	-1.56	0.122	-3.00-0.33	0.80
		Time	0.28	0.53	97.69	0.53	0.594	-0.75-1.33	0.10
		Gender	-0.03	1.06	101.67	-0.03	0.978	-2.09-2.03	0.00
		Age	-0.02	0.06	99.08	-0.18	0.856	-0.18-0.15	0.02
		Condition*Time	-0.86	0.75	97.63	-1.15	0.255	-2.33-0.61	
TPBQ	PBC	Intercept	16.37	1.50	105.94	10.95	<0.001	13.47-19.27	
		Condition	0.39	0.59	154.24	0.65	0.515	-0.77-1.54	0.57
		Time	0.22	0.40	100.19	0.55	0.587	-0.57-1.00	0.73
		Gender	-0.53	0.72	104.25	-0.73	0.465	-1.92-0.87	0.28
		Age	0.01	0.06	100.76	0.10	0.920	-0.11-0.12	0.01
		Condition*Time	0.68	0.57	100.87	1.19	0.238	-0.43-1.80	
TPBQ	Behavioural intentions	Intercept	14.58	1.50	103.42	9.72	<0.001	11.67-17.50	
		Condition	-0.49	0.59	148.00	-0.83	0.408	-1.63-0.65	0.01
		Time	-0.28	0.38	98.79	-0.74	0.462	-1.02-0.46	0.21
		Gender	0.83	0.72	101.28	1.16	0.251	-0.56-2.23	0.23
		Age	0.08	0.06	99.68	1.32	0.190	-0.04-0.19	0.28
		Condition*Time	1.15	0.54	99.76	2.13	0.036	0.09-2.22	
Daily diary outcomes									
Steps/day[a]		Intercept	8.80	0.16	93.81	54.36	<0.001	8.49-9.12	
		Condition	-6.93e-03	6.19e-02	140.40	-0.11	0.911	-0.13-0.11	0.41
		Intervention day	-2.61e-03	1.30e-03	4285.00	-2.01	0.045*	-0.01-0.00	1.00
		Gender	0.05	0.08	91.51	0.76	0.449	-0.09-0.20	0.97
		Age	6.10e-03	5.95e-03	90.70	1.02	0.309	-0.01-0.02	0.98
		Condition*Intday	2.47e-04	1.85e-03	4280.00	0.13	0.894	-0.00-0.00	
Mood		Intercept	72.24	7.09	96.12	10.19	<0.001	58.50-85.99	
		Condition	4.07	2.60	122.52	1.56	0.121	-0.98-9.11	0.46
		Intervention day	0.02	0.04	4835.77	0.29	0.772	-0.07-0.10	0.37

	Gender	-4.69	3.31	94.80	-1.42	0.160	-11.11-1.73	0.41
	Age	-0.30	0.26	94.50	-1.13	0.260	-0.80-0.21	0.31
	Condition*Intday	-0.10	0.06	4823.94	-1.70	0.089	-0.22-0.02	
Depressed	Intercept	17.82	8.30	95.27	2.15	0.034	1.73-33.91	
	Condition	-1.19	3.00	115.07	-0.40	0.693	-7.01-4.64	0.26
	Intervention day	0.10	0.04	4831.85	2.29	0.022*	0.01-0.19	0.97
	Gender	6.83	3.88	94.28	1.76	0.092	-0.69-14.36	0.87
	Age	0.13	0.31	94.04	0.43	0.672	-0.46-0.72	0.29
	Condition*Intday	0.04	0.06	4830.87	0.67	0.502	-0.08-0.16	
Anxious	Intercept	19.00	10.41	95.75	1.83	0.071	-1.19-39.19	
	Condition	3.93	3.72	109.34	1.06	0.292	-3.27-11.14	0.06
	Intervention day	0.06	0.05	4828.57	1.39	0.163	-0.03-0.15	0.22
	Gender	11.09	4.87	95.06	2.28	0.025*	1.64-20.54	0.22
	Age	0.25	0.39	94.89	0.66	0.513	-0.49-1.00	0.02
	Condition*Intday	-0.28	0.07	4827.61	-4.26	<0.001***	-0.41- -0.15	
Stressed	Intercept	21.03	10.49	95.09	2.01	0.048	0.70-41.37	
	Condition	5.63	3.76	110.41	1.50	0.137	-1.65-12.92	0.05
	Intervention day	0.22	0.05	4829.12	4.52	<0.001***	0.12-0.32	0.00
	Gender	9.60	4.91	94.32	1.96	0.053	0.08-19.12	0.08
	Age	0.35	0.39	94.12	0.91	0.365	-0.40-1.10	0.02
	Condition*Intday	-0.46	0.07	4828.13	-6.56	<0.001***	-0.59- -0.32	
PA enjoyment	Intercept	5.52	0.55	78.32	10.05	<0.001	4.45-6.58	
	Condition	0.02	0.21	109.28	0.09	0.933	-0.39-0.42	0.00
	Intervention day	0.02	0.00	2120.87	5.71	<.001***	0.01-0.03	0.93
	Gender	-0.00	0.26	83.06	-0.01	0.995	-0.51-0.51	0.00
	Age	-0.02	0.02	74.40	-1.17	0.247	-0.06-0.02	0.31
	Condition*Intday	-0.01	0.01	2121.73	-1.73	0.084	-0.02-0.00	
PA confidence	Intercept	5.82	0.59	86.05	9.94	<0.001	4.69-6.96	
	Condition	0.13	0.22	110.70	0.60	0.550	-0.29-0.55	0.05
	Intervention day	0.01	0.00	2114.00	3.45	0.001***	0.01-0.02	0.43
	Gender	-0.40	0.28	90.50	-1.43	0.156	-0.94-0.14	0.25
	Age	-0.01	0.02	82.28	-0.61	0.545	-0.05-0.03	0.06
	Condition*Intday	-0.01	0.00	2115.00	-2.52	0.012*	-0.02- -0.00	
PA motivation	Intercept	4.73	0.61	83.21	7.79	<0.001	3.55-5.90	
	Condition	0.12	0.23	115.30	0.51	0.614	-0.33-0.56	0.16
	Intervention day	0.02	0.00	2123.00	4.41	<0.001***	0.01-0.03	0.95

Gender	0.04	0.29	88.19	0.14	0.890	-0.52-0.60	0.01
Age	0.00	0.02	79.13	0.17	0.865	-0.04-0.05	0.02
Condition*Intday	-0.00	0.01	2124.00	-1.16	0.245	-0.02-0.01	

Note. IPAQ-SF—International Physical Activity Questionnaire short form. METmin/wk—Metabolic equivalent-minutes per week. WEMWBS—Warwick-Edinburgh Mental Well-Being Scale. MiniDASS—Depression, Anxiety and Stress Scales mini form. PMS—Philadelphia Mindfulness Scale. MFPA—Mindfulness in Physical Activity scale. ESES—Exercise Self-Efficacy Scale. BREQ-3—Behavioural Regulation in Exercise Questionnaire 3rd version. TPBQ—Theory of Planned Behaviour Questionnaire. PBC—Perceived behavioural control. Condition was coded as follows for the main analyses [0 = PA only; 1 = MPA], whereas the coding of condition was reversed for the EMA/daily diary analyses [1 = MPA; 2 = PA only]. [a]Data were log-transformed to meet the assumption of normality of residuals. * denotes $p < 0.01$. ** denotes $p < .01$. *** denotes $p < .001$. See supplementary materials for model building and fit parameters.

FIGURE 1. Hypothesised theory of change for the tailored mindfulness intervention promoting physical activity engagement and enjoyment.



Note. Drawing on Schuman-Olivier and colleagues (2020), Hall and Fong (2007, 2015), Ajzen (1985), Remskar and colleagues (2022, 2024). PA—physical activity. PBC—perceived behavioural control.

FIGURE 2. CONSORT diagram of recruitment and retention during the trial.

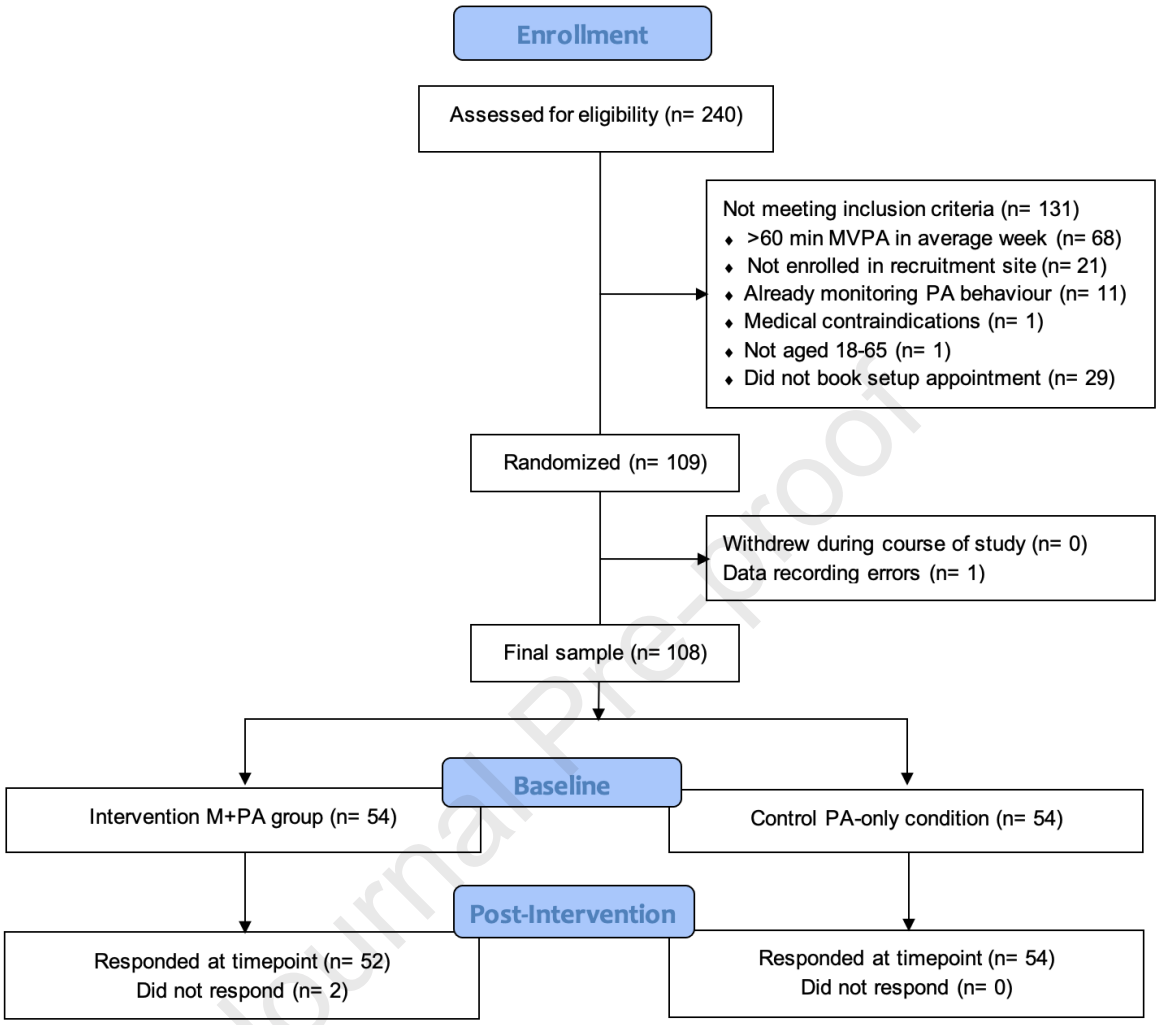
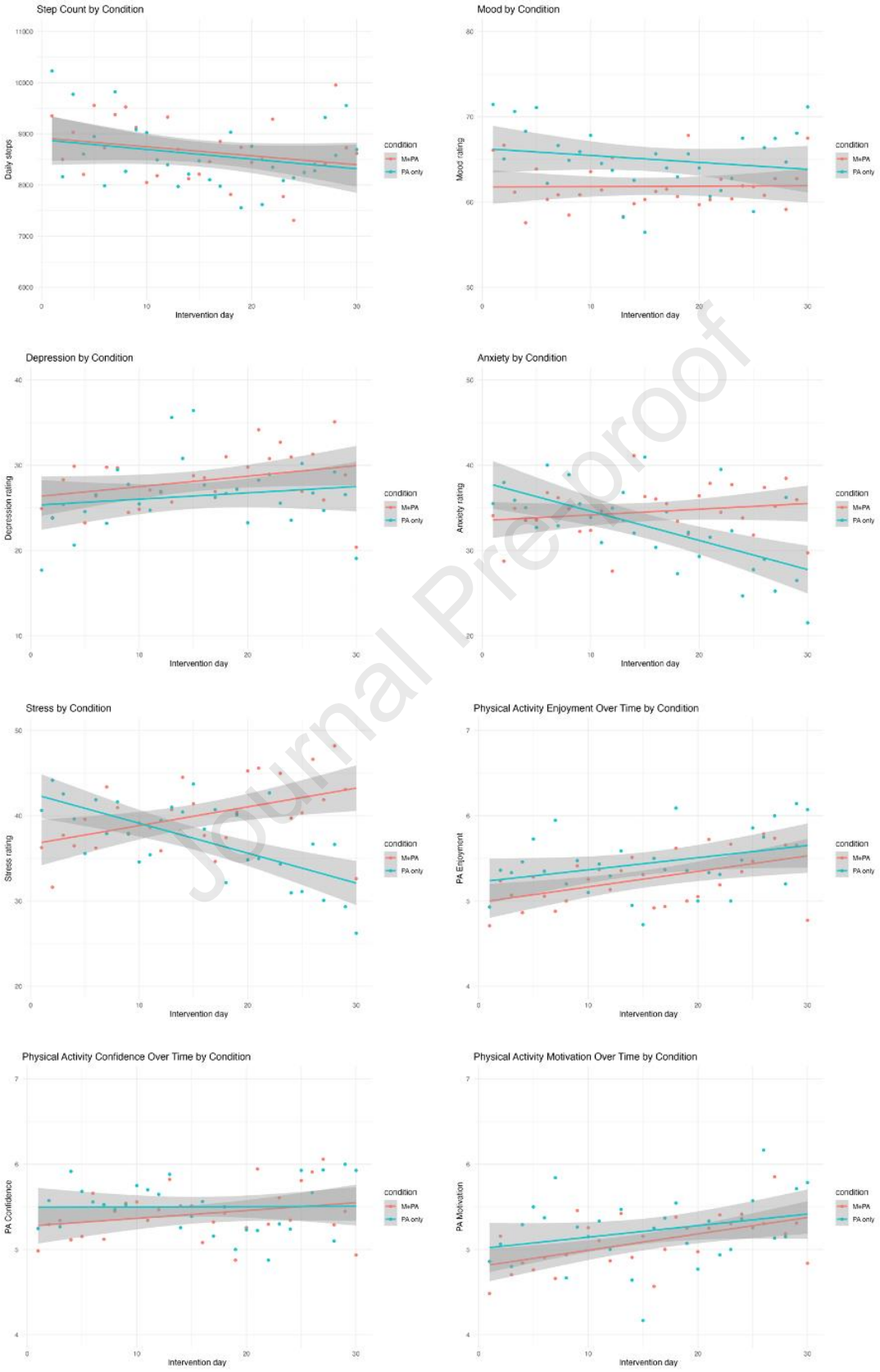


FIGURE 3. Graphs of daily diary outcomes during the trial.



Highlights:

- Tests the first digital mindfulness intervention supporting physical activity
- Multi-method approach: pre-post surveys and daily ecological momentary assessments
- No short-term activity increase, but stronger intentions compared to active control
- Helps detangle mechanisms and time dynamics of physical activity behavior change

Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Masha Remskar reports financial support was provided by UK Research and Innovation Economic and Social Research Council. MR previously served as non-compensated Medito Foundation's Research Officer and is a non-compensated member of Medito Foundation's Scientific Advisory Board. BA is a non-compensated member of Medito Foundation's Scientific Advisory Board. Medito Foundation had no input into design, access to data beyond anonymous app metrics, analysis or interpretation of, nor the decision to submit for publication, although were asked to provide information for the manuscript. Other authors declare no conflicts of interest. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.