A method of measuring the ability of disengagement from mind-wandering using electroencephalogram and its relationship to mindfulness and depressive symptoms

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Author note

We thank Prof. Rieko Osu, Waseda University, for her revision of the manuscript. Additionally, we are grateful to Masahiro Fujino, Ph.D., Kyoto University for helping with recruitment of participants. We would like to thank Editage (www.editage.jp) for English language editing. This work was supported by Waseda University Ibuka Funding for “Human Science Research Project Associating Oriental Medicine,” Waseda University Grants for Special Research Projects, JSPS KAKENHI Grant Number 18K13332, National Institute of Information and Communications Technology (NICT), Japan. The authors declare that there is no conflict of interest.

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Abstract

Objective: Mindfulness meditation might improve the ability of disengagement from mind-wandering, that is, the ability to shift attention from mind-wandering. Disengagement from mind-wandering could mediate the relationship between mindfulness and reduced depression. However, no studies have confirmed this relationship because of limitations in measurement methodology. Since the mindfulness-based intervention, which instructs participants to be aware of the occurrence of, and their own engagement in, mind-wandering, might bias self-reports of mind-wandering, a measurement method that does not rely on participants' verbal report is needed. Therefore, we propose a novel method to evaluate the ability of disengagement from mind-wandering, based on mind-wandering intensity estimation by machine-learning using electroencephalography.

Methods: Mind-wandering intensity was estimated using one-second electroencephalogram samples and a machine-learning model developed in previous research. Thus, fluctuations in mind-wandering were observed during a 14-minute meditation and the time required to shift attention from mind-wandering was defined as an index of mind-wandering disengagement. Two experiments were performed: The first targeted experienced meditators and the second assessed non-meditators before and after participating in a mindfulness-based intervention.

Results: The experiments revealed that disengagement from mind-wandering correlated with the extent of meditation experience. A correlation was also found between the magnitude of change in disengagement and severity of depression following the intervention.

Conclusions: Though further verification of validity is required, this study suggested the possibility that disengagement from mind-wandering has a mediating function on reducing depression by mindfulness-based intervention, and that improved disengagement from mind-wandering is more essential for mindfulness than trait mind-wandering.

Keywords: Mind-wandering; Electroencephalogram; Mindfulness; Depression

Public Significance Statement

The ability of disengagement from mind-wandering could mediate the relationship between mindfulness and reduced depression. However, no studies have explored this relationship due to limitations in measurement methodology. This study suggested a method to evaluate the disengagement from mind-wandering and indicated that the disengagement relates to mindfulness and depression.

Introduction

Mindfulness is a concept derived from Buddhism that denotes purposefully and non-judgmentally paying attention to the present moment (Kabat-Zinn, 2015). The training method to cultivate mindfulness is called mindfulness meditation, which is practiced primarily in two contexts: a traditional meditation retreat and group sessions centered on mindfulness meditation, such as mindfulness-based stress reduction or mindfulness-based cognitive therapy. Both types of mindfulness-based interventions (MBI) have shown to ameliorate several symptoms, including those of depression (Alsubaie et al., 2017; Khoury et al., 2013, 2017). Research has focused on mind-wandering (MW; Smallwood & Schooler, 2006) as one of the mechanisms underlying mindfulness, that is, thoughts irrelevant to the current task or situation. High trait MW — a tendency to become absorbed in MW — is associated with depressive symptoms and low mood (Burg & Michalak, 2010; Hoffmann et al., 2016; Killingsworth & Gilbert, 2010; Smallwood et al., 2007), and mindfulness meditation appears to decrease trait MW (Bennike et al., 2017; Brewer et al., 2011; Cardeña et al., 2015; Morrison et al., 2013; Mrazek, Franklin, et al., 2013; Mrazek et al., 2012; Rahl et al., 2017; Xu et al., 2017). Based on these findings, it has been hypothesized that trait MW mediates the effect of mindfulness on depression (Wang et al., 2017).

However, we suggest that the ability of disengagement from MW — that is, the ability to shift attention from MW as necessary — is a more plausible mediator of the relationship between MBI and depressive symptoms or mood than trait MW. This is because the notion that the harmfulness of MW diverges based on its contents, including temporal orientation and affect value (Marcusson-Clavertz et al., 2016; Ruby et al., 2013), is not consistent with the frequency of general MW as a mediator of MBI. Further, mindfulness meditation appears to improve the disengagement from MW while reducing trait MW, which seems to be its secondary effect. General mindfulness meditation instructs participants to maintain their attention; simultaneously, it emphasizes the awareness of MW and returning attention to the original place (Segal et al., 2002). Zanesco et al. (2016) found that a month-long MBI reduced MW only when the subjects were aware of MW, and interpreted this result that MBI may enhance the ability to disengage from MW and reorient attention, and thereby reduce trait MW. Based on mindfulness and Buddhism teachings and recent neuroscientific reports, Vago and Zeidan (2016) also suggested the importance of MW disengagement in mindfulness. Reduction of trait MW by MBI could be explained by enhanced disengagement from MW. The main methods to validate trait MW are generally divided into three types. First is the experience-sampling method or probe-caught method, in which subjects are asked about their ongoing MW at random times while focusing on a task or engaging in daily life; the frequency of their reported MW is considered to represent their trait MW (e.g., Mrazek, Phillips, et al., 2013; Xu et al., 2017). Being suddenly presented with questions about MW makes subjects aware of their ongoing MW. Therefore, this method is considered to catch MW that is usually not noticed (i.e., MW without meta-awareness; Smallwood & Schooler, 2006). The second is the behavioral score method: Subjects perform a Go/NoGo task called the sustained attention to response task (SART; Robertson et al., 1997); the performance score, such as the number of commission errors, is known as a behavioral index of trait MW (Cheyne et al., 2009; Cheyne et al., 2006; Seli, 2016). The third is the questionnaire method: Questionnaires such as the Mind Wandering Questionnaire (MWQ; Mrazek, Phillips, et al., 2013) have been developed to assess trait MW (Bennike & Wieghorst, 2017). Immediately shifting attention from MW can reduce the time spent in MW during a task or in daily life, and it is likely that the scores of these indices decrease when the disengagement from MW increases. Thus, the essential effect of MBI may be increased disengagement from MW, with a secondary outcome of decreased trait MW.

Nonetheless, there is lack of knowledge regarding MW disengagement, including its effect on mood or trait MW. In particular, no studies have investigated the potential mediating relationship between MBI and depression, because of a measurement limitation — the difficulty of measuring changes in disengagement from MW induced by mindfulness. The current method of measuring the disengagement from MW depends on participants' self-report (e.g., van Vugt & Broers, 2016). Self-report measurements are subject to bias, especially in intervention studies of MBI, because MBI instructs participants to be aware of MW, which may directly alter the magnitude of the bias. Additionally, although self-report of ongoing MW is generally considered to provide acceptable data (Schooler et al., 2011; Weinstein, 2018), the validity of self-report of disengagement has not been discussed. For individuals, reporting whether they disengaged from MW may be more difficult than reporting the existence or intensity of current MW.

Therefore, the present study developed a novel evaluation method and used the method to assess the mediating function of disengagement from MW. This method depends on only the self-report of ongoing MW (not self-report of disengagement) by subjects in a prior study, which was used to develop the model, and it requires no self-report by MBI participants themselves. Thus, the method is advantageous for assessing disengagement from MW in the context of an intervention study of MBI. A recently developed machine-learning estimator was used to predict the intensity of MW from electroencephalogram (EEG) data. This estimator has been shown to robustly predict the MW intensity of unknown individuals (novel individuals, whose EEG data are not used for estimator fitting). The model estimates MW intensity from power and coherence in a wide range of frequency bands using eight electrodes distributed on the frontal and parietal regions of the scalp (Kawashima & Kumano, 2017). Kawashima and Kumano (2017) suggested that these features reflect the activity of the default-mode network (Raichle et al., 2001) and the executive-control network (Seeley et al., 2007). The estimator model, which fits the self-reported current MW intensity and EEG recording before self-reporting, uses EEG in the range 1.5 Hz–44 Hz frequency bands to make predictions. Thus, it can convert sub-second EEG samples into MW intensity in that period and enable observation of MW fluctuations as a wave. The time required to shift attention from MW to the current task can thereby be obtained. This "shifting-time" is a direct index of the ability to shift attention from MW (i.e., MW disengagement). Although the estimating model fit is based on self-report data, the measurement of shifting-time does not require new self-reports of MW from the participant; thus, it is free of the bias problems mentioned above. The shifting-time index was calculated and validated in two ways: First, estimated MW fluctuations and MW reports were compared. Then, correlations with questionnaire scores reflecting top-down attentional switching and trait non-reactivity were investigated. Non-reactivity, which is the trait to refrain from impulsive emotional reactions as cultivated by mindfulness training, is thought to weaken engagement with MW content, and thus influence shifting attention from MW as well as voluntary attentional control. Indeed, previous research with subjects who had participated in MBI without a non-reactivity component demonstrated higher trait MW than participants who had engaged in MBI with non-reactivity instruction; this demonstrates the effect of non-reactivity on MW processes (Rahl et al., 2017). Based on the hypothesis that disengagement from MW mediates the relationship between MBI and depression, the present study investigated whether MW shifting-time correlated negatively with meditation experience among experienced meditators who had participated in mindfulness retreats (Experiment 1). Further, the study tested whether the shifting-time correlated positively with depression of patients, and whether the degree of change in depression correlated positively with the amount of change in the shifting-time (Experiment 2). Additionally, for comparison, the same statistical analysis was performed using a traditional questionnaire and behavioral scores that indicate trait MW instead of shifting-time.

Experiment 1

Methods

The protocol was approved by Ethics Review Committee on Research with Human Subjects, Waseda University (2016-065). All participants provided written informed consent in accordance with the Declaration of Helsinki.

Participants

Participants were 17 individuals (13 males, four females; mean age = 41.53 years, *SD* = 9.96) who had participated twice or more in a 10-day meditation camp held by the Japan Vipassana Association, and who continued to perform mindfulness meditation regularly. The camp was an intensive retreat that included approximately 10 hours of meditation per day.

Procedure

First, participants completed a 15-minute SART. One trial of the task was composed of a one-time presentation of a numerical digit (0, 1, 2, …, or 9) and subsequent button-press by the participant. Participants were instructed to respond to the number presentation as quickly as possible; however, if “3” was presented, they were not to press a key. The trials were 2 s in duration, and the order of digit presentation was pseudo-randomly shuffled. The frequency of presentation of the digit “3” was lower (0.5%) than other digits. The number of commission errors was counted as a behavioral trait MW index. Note that participants had previously attended the laboratory and completed the same SART task twice or four times on another day before the experiment, for another study. After a break, EEG was recorded during 20 minutes of mindfulness meditation, during which the participants continued to focus their attention on the sensation of their breath without attempting to control its rhythm or depth of respiration; when participants became aware that their mind was wandering, they returned their attention to breathing. When they became aware of their mind-wandering during the meditation, they pressed a button held in their hand. Their shifting-time during the meditation was scored with the recorded EEG (mentioned later). Participants were asked to practice this meditation for 20 minutes every day for seven days prior to the experiment day.

Measurements

We collected answers to the MWQ, the nonreactivity sub-scale from the Five Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006; Sugiura et al., 2012), and the switching attention sub-scale from the Voluntary Attention Control Scale (VACS, VACS-SW; Imai et al., 2015). The MWQ is a widely used five-item questionnaire designed to measure trait MW in daily life. The FFMQ includes five sub-scales that reflect five aspects of trait mindfulness: observing (Observe), describing (Describe), acting with awareness (ActAware), nonjudging of inner experience (Nonjudge), and non-reactivity to inner experience (Nonreact). The VACS is a scale for assessing voluntary attentional control ability in three areas: selective attention, divided attention, and switching attention. The VACS-SW subscale is composed of six items that ask whether participants can switch their attention to a current or new task from an old task, body sensations, or MW. A higher score indicates that one has better switching ability. The instrument has verified reliability and validity in Japan, and a correlation between its score and a switching task score was shown (Imai et al., 2015). Though subjects answered all items of the FFMQ and VACS, to reduce the number of statistical tests, only the Nonreact and VACS-SW subscales were used in the analysis, which were included in the hypothesis. Additionally, participants were requested to provide a detailed written account of how long they had been practicing meditation, how many days per week they meditated, how many hours they meditated per day, how many days they had participated in intensive retreats, and how many hours they had meditated during those retreats. From this information, we calculated and estimated their lifetime hours of meditation experience.

EEG recording

Based on Kawashima and Kumano (2017), the present study recorded EEG during meditation using a 64-electrode Geodesics EEG system (Electrical Geodesics Inc.). A band-pass filter (1–47 Hz) was applied using Waveform Tools, Net Station Version 4.4 (Electrical Geodesics Inc.) The sampling rate was 500 Hz; data were then downsampled to 250 Hz. To match the design of Experiment 2 (in which 15 minutes of EEG was recorded; mentioned later), the final five minutes of data were removed. Additionally, the first minute of data was removed, owing to EEG instability. The remaining 14 minutes of EEG data were divided into one-second epochs. In each epoch, bad channels were detected — defined as degraded measurement accuracy due to temporary loss of contact between electrodes and skin, or body motion artifacts — using algorithms provided by Waveform Tools.

Estimation of mind-wandering

The fitted estimation model was applied to each EEG epoch. This model learned the relationship between probe-caught momentary MW intensity and the power and coherence in 1.5 – 44 Hz frequency bands from eight electrodes (F3, F4, F8, Pz, P6, P9, P10, O1) just before the probe presentation. It was validated that the model can precisely predict MW intensity in the novel (i.e., not used for learning) subjects (r = .49; see Kawashima &

Kumano, 2017, for details). Among the five Support Vector Machine Regression models provided by Kawashima and Kumano (2017), they suggest that one of them (Model 2), using eight electrodes, estimates MW intensity via activity of the default-mode network (Raichle et al., 2001), which is considered the neural basis of MW, and the executive-control network (Seeley et al., 2007), which acts in opposition to the default-mode network (Menon, 2011). They suggested that this model is suitable for EEG assessment during a task that requires simple maintenance of attention.

We calculated power and coherence with each one-second EEG sample, and the model converted them to the intensity of MW; thus, the time-varying MW wave was plotted. In each epoch, if the electrodes necessary for estimation were detected as bad channels, that period was removed and linearly interpolated (Figure 1 (a)). The present study intended to completely remove a subject from analysis if more than five consecutive seconds of their data were removed or if more than five percent of all of their MW waves were removed. However, all participants' MW waves met these criteria.

Calculating the shifting-time

Similar to previous research (Hasenkamp & Barsalou, 2012; Voss et al., 2018; Zukosky & Wang, 2021), the present study also assumed that in mindfulness meditation, the MW and concentration states emerge in turn. The consciousness state was classified into four phases: "concentrating phase"; "MW phase"; "absorbing phase," in which participants are gradually losing their concentration and becoming absorbed in MW; and "shifting phase," in which they are disengaging from MW and returning to the concentrating phase. The duration of the shifting phase is the time required to redirect attention from MW to a state of concentration. This shifting-time was used as the reverse index of the ability of disengagement from MW (i.e., the shorter the shifting-time, the greater the disengagement). To classify the MW wave into the aforementioned phases, the data were first smoothed using a three-point moving average and 1/60 Hz high-pass filter (Figure 2 (b)). Second, to extract stable states (i.e., MW or concentrating states), a fused lasso (Tibshirani et al., 2005) was used. The fused lasso solves the following:

$$\min_{\beta}\left[\sum_{i=1}^{N}(y_i-\beta_i)^2+\lambda\sum_{j-i}^{N-1}|\beta_{i+1}-\beta_i|\right]$$

Here, y_i and β_i are values of an arbitrary point before and after applying the fused lasso, respectively. N is 840 because we plotted 14 minutes of data at one-second intervals. After minimization, the former term of the formula encourages the wave to be same as previous, and the latter term smooths the wave by encouraging adjacent pairs of points to have the same value. We set $\lambda = 0.5$; this is a user-defined parameter that controls the degree of smoothing. By this procedure, MW waves were classified into several stable (i.e., values are constant for a certain duration) phases (Figure 1 (c)). Third, based on the assumption that concentrating states and MW states emerge in turn (Hasenkamp & Barsalou, 2012; Voss et al., 2018; Zukosky & Wang, 2021), the peaks of waves were extracted. We then defined phases with local maxima as MW phases and phases with local minima as concentrating phases. The other periods were removed and linearly interpolated (Figure 1 (d)). Fourth, small transitions, in which the absolute difference between two consecutive values was less than a threshold value, were eliminated. In such cases, the later value was replaced by the preceding value, moving sequentially from the beginning of the wave. The threshold was set at the average of the absolute differences between consecutive values (excluding 0, i.e., the duration over which values are stable) in each MW wave. Finally, maxima and minima were extracted again and MW phases and concentrating phases were redefined in the third step (Figure 1 (e)). The parameters in these smoothing protocol (e.g. λ) were set arbitrarily. We defined the shifting phase as ending at the next concentrating phase (Figure 1 (f)), and calculated the mean shifting duration. This average of durations of shifting-time was defined as the index of the ability of disengagement from MW.

Validation of phase division and shifting-time index

As stated above, MW waves were divided into four phases. To validate this phase division, button pressing timing that signaled when participants realized they had begun MW was analyzed. We concatenated button-press timing data from subjects who pressed more than once, and counted numbers of button presses and their durations for each phase. The observed frequency of button-pressing during each phase (=pressed counts during the phase / duration of the phase) was tested using a chi-squared test. Thus, it was tested whether the button was pressed more frequently during their MW phase and shifting phase than during the other phases, given the possibility that when they noticed MW, they had already started to return their attention to the task (Cunningham et al., 2000). Next, to support the validity of shifting-time as an index of the disengagement from MW, we investigated Spearman's correlations for shifting-time with the Nonreact sub-scale of the

FFMQ and with VACS-SW as an attentional control scale. For hypothesis testing, we investigated the correlation between meditation experience and MWQ score and SART commission error number as MW frequency trait indices, and with shifting-time as a measure of MW disengagement. The Spearman's ranked correlation test was used because of the small sample size. A post-hoc statistical power test was performed on these correlation tests.

Result

The average amount of meditation experience was 3579.56 hours (*SD* = 3347.45); the other descriptive statistics are shown in Table 1. To validate the phase division, chi-squared tests were performed to confirm the tendency to press the button during MW or the shifting phase. Button-press data from 16 participants (one did not press the button) were used. Chi-squared tests indicated that participants tended to press the button during the MW phase rather than during the concentrating and absorbing phases ($\chi^2 = 44.48$, $p < .001$, $V = .055$). The sensitivity of phase estimation (the rate between button press counts in MW phase and counts in MW or concentrating or absorbing phase) was 58.19% (chance level was 34.26%). Further, we found a trend of a significant increase in button-pressing during the shifting phase from concentrating and absorbing phases ($\chi^2 = 2.74$, $p = .098$, $V = .014$), and that the sensitivity was 35.09% (chance level was 27.74%). The numbers of button pressing in each phase are shown in Table 2. Thereafter, the Spearman's correlation analysis was conducted between shifting-time and VACS-SW and FFMQ-Nonreact scores to support the validation of the shifting-time index. A negative significant correlation between FFMQ-Nonreact and shifting-time was observed ($\rho = -.49$, $p = .047$). No significant relationship between shifting-time and the VACS-SW was indicated (ρ = -.31, p = .22). Finally, although the Spearman's rank correlations revealed a significant negative correlation between shifting-time and meditation experience (ρ = -.50, p = .041), no correlation was found between MWQ or number of commission errors and meditation experience (ρ = .23, p = .38; ρ = .053, p = .84; Figure 2a).

Discussion

In Experiment 1, the validity of shifting-time was investigated in two ways. First, the phase division of the MW wave was validated via button pressing, which indicated that participants noticed their MW. If the phase division was correct, button-press timings should have been concentrated within the MW or shifting phases. Given the propensity to press the button during the MW phase, the validity of the phase division was supported. Though a previous research indicated that non-meditating participants may have pressed the button after they started to shift their attention back to the task (Cunningham et al., 2000), the subjects of the present study, who had experience of mindfulness meditation, could have possibly noticed MW sooner. Second, to validate shifting-time as an index of disengagement from MW, this study investigated correlations of the former with voluntary attentional switching and non-reactivity, based on the hypothesis that MBI shortens shifting-time by enhancing these two traits. While it was found that shifting-time significantly correlated with the FFMQ-Nonreact score, the correlation with the VACS-SW score was not significant. This may be due to the small sample size and statistical power. However, given that several studies have failed to show a significant change in attentional re-orientation due to MBI, the effect of MBI on attentional switching may also be small. A systematic review of the MBI effect on cognitive abilities found that several studies failed to show a significant change in attentional re-orientation due to MBI (Chiesa et al., 2011; see also Ainsworth et al., 2013; Jha et al., 2007). Mindfulness meditation may affect disengagement from MW primarily by enhancing non-reactivity to the content of MW, rather than by altering attentional control. Thus, the validity of shifting-time as an index of MW disengagement was partially supported.

The significant negative correlation between meditation experience and shifting-time in Experiment 1 supports the suggestion that mindfulness meditation increases disengagement from MW. In contrast, the correlations between meditation experience and trait MW measured by questionnaire and behavioral performance were not significant. Previous research has shown that trait MW is reduced by single MBI (Mrazek et al., 2012) or short-term MBI (Mrazek, Franklin, et al., 2013), and expert meditators experience less MW during meditation or tasks than do beginners (Brewer et al., 2011; Cardeña et al., 2015). However, the present study first investigated the relationship between meditation proficiency and trait MW among experienced meditators. All participants of Experiment 1 were considered to already have sufficient meditation experience to suppress their MW, and their meditation training primarily affected the effort required to control MW (Tang et al., 2012). In contrast, since the correlation between meditation experience and shifting-time was significant even in meditators with considerable experience who could control MW appropriately, meditation enhanced the disengagement from MW.

Experiment 2

Methods

The protocol was approved by A University Academic Research Ethical Review Committee. All participants provided written informed consent in accordance with the Declaration of Helsinki.

Procedure

Before (pre) and after (post) participation in the MBI, participants completed a 15-minute SART and 15-minute mindfulness meditation and answered questionnaires. The content of the mindfulness meditation was similar to Experiment 1. However, in Experiment 1, participants meditated with closed eyes, whereas in Experiment 2, participants' eyes were open. Additionally, in Experiment 2, participants did not press a button when they became aware that their mind had wandered, unlike in Experiment 1.

The EEG was recorded with 250 Hz sampling rate during meditation and the shifting-time was calculated as in Experiment 1. Then, the same exclusion criteria concerning the quality of their MW wave, as in Experiment 1, was applied to participants (i.e., participants were removed from analysis if a period of more than five seconds or more than five percent of all MW waves were removed); three of the 37 participants whose pre-MBI data fulfilled these criteria were excluded. All participants were requested to answer the Beck Depression Inventory-II (BDI-II; Beck et al., 1996), which assessed the severity of depression, and the MWQ. Three participants who failed to fully answer the pre-MBI questionnaires were excluded. The number of commission errors were counted, as in Experiment 1. However, five pre-MBI SART results were lost because of technical errors.

Participants

A total of 37 participants were recruited, who were part of the MBI held in a clinic for those with depression or anxiety symptoms (Takahashi et al., 2020, 2019). The program organizer introduced the experiment to the MBI participants before the program started, and those interested in participating contacted the experimenter of this study. The MBI, which was constructed based on mindfulness-based cognitive therapy (Segal et al., 2002), provided eight weeks of mindfulness-based group sessions once per week, and daily homework involving mindfulness meditation practice. Six participants whose MW waves were of inadequate quality (see the last section) or who failed to answer pre-MBI questionnaires were excluded. Thus, data obtained from 31 participants (14 males, 17 females; mean age = 42.55 years, *SD* = 8.53) were analyzed. It was confirmed that all variables from the rejected six subjects were not biased (within ±2 *SD* of the mean of 37 participants). Three subjects dropped-out from the MBI program, leaving 28 participants.

The data from five pre-MBI SART results were lost and 26 remained. Out of 28, three participants completing the MBI failed to answer the post-MBI questionnaires; thus, 25 provided both pre- and post-MBI questionnaires scores. A total of four, out of 28, declined to participate in the post-MBI SART and EEG recording and only answered the questionnaire. Therefore, we calculated Δshifting-time with 24 samples and Δcomission error with 20 samples because we had lost four of 28 pre-MBI SART data. Further, three of

20 participants failed to answer the post-MBI questionnaire, leaving 17 with paired SART and questionnaire data.

Statistical tests

First, to confirm the difference between pre- and post-MBI values, paired difference tests were performed for BDI-II score ($N = 25$), shifting-time ($N = 24$), MWQ score ($N = 25$), and the number of commission errors ($N = 20$). Because the Shapiro-Wilk test did not support the normality of post-MBI BDI-II ($W = .690$, $p < .001$) and pre-MBI number of commission errors ($W = .85$, $p = .004$), the Wilcoxon signed-rank test was used. Second, correlation coefficients were calculated between pre-MBI scores for BDI-II and shifting-time ($N = 31$), MWQ ($N = 31$), and the number of commission errors ($N = 26$). Then, we investigated whether the change in BDI-II (post score minus pre score; ΔBDI-II) correlated with the degree of change in the shifting-time (ΔShifting-time; $N = 24$), MWQ (ΔMWQ; $N = 25$), and number of commission errors (Δcommission errors; $N = 17$). For these correlation analyses, the Spearman's rank correlation was used, as in Experiment 1. Post-hoc statistical power analyses were performed for these tests.

Result

The descriptive statistics for Experiment 2 are shown in Table 3. Analysis using Wilcoxon signed-rank test indicated that while the post-MBI BDI-II scores, MWQ scores, and number of commission errors were significantly lower than the pre-MBI scores ($W = 35$, p < .001, *RBC* = .79; $W = 48.50$, $p = .007$, *RBC* = .65; $W = 18$, $p = .017$, *RBC* = .70, respectively), no significant difference was present between the pre- and post-MBI scores for shifting-time (W = 139, p = .77, RBC = -.073; Table 3). Spearman's rank correlations revealed a positive relationship between pre-MBI scores for BDI-II and MWQ (ρ = .55, p = .001) and commission error (ρ = .41, p = .039), while the correlation between pre-MBI BDI-II and shifting-time approached significance (ρ = .34, p = .059). In addition, ΔBDI-II score significantly correlated with Δshifting time (ρ = .56, p = .009) and with ΔMWQ (ρ = .46, p = .021), but not with Δcommission error (ρ = .38, p = .13; Table 4 and Figure 2b).

Discussion

In Experiment 2, we measured and compared participants' traits including shifting-time before and after MBI in a clinic. While the MWQ scores and number of commission errors significantly correlated with the severity of depression before the MBI, the relationship between depression and shifting-time was limited to a tendency toward significance. Thus, part of the study's hypothesis that the ability of disengagement from MW correlates with depression was not fully supported. However, the degree of change (before-MBI score minus after-MBI score) in shifting-time and MWQ score correlated with the degree of improvement in depression. These results show that disengagement from MW may be a mediator between MBI and depression, in addition to trait MW (Wang et al., 2016). Though shifting-time scarcely changed in the total, it was determined based on the distribution that some individual participants shortened their shifting-time, while others did not (Figure 2b). Given that repeated task execution increases the intensity of MW (Krimsky et al., 2017), we consider that participants tended to be absorbed in deeper MW and lengthen their shifting-time in the second measurement. The fact that ΔBDI-II score significantly correlated with Δshifting time and ΔMWQ, but not with Δcommission error, may indicate that the disengagement from MW has a more stable mediating function than trait MW.

General discussion

This study developed a novel method to evaluate the ability of disengagement from MW and its purported role in MBI. We proposed a method to evaluate participants' disengagement from MW, in which the time required to shift attention from MW to a concentrating state (shifting-time) was calculated using EEG, to estimate MW intensity. Further, we investigated the relationship of the metric to MBI effects and depression.

The validity of shifting-time was investigated in two ways. First, we confirmed that the meditators were significantly prone to report their MW during the duration estimated as MW phase. Second, we examined the relation between mean shifting-time and two types of trait assessed by questionnaires, and the significant correlation with non-reactivity trait supports the validity.

The correlation between the extent of change in disengagement and the degree of improvement in depression suggests that disengagement from MW has a mediating function in addition to trait MW. Further, the relationship between meditation experience and disengagement indicates that improved disengagement from MW is more essential for mindfulness than is trait MW. MBI can alter self-reporting bias; thus, directly investigating the effect of MBI on disengagement from MW was difficult. This study proposed a methodology to overcome such an obstruction.

However, the current method was not fully supported for assessing the relationship between disengagement from MW and MBI, owing to several limitations. First, further verification of validity is required. Although this study verified the shifting-time index using self-caught MW and questionnaires, the sample size was not large enough to investigate the correlations. Further, verification with a general sample (i.e., non-meditating healthy sample) is also needed. Additionally, although this study showed the relationship between MBI and shifting-time to some extent, the result was unstable because of the small sample size and statistical power; a study with a control group is needed for further clarification. Randomized controlled trials with a waiting list and/or active control group and mediation analysis would confirm the possibility indicated in this study, namely, that disengagement from MW is a mediator between MBI and depression. Finally, the stability of the index proposed here is yet to be confirmed. For trait MW, MW tendency is considered stable to some extent, and the dispositional MW trait can be measured by MW index (e.g., commission error rate; Robertson et al., 1997) acquired in a laboratory (Ottaviani & Couyoumdjian, 2013; Seli et al., 2016). Likewise, we regard the shifting-time index scored in the laboratory to also reflect subjects' dispositional traits. However, this must be confirmed by future research.

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Table 1

Descriptive statistics of Experiment 1.

Measure	*Average*	*SD*
Meditation exp. (hours)	3579.56	3347.45
Shifting-time (seconds)	10.59	3.14
MWQ score	16.65	4.14
Number of commission errors	4.35	3.53
VACS-SW score	26.06	4.19
FFMQ-Nonreact score	24.94	3.44

Meditation exp.: lifetime experience of mindfulness meditation; MWQ: Mind Wandering Questionnaire score; SART: Sustained attention to response task; VACS-SW: Attentional Switching subscale of the Voluntary Attention Control Scale; FFMQ-Nonreact: Nonreactivity to Inner Experience subscale of the Five-facet Mindfulness Questionnaire.

Table 2

Expected frequency and observed count of button pressing during each phase in Experiment 1.

Type of Frequency	Focus	Absorbing	MW	Shifting
Expected	62.11	51.79	59.37	43.72
Observed	36	38	103	40

Expected: Expected frequency of button-press calculated by the proportion of durations of each phase; Observed: Observed frequency of button-press in each phase.

Table 3

Descriptive statistics and Wilcoxon signed-rank tests comparing scores before and after MBI.

Measure	Pre-MBI		Post-MBI		*W*	*p*	*RBC*	*N*	power
	Mean	*SD*	*Mean*	*SD*					
BDI-II	17.56	11.14	8.84	10.23	35.0	< .001	.79	25	.97
Shifting-time	12.43	5.07	13.22	3.84	139.0	.77	-.07	24	.13
MWQ	20.56	3.98	18.32	3.44	48.0	.007	.65	25	.82
Commission errors	4.85	4.08	3.30	2.43	18.0	.017	.70	20	.50

"Pre-MBI" and "Post-MBI" denote the scores before and after the mindfulness-based intervention. BDI-II: Beck Depression Inventory-II; Shifting-time: Duration of attention shifting from mind-wandering; MWQ: Mind Wandering Questionnaire; RBC: Rank-biserial correlation.

Table 4

Spearman's rank correlations for pre-MBI BDI-II and ΔBDI-II scores with three measures.

Measure	(pre- or Δ) Shifting-time				(pre- or Δ) MWQ				(pre- or Δ) Commission error			
	ρ	*p*	*N*	power	*ρ*	*p*	*N*	power	*ρ*	*p*	*N*	power
pre-MBI BDI-II	.34	.059	31	.48	.55	.001	31	.92	.41	.039	26	.64
ΔBDI-II	.56	.009	21	.92	.46	.021	25	.76	.38	.13	17	.57

"Pre-MBI" denotes the score before the mindfulness-based intervention. BDI-II: Beck Depression Inventory II; Shifting-time: Duration of attention shift from mind-wandering; MWQ: Mind Wandering Questionnaire score; The Δ denotes post-intervention score minus pre-intervention score.

Figures

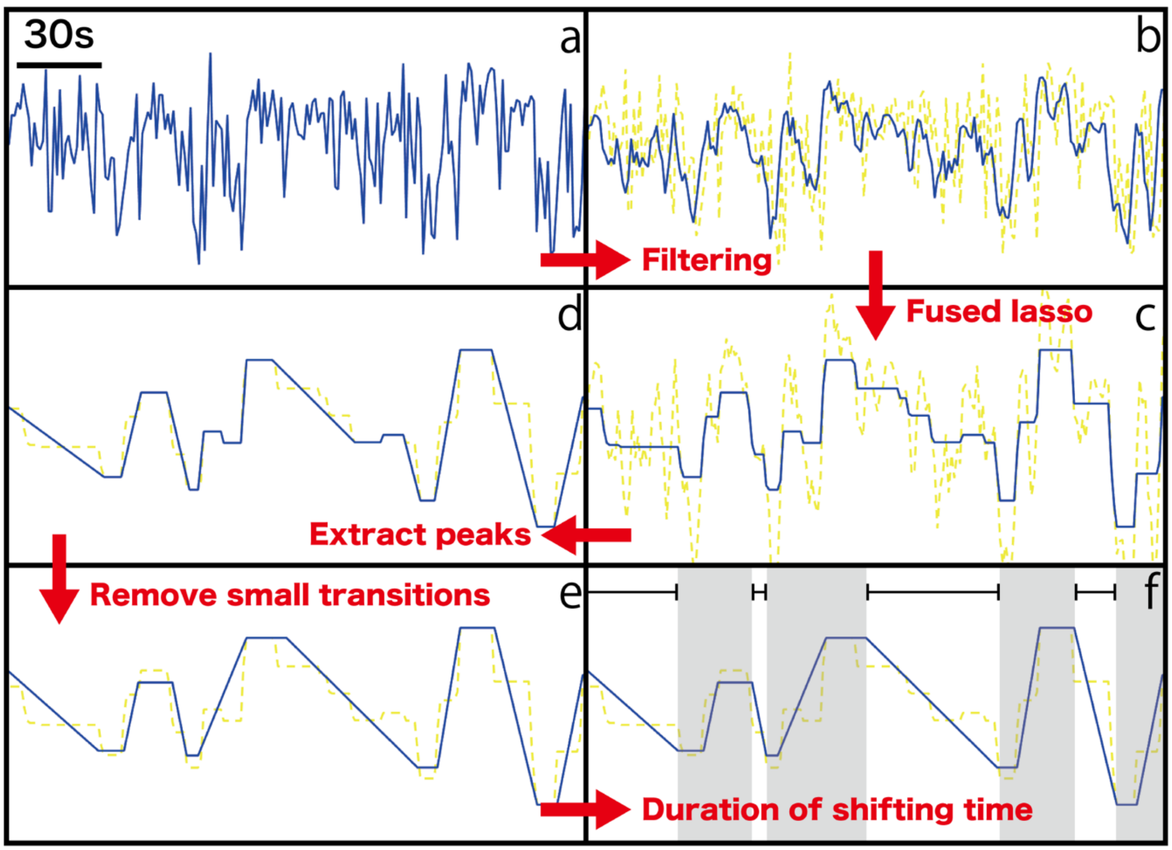

Figure 1. Processing of the MW wave. (a) Raw MW wave for an arbitrary subject and period. (b) First, the MW wave was processed by taking a moving average and applying a high-pass filter. (c) Second, a fused lasso was applied. (d) Next, maxima/minima were extracted. (e) Then, small transitions were removed, and maxima/minima were extracted again. (f) Finally, the duration of attention shifting due to MW was calculated. Yellow lines indicate the plot before a processing step.

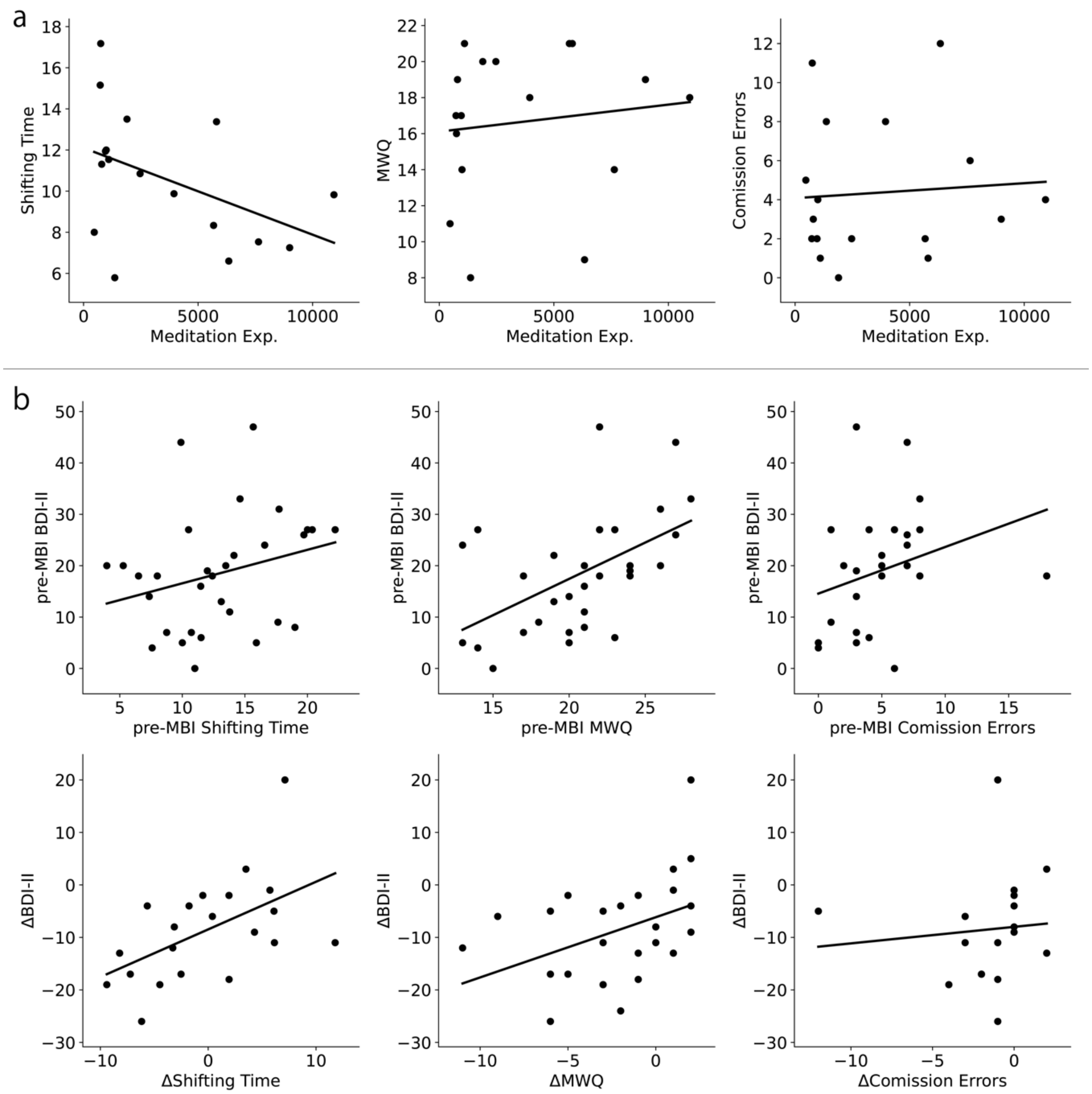

Figure 2. Scatter Plots and Regression Lines. (a) Scatter plots and regression lines for Experiment 1. Meditation Exp.: lifetime experience of mindfulness meditation; MWQ: Mind Wandering Questionnaire score. (b) Scatter plots and regression lines for Experiment 2. “pre-MBI” denotes scores obtained before the mindfulness-based intervention. The Δ denotes the magnitude of increase after the mindfulness-based intervention. BDI-II: Beck

Depression Inventory-II; Shifting Time: Duration of attention shifting from mind wandering. MWQ: Mind Wandering Questionnaire.