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Does mindfulness practice promote psychological functioning or is it the other way around? A daily diary study

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Abstract

Mindfulness-based interventions are commonly used to reduce psychological symptoms and enhance positive qualities of human functioning. However, the influence of mindfulness practice dosage remains poorly understood, limiting dissemination and implementation efforts. The current study examined the association between practice dosage and several constructs related to psychological functioning (positive and negative affect, state mindfulness) over the course of a standardized mindfulness-based intervention (Mindfulness-Oriented Recovery Enhancement). Twenty-five participants completed daily diary assessments for 12 weeks. Two-part gamma regression models examined the dichotomous (did practice occur?) and continuous (how much practice?) components of practice minutes. Practice time and outcomes showed same day relationships in the expected directions. Lagged models, however, showed no evidence that current day practice time predicts subsequent day outcomes. In contrast, higher current day negative affect predicted less subsequent day practice time and higher current day mindfulness predicted more subsequent day practice time. In a *post hoc* analysis, practice time moderated the link between day-to-day affect, strengthening the link for positive affect and weakening the link for negative affect. Collectively, these findings suggest that the causal direction linking practice time and outcome may flow from outcome to practice time, rather than the reverse – with potential recursive relationships between these factors. Further examination of lagged relationships between

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practice time and outcome as well as random assignment of participants to varying practice dosages (e.g., in within-person micro-randomized trials) may help clarify the influence of this central treatment ingredient within mindfulness-based interventions.

Keywords

mindfulness; meditation; mindfulness-oriented recovery enhancement; practice time; psychological health

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Mindfulness meditation and mindfulness-based interventions (MBIs) have become increasingly visible in the past several decades (Wieczner, 2016). Coupled with an exponential increase in scientific work on mindfulness (Goldberg, 2018; Van Dam et al., 2018), use of meditation in the United States tripled between 2012 and 2017, with 14.2% of adults reporting past year use (Clarke, Barnes, Black, Stussman, & Nahin, 2018). Several large-scale meta-analyses of randomized clinical trials testing MBIs have documented the benefits of these approaches on psychological symptoms (e.g., depression, anxiety) in clinical and non-clinical samples (Goldberg et al., 2018; Khoury et al., 2015). Likewise, meta-analytic evidence supports the potential of meditation to promote various aspects of psychological flourishing, including enhanced positive emotions, empathy, well-being, and compassion (Donald et al., 2019; Sedlmeier et al., 2012). Although this body of research is not without its limitations (e.g., difficulties in defining mindfulness, use of small sample sizes, lack of follow-up assessment; Goldberg et al., 2017; Van Dam et al., 2018), mindfulness-based interventions appear to confer a variety of psychological benefits.

The rise in scientific and popular interest MBIs have enjoyed in the past several decades has been mirrored by a dramatic increase in interest in positive psychology generally (Bolier et al., 2013; Seligman, Steen, Park, & Peterson, 2005). Positive psychology has been defined as “the study of positive emotion, positive character, and positive institutions” (Seligman et al., 2005, p. 410). This subfield is broadly interested in human flourishing, a multicomponent construct which includes the promotion of physical and mental health along with happiness and life satisfaction, meaning and purpose, character and virtue (i.e., character strengths such as wisdom and kindness), and close social relationships (VanderWeele, 2017). There are strong theoretical and empirical ties between mindfulness, positive psychology, and human flourishing (Niemiec, Rashid, & Spinella, 2012). Although often focused on the treatment of mental and physical illness (Goldberg et al., 2018), robust evidence suggests that MBIs indeed promote flourishing through increasing quality of life and positive affect (de Vibe, Bjørndal, Tipton, Hammerstrøm, & Kowalski, 2012; Goyal et al., 2014), strengthening social connections (Lindsay, Young, Brown, Smyth, & Creswell, 2019), and cultivating character strengths such as kindness and prosociality (Donald et al., 2019). Theorists have argued that positive psychological processes (e.g., self-regulation, curiosity, gratitude, positive reappraisal, savoring) may both promote and be promoted by mindfulness practice (Garland, Farb, Goldin, & Fredrickson, 2015; Niemiec et al., 2012). As MBIs are derived primarily from contemplative practices drawn from Buddhist traditions (Harrington & Dunne, 2015) rather than the contemporary positive psychology movement (e.g., Seligman & Csikszentmihalyi, 2000), they are sometimes (e.g., Sin & Lyubomirsky, 2009) but not always (e.g., Bolier et al., 2013) viewed as positive psychological interventions.

Regardless of whether MBIs are categorized as positive psychological interventions or not, empirical evidence supporting the efficacy of MBIs has encouraged researchers to begin focusing on dissemination and identifying mechanisms of change in MBIs (Wielgosz, Goldberg, Kral, Dunne, & Davidson, 2019). A key mechanism of action in MBIs is practice. MBIs typically recommend substantial home meditation practice. Both Mindfulness-Based Cognitive Therapy (MBCT; Segal, Williams, & Teasdale, 2013) and Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, 2013) recommend 45 minutes per day, six days per week. While this dosage of home practice has long been the standard recommendation within many MBIs (e.g., Kabat-Zinn, 1982), to our knowledge, there is not an established empirical rationale for this specific amount, nor has the amount of practice necessary for addressing specific clinical concerns or achieving clinical benefits been systematically evaluated. Nonetheless, home practice is emphasized in MBIs and thought to support development of psychological capacities presumed to underlie the efficacy of MBIs (e.g., increased meta-awareness, nonreactivity to experience, dereification of thought and perception; Wielgosz et al., 2019). A recent meta-analysis ($k = 43$ studies) evaluated home practice in MBIs (Parsons, Crane, Parsons, Fjorback, & Kuyken, 2017). The majority of studies reviewed asked participants to practice the standard 45 minutes per day, six days per week, while 10 studies recommended a lower dosage of home practice (average across the 10 studies was 30 minutes per day, six days per week). In support of the notion that home practice is important for producing beneficial effects within MBIs, Parsons et al. found a positive correlation between total amount of mindfulness practice and pre- to post-treatment symptom improvement ($r = .26$) across 28 studies that provided relevant data. Similar magnitude correlations were found across both clinical ($r = .22$) and non-clinical samples ($r = .29$). Practice has also been linked to decreased inflammatory biomarkers (Rosenkranz et al., 2013), lower perceived stress, and decreased behaviorally-assessed mind wandering within MBIs delivered online (Bennike, Wieghorst, & Kirk, 2017; Morledge et al., 2013), although other studies show no practice-outcome relationship (e.g., Bondolfi et al., 2010). Mindfulness practice is thought to produce clinical benefits and engender increased mindfulness in everyday life (e.g., dispositional mindfulness) by inducing the state of mindfulness during mindfulness practice sessions, and indeed, longitudinal data support this notion (Kiken, Garland, Bluth, Palsson, & Gaylord, 2015). In turn, mindfulness practice is hypothesized to facilitate psychological flourishing by modulating the system dynamics of affective experience, stimulating self-reinforcing cycles of positive emotional states and disrupting the accretion of momentary negative emotions into enduring dysphoric mood (Garland et al., 2010). According to the Mindfulness-to-Meaning Theory (Garland et al., 2015), by virtue of the cognitive-affective mechanisms of mindfulness (e.g., enhanced regulation of attention, affective appraisal, and interoceptive awareness), the practice of focusing mindful awareness on positive emotions in one moment is thought to beget increased positive emotions in the next moment (an *upward spiral*), whereas focusing mindfulness on negative emotions in one moment is thought to dampen positive emotions in the next (a *downward spiral*).

Yet despite a positive association between participants' total amount of practice and outcomes within MBIs (Parsons et al., 2017), a causal relationship between practice time on outcomes has not been established. The dosage recommendations made in many MBIs (e.g., as much as 45 minutes per day) are based on experience and clinical judgment but have not been evaluated empirically. Clarifying the relationship between practice and outcomes is important for three reasons. First, the causal direction linking practice time and outcomes may be opposite of what is hypothesized. Specifically, increased practice time may be a consequence of benefitting from MBIs (e.g., due to expectancy, social support, therapeutic alliance, or in-session mindfulness meditation practice; Goldberg, Davis, & Hoyt, 2013; Imel, Baldwin, Bonus, & MacCoon, 2008). Individuals benefiting from MBIs may find practice easier and less aversive (i.e., a less unpleasant internal experience). Further, individuals benefiting from MBIs may be more likely to comply with practice requirements due to increased treatment "buy-in" (i.e., greater agreement on the task of the MBI; Horvath & Greenberg, 1989). Second, a lack of understanding of how practice time and outcomes relate (see Segal, Dimidjian, Vanderkruik, & Levy, 2019) may limit efforts to clarify the optimal dosage of practice within MBIs. These efforts are crucial as overly burdensome practice time requirements may limit the acceptability and feasibility of MBIs. Third, dosage may be particularly relevant for implementation of MBIs via mobile health technology (e.g., smartphone- and web-based platforms; Riley et al., 2011) because practice is a central component (in the absence of other treatment ingredients, e.g., fellow group members; Imel et al., 2008).

Research moving beyond mere associations between practice time and pre-post outcomes are rare within the mindfulness research literature. One recent study randomly assigned participants ($n = 77$) to two dosages (10 or 20 minutes per day) of a two-week MBI, finding no significant differences in outcomes between the groups (Berghoff, Wheeless, Ritzert, Wooley, & Forsyth, 2017). Two other studies experimentally manipulated dosage within similar interventions. Adams et al. (2018) randomly assigned 64 adults with hypertension to three dosages of breathing awareness meditation (5, 10, or 15 minutes, twice daily) delivered via a smartphone app. Dosage was positively associated with decreases in systolic blood pressure at both three- and six-month follow-up. Greenberg et al. (2018) randomly assigned 84 stressed participants to three home practice conditions (60, 150, or 240 minutes per week) within a yoga-based mind-body intervention, finding significant stress reduction only within the high dose condition (although no time by group differences between groups).

Assessing the Practice Time – Outcome Relationship Using Longitudinal Data

Experimental manipulation of practice time is one approach to clarifying the practice-outcome relationship. Another approach is a longitudinal analysis of the interrelationship between practice and outcomes over the course of MBIs. Similar analyses have been used to understand key inter-session (i.e., between session) processes in psychotherapy such as the alliance-outcome relationship in psychotherapy (e.g., Falkenström, Granström, & Holmqvist, 2013; Flűckiger, Del Re, Wampold, & Horvath, 2018; Zilcha-Mano, 2017). Models examining inter-session processes can help clarify the development of and interplay between variables such as alliance and outcome that may impact each other (Falkenström et al., 2013).

Lagged models.

Models examining the interplay between inter-session variables can specifically provide evidence to assist with causal inferences (Bollen & Curran, 2006; Falkenström et al., 2013). One family of models that can be used to explore how two variables relate to one another over time is the lagged model. Lagged models typically involve predicting a dependent variable of interest measured at a future time point (e.g., tomorrow, $t + 1$) from that same variable and a predictor of interest measured at a current time point (e.g., today, t). In the present study, that would mean tomorrow's ($t + 1$) outcomes predicted by today's (t) practice time controlling for today's outcomes. Similarly, if considering practice time to be the dependent variable of interest, a model could predict tomorrow's practice time from today's outcomes controlling for today's practice time.[1] Experimental manipulation of dose of practice provides stronger evidence of causality than observing how practice time is related to outcomes over time. Nevertheless, studying whether there is a relationship between practice and outcomes across time is a necessary aspect of understanding the causal relationships (Shadish, Cook, & Campbell, 2002). Furthermore, manipulating dosage of practice typically limits researchers to studying two to three dosage values and researchers may not have good correlational evidence to help support what dosages are best. Allowing participants to practice at whatever rate they wish should increase variability and help establish the dosage levels that are most related to positive outcomes. To our knowledge, no prior studies have applied these methods to evaluate the practice-outcome relationship in MBIs.

Current Study

The current study sought to disentangle the relationship between practice time and outcomes[2] using intensively sampled longitudinal data collected over the course of a twelve-week, standardized MBI based on a combination of mindfulness techniques, cognitive-behavioral therapy, and positive psychology (Mindfulness-Oriented Recovery Enhancement [MORE]; Garland, 2013). Due to the expectation that practice time would be positively skewed (i.e., large number of zeros when no meditation occurred akin to physical activity; Baldwin, Fellingham, & Baldwin, 2016), we used a two-part longitudinal model (see Method section). Due to prior evidence that meditation practice may reduce psychological symptoms (Goldberg et al., 2018) as well as promote flourishing (Garland, Farb, Goldin, & Fredrickson, 2015; Sedlmeier et al., 2012), outcomes examined included both negative and positive affect as well as state mindfulness. We aimed to evaluate both same-day and lagged relationships between practice time and outcomes in order to clarify potential causal linkages between these constructs. We also examined the degree to which practice time moderates the relationship between current day and subsequent day affect.

[1]Simultaneously estimating both lagged models produces a cross-lagged model (Bollen & Curran, 2006). Unfortunately, a cross-lagged model was not possible in this study due to the zero-inflated nature of the practice time data (see Methods).
[2]We refer to positive and negative affect and state mindfulness as "outcomes," although they could also be conceptualized as process variables within MORE.

Given the lack of previous literature linking practice time and outcomes on a daily basis within MBIs, we made no *a priori* hypotheses. Rather, models were considered exploratory; results should therefore be considered as such and re-examined in future studies.

Method

Participants and Procedure

Participants were social work undergraduate and graduate students enrolled in a semester-long course designed to train clinicians to deliver the MORE intervention at a large, Western university. The course was not required but rather offered as an elective. Data were collected from one course offering. The study was presented as an opportunity to evaluate the impact of the course on student well-being. All eligible participants (n = 25) provided written consent for their data to be used for research purposes. As part of the course, students were graded on entering daily diary data into an electronic spreadsheet and encouraged to practice mindfulness. Students were not graded on the amount of mindfulness practice in which they engaged at home. Students were informed that participation in this study was completely voluntary and consent to participate in no way affected their grade or participation in the course. Data were not analyzed during the course and de-identified data were only analyzed long after course completion.

Although a modest sample size for person-level analyses, our use of longitudinal data is more akin to 25 single-subject design studies due to the daily sampling of practice time and outcomes. Study procedures were approved by the relevant Institutional Review Board. The sample was on average 33.8 years old (SD = 9.1) and included 19 women and 6 men. Sample race/ethnicity was: 18 white, 1 Latino, 2 Asian American, 1 African American, and 3 other race/ethnicity.

The MORE training course was delivered over twelve weeks and included the typical therapeutic content from the MORE treatment manual (Garland, 2013), along with in-depth didactic coverage of theory and empirical evidence in support of the intervention. MORE unites aspects of MBIs, third-wave cognitive behavioral therapies, and principles from positive psychology (Garland, 2013; Garland et al., 2014). MORE has shown promise for the treatment of chronic pain and long-term opioid use (Froeliger et al., 2017; Garland & Howard, 2013; Garland et al., 2014; Garland et al., in press) as well as for addictive behaviors more generally (Garland, Gaylord, Boettiger, & Howard, 2011; Garland, Roberts-Lewis, Tronnier, Graves, & Kelley, 2016; Thomas et al., 2019). MORE involves training in mindfulness meditation to reduce reactivity and automatic behavior; positive reappraisal to reduce negative affect and increase meaning in life; and savoring to address deficits in reward processing and increase positive affect (Garland et al., 2014). In each class period, students practiced 15 to 30 minutes of mindfulness techniques, and participants were instructed to engage in 15 to 30 minutes of mindfulness-based practices at home each day. The MORE course was delivered in three-hour, weekly sessions by the senior author.

Measures

Each evening, participants completed surveys assessing mindfulness practice time and outcomes throughout the MORE course via a daily diary.

Practice time.—As MORE includes instruction in several mindfulness- and positive psychology-based techniques, separate items assessed minutes spent engaging in each practice type outside of class (i.e., time spent engaging in practice during class was not counted). These included mindful breathing, body scan, mindful reappraisal, mindful savoring, and visualization practice. A total score was computed by summing across all practice types.

Outcomes.—The *Positive and Negative Affect Schedule* (PANAS; Watson et al., 1988) assessed daily positive and negative affect. The PANAS is a widely used measure for assessing affect, with numerous desirable psychometric properties. Participants endorsed "the extent to which you felt this way today" across ten positively (e.g., interested, excited) and ten negatively (e.g., upset, guilty) valenced adjectives. Ratings ranged from 1 (very slightly or not at all) to 5 (extremely). Separate positive and negative affect scores were computed by averaging across items. Internal consistency reliability was high in the current sample (αs = .94 and .84, for positive and negative affect, respectively).

Participants also completed the *Toronto Mindfulness Scale* (TMS; Lau et al., 2006) in relation to their experience during meditation. The TMS is a widely used 13-item measure intended to assess state mindfulness.[3] Participants endorsed the degree to which various experiences matched their experience during daily meditation practice on a scale from 0 (not at all) to 4 (very much). TMS scores were not provided when an individual did not engage in meditation practice. Items were designed to capture two aspects of state mindfulness: curiosity (e.g., "I was curious about my reactions to things") and decentering (e.g., "I experienced myself as separate from my changing thoughts and feelings"). The TMS has shown acceptable reliability and validity (e.g., responsiveness to mindfulness training; Lau et al., 2006). As has been done previously (e.g., Garland, Hanley, Farb, & Froeliger, 2015), a total score was used in the current study by averaging across items. Internal consistency was high (α = .93).

Data Analysis

Two-part models.—Two-part, longitudinal multilevel modeling was used to examine the relationship between practice time (in minutes) and outcomes over the course of MORE. These models accommodate the clustering (i.e., nesting) of data within participants and also allow evaluation of cluster-to-cluster variability (i.e., random intercepts; Singer & Willet, 2003). However, in order to model both the continuous and dichotomous elements of the practice time data (see Supplemental Materials Figure 1, two-part models were used (Olsen & Schafer, 2001). This was necessary because practice time likely does not follow a normal (i.e., Gaussian) distribution when participants self-select the amount of practice and

[3]We have referred to the TMS as a measure of mindfulness in keeping with the original authors' nomenclature. However, some have argued it may more accurately assess the related constructs of curiosity and decentering (see Bernstein et al., 2015 for a discussion of decentering and related constructs).

assuming a normal distribution can be problematic (Cohen, Cohen, West & Aiken, 2003). We anticipated the distribution of practice time would be positively skewed with a large number of zeros. Zero is the lower bound of time and will be common because there will be days that participants do not practice. Time will be positively skewed because when practice does occur it will typically be for less than the recommended amount (Parsons et al., 2017), but there will also be participants who practice for a long time. Two-part longitudinal models (Olsen & Schafer, 2001) allow assessment of both a dichotomous element to practice time data (i.e., did the participant practice on a given day?) as well as a continuous element (i.e., if the participant practiced on a given day, how much?). The first part evaluates whether practice occurred or not (i.e., $Y_{ti} = 0$ or $Y_{ti} > 0$). The second part evaluates how much practice occurred when participants practiced (i.e., the expected value of a positive Y_{ti}). The two parts of the mixture distribution reflect these elements:

$$Y_{ti} \sim \begin{Bmatrix} \pi_{ti} & \text{if} \quad Y_{ti} = 0 \\ (1 - \pi_{ti})h(Y_{ti}) & \text{if} \quad Y_{ti} > 0 \end{Bmatrix} \tag{1}$$

The top portion of Equation 1 includes π_{ti} which represents the probability that person i did not practice on day t.[4] The bottom portion includes $h(Y_{ti})$ which represents the probability distribution for the positive practice time values. For the continuous portion, we used the gamma distribution, which performs well for positively skewed continuous variables (Baldwin et al., 2016). Thus, the following equations were used for the dichotomous (Equation 2) and continuous (Equation 3) parts of the mixture distribution. First, the equation predicting whether practice occurred is:

$$\log\left(\frac{\pi_{ti}}{1 - \pi_{ti}}\right) = \beta_{00} + \beta_{01} Time_{ti} + \beta_{02} Time^2{}_{ti} + U_{0i} + U_{1i} \tag{2}$$

where β_{00} is the overall intercept, β_{01} the expected change in log-odds of no practice for a one-unit increase in time (scaled from 0 to 1), β_{02} the expected change in log-odds of no practice for a one-unit increase in time^2 (scaled from 0 to 1), U_{0i} the person-specific random intercept representing variation in the probability of no practice unique to each person, and U_{1i} the random slope representing variation in log-odds of no practice over linear time. Second, the equation predicting how much practice occurred is:

$$\log(\mu_{ti}) = \beta_{10} + \beta_{11} Time_{ti} + \beta_{12} Time^2{}_{ti} + U_{2i} + U_{3i} \tag{3}$$

where β_{10} is the overall intercept, β_{11} the expected change in log practice minutes for a one-unit increase in time (scaled from 0 to 1), β_{12} the expected change in log practice minutes for a one-unit increase in time^2 (scaled from 0 to 1), along with random intercept (U_{2i}) and slopes (U_{3i}). Slope coefficients are interpreted by exponentiating the coefficients, similar to Poisson regression (Baldwin et al., 2016).

Longitudinal, same-day, and lagged models.—A series of models were constructed.

[4]We have maintained the typical convention for two-part gamma regression models in which the likelihood of no practice is predicted. This is somewhat counterintuitive (i.e., predicting the absence of something rather than the presence), but in keeping with previous research (Baldwin et al., 2016).

Longitudinal models.: Initial models characterized longitudinal changes in practice time (minutes and occurrence) or outcomes over the course of MORE. Models were evaluated with fixed linear and quadratic effects of chronological time and random linear effects for chronological time, with the most parsimonious models retained for use in same-day and lagged models.

Same-day models.: Same-day models examined the relationship between practice time (minutes and occurrence) and outcomes measured on the same day. For these models, outcomes were entered as predictors of practice time. Due to the fact that mindfulness was only assessed when practice occurred, practice occurrence was not modeled when mindfulness was the predictor (in same-day model) or outcome (in lagged model). For the same day model, a traditional multilevel model predicting practice time from mindfulness was used instead of the two-part gamma model.

Lagged models.: Separate models examined lagged effects of current day practice time (minutes and occurrence) on subsequent day outcomes and lagged effects of current day outcomes on subsequent day practice time. In all lagged models, current day levels of the dependent variable of interest (i.e., practice time or outcomes) was also modeled. Separate models were constructed for the three outcomes (i.e., positive affect, negative affect, mindfulness). For ease of interpretation, outcomes were scaled to include a mean of zero and a standard deviation (*SD*) of 1 (i.e., z-transformed). Practice time was converted to hours per day for ease of interpretation in models predicting outcomes. Chronological time was scaled from zero to one (i.e., day [ranging from 0 to 83] divided by the 83), so that chronological time-related coefficients would reflect change from pre- to post-treatment. For the model predicting subsequent day mindfulness, current day practice occurrence was not modeled (as it was invariant in cases where current day mindfulness was available).

Statistical software.—Analyses used the ‘brms’ package (Bürkner, 2017) in R (R Core Team, 2018). Specifically, the ‘brm’ function was used which fits Bayesian generalized multivariate multilevel models (see Supplemental Materials Table 2 for R syntax). Models used four Markov chains and 4000 iterations per chain.

Missing data.—Due to the longitudinal and intensive nature of our daily diary study, we anticipated some degree of missingness. Importantly, longitudinal models can accommodate unbalanced designs (i.e., in which differing number of observations are available across participants). However, to evaluate potential bias introduced through missingness, we examined the association between a given participants’ number of available assessments (e.g., non-missing reports of practice time) and their aggregate score on the given outcome (i.e., average practice time). We also examined whether participants’ with more missing data (i.e., 20%) differed from those without.

Results

Descriptive Statistics

Sample descriptive statistics, including means and standard deviations at Level 1 (observation-level) and Level 2 (person-level), are reported in Table 1. A total of 1934 observations were available from 25 participants over the course of 84 days. Average compliance with practice time assessment was high (77.36 out of 84 potential assessments, 92% compliance) and somewhat lower for assessment of outcomes (79 to 85% compliance). All participants provided ratings within the last five days of the study, suggesting no participants dropped out. Participants' number of non-missing assessments was not correlated with participants' average response for any of the assessments (*r*s = .02, −.16, .02, .14, for practice minutes, positive affect, negative affect, and mindfulness, respectively, all *p*s > .40). Similarly, having compliance rates less than 80% for a given assessment did not predict average response on that assessment (*r*s = .11, .15, −.04, −.13, for practice minutes, positive affect, negative affect, and mindfulness, respectively, all *p*s > .40).

Participants reported practicing an average of 20.43 minutes per day (*SD* = 18.27), which was similar to the person-level average (20.39 minutes, *SD* = 13.12). Practice occurred on 88% of the observations. Intraclass correlations were computed to investigate the proportion of variance in practice time and outcomes appearing at the person-level (i.e., as opposed to residual variance). ICCs were as follows: practice minutes = .51, practice occurrence = .56, positive affect = .69, negative affect = .38, mindfulness = .40.

Intercorrelations between study variables at Level 1 and Level 2 are presented in Supplemental Materials Table 1. At the observation level (Level 1), occurrence of practice was positively correlated with positive and negative affect (*r*s = .24 and .06, respectively, *p*s < .05). Occurrence of practice could not be correlated with mindfulness as state mindfulness was assessed only when practice occurred. Higher practice minutes was moderately associated with higher positive affect and mindfulness (*r*s = .44, .35, respectively) and weakly associated with lower negative affect (*r* = −.07, all *p*s < .05).

At the person-level (Level 2), participants who reported higher positive affect reported greater average practice minutes (*r* = .47) and higher mindfulness (*r* = .41, *ps* < .05). No other person-level correlations between practice time (minutes or occurrence) were statistically significant, although they mirrored the observation-level associations in direction.

Changes Over Time

A two-part model was used to examine changes in practice time over the course of MORE. Within this model, the random intercepts and random slopes for both the continuous (minutes) and dichotomous (occurrence) portions did not include zero in their respective Bayesian credible intervals, indicating variation in changes in practice minutes and occurrence across participants. Linear and quadratic effects for time also did not include zero (*B* = 0.98 95% credible interval [CI] [0.59, 1.35] and −0.68 [−0.96, −0.41], respectively), although both the linear and quadratic hurdle coefficients did. This indicates a linear increase in practice time, qualified by a negative quadratic effect, with no changes in the likelihood of practice over time. Longitudinal data are plotted in Figure 1, displaying both the overall trajectory as well as the individual variation around the overall trajectory. Curves were fit using local polynomial regression (i.e., loess).

Interpretation of coefficients within two-part gamma models is somewhat complex. First, coefficients must be converted out of log units. In addition, coefficients related to linear time reflect log rates and must be interpreted as such. For the continuous (i.e., gamma) portion, the intercept (B = 2.74 [2.57, 2.91]) reflects an average of 15.49 [13.07, 18.36] (i.e., $e^{2.74}$) minutes of practice at baseline (i.e., chronological time = 0). To compute change in practice time, the linear and quadratic time coefficients can be summed (i.e., 0.98 + −0.68 = 0.30, given that time at post-treatment = 1 so Time^2 is also equal to 1) and then converted from log-rate ($e^{0.30}$). This indicates a 1.35 rate increase in minutes of practice from pre- to post-treatment, yielding a predicted post-treatment practice time estimate of 20.90 [16.06, 26.87] minutes per day (i.e., 15.49 * 1.35). Odds of no practice at baseline was 7.6% [2.1%, 22.5%] (i.e., $e^{-2.58}$). This did not change significantly over time.

Results from multilevel models predicting the three outcome variables do not require exponentiation for interpretation. All three outcome variables also showed random intercepts and random slopes that did not include zero in their respective credible intervals (Table 2). Positive affect showed a linear increase over time (B = 0.36 [0.14, 0.59]; Figure 1). The quadratic time moment did not differ from zero for positive affect, so the model including only a linear effect for time was used. Again, as chronological time was scaled from 0 to 1 and positive affect z-transformed, this coefficient can be interpreted as the pre-post change in positive affect in standardized units (i.e., d = 0.36, reflecting a small magnitude effect by Cohen's [1988] standards). Negative affect showed a linear decrease over time (B = −0.87 [−1.50, −0.23]), qualified by a positive quadratic effect (B = 0.62 [0.16, 1.07]). These coefficients can be added to yield pre-post change in negative affect in standardized units (i.e., d = 0.25, reflecting a small magnitude effect by Cohen's [1988] standards). Mindfulness showed a linear increase (B = 2.32 [1.68, 2.98]), qualified by a negative quadratic effect (B = −1.23 [−1.63, −0.82]), yielding a large pre-post change (d = 1.09).

Same-Day Effects

Same-day models built on the longitudinal models. In the model predicting practice from same-day positive affect, greater positive affect was associated with more practice minutes (B = 0.19 [0.15, 0.23]) and well as lower odds of no practice (B = −2.75 [−3.58, −2.02]). Again, for interpretation, coefficients need to be exponentiated. Thus, this indicates that a one standard deviation-unit increase in positive affect was associated with a 21% increase in minutes of practice on that day (i.e., 1.21 rate difference, $e^{0.19}$) and a 94% decrease in the odds of not practicing (i.e., increase in the likelihood of practicing, $e^{-2.75}$ = 0.06). Greater negative affect was associated with fewer practice minutes (B = −0.05 [−0.07, −0.02]), although not with odds of no practice (B = 0.21 [−0.21, 0.59]). This indicates that a one standard deviation-unit increase in negative affect was associated with a 5% decrease in minutes of practice on that day (i.e., 0.95 rate difference, $e^{-0.05}$). A two-part model could not be run for same-day effects of mindfulness on practice time due to invariance in practice occurrence (i.e., mindfulness was only assessed when practice occurred). In a multilevel model, greater same-day mindfulness was associated with more practice minutes (B = 2.68 [2.00, 3.36]). Specifically, a one standard deviation increased in mindfulness was associated with 2.68 more minutes of practice on a given day.

Lagged Effects

Current practice time predicting subsequent day outcomes.—Current day practice (i.e., practice minutes and occurrence of practice) showed no subsequent day effects on any of the three outcomes, when controlling for respective current day outcomes (Table 3).[5]

Current outcomes predicting subsequent day practice time.—Current day positive affect was not associated with subsequent day practice minutes ($B = 0.01$ [−0.03, 0.06]) or odds of no practice ($B = -0.23$ [−0.51, 0.06]).[6] In contrast, higher current day negative affect was associated with fewer subsequent day practice minutes ($B = -0.05$ [−0.08, −0.02]) and greater odds of subsequent day no practice ($B = 0.35$ [0.13, 0.56]; Table 3). This indicates that a one standard deviation-unit increase in current day negative affect predicted a 5% decrease in subsequent day practice minutes (i.e., 0.95 rate difference, $e^{-0.05}$) and a 42% increase in subsequent day odds of no practice (i.e., 1.42 rate difference, $e^{0.35}$). Higher current day mindfulness was associated with more subsequent day practice minutes ($B = 0.04$ [0.01, 0.07]), although not with the odds of not practicing in the subsequent day ($B = -0.22$ [−0.48, 0.05]). This indicates that a one standard deviation-unit increase in current day mindfulness predicted a 4% increase in subsequent day practice minutes (i.e., 1.04 rate difference, $e^{0.04}$).

Practice Time as Moderator of Lagged Associations in Day-to-Day Affect— Having not observed the lagged effect of practice time on outcomes we might expect based on clinical experience, we conducted two additional exploratory analyses examining whether practice time moderated the link between current day and subsequent day affect (i.e., autoregressive relationship). This was based on theoretical models that suggest mindfulness practice may disrupt the downward spiral of negative affect and engender an upward spiral of positive feedback in which mindful awareness of positive affective states in one moment kindles greater positive affect in subsequent moments (Garland et al., 2010; Garland, Geschwind, Peeters, & Wichers, 2015). To examine this, longitudinal multilevel models were constructed predicting subsequent day affect (separately for positive and negative affect) by current day affect (positive and negative), practice time (minutes and occurrence), and the interaction between current day affect and practice time (with separate interaction terms for minutes and occurrence, see Supplemental Materials Table 2 for R syntax).

A significant interaction was found between practice time (scaled into hours per day for ease of interpretation) and current day positive affect when predicting subsequent day positive affect ($B = 0.18$ [0.03, 0.31], Supplemental Materials Table 3). The direction of the coefficient indicates that higher current day practice was associated with a strengthening of the day-to-day relationship in positive affect (i.e., a stronger positive association). Absence of current day practice did not moderate day-to-day positive affect ($B = -0.05$ [−0.24, 0.14]).

[5]Current day practice was scaled in hours per day for ease of interpretation. In addition, the model predicting mindfulness did not include practice occurrence as mindfulness was only rated when practice occurred.

[6]Due to issues with non-convergence, the random slope for linear time was dropped from lagged models predicting practice time from outcomes.

A significant interaction was also detected between current day practice minutes (again scaled as hours per day) and current day negative affect ($B = -0.23$ [−0.40, −0.07]) as well as between current day absence of practice and current day negative affect ($B = -0.21$ [−0.40, −0.03]). The negative direction of the interaction term indicates that as practice minutes increased the correlation between current day negative affect and subsequent day negative affect decreased (i.e., was attenuated). Occurrence of no practice (i.e., lack of practice occurrence) also attenuated the link between current day negative affect and subsequent day negative affect with a negatively signed interaction term. Of note, these two interactions imply divergent effects of current day practice on the link between day-to-day negative affect, depending on whether practice time is operationalized as practice minutes (or hours in this case) and occurrence (or lack of occurrence in this case).

Discussion

To our knowledge, this is the first study to examine day-by-day relationships between mindfulness practice time and outcomes within the context of a standardized MBI. This study aimed to move beyond person-level associations between practice time and outcome (e.g., Parsons et al., 2017) and evaluate ways that these variables interrelate over the course of a training based on mindfulness and positive psychology. Our results suggest that the relationship between practice time and outcome is nuanced and variable across participants.

In keeping with positive links between practice time and outcome in person-level analyses (Parsons et al., 2017) as well as studies examining the impact of very brief mindfulness interventions (e.g., mindfulness inductions; Leyland, Rowse, & Emerson, 2018), we found consistent evidence linking same day practice and outcomes. Effects were particularly strong for positive affect, which was associated with both the continuous (i.e., amount of practice) and dichotomous (i.e., occurrence of practice) aspects of practice time. On days with positive affect one standard deviation above the mean, participants were expected to spend 21% more time practicing and were 94% less likely not to practice. This finding supports the notion that mindfulness practice and positive outcomes co-occur.

Lagged models, designed to move closer to establishing causal links between longitudinal variables (although still lacking the experimental design necessary for firm causal inferences; Bollen & Curran, 2006), indicated that the relationship between practice time and outcome may be contrary to the received view (i.e., that more practice leads to greater improvement on outcomes). In fact, there was no evidence suggesting that current day practice leads to better subsequent day outcomes; neither amount of current day practice nor occurrence of current day practice predicted subsequent day outcomes (while controlling for current day outcomes).

In contrast, some current day outcomes did predict subsequent day practice. Current day negative affect showed the most consistent relationship. On days with negative affect one standard deviation above the mean, participants were predicted to show a 5% decrease in subsequent day practice time and a 42% increase in the likelihood of not practicing the next day. Current day state mindfulness predicted greater practice time the next day, with a 4%

increase in subsequent day practice minutes per one standard deviation unit elevation in current day mindfulness.

These lagged findings introduce the possibility that the causal direction linking practice time and outcomes may reverse that theorized within MBIs. In particular, it may be that individuals are more likely to engage in mindfulness practice when they are feeling better (i.e., lower negative affect, higher positive affect). One straightforward explanation for this is that mindfulness practice, which centers on attending to one's internal experience (Kabat-Zinn, 2013), is simply easier to do when one's internal experience (e.g., mood) is more pleasant and less unpleasant. This possibility is in keeping with the notion of experiential avoidance that highlights the common human tendency to avoid experiencing unpleasant internal states (Hayes et al., 2004). These data are also consistent with a traditional contemplative perspective, in which positive affective states were held to promote Shamatha (meditative stabilization of attention) and Samadhi (meditative absorption) (Tsongkhapa, in Kilty, 2012). It is also in keeping with other fundamental processes guiding human and non-human behavior alike (i.e., operant condition; Skinner, 1963). Further, it is consistent with dynamic emotion models of depression and vulnerability indicating that negative mood makes people less likely to engage in health behaviors (e.g., toothbrushing; Anttila, Knuuttila, Ylöstalo, & Joukamaa, 2006).

Although replication in a larger sample is needed, this finding, if replicated, puts into question the causal direction implied in practice time by outcome correlations reported in previous studies (Parson et al., 2017). Practice time and outcome may be correlated (as was seen in the current sample), but this does not necessary mean that more practice *causes* better outcomes. This possibility contradicts how practice time may be traditionally conceptualized within MBIs (i.e., that more is better). However, it is in keeping with process research suggesting that other aspects of mindfulness practice (e.g., practice quality; Del Re, Flűckiger, Goldberg, & Hoyt, 2013) may be a stronger predictor of outcome than practice time alone (Goldberg, Del Re, Hoyt, & Davis, 2014; Goldberg, Knoeppel, Davidson, & Flook, in press). Indeed, the ideal method to examine questions of causality, of course, will require random assignment of individuals to varying practice dosages (as has begun to appear in the literature, e.g., Adams et al., 2018; Berghoff et al., 2017; Greenberg et al., 2017).

A separate set of analyses examined the possibility that current day practice time attenuates the link between day-to-day positive and negative affect. Results indicated that greater current day practice was associated with a strengthened link between current and subsequent day positive affect and an attenuated link between current and subsequent day negative affect. These results suggest that greater time spent practicing mindfulness is associated with alterations in day-to-day linkages in affect, indicative of fostering an upward spiral of positive affect and weakening a downward spiral of negative affect (Garland et al., 2010). Such upward spiral processes have also been observed via multivariate autoregressive latent trajectory modeling in prior EMA and daily diary studies (Garland, Geschwind, et al. 2015; Garland, Kiken, Faurot, Palsson, & Gaylord, 2017).

The collective pattern of results suggests several future directions. An obvious next step in this area would be simply replicating the models used here in a larger sample of participants. It could be especially intriguing to examine the lagged relationship between practice time and outcome within a clinical sample. In this context, a proximal mechanism purported to link mindfulness training with distal outcomes could be used instead of affect and mindfulness. For example, in a sample of individuals with depression or anxiety, lagged links between rumination and practice time could be examined (Desrosiers et al., 2013). Or, similarly, it could be informative to examine a richer set of characteristics drawn from positive psychology in a non-clinical samples (e.g., measures of well-being, gratitude, hope) as proximal measures. Models could specifically examine the interplay between the acquisition of mindfulness skills, mindfulness practice time, and the cultivation of character strengths that have been hypothesized to both promote and be promoted by mindfulness training (e.g., curiosity, self-regulation, kindness; Niemiec et al., 2012). As numerous character strengths have already been assessed in previous mindfulness research and are represented in existing self-report measures of mindfulness (e.g., curiosity, self-regulation; Quaglia, Braun, Freeman, McDaniel, & Brown, 2016), it would be helpful to clarify the relationship between and potential conceptual overlap of mindfulness and positive psychology in future theoretical work. As noted previously, randomly assigning participants to various dosages of home practice is a straightforward way to clarify causal links (as in Adams et al., 2018), albeit requiring a larger sample.

Another possibility that has been increasingly used in the context of mobile health is micro-randomized trials (Klasnja et al., 2015). This experimental design involves within-person randomization to time-varying interventions. In the current context, that could mean randomly assigning different MORE participants different dosages of home practice on different days (e.g., 20 minutes on Day 1, 10 minutes on Day 2, etc.). Micro-randomized trials appear to allow more efficient experimental manipulation of dosage (Klasnja et al., 2015). However, any design involving random assignment to dosages is dependent on individuals’ adherence with their assigned dosages (which is not guaranteed, e.g., Berghoff et al., 2017). Lastly, more intensive assessment throughout the day (as in ecological momentary assessment; Shiffman, Stone, & Hufford, 2008) could help clarify even more minute interrelationships between practice time and outcomes.

Several limitations are worth noting. The most obvious is the relatively small number of participants. Although statistical power was increased due to the large number of observations per participant (up to 84 observations), it will be important to examine the associations reported here in a larger sample. A second limitation was the implementation of MORE within a sample of social work students. Although MBIs may certainly be relevant for university students (Regehr, Glancy, & Pitts, 2013), the sample may not be representative of the university student population generally, much less the general population. To be clear, MORE was developed as a clinical intervention for individuals with comorbid psychopathology (i.e., addiction, emotion dysregulation, and/or chronic pain). The student population under investigation here likely differs in important ways from the typical target of the MORE intervention. In that regard, participants may have been especially compliant due to their interest in the topic. However, in contradiction of this possibility, the current sample reported average daily practice time (20.39 minutes per day) similar to (or slightly lower than) that found in a meta-analysis of practice time in MBSR and MBCT (about 30 minutes per day, six days per week; Parsons et al., 2017). Similarly, participants' responses to survey measures may have been unduly influenced by social desirability (e.g., a tendency to over-report improvement) associated with having the senior author as their course instructor. A third limitation was our use of repeated daily diary assessments. Though more intensive sampling is a strength for many reasons (see Shiffman et al., 2008), repeated sampling can introduce bias (e.g., through measurement reactivity and fatigue effects; Reynolds, Robles, & Repetti, 2016). A fourth limitation was implementation of MORE rather than one of the more widely implemented MBIs (i.e., MBSR or MBCT). MORE includes a greater variety of mindfulness practices as well as unique content drawn from positive psychology. Thus, it would be worthwhile employing the current methods within the context of other standardized MBIs. A fifth limitation was exclusive reliance on self-report outcomes and practice time. Associations between these variables may have been inflated due to shared method variance (e.g., social desirability). It seems unlikely, however, that this source of bias could explain the novel lagged associations found in the current study.

These limitations notwithstanding, our study is the first to examine potentially fine-grained associations between practice time and outcomes over the course of a standardized MBI. A more sophisticated understanding of these dynamics is worthwhile, given the promising experimental data suggesting that mindfulness training may promote flourishing (Garland, Farb, et al., 2015; Sedlmeier et al., 2012) and reduce psychological symptoms (Goldberg et al., 2018) coupled with the centrality of mindfulness practice within these interventions. At the broadest level, our findings suggest this relationship may be nuanced and variable, and due attention in future studies. In particular, our results replicate prior studies demonstrating person-level associations between practice time and outcome (seen in our same-day models). However, lagged model results suggest that the causal direction of this relationship may be reversed, with outcomes driving practice time, rather than the other way around. Yet, practice time seemed to strengthen positive feedback loops between positive affect on successive days, suggesting the possibility that relations between practice time and outcomes may be recursive and interdependent. Given the likelihood that practice time dosage recommendations will impact the feasibility and acceptability of MBIs, continuing to explore the relationship between practice time and outcome using intensive longitudinal data may provide insights directly relevant for the dissemination and implementation of MBIs.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Clinical Impact Statement

Question:

We sought to clarify the relationship between practice time and outcomes within a standardized mindfulness-based intervention.

Findings:

It is possible that more mindfulness practice does not necessarily produce better outcomes, but that individuals may be more prone to practice when they are experiencing benefits or feeling better.

Meaning:

Discussing clients' experience of mindfulness practice when recommending dosage could be valuable.

Next steps:

Future studies using both longitudinal data and random assignment to dosage conditions could help clarify these relationships.

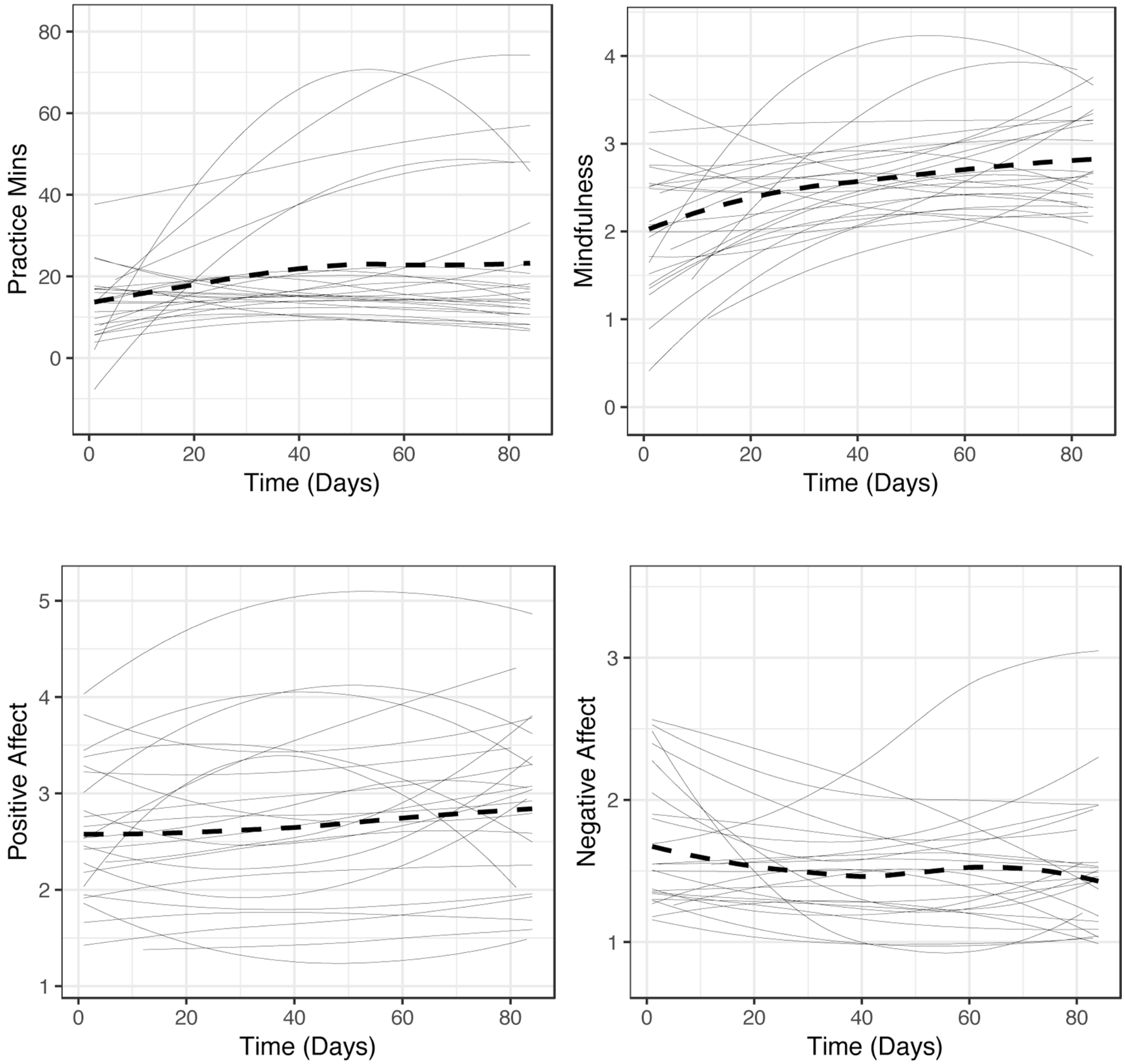

Figure 1.
Longitudinal models for practice time and outcomes. Dashed line represents overall trajectory and thin lines represent participant-specific trajectories, both as loess curves.

Table 1.

Sample descriptive statistics

Variable	n	Mean	SD	Min	Max	Skew	Kurtosis	*ICC*	*r*
Practice minutes	1934	20.43	18.27	0	130	1.67	3.52	.51	.70
Practice occurrence	1934	0.88	0.33	0	1	−2.29	3.26	.56	.30
Positive affect	1790	2.68	1.02	1	5	0.41	−0.58	.69	.82
Negative affect	1784	1.52	0.54	1	4.1	1.83	4.58	.38	.65
Mindfulness	1661	2.54	0.71	0	4	−0.15	0.22	.40	.72
Level 2 practice minutes	25	20.39	13.12	8.17	52.62	1.51	0.93		
Level 2 practice occurrence	25	0.88	0.16	0.44	1	−1.58	1.48		
Level 2 positive affect	25	2.7	0.84	1.39	4.85	0.39	−0.22		
Level 2 negative affect	25	1.52	0.34	1.02	2.37	0.72	−0.22		
Level 2 mindfulness	25	2.49	0.45	1.58	3.64	0.20	0.06		
Completed practice time assessments	25	77.36	11.59	46	84	−1.77	1.85		
Completed positive affect assessments	25	71.60	14.35	38	84	−0.90	−0.57		
Completed negative affect assessments	25	71.36	14.68	38	84	−0.88	−0.66		
Completed mindfulness assessments	25	66.44	15.70	36	84	−0.67	−1.09		

Note: Descriptive statistics based on raw values, although practice time was scaled into minutes per week and outcomes z-transformed for ease of interpretation. *ICC* = intraclass correlation coefficient representing the proportion of variance occurring at the person-level; r = correlation between current day and subsequent day practice and outcome variables (i.e., within the same construct), all significant at $p < .001$.

Table 2.

Longitudinal model results

Parameter	Practice Minutes	Positive Affect	Negative Affect	Mindfulness
		Random Effects		
Zero portion				
SD(hu_Intercept)	2.31 [1.33, 3.92]			
SD(hu Time)	4.07 [1.59, 8.50]			
Positive portion				
SD(Intercept)	0.38 [0.28, 0.54]	0.88 [0.65, 1.22]	0.73 [0.54, 1.00]	0.94 [0.70, 1.28]
SD(Time)	0.63 [0.46, 0.87]	0.52 [0.36, 0.74]	1.06 [0.77, 1.46]	1.25 [0.92, 1.71]
		Fixed Effects		
Zero portion				
hu_Intercept	−2.58 [−3.88, −1.49]			
hu_Time	−2.08 [−5.26, 0.96]			
hu_$Time^2$	0.33 [−1.96, 2.60]			
Positive portion				
Intercept	2.74 [2.57, 2.91]	−0.15 [−0.49, 0.21]	0.21 [−0.09, 0.51]	−0.77 [−1.16, −0.40]
Time	0.98 [0.59, 1.35]	0.36 [0.14, 0.59]	−0.87 [−1.50, −0.23]	2.32 [1.68, 2.98]
$Time^2$	−0.68 [−0.96, −0.41]		0.62 [0.16, 1.07]	−1.23 [−1.63, −0.82]

Note: Results from four separate longitudinal models characterizing changes in practice minutes (continuous [positive] and dichotomous [zero] portions, i.e., amount and occurrence), positive affect, negative affect, and mindfulness over the course of MORE. Two-part multilevel gamma model used only for practice minutes. Multilevel models with Gaussian distributions were used for the outcomes (i.e., no separate zero portion). Values reflect parameters with 95% credible intervals. Outcomes z-transformed for ease of interpretation. Number of observations across models: Practice time n = 1934, negative affect n = 1784, positive affect n = 1790, mindfulness n = 1661. hu = hurdle component, *SD* = standard deviation.

Table 3.

Same-day and lagged model results

Model	Parameter	Practice Time	Positive Affect	NegativeAffect	Mindfulness
Same Day	Linear		0.19 [0.15, 0.23]	−0.05 [−0.07, −0.02]	2.68 [2.00, 3.36]
Same Day	Hu		−2.75 [−3.58, −2.02]	0.21 [−0.21, 0.59]	
Lagged: Pos Affect ~ Practice	Practice Hours	0.00 [−0.15, 0.16]			
Lagged: Pos Affect ~ Practice	No Practice	−0.12 [−0.27, 0.02]			
Lagged: Neg Affect ~ Practice	Practice Hours	−0.14 [−0.35, 0.07]			
Lagged: Neg Affect ~ Practice	No Practice	0.04 [−0.16, 0.24]			
Lagged: Mindfulness ~ Practice	Practice Hours	−0.02 [−0.24, 0.20]			
Lagged: Mindfulness ~ Practice	No Practice	NA			
Lagged: Practice ~ Outcome	Linear		0.01 [−0.03, 0.06]	−0.05 [−0.08, −0.02]	0.04 [0.01, 0.07]
Lagged: Practice ~ Outcome	Hu		−0.23 [−0.51, 0.06]	0.35 [0.13, 0.56]	−0.22 [−0.48, 0.05]

Note: Same-day model and lagged time predicted by outcome models include practice minutes (continuous and dichotomous portions) predicted by one of three outcomes (i.e., examined in separate models). Continuous practice minutes converted to hours for ease of interpretation in lagged models in which outcomes were predicted by practice time. Values reflect parameters with 95% credible intervals. Two-part models were not possible for same day model with mindfulness as predictor of time as mindfulness was only assessed when practice occurred (i.e., occurrence is invariant); a traditional multilevel model was used instead. ~ = predicted by; Linear = continuous portion of two-part multilevel gamma model; Hu = dichotomous portion of two-part gamma model; Lagged = lagged; NA = not applicable as lagged effect of practice occurrence on mindfulness could not be estimated as mindfulness was only assessed when practice occurred (i.e., occurrence of practice was invariant when prior day mindfulness was non-missing).