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The relationship between mindfulness meditation and well-being during 8 weeks of ecological momentary assessment

Oskari Lahtinen[1] · Christina Salmivalli[1,2]

Abstract

Objectives The main effects of 8-week mindfulness-based programs (MBP) on anxiety and depression are now supported by reasonably robust evidence. However, few to no studies have looked at whether and how these main effects come to be over the course of the MBP. The goal of the present study was to look at how meditation practice predicted changes in well-being, and vice versa, at a weekly level, within an 8-week online MBP.

Methods The participants were 457 Finnish upper secondary education students who underwent an 8-week online MBP. App-based ecological momentary assessment data were collected on how many minutes the participants meditated (daily) and their anxiety, happiness, and sleep problems (weekly). These data were analyzed using a longitudinal (nine time point) path model.

Results Participants' weekly minutes of mindfulness meditation were a consistent, albeit weak, predictor of decreases in anxiety and increases in happiness. During the course of the study, answer rates declined from 75.7% (Time 0) to 27.4% (Time 8) for anxiety, happiness, and sleep and from 80.5% to 37.0% for meditation minutes.

Conclusions Results suggest well-being improvement from mindfulness meditation is an ongoing process and that ecological momentary assessment is a promising methodology for studying it.

Keywords Mindfulness · Ecological momentary assessment (EMA) · Upper secondary education · Anxiety · Well-being

An accumulating evidence base now points to mindfulness meditation having beneficial effects on, at least, anxiety and depression (Creswell 2017; Goyal et al. 2014; de Vibe et al. 2017). On the other hand, the research community has seen recent voicing of concern over "mindfulness hype" getting ahead of the science (Van Dam et al. 2018; Davidson and Dahl 2018). Though the field sees hundreds of new studies each year, it is still lacking in large sample studies that shed light on more nuanced mechanisms of mindfulness meditation and its impact on well-being or adversity.

Mindfulness is an umbrella term that lacks an all-encompassing definition (Van Dam et al. 2018). However, the most commonly offered definitions include paying attention to present moment experience with an attitude of curiosity and acceptance (e.g., Bishop et al. 2004; we use this definition). A common way to begin mindfulness practice is with "concentration" meditation, i.e., focusing attention on a given object and returning attention to the object when the mind wanders. Another often taught form of practice is open awareness meditation, where attention is allowed to encompass any object in consciousness. Many varieties of meditation exist, depending on, e.g., what attention is focused on, how intensely, and whether the focus moves (for instance from body part to body part) or is fixed (Van Dam et al. 2018). In some meditation practices, a particular positive state is cultivated through visualization and mantra practice—this is common in loving-kindness and compassion practice. The temporal variation of meditation practice can range anywhere from the briefest (a minute, for instance) to intensive silent retreats of weeks, months, or even years.

Mindfulness meditation practice is often learned in mindfulness-based programs (MBPs). The most rigorously standardized and studied examples are mindfulness-based stress reduction and mindfulness-based cognitive therapy (MBSR and MBCT; Kabat-Zinn 1990; Teasdale et al. 2000). These MBPs have mostly shown to benefit participants by

✉ Oskari Lahtinen
polaht@utu.fi

[1] Department of Psychology and Speech-Language Pathology, University of Turku, FI-20014 Turku, Finland

[2] Shandong Normal University, Jinan, China

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alleviating or preventing depression ($d = 0.30$, $p = 0.05$) and anxiety ($d = 0.38$, $p < 0.05$; Goyal et al. 2014; Kuyken et al. 2015). For adolescents and children, sparser meta-analytic evidence has pointed to comparable effects from undergoing MBPs (Dunning et al. 2018). The amount MBP participants practice appears to be related to the magnitude of benefit derived from practice (Parsons et al. 2017). Thus far, there appears to be little research on which kinds of MBP participants adhere to the practice and which drop out, though this question is essential in designing MBPs that present participants with minimal barriers to entry and support for sustained practice. Adhering to a meditation practice routine can require effort from the participant, so it is possible that participants with higher well-being levels would be less likely to drop out. On the other hand, participants with less well-being might feel more motivated to improve their situation.

Recently, mobile technology has offered a highly scalable medium through which mindfulness can be taught. Meditation apps like Headspace and Waking Up now cater to tens of millions of smartphone users (Harris 2018; Pierson and Puddicombe 2012). App-based meditation courses and other online MBPs have been studied to a lesser extent, but meta-analysis indicates the benefits could be slightly smaller but comparable with those from face-to-face MBPs (Spijkerman et al. 2016).

Ecological momentary assessment (EMA) is a methodology through which real-time reports are collected from participants, usually via smartphone apps. This technology was harnessed by Killingsworth and Gilbert (2010), when they found, using ongoing experience sampling, that the study participants' minds wandered about 50% of the time and they were less happy when this happened. Jazaieri et al. (2016) used similar methodology to study how participants' minds wandered during a 9-week compassion meditation course.

Hill and Updegraff (2012; $n = 96$) used EMA to assess the relationship between mindfulness and emotion regulation in young adults. Another study tracked participants' anxiety, depression, and mindfulness levels during an MBSR course (Moore et al. 2016; $n = 67$). The study also compared the EMA assessments, and found them superior, to traditional pen and paper assessments. Another (pilot) study used EMA to study whether mindfulness meditation can be used to reduce smoking over time (Ruscio et al. 2015; $n = 44$; the group also published two other studies based on related data). Overall, as in the Ruscio et al study, a key application for EMA technology has been tobacco and substance abuse studies, where immediate access to participants' experience yields more reliable information on craving, mood, and other factors related to relapse (e.g., Shiffman et al. 2002; for an EMA overview, see Shiffman et al. 2008).

MBP main effects on, e.g., anxiety and depression are becoming well known. Less is known about exactly how practicing meditation during an MBP causes well-being to improve and how improved well-being affects the meditation practice. For example, is a week's practice predictive of less anxiety in the next week, and is less anxiety predictive of more future practice? These kinds of questions are well suited for week-by-week EMA targeting.

Of interest is also how varying quantities of meditation practice during an MBP affect participants' well-being gains from the practice. Thus far, this topic has mostly been investigated via pre- and post-MBP measurements—a somewhat crude metric for what could be a nuanced process over many weeks. If a study only obtains retrospective practice frequency data at the post-MBP measurement, it is susceptible to recall bias and risks being less reliable (Kahneman and Riis 2005). Daily or weekly EMA reports from participants offer a clearer window into what participants actually experience and do during the multi-week courses.

In the present study, we harnessed daily and weekly app-based EMA to assess whether engaging in meditation practice at different stages of an 8-week online MBP would result in immediate benefit. Our aims were (1) to investigate the direction of possible causal effects between meditation practice and well-being (operationalized as anxiety, sleep problems, and happiness) and (2) to examine which baseline characteristics of participants would predict developing and sticking to a practice routine and which characteristics would make a participant more likely to drop out. Our hypotheses were that (1) practicing meditation would result in well-being gains and (2) the more participants practiced, the more they would benefit.

Method

Participants

Participants ($n = 457$) were upper secondary education students and represented all of Finland geographically. Median age for participants was 17 (ranging from 15 to 24+), 88.0% of participants were female (358 females, 43 males, 6 identified as "other"), and 80.6% went to upper secondary school (328 upper secondary school, 79 vocational institute). Participants volunteered to take part in the online *Tita* MBP and the study in response to nationwide recruitment emails to all Finnish upper secondary education institutions (approximate n = 554), describing the program and (evidence-based) benefits of mindfulness meditation.

Procedure

We instructed the participants to download an ecological momentary assessment (EMA) app *Paco* (Google Commerce Ltd. 2014). Out of 717 eligible students, the sample of the present study (457 students; 63.7% of all) were the students who downloaded the app and answered at least one daily ("how many minutes did you practice yesterday") question or at least one weekly (anxiety, sleep problems, happiness) questionnaire.

The MBP The website-based online MBP, *Tita*, comprises 7 guided meditations (sitting meditation for 5 min, 10 min, and 20 min; body scan for 20 min, walking meditation, self-compassion for 5 min, and loving-kindness for 12 min) and 9 lectures (10–20 min each) with topics ranging from what mindfulness is, through the relationship between thoughts, emotions, and the body to compassion and dealing with stress. Participants were presented a new lecture on each Sunday during 8 weeks. The lectures gradually introduced new meditation practices throughout the course. However, participants were also able to access any guided meditation (including the ones that had not been introduced yet) any time they wanted to, as we wanted to maximize their opportunity to practice on their own. The MBP did not include prompts to practice.

Data collection Participants were asked questions via the Paco app daily (number of minutes practiced yesterday; question prompt at 9 a.m.) and weekly (anxiety scale (GAD-7), happiness item, and sleep problems item). Baseline measurement (T_0) was on the day they gained access to the program. The daily questions were asked on 56 days (2 October 2017 to 26 November 2017) and the weekly questions on 9 Sundays (T_0: 1 October 2017, T_8: 26 November 2017). To maximize the participant response rate, the weekly questionnaire was designed to be as light as possible while attempting to maximize the extent to which it operationalizes well-being.

Measures

Anxiety Anxiety was measured with the brief generalized anxiety measure, the GAD-7 (Spitzer et al. 2006). GAD-7 comprises seven items asking about respondent anxiety over the last two weeks (e.g., asking respondents how often they have been bothered by "Not being able to stop or control worrying"), each with four answer options ranging from 0 ("not at all") to 3 ("nearly every day"). Scores for GAD-7 range from 0 to 21. Cronbach's $\alpha = 0.86$.

Happiness Happiness was measured with a global item adapted from the UN World Happiness Report: "Overall, how good do you consider your life, that is, the quality of your life, to have been during the last week?" (Helliwell et al. 2018). Options were in numerical form and ranged from 0 ("the worst possible quality of life") to 10 ("the best possible quality of life").

Sleep problems Sleep problems were measured with a global item "How well do you feel you slept last week?" with five options: 1 = well, 2 = somewhat well, 3 = not well, not poorly, 4 = somewhat poorly, 5 = poorly. The item was an adaptation from Partinen & Gislason (Finnish version of the Basic Nordic Sleep Questionnaire (BNSQ-FIN); Partinen and Gislason 1995).

Meditation minutes Each day, for 56 days, participants were asked to enter the number of minutes they practiced meditation yesterday. They would then type in, e.g., "10" or "0" (entries ranged from 0 to 90 min). Meditation minutes were summed up to form weekly aggregates for each span between time points from T_0–T_1 to T_7–T_8 (missing answers were equated to zero minutes).

Data analyses

First, we looked at correlations between and descriptives of study variables at baseline (T_0). We then compared the baseline characteristics and total meditation minutes of (1) boys and girls, (2) upper secondary school and vocational institute students, and (3) completers and dropouts using independent samples T tests. We evaluated whether benefit from the MBP (T_8 anxiety, happiness, and sleep problems while controlling for gender and school type) could be predicted from total meditation minutes. We also examined whether total meditation minutes could be predicted from baseline characteristics. We then calculated percentage-changes for main outcomes for comparison to ones obtained in our previous study. We also looked at correlations between T_8–T_0 difference scores and baselines for indication of what types of participants benefited most.

We then formed a path model with nine time points, encompassing all measurements for anxiety, happiness, sleep problems, and meditation minutes (Fig. 1). In the model, the outcome at T_k was auto-regressed on the outcome at T_{k-1}. The sum of meditation minutes for each week (i.e., meditation minutes between T_{k-1} and T_k) was also auto-regressed on meditation minutes from the previous week (between T_{k-2} and T_{k-1}). In addition, meditation minutes between T_{k-1} and T_k were regressed on each outcome at T_{k-1} and, conversely, each outcome at T_k was regressed on meditation minutes between T_{k-1} and T_k. Gender and school type were initially controlled for but, as they had little effect on the results, were left out of the final model for the sake of parsimony. All variables were standardized for the path analyses. Analyses were run in Mplus 8.1 (Muthén and Muthén 1998-2017). Missing values were handled via the full-information maximum likelihood (FIML) mechanism built in the Mplus software. As our sample size was on the larger side for most time points and the model complex, power analyses were not run.

Attrition Both the daily and weekly EMA response rates declined during the 8-week duration of the MBP. At T_0 the respondents/missing ratio for the weekly survey (measuring

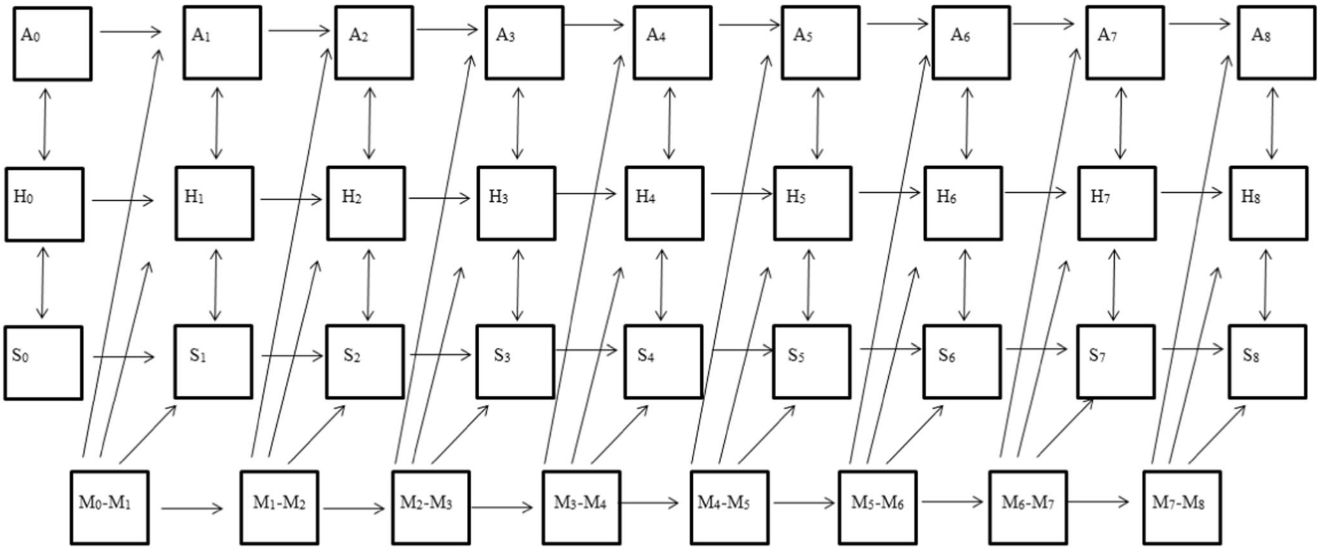

Fig 1 Path model for study outcomes (*A*, anxiety; *H*, happiness; *S*, sleep problems) and meditation (*M*). Subscript numbers denote time points (0 = before program, 8 = after program; e.g., H_0, happiness at T_0; M_2–M_3, meditation between T_2 and T_3)

anxiety, happiness, and sleep problems) was 346/457. The attrition pattern for the weekly survey (as for the aggregate weekly meditation minutes) is presented in Table 1. For the daily meditation minutes question, there were 182 answers on day 1, 207 on day 2, 220 on day 3, and then slowly decreasing over the 56-day span to bottom out at 74 answers on day 56. On the weekly meditation minutes aggregates, 368 people answered at least once during week 1 (T_0–T_1). It is important to note that attrition here only pertains to subjects who stopped answering EMA prompts and does not mean they dropped out of the MBP altogether.

Results

The outcome variables (anxiety, happiness, and sleep problems) were moderately to strongly intercorrelated. Anxiety was negatively correlated with happiness ($r = -0.49$) and positively correlated with sleep problems ($r = 0.37$). Happiness was negatively correlated with sleep problems ($r = -0.32$). Out of 56 possible days, participants reported meditation practice (or lack of it), on average, on 17 days (ranging from 1 to 55 days; Table 3). Average total meditation time reported during the MBP was 138.5 min (ranging from 0 to 1068 min, or 17.8 h).

There were no statistically significant differences in study variables at T_0 between boys and girls or upper secondary school students and vocational institute students ($t < 1.7$, $p > 0.10$; Table 2). The single statistically significant difference in study variables at T_0 between dropouts and completers was that completers reported substantially more meditation minutes than dropouts ($t = 22.92$, $p < 0.01$). We defined dropout as not responding at week 7 or later. As most attrition occurred in the final week of the program, a cutoff at week 7 was deemed more informative than week 8, because, using the latter criterion, the majority of participants would have been classed as dropouts. Dropout could not be predicted by regressing it on baseline values of the outcome variables (betas < 0.05, $p > 0.10$). Also, total meditation minutes were not a statistically significant predictor of anxiety, happiness, or sleep problems at T_8, when controlling for gender, school type, and the baseline value for the T_8 outcome variable under investigation. For every day of the study period, the mode for reported meditation practice was 5 min (followed by 10 min), with daily means ranging from 6.86 to 10.86 min. Finally, baseline anxiety, happiness, or sleep problems were not statistically significant predictors of meditation minutes, when controlling for gender and school type.

Table 1 EMA attrition during the course of the MBP

Weekly survey	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
	346(/457)	301	261	235	216	198	178	170	125
Aggregate meditation minutes	T_0–T_1	T_1–T_2	T_2–T_3	T_3–T_4	T_4–T_5	T_5–T_6	T_6–T_7	T_7–T_8	
	368(/457)	306	268	236	219	201	194	169	

Table 2 Baselines for study variables

	Anxiety			Sleep problems			Happiness			Meditation minutes		
	M	SD	*n*	*M*	SD	*n*	*M*	SD	*n*	*M*	SD	*n*
Girls	8.11	4.53	279	1.80	1.02	279	6.88	1.55	279	136.40	145.31	319
Boys	6.76	4.60	33	1.67	1.02	33	6.88	1.75	33	137.87	126.80	39
Upper*	7.82	4.47	257	1.79	1.02	257	6.89	1.57	257	140.84	144.98	300
Vocational*	8.92	5.08	60	1.80	0.99	60	6.72	1.63	60	117.56	135.55	63
Completer	7.84	4.11	170	1.78	0.97	170	6.85	1.52	170	228.60	153.38	202
Dropout	8.25	4.96	176	1.83	1.08	176	6.79	1.70	176	49.34	57.12	204
All	8.05	4.56	346	1.81	1.02	346	6.82	1.61	346	138.53	146.16	406

*Upper, upper secondary school students; vocational, vocational school students

Between T_0 ($n = 346$) and T_8 ($n = 125$), sample anxiety decreased from 8.05 to 4.85 (39.7%), happiness increased from 6.82 to 7.62 (11.7%), and sleep problems decreased from 1.81 to 1.19 (34.3%; Table 3). Benefit from the MBP (measured as $T_8 - T_0$ difference scores) was associated with lower baseline anxiety ($r = -0.54$), higher happiness level ($r = 0.14$) and less sleep problems ($r = -0.12$).

After evaluating initial model fit for an unmodified model (root mean square error for approximation, i.e., RMSEA 0.06; comparative fit index, i.e., CFI 0.81), 24 additional autoregressions were added based on standardized expected parameter change (SEPC) values, after determining their adding was in alignment with the theory-driven model. RMSEA for the final model was 0.04, indicating good fit (MacCallum et al. 1996), whereas CFI for the model was 0.91, indicating acceptable fit (Hu and Bentler (1999) recommend "close to 0.95" as a cutoff; other model fit indices: SRMR = 0.14; χ^2 ($p < 0.05$) = 862.95). Since many meditation minutes variables were skewed (> 2) and had high kurtosis (> 2; Garson 2012), we used robust maximum likelihood estimation.

All but one of the autoregressions were statistically significant ($p < 0.05$; Table 4). Seven out of eight anxiety

Table 3 Means, standard deviations, and ranges for study variables by time point

Variable	T_0		T_1		T_2		T_3		T_4	
	M	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
Anxiety	8.05	4.57	6.50	4.16	5.73	4.14	5.29	4.02	4.67	3.56
Happiness	6.82	1.61	7.06	1.44	7.18	1.42	7.43	1.34	7.56	1.26
Sleep p	1.81	1.02	1.51	0.99	1.42	0.98	1.37	1.01	1.36	1.07
Med mins			27.8	22.6	27.9	21.1	26.9	23.4	29.1	28.6
	Range	*n*	Range	*n*	Range	*n*	Range	*n*	Range	*n*
Anxiety	0–21	346	0–19	301	0–21	261	0–21	235	0–21	216
Happiness	0–10	346	2–10	301	2–10	261	3–10	235	1–10	216
Sleep p	0–4	346	0–4	301	0–4	261	0–4	235	0–4	216
Med mins			0–110	368	1–150	306	0–180	268	2–310	236
	T_5		T_6		T_7		T_8			
	M	SD	*M*	SD	*M*	SD	*M*	SD		
Anxiety	5.09	3.96	5.11	3.87	4.91	4.22	4.85	4.46		
Happiness	7.38	1.35	7.31	1.35	7.41	1.41	7.62	1.52		
Sleep p	1.24	1.03	1.46	1.04	1.26	1.04	1.19	1.06		
Med mins	31.0	23.5	31.9	25.4	27.9	23.2	28.2	27.8		
	Range	*n*	Range	*n*	Range	*n*	Range	*n*		
Anxiety	0–20	198	0–21	178	0–21	170	0–21	125		
Happiness	2–10	198	1–10	178	3–10	170	2–10	125		
Sleep p	0–4	198	0–4	178	0–4	170	0–4	125		
Med mins	1–141	219	2–150	201	1–125	194	1–165	169		

Sleep p sleep problems, *Med mins* meditation minutes measurements regressed on meditation minutes from the past week had a negative sign indicating a possible predictive effect of meditation on anxiety was likely to be inverse. One of these coefficients (M_0–M_1 → A_1) was statistically significant.

All happiness variables regressed on meditation minutes had a positive sign, indicating a possible predictive effect of meditation on happiness. Two of these regression coefficients (M_1–M_2 → H_2 and M_6–M_7 → H_7) were statistically significant. Seven out of eight sleep problems measurements regressed on meditation minutes had a negative sign. None of these coefficients was statistically significant. Six out of eight meditation variables regressed on sleep problems in the previous week were negative. All regressions added based on SEPC were also statistically significant.

Discussion

The present study set out to investigate how practicing mindfulness meditation during an 8-week online MBP would affect participants' well-being in real time. Conversely, we looked at how well-being (or lack of it) would affect participants' meditation practice during the MBP. We also investigated what baseline characteristics of participants would predict continuing to practice or dropping out. The results indicate meditation practice during a given week in the program weakly predicted improvements in the well-being outcomes, though only three of these relationships were statistically significant (M_0–M_1 → A_1, M_1–M_2 → H_2, and M_6–M_7 → H_7). This is likely partly due to attrition and smaller sample sizes in later stages of the MBP, resulting in lower power for later time point regression coefficients.

Conversely, the results indicate prior well-being (or adversity) did not have a statistically significant effect on how much participants practiced meditation during a given week, though results regarding sleep problems trended in this direction. Also, in the weeks when participants benefitted the most from practice, there were not corresponding boosts to practice more (e.g., M_6–M_7 → A_7 was statistically significant but A_7 → M_7–M_8 was not). Baseline differences of participants were not found to be predictive of continuing to practice or dropping out. Overall, the study provided a look at whether well-being (or adversity) during the course of the MBP may be in bidirectional causal relations with the meditation practice. Our results provide some evidence benefit from MBPs is likely an ongoing process fed by a sustained meditation practice.

Completing the 8-week MBP and answering the ecological momentary assessment questions resulted in some benefit in terms of outcome effects. Participants that answered the T_8 EMA query experienced an average reduction in their GAD-7 scores from 8.05 to 4.85, suggesting answering daily or weekly prompts, asking about the participants' mood and whether they meditated, could result in a positive effect of its own. This 3.2-point reduction is less than the 5-point cutoff for "reliable improvement" on the GAD-7 (Richards and Borglin 2011). Our sample was subclinical and it is possible there is a floor effect for how much the participants are likely to improve. Out of the 23 participants scoring above the clinical threshold of 10 in anxiety and answering both T_0 and T_8 anxiety surveys ($n = 92$), 17 (73.9%) experienced a clinically significant reduction in their anxiety (from above 10 to below 9; Richards and Borglin 2011). It is possible participants who feel better are more motivated to answer questions, but as completers and dropouts did not differ in baseline characteristics in this study, it is unlikely this is a major cause for the effect. Taken together, our results give some evidence that clinically significant improvement in anxiety may be obtained by taking part in an online MBP, provided the participant adheres to the program.

The beneficial effect was immediate, as there was a marked decrease in anxiety and sleep problems and an increase in happiness in the first weeks of the program. In MBP studies that only use pre- and post-measurements, it is hard to know whether salutary effects occur in the beginning, in the middle, in the end, or throughout the course of the MBP. Amount of practice was not a major contributor to benefit in our data which is contrary to what other studies have found (Carmody and Baer 2008; Huppert and Johnson 2010; Parsons et al. 2017). This may partly be due to participants reporting relatively few meditation minutes overall. A dose-response effect may only arise once a threshold is surpassed in terms of practice time. Early stages of meditation practice are particularly effortful (Tang et al. 2012) and it may well be that benefit from practice starts to differentiate meditators only after they have cleared initial stages of practice.

The average total meditation minutes the participants reported in our study amounted to less than 2.5 h, but the average MBSR/MBCT participant engages in 3 h of practice per week (Parsons et al. 2017). This disparity in amounts of practice could be at least partly due to (1) the most commonly used Tita meditation being only 5 min in length and (2) our sample consisting mostly of adolescents, as they may still be in the process of developing the self-discipline and motivation a sustained practice requires.

Given there have thus far been few mindfulness studies employing ecological momentary assessment methodology, the present study can be seen as a contribution to the field in a number of ways (see, e.g., Hill and Updegraff 2012; Moore et al. 2016; Ruscio et al. 2015). First, to our knowledge, it is the first of its kind to take a series of concurrent, within MBP measurements of how dosage (how much participants meditate) affects effect (well-being benefit) and vice versa. Second, with 457 participants, the study has a larger than usual sample size in the field (compare with $n = 96$ in Hill and Updegraff (2012), $n = 67$ in Moore et al. (2016), and $n = 44$ in Ruscio

Table 4 Regression coefficients for model

Regression	β					Modified	β
$A_0 \rightarrow A_1$	*0.54*	M_3–$M_4 \rightarrow M_4$–M_5	*0.35*	M_7–$M_8 \rightarrow \mathrm{S}_8$	− 0.09	M_0–$M_1 \rightarrow M_2$–M_3	*0.22*
$A_1 \rightarrow A_2$	*0.53*	M_4–$M_5 \rightarrow M_5$–M_6	*0.61*	$A_0 \rightarrow M_0$–M_1	− 0.06	M_2–$M_3 \rightarrow M_4$–M_5	*0.33*
$A_2 \rightarrow A_3$	*0.63*	M_5–$M_6 \rightarrow M_6$–M_7	*0.45*	$A_1 \rightarrow M_1$–M_2	0.02	M_3–$M_4 \rightarrow M_5$–M_6	*0.25*
$A_3 \rightarrow A_4$	*0.44*	M_6–$M_7 \rightarrow M_7$–M_8	*0.51*	$A_2 \rightarrow M_2$–M_3	− 0.09	M_4–$M_5 \rightarrow M_6$–M_7	*0.28*
$A_4 \rightarrow A_5$	*0.48*	M_0–$M_1 \rightarrow A_1$	*− 0.08*	$A_3 \rightarrow M_3$–M_4	0.09	M_5–$M_6 \rightarrow M_7$–M_8	*0.29*
$A_5 \rightarrow A_6$	*0.43*	M_1–$M_2 \rightarrow A_2$	− 0.05	$A_4 \rightarrow M_4$–M_5	− 0.02	$H_1 \rightarrow H_3$	*0.28*
$A_6 \rightarrow A_7$	*0.64*	M_2–$M_3 \rightarrow A_3$	− 0.08	$A_5 \rightarrow M_5$–M_6	0.03	$H_3 \rightarrow H_5$	*0.39*
$A_7 \rightarrow A_8$	*0.46*	M_3–$M_4 \rightarrow A_4$	− 0.01	$A_6 \rightarrow M_6$–M_7	0.02	$H_4 \rightarrow H_6$	*0.34*
$H_0 \rightarrow H_1$	*0.21*	M_4–$M_5 \rightarrow A_5$	− 0.02	$A_7 \rightarrow M_7$–M_8	− 0.02	$H_5 \rightarrow H_7$	*0.27*
$H_1 \rightarrow H_2$	*0.67*	M_5–$M_6 \rightarrow A_6$	0.02	$H_0 \rightarrow M_0$–M_1	− 0.03	$H_5 \rightarrow H_8$	*0.23*
$H_2 \rightarrow H_3$	*0.55*	M_6–$M_7 \rightarrow A_7$	− 0.09*	$H_1 \rightarrow M_1$–M_2	− 0.02	$H_6 \rightarrow H_8$	*0.40*
$H_3 \rightarrow H_4$	*0.73*	M_7–$M_8 \rightarrow A_8$	− 0.04	$H_2 \rightarrow M_2$–M_3	− 0.02	$A_0 \rightarrow A_2$	*0.22*
$H_4 \rightarrow H_5$	*0.37*	M_0–$M_1 \rightarrow H_1$	0.10*	$H_3 \rightarrow M_3$–M_4	0.11	$A_1 \rightarrow A_4$	*0.22*
$H_5 \rightarrow H_6$	*0.41*	M_1–$M_2 \rightarrow H_2$	*0.10*	$H_4 \rightarrow M_4$–M_5	− 0.09	$A_1 \rightarrow A_7$	*0.22*
$H_6 \rightarrow H_7$	*0.49*	M_2–$M_3 \rightarrow H_3$	0.03	$H_5 \rightarrow M_5$–M_6	0.04	$A_2 \rightarrow A_4$	*0.23*
$H_7 \rightarrow H_8$	*0.27*	M_3–$M_4 \rightarrow H_4$	0.06*	$H_6 \rightarrow M_6$–M_7	0.07	$A_3 \rightarrow A_5$	*0.30*
$\mathrm{S}_0 \rightarrow \mathrm{S}_1$	*0.42*	M_4–$M_5 \rightarrow H_5$	0.03	$H_7 \rightarrow M_7$–M_8	− 0.09	$A_4 \rightarrow A_6$	*0.34*
$\mathrm{S}_1 \rightarrow \mathrm{S}_2$	*0.19*	M_5–$M_6 \rightarrow H_6$	0.03	$\mathrm{S}_0 \rightarrow M_0$–$M_1$	0.02	$A_6 \rightarrow A_8$	*0.38*
$\mathrm{S}_2 \rightarrow \mathrm{S}_3$	*0.42*	M_6–$M_7 \rightarrow H_7$	*0.11*	$\mathrm{S}_1 \rightarrow M_1$–$M_2$	0.02	$\mathrm{S}_0 \rightarrow \mathrm{S}_2$	*0.27*
$\mathrm{S}_3 \rightarrow \mathrm{S}_4$	*0.28*	M_7–$M_8 \rightarrow H_8$	0.07*	$\mathrm{S}_2 \rightarrow M_2$–$M_3$	− 0.04	$\mathrm{S}_1 \rightarrow \mathrm{S}_5$	*0.23*
$\mathrm{S}_4 \rightarrow \mathrm{S}_5$	*0.33*	M_0–$M_1 \rightarrow \mathrm{S}_1$	− 0.02	$\mathrm{S}_3 \rightarrow M_3$–$M_4$	− 0.07	$\mathrm{S}_1 \rightarrow \mathrm{S}_6$	*0.23*
$\mathrm{S}_5 \rightarrow \mathrm{S}_6$	*0.17*	M_1–$M_2 \rightarrow \mathrm{S}_2$	− 0.04	$\mathrm{S}_4 \rightarrow M_4$–$M_5$	− 0.06	$\mathrm{S}_3 \rightarrow \mathrm{S}_5$	*0.19*
$\mathrm{S}_6 \rightarrow \mathrm{S}_7$	*0.59*	M_2–$M_3 \rightarrow \mathrm{S}_3$	− 0.03	$\mathrm{S}_5 \rightarrow M_5$–$M_6$	− 0.04	$\mathrm{S}_4 \rightarrow \mathrm{S}_6$	*0.24*
$\mathrm{S}_7 \rightarrow \mathrm{S}_8$	*0.56*	M_3–$M_4 \rightarrow \mathrm{S}_4$	− 0.01	$\mathrm{S}_6 \rightarrow M_6$–$M_7$	− 0.11*	$\mathrm{S}_5 \rightarrow \mathrm{S}_7$	*0.23*
M_0–$M_1 \rightarrow M_1$–M_2	*0.51*	M_4–$M_5 \rightarrow \mathrm{S}_5$	0.03	$\mathrm{S}_7 \rightarrow M_7$–$M_8$	− 0.12*		
M_1–$M_2 \rightarrow M_2$–M_3	*0.45*	M_5–$M_6 \rightarrow \mathrm{S}_6$	− 0.00				
M_2–$M_3 \rightarrow M_3$–M_4	*0.62*	M_6–$M_7 \rightarrow \mathrm{S}_7$	− 0.07				

$p \leq 0.05$ in italics

*$0.05 < p < 0.10$

A anxiety, *H* happiness, *S* sleep problems, *M* meditation minutes

Subscript numbers denote time points (0 = before program, 8 = after program; e.g., H_0 = happiness at T_0, M_2–M_3 = meditation between T_2 and T_3)

et al. (2015))—even with attrition in the later weeks of the MBP. Third, the sample consisted of volunteers from all over Finland and can be considered an ecologically valid look at who volunteers for online MBPs for upper secondary education students in Finland. Finally, our tentative finding that participants who answer EMA prompts may improve over and above regular MBP participants can also be seen as potentially useful in improving MBP designs.

Limitations and future research

Some limitations of the study should be noted. First, the EMA data were collected only from the MBP group, as part of an efficacy study, and there are no equivalent data from the waitlist control group. The rationale for this decision was that our previous study already resolved how the MBP impacted participants when compared with waitlist controls and, in the present study, we only intended to look at how the MBP achieved its effects.

Second, even though we went to some lengths to minimize attrition (participants were contacted with newsletters multiple times during the efficacy study—in addition to the Paco prompts they were already receiving daily), the dwindling sample size still presented some problems for the analyses. Even with full-information maximum likelihood analyses in Mplus allowing us to take full advantage of all gathered data, the sample size was inconveniently small in the later weeks of the study period. However, as the sample size stayed above 200 for nearly all time points and as statistically or marginally statistically significant findings appeared in the later weeks (where power is lower), the model should be adequately powered overall. Also, because of attrition in the meditation minutes data, it is hard to know how well the totals reflect the actual meditation minutes totals (including possible practice participants failed to report). Possible reasons for the EMA attrition are (1) some participants quitting the MBP altogether and consequently ceasing to answer EMA prompts and (2) finding answering the daily/weekly prompts tiresome or demanding and ceasing to answer while continuing with the MBP.

Third, the volunteer sample skewed strongly towards female and upper secondary school. This was an unavoidable consequence of obtaining an ecologically valid sample based on accepting the people that wanted to be included. It appears that using mindfulness to increase well-being currently appeals to adolescent females more than to males. Mainstream conceptions of mindfulness (as having to do with yoga or self-care, for instance) in Finland may well account for the discrepancy. We could have attempted to balance gender and school type, but this would have led to having a much smaller sample size. There were no statistically significant baseline differences in study outcome variables based on gender or school type. However, because the sample consisted of volunteers, a selection bias may have resulted, for example, in overrepresentation of anxious or depressed students or students with a favorable idea of mindfulness. Students higher in baseline well-being reported more benefit from the MBP and this was not due to them practicing more. However, they may have had a better than average ability to learn from the practice they did.

Fourth, our use of single item measures (happiness and sleep problems) was methodologically suboptimal, though justified by the need to keep the weekly questionnaires minimally demanding for the participants. Lengthier scales could be used in the future to see whether this creates more missing data or not.

Fifth, as effects were statistically significant for only some time points, they are to be taken as weak evidence for causal relations between meditation minutes and well-being. Stronger confirming or disconfirming evidence can be obtained in future studies.

For future directions, researchers could take note of the positive aspects of employing (1) online MBPs and (2) EMA technology to study these MBPs. It has never been easier and less costly to obtain large samples on MBPs, which should then facilitate devising many kinds of novel study designs and foci. Large sample size data sets make it possible, e.g., to study individual differences of MBP participants in a way face-to-face MBP studies lack the power to do (Davidson and Dahl 2018). Online MBPs are highly scalable and, if beneficial, as early evidence indicates (Spijkerman et al. 2016), can expand MBP reach and resulting benefits to new populations. EMA technology makes it easier to study specific components of programs and to obtain real-time data on their effects. Specifically, future research could (1) adopt the EMA technology to obtain practice and outcome data during face-to-face MBPs and (2) build an evidence-base around a promising online MBP (similar to what has been done with MBSR/MBCT in face-to-face MBP research). The research community would do well to embrace this methodology and come up with innovative applications for it in the study of mindfulness and MBPs.

Author contributions Oskari Lahtinen: Designed the study, collected the data, conducted the analyses, and wrote the manuscript.

Christina Salmivalli: Supervised Oskari Lahtinen's work and offered comments on the manuscript.

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Compliance with ethical standards

Conflict of interest Oskari Lahtinen declares he developed the program being studied. Christina Salmivalli declares no conflict of interest.

Ethical approval Ethical review of the study plan was conducted by the University of Turku Ethics Committee. The Committee approved the plan with minor suggestions to improve the protocol. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Statement of informed consent Informed consent was obtained from all individual participants included in the study.

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