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ORIGINAL PAPER

Neurophysiological Evidence of the Transient Beneficial Effects of a Brief Mindfulness Exercise on Cognitive Processing in Young Adults: An ERP Study

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Abstract

Objectives It has been demonstrated that long-term mindfulness programs have beneficial effects on cognitive functioning. However, research findings to date regarding the impact of a brief mindfulness exercise are mixed. Moreover, evidence is scarce regarding the neurophysiological mechanisms underlying brief mindfulness exercises. This study aimed to investigate the effects of a brief mindfulness exercise on cognitive processing using behavioral measures and the P3 component of event-related brain potentials.

Method Forty-eight healthy young adults were randomly assigned to either a brief mindfulness group or a sitting control group. The mindfulness group performed a 20-min session of mindfulness exercise while the control group remained seated for the same length of time. The Flanker task with electroencephalography recording was completed before and after the treatments.

Results The mindfulness group showed a higher response accuracy and a smaller P3 amplitude at the post-test relative to the pre-test across Flanker conditions, whereas no such changes were observed in the control group. The response time and P3 latency did not change across the groups. These results suggest that a brief mindfulness exercise prompts more accurate responses and reduces attentional resources during the Flanker task, indicating more efficient cognitive processing.

Conclusions A brief mindful exercise in novices could enhance the accuracy of cognitive performance and calm the neural response in P3. The current study demonstrates that the benefits of mindfulness extend to short sessions and provides a possible explanation for the neural mechanisms driving these benefits.

Preregistration This study is not preregistered.

Keywords Single-session mindfulness · Cognitive control · Event-related potential · P3

Mindfulness, which is practiced through meditation-based exercises combining awareness and non-judgmental acceptance of internal and external experiences, has attracted tremendous interest over the last decade. The most common understanding of this concept would be described as the practice of observation of mind and body and of full engagement in the current moment (Bishop et al., 2004; Clarke et al., 2015). Such a practice has been reported to yield a wide range of positive effects on psychological well-being and quality of life (Davis & Hayes, 2011; Guendelman et al., 2017; Shapiro et al., 2008; Tomlinson et al., 2018). It has also been demonstrated that mindfulness practice can enhance attention and improve emotional and behavioral regulation (Chambers et al., 2008; Chiesa et al., 2011). Research has expanded beyond 8-week mindfulness programs such as Mindfulness-Based Stress Reduction (Kabat-Zinn, 1982) and Mindfulness-Based Cognitive Therapy (Teasdale et al., 2000) to investigate short-term training. These interventions can be broadly categorized as weekly programs (Chambers et al., 2008; Greenberg et al., 2017; Nien et al., 2020), intensive programs lasting a few days (Adhikari et al., 2018; Quach et al., 2016; Taren

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et al., 2017), and a brief session lasting for minutes (Deng et al., 2019; Jankowski & Holas, 2020; Norris et al., 2018).

The benefits of mindfulness practices have been shown to extend to the cognitive domain as it contains fundamental elements of sustained attention and self-regulation (Brown & Ryan, 2003). Research has demonstrated that mindfulness training has a performance-enhancing effect on cognitive and affective variables, especially those related to mindfulness practice such as awareness of the present experience, attentional skills, and emotional stability in clinical and non-clinical populations (Creswell, 2017). Further, it has been demonstrated that mindfulness practice can improve cognitive control (also known as executive function; Chang et al., 2018; Short et al., 2016), which refers to the ability to regulate cognitive processes to achieve a goal or task (Miyake et al., 2000). Although the exact mechanism by which mindfulness improves cognition is not fully understood, some studies have proposed that mindfulness training may lead to changes in regional cerebral blood flow and white matter connectivity in brain regions associated with cognitive control, emotion regulation, and self-awareness such as the anterior cingulate cortex (ACC) and prefrontal cortex (PFC). These changes are thought to be the underlying mechanism by which mindfulness improves cognition (Tang et al., 2015). Thus, mindfulness practices are a powerful tool for promoting brain health and cognition.

While most research on mindfulness and cognition has focused on long-term training (e.g., multiple sessions over a period of weeks or full immersion programs; Eberth & Sedlmeier, 2012; Falcone & Jerram, 2018), a limited number of studies have sought to understand the impact of a brief session of mindfulness exercise on cognitive processes (Jankowski & Holas, 2020; Mrazek et al., 2012; Watier & Dubois, 2016). In the present study, we defined a brief mindfulness exercise/intervention as a single session lasting for a short duration of time (e.g., 20 min) dedicated to focusing on the present moment through practices (e.g., deep breathing). Examining the transient effects of a single session of mindfulness exercises on cognitive processes is important for scientific and practical reasons. Specifically, it helps to gain a deeper understanding of the underlying mechanisms of mindfulness and its effects on cognitive processes. For instance, examining such effects may help to analyze the core exercise involved in mindfulness-based practices, identify cognitive processes that are impacted, as well as understand the limits of the effects of these practices on cognitive processes. This information can then be used to develop cost-effective behavioral interventions that have a direct application to cognitive performance in various settings (i.e., classroom, workplace).

Although several studies have attempted to elucidate the effects of a brief mindfulness exercise on cognitive control, the results are mixed. For instance, Mrazek et al. (2012) demonstrated that a single session of mindfulness exercise improved inhibitory control as measured by the Go/No-Go task (i.e., higher response accuracy). Further, Jankowski and Holas (2020) found that a single session of mindfulness exercise can have an effect on cognitive flexibility as measured by task-switching task (i.e., shorter response time). By contrast, Johnson et al. (2015) reported that a brief mindfulness exercise had no significant impact on cognitive performance using several cognitive tasks that assess working memory, short-term memory, cognitive flexibility, and visual tracking using behavioral measures (i.e., response times and response accuracy). In line with this argument, Larson et al. (2013) also reported null effects on cognitive performance using the Flanker task. The cognitive tasks used in these studies primarily measured cognitive control, and a convergent single session of mindfulness ranging from 10 to 25 min was also utilized. Thus, whether or not a brief mindfulness exercise enhances cognitive control remains an open question. One plausible explanation for the contradictory findings described above is that the sensitivity of the behavioral measures may not be sufficient enough to detect the effects of a single session of mindfulness exercise.

Examining the neuroelectric system has started to gain popularity in the study of mindfulness and cognition since it provides more sensitive and objective means for determining the underlying processes. Specifically, the high temporal resolution of neuroelectric measures allows for evaluating a subset of processes between stimulus encoding and response execution. As a consequence, these measures enable researchers to capture the influence of a brief mindfulness exercise more precisely on cognition than behavioral task performance measures (i.e., response accuracy and response time). Event-related potentials (ERPs) refer to the electrical activity recorded over the scalp in response to a specific timed event. ERPs generally consist of several components, among which the P3 is a well-studied endogenous component that occurs approximately 300–800 ms after stimulus onset and has a parietal distribution (Kropotov, 2010). P3 is thought to reflect the allocation of attentional resources as amplitude is proportional to the amount of neural resources devoted to a given task (Donchin & Coles, 1988; Polich, 2007), and P3 latency is correlated with the speed of processing stimulus (Polich & Kok, 1995). To the best of our knowledge, only two studies have examined the effect of a brief mindfulness exercise on cognitive processing through the measurement of ERPs. Eddy et al. (2015) showed that a 20-min mindfulness exercise decreased P3 amplitude responses to negative versus neutral pictures. Andreu et al. (2018) also reported that a 15-min mindfulness exercise reduced P3 amplitude among smokers during an adapted “smoking Go/No-Go task”. These results suggest that a brief mindfulness exercise results in more efficient emotional and cognitive processing. The lack of behavioral evidence for the beneficial effects of a brief mindfulness exercise on cognition in these two ERP studies raises questions about the relationship between P3 amplitude and cognitive performance. In contrast, the beneficial effects of physical exercise, which is a well-studied behavioral intervention, on cognitive control have been shown by an increased P3 amplitude accompanied by improvements in behavioral performance (Aly & Kojima, 2020; Hillman et al., 2009; Kamijo et al., 2009; Kao et al., 2020). The lack of behavioral evidence in the ERP-brief mindfulness studies described above (Andreu et al., 2018; Eddy et al., 2015) could stem from the fact that the authors used a specific cognitive task (i.e., the emotional picture and smoking Go/No-Go tasks) and a specific sample (i.e., smokers; Andreu et al.). As such, research testing the effects of a brief mindfulness exercise on neurocognitive processing is highly needed to provide a pathway through how mindfulness exercise may lead to behavioral and physiological changes associated with cognitive enhancements.

Therefore, this study was designed to investigate the transient effects of a brief mindfulness exercise on behavioral and neuroelectric indices of cognitive processing in healthy young adults. We examined whether a brief mindfulness exercise would enhance cognitive processing, as indexed by a shorter response time and/or higher response accuracy among the naïve participants assigned to the mindfulness group or the control group. The authors did not have a hypothesis for how P3 amplitude would be affected by a brief mindfulness exercise, given the lack of research on this topic. However, if a single session of mindfulness exercise resulted in more efficient cognitive processing, as observed in ERP mindfulness studies (Andreu et al., 2018; Eddy et al., 2015), the P3 amplitude would be decreased as a result of a brief mindfulness exercise.

Method

Participants

Forty-eight undergraduate and graduate students were recruited from Kanazawa University. All participants had normal or corrected-to-normal vision, were right-handed, were non-smokers, and had no history of neurological or psychiatric illness. They were not taking any medications and did not exhibit anxiety symptoms that could have affected their cognitive performance (Gulpers et al., 2016). Participants had no prior experience in mindfulness practices or engaged in long-term practices. Participants were randomly assigned to either the mindfulness group (n = 24) or the control group (n = 24). A power analysis conducted using G*Power 3.1 software (Faul et al., 2007) indicated that a sample size of 48 participants was required for this study, based on the average effect size reported in similar research on brief mindfulness exercises (Deng et al., 2019; Larson et al., 2013), with a statistical power of 0.80 and α = 0.05. All participants gave informed consent before participating. The characteristics of the participants are shown in Table 1.

Procedure

Participants completed two lab visits approximately 5 days apart. Participants were instructed to abstain from strenuous exercise, caffeine consumption, and alcoholic beverages for 24 hr before the visits. On the first day, participants completed informed consent and several self-report questionnaires to assess anxiety, trait mindfulness, and physical activity. We then measured height and weight to calculate body mass index (BMI, kg/m^2). On the second day, participants were instructed to sit comfortably in front of a computer screen in a dimly lit, sound-proof, electrically shielded room. An electro-cap was fitted to the participants'

Table 1 Characteristics of the participants

Measure	Group		p-value
	Mindfulness (n = 24)	Control (n = 24)	
Sex	12 M/12 F	10 M/14 F	
Age (years)	23.33 ± 4.11	22.75 ± 2.31	0.55
Height (m)	1.67 ± 0.09	1.65 ± 0.15	0.60
Weight (kg)	61.00 ± 11.33	63.60 ± 10.45	0.41
BMI (kg/m^2)	21.78 ± 3.33	23.75 ± 6.24	0.18
Physical activity, MET, min/week (IPAQ)	2316.63 ± 1877.72	2363.54 ± 2055.40	0.93
Psychological distress (K10)	17.33 ± 5.18	19.21 ± 6.90	0.29
Mindfulness trait (MAAS)	3.93 ± 0.55	4.15 ± 0.83	0.27

BMI, body mass index; *IPAQ*, International Physical Activity Questionnaire; *K10*, Kessler Psychological Distress Scale; *MAAS*, Mindful Attention Awareness Scale. Data are presented as the mean ± *SD* heads, and they were instructed to avoid unnecessary movements. Participants performed 12 practice trials to familiarize themselves with the Flanker task; then critical trials were performed while collecting brain activity data for pre-test measures. Participants in the mindfulness group performed guided mindfulness exercises for 20 min, adapted from Fujino et al. (2019). The mindfulness exercises focused on awareness of breath and body in the present moment, ignoring distractions, and cultivating relaxation. After the mindfulness exercise, the participants were asked to rate whether they were able to follow the audio instructions on a scale from 1 to 5 (mean 4.08 ± 0.65), where 1 indicated *cannot follow the instructions at all* and 5 indicated *perfectly follow the instructions*. The participants' responses ranged from 3 to 5. Participants in the control group were asked to wait idly during the same period, and they were not permitted to use their mobile or any smart device during that time. Subsequently, all participants performed the Flanker task while collecting electrical brain activity again to collect post-test measures. Measurements were conducted during the same time of the day for all participants to minimize circadian effects.

Measures

Participants' Characteristics

All participants completed self-report measures including the Kessler Psychological Distress Scale (K10; Kessler & Mroczek, 1992), Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003), and International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) to assess anxiety, trait mindfulness, and physical activity, respectively. Participants' height and weight were also measured and BMI was calculated. The anxiety and trait mindfulness assessments showed good internal consistency (McDonald's omega = 0.89 and 0.82, respectively). The IPAQ has been shown to have satisfactory reliability and validity (Craig et al., 2003). These measures were utilized to comprehensively evaluate the psychological and physical states of the participants, while also accounting for any possible confounding variables (Etnier et al., 2006; Hofmann & Smits, 2008).

Flanker Task

Participants completed a modified version of the Flanker task under congruent and incongruent trial conditions (Eriksen & Eriksen, 1974). They were instructed to make a response as fast and accurately as possible to a series of arrows (stimuli) presented focally on a monitor placed 70 cm in front of the observer. The arrows were 3 cm in square size and located against a black background. A response pad (Cedrus Inc. San Pedro, CA, USA) was provided with a right and a left button and was aligned with the vertical meridian of each participant's posture. A white fixation cross was presented for 500 ms, followed by a horizontal array of five arrows of equal size for 120 ms with a randomized intertrial interval (ITI) between 2000 and 3000 ms. On congruent Flanker condition, the stimuli were those in which all arrows were pointed to the right (> > > > >) or to the left (< < < < <). On incongruent condition, the flanking arrows were pointed in the opposite direction relative to the target arrow in the center (> > < > > or < < > < <). Participants were asked to (1) keep their attention on the central target arrow and ignore the four flanking arrows and (2) press a button with their index fingers corresponding to the direction of a centrally presented target arrow. Four blocks of 50 trials (with an equal probability of congruent and incongruent Flanker trials) were randomized. E-Prime 3.0 software (Psychology Software Tools, Inc., USA) was used to generate the task and collect participants' responses.

Electrophysiology Recording and Preprocessing

Brain activity was recorded using a 19-electrode cap (Electro-Cap, International, Inc., USA) according to the International 10–20 system (Klem, 1999). Vertical and horizontal eye movements were recorded by electrooculograms (EOG) with electrodes placed below the left eye and beside the outer canthi of each eye to remove eye movements and blinking artifacts. Electroencephalogram (EEG) data were acquired using Digitex, JP, Polymate AP-1524 system. The EEG signal was recorded at a sample rate of 1000 Hz and amplified 1000-fold with a 60-Hz notch filter, and the impedance was kept below 10 kΩ. AFz was used as the ground electrode. Subsequent data processing steps were performed using MATLAB (R2018a) program with EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) toolbox plugins. Continuous EEG data were referenced to linked earlobes. Stereotypical eye-blink artifacts were removed using independent component analysis (ICA) followed by an autocorrelation procedure for rejecting ICA components related to EOG activity (Comon, 1994). There was no significant difference in the number of rejected components between the mindfulness and control groups (pre-test: 1.08 ± 0.65 vs. 1.21 ± 0.59; post-test: 1.13 ± 0.99 vs. 1.21 ± 0.93). Stimulus-locked epochs were extracted (−100 to 800 ms relative to target stimulus onset), baseline corrected (−100 ms pre-stimulus onset), and band-pass filtered (zero phase shift of 30 Hz with 24 dB/octave roll-off). Epochs were identified and rejected if a moving window peak-to-peak amplitude exceeded ± 75 μV. The number of trials used to create ERP waveforms did not significantly differ between the mindfulness and control groups (pre-test: 90.51 ± 6.64 vs. 92.49 ± 6.18; post-test: 91.16 ± 6.46 vs. 90.95 ± 7.12). P3 amplitude was analyzed as the local peak amplitude between 300 and 500 ms latency window at Pz where it reached its maximum. The electrode and latency window were selected according to previous literature (Aly & Kojima, 2020; Eddy et al., 2015; Hillman et al., 2009) and visual inspection of the group-averaged ERP waveforms.

Data Analyses

Prior to our main analysis, independent *t*-tests were first conducted where appropriate to examine the significance of differences between means of demographic variables (age, height, weight, BMI, physical activity, trait mindfulness, and anxiety) for the mindfulness group and control group. Initial Pearson product-moment correlations were also conducted between the pre-test dependent variables (response accuracy, response time, P3 amplitude, P3 latency) and all demographic variables to identify any confounding factors as a covariate for the main analysis. Trials with incorrect responses and responses faster than 100 ms or above the individual mean ± 3 *SD* were excluded from response time analysis.

For the main analysis, behavioral (i.e., response accuracy, response time) and neuroelectric measures (i.e., P3 amplitude, P3 latency) were analyzed with a mixed-model analysis of variance (ANOVA), with the main effects examined with Time (pre-test and post-test) and Condition (congruent and incongruent Flanker trials) as the within-subjects factor and Group (mindfulness and control) as between-subject factor. Follow-up analyses were performed using post hoc tests with Bonferroni correction when there were significant interactions. The partial eta-square (η_p^2) was calculated to provide estimates of the effect size. All data were processed using SPSS (SPSS v. 25, Chicago, IL), and the significant level was set to 0.05.

Results

The participants' characteristic details are presented in Table 1. Independent *t*-tests revealed no significant differences between the mindfulness group and control group in terms of age, height, weight, BMI, physical activity, and trait mindfulness ($t(46) = 1.36$ to 0.08, $p =$ 0.18 to 0.93), suggesting that the two groups had similar characteristics. Pearson product-moment correlations revealed no significant relationships between the pre-test dependent variables and all demographic variables, indicating that no variables need to be included as a covariate (see Supplementary Table S1).

Behavioral Data

Regarding the response accuracy, ANOVA showed a significant main effect of Time, $F(1, 46) = 5.30$, $p < 0.05$, $\eta_p^2 = 0.10$, with post-test accuracy being higher than pre-test accuracy. ANOVA also showed a main effect of Condition, $F(1, 46) = 53.58$, $p < 0.01$, $\eta_p^2 = 0.54$, with the incongruent condition having higher accuracy than the congruent condition. There was a marginally significant interaction of Time and Group, $F(1, 46) = 4.00$, $p = 0.05$, $\eta_p^2 = 0.08$. Although the interaction was not statistically significant, we performed post hoc analyses based on our a priori hypothesis of the significant interaction that found in ERP data (see later). Post hoc analyses with a Bonferroni correction method revealed that the mindfulness group had higher accuracy on the post-test compared to the pre-test ($p = 0.004$). However, this was not true for the control group ($p = 0.83$; see Fig. 1a). Neither a significant main effect of Group nor an interaction between Condition and Group was found ($p > 0.05$).

With respect to response time, analyses revealed a main effect of Condition, $F(1, 46) = 648.27$, $p < 0.01$, $\eta_p^2 = 0.93$, with the incongruent condition yielding a longer response time than the congruent condition. No other significant main effects or interactions were detected ($p > 0.05$; see Fig. 1b).

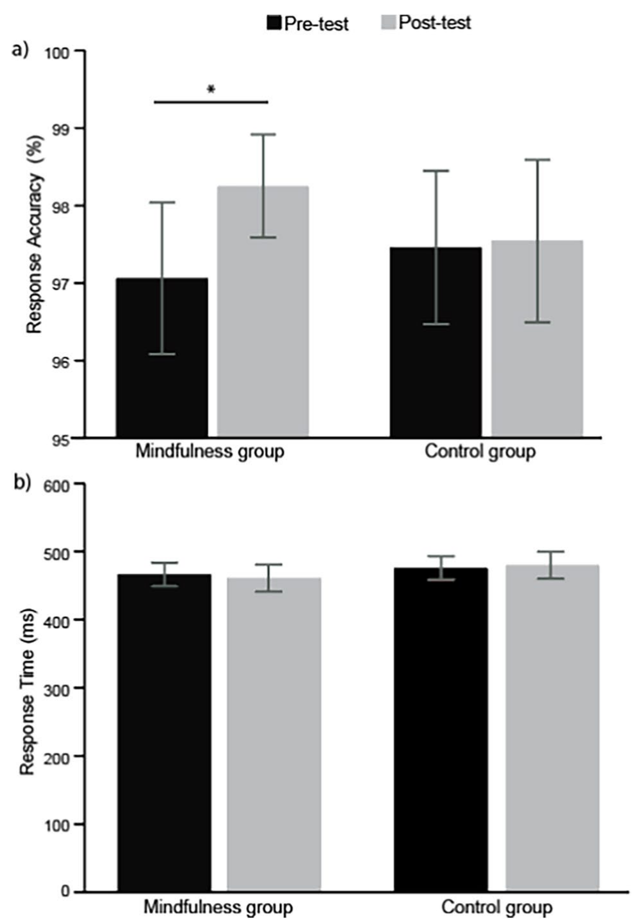

Fig. 1 (**a**) Response accuracy and (**b**) response time in the Flanker task for the mindfulness and control groups in pre- and post-tests. Error bars, 95% confidence interval

Event-Related Potential Data

Regarding P3 amplitude, ANOVA showed a main effect of Condition, $F\ (1, 46) = 33.52$, $p < 0.01$, $\eta_p^2 = 0.42$, with the incongruent condition yielding a smaller amplitude than the congruent condition, and a main effect of Time, $F\ (1, 46) = 4.94$, $p < 0.05$, $\eta_p^2 = 0.10$, with the post-test amplitude being smaller than the pre-test amplitude. There was a significant interaction of Time and Group, $F\ (1, 46) = 4.17$, $p < 0.05$, $\eta_p^2 = 0.08$. Post hoc analyses with a Bonferroni correction method revealed that the mindfulness group had smaller P3 amplitude on the post-test relative to pre-test ($p < 0.01$). This was not the case for the control group ($p = 0.89$). Further analysis showed that the mindfulness group had smaller P3 amplitude relative to the control group in the post-test ($p < 0.05$), but not in the pre-test ($p = 0.81$). No significant interaction was found between Time, Condition, and Group ($p > 0.05$). Figure 2 shows (a) ERP waveforms and (b) the topographic distribution of the P3 amplitude.

As for P3 latency, analyses showed a main effect of Condition, $F\ (1, 46) = 37.36$, $p < 0.01$, $\eta_p^2 = 0.45$, with longer latency in the incongruent condition than the congruent condition. No other significant main effects or interactions were found ($p > 0.16$).

Discussion

The current study examined the effects of a single session of mindfulness exercise on cognitive functioning using behavioral and electrocortical measures in healthy young adults. Before and after undergoing a brief mindfulness exercise or a sitting control, the participants completed the Flanker task. The primary findings of the present study were that a higher response accuracy and decreased P3 amplitude were observed after a brief mindfulness exercise. No such effects were found regarding response time and P3 latency. The findings of this study validate and support the hypothesis that a brief mindfulness exercise has a facilitative effect on cognitive processing at both the behavioral and neuroelectric levels, even in healthy young adults. In addition, our findings have implications for understanding the neural mechanism that underlies a single session of mindfulness exercise, especially given the meditation-naïve sample.

The observed positive effects on cognitive performance (i.e., enhanced response accuracy) are consistent with those reported in several previous studies (Jankowski & Holas, 2020; Mrazek et al., 2012). Conversely, other studies failed to find such beneficial effects (Andreu et al., 2018; Johnson et al., 2015; Larson et al., 2013). One possible explanation for why some studies reported null effects could be that the brief mindfulness effects on cognitive performance were moderated by an individual's innate capacity for mindfulness (Brown & Ryan, 2003). Specifically, Watier and Dubois (2016) demonstrated that the positive effects of a brief session of mindfulness exercise on Stroop task performance were only apparent in individuals with a low mindfulness trait and not in those with a high mindfulness trait. It has also been shown that individuals with higher mindfulness trait levels perform better on attentional tasks (Dickenson et al., 2013; Moore & Malinowski, 2009). Accordingly, participants with low mindfulness trait levels might have a greater chance of benefiting from the mindfulness exercise than those with higher trait levels. In our study, the assessment of the mindfulness trait confirmed that this factor did not affect our results as both the mindfulness and control groups had a moderate level of mindfulness trait. Furthermore, the effect of a single mindfulness exercise session on cognitive function might be task dependent. More specifically, mindfulness training includes two fundamental elements: sustained attention and self-regulation (Brown & Ryan, 2003). It seems that tasks tapping into these two elements are more likely to be able to detect the effects of a brief mindfulness exercise. In other words, a brief mindfulness exercise might be more beneficial for specific aspects of cognitive control related to sustained attention and self-regulation. Supporting this assumption, Watier and Dubois (2016) found that a brief mindfulness exercise was effective in reducing emotional interference on an emotional Stroop task, but did not have an effect on recognition memory. This speculation does not necessarily mean that brief mindfulness exercises cannot influence other aspects of cognitive control but rather one session may not be sufficient to elicit an effect. Future research should consider examining various aspects of cognitive function in relation to trait mindfulness and the length of the interventions.

Another plausible reason for the null effects reported in previous studies is that behavioral cognitive measures might not be sensitive enough to the transient effect of brief mindfulness exercises. In the current study, we found that the brief mindfulness exercise decreased P3 amplitude, which corroborated previous P3 studies by Andreu et al. (2018) and Eddy et al. (2015). There is broad consensus that the P3 amplitude indexes the amount of cognitive resources that a participant allocates in a cognitive task (Polich, 2007); as mental effort increases, so does P3 amplitude, and vice versa (Luck, 2014). Accordingly, our P3 findings suggest that a lower neural activation level may be sufficient for successfully completing the task after a brief mindfulness exercise, indicating more efficient cognitive processing. Therefore, as stated in the Introduction, Andreu et al. and Eddy et al. found no effects of a brief mindfulness exercise on behavioral measures using specific cognitive tasks (i.e., the emotional picture and smoking Go/No-Go tasks), while the current findings extend these previous neuroelectric studies and suggest that a more efficient stimulus processing can lead

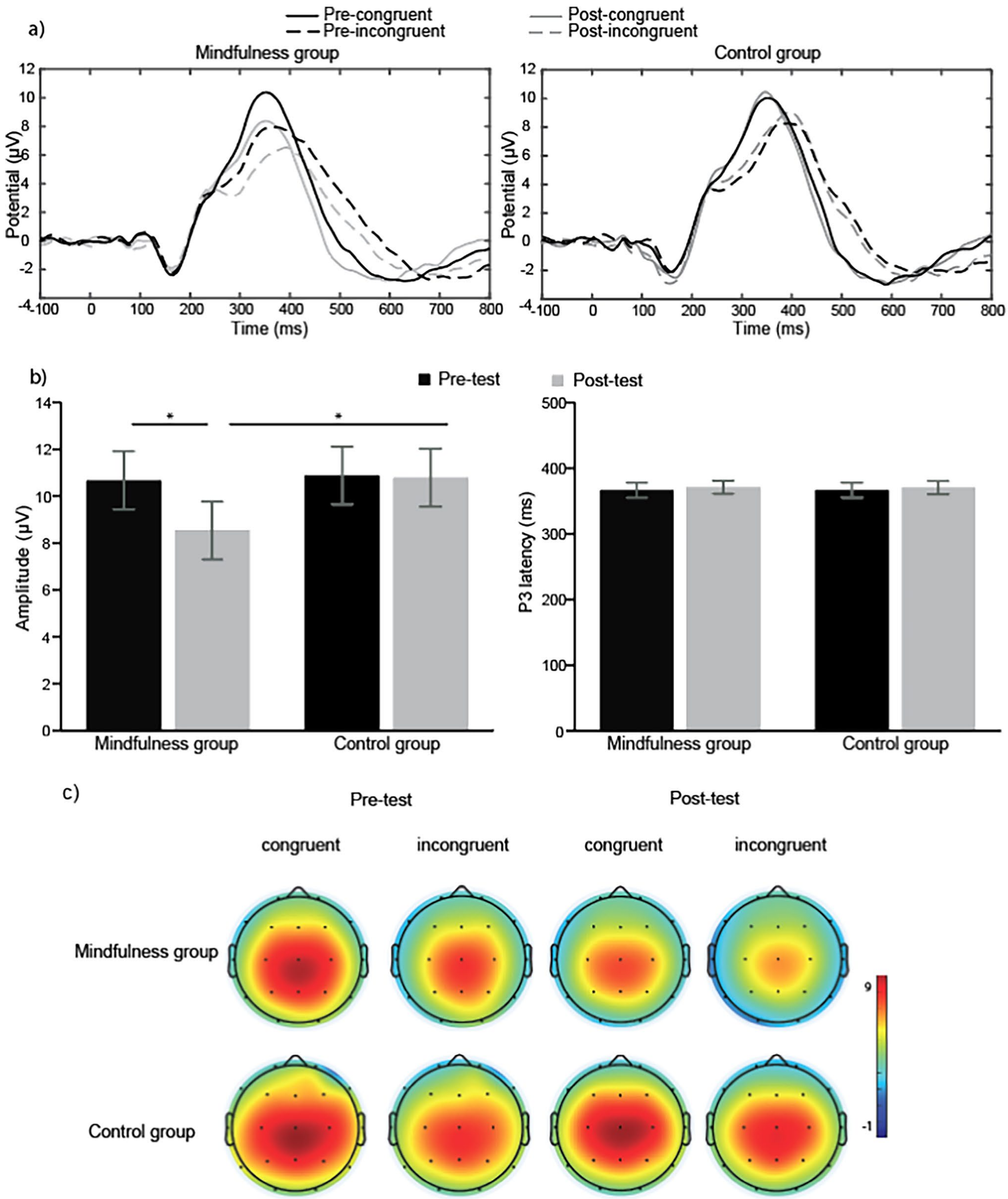

Fig. 2 (**a**) Grand-averaged ERP waveforms at Pz as a function of group and Flanker condition. (**b**) The interaction effect on P3 amplitude for time × group; *$p < 0.05$. (**c**) Topographic scalp distribution of the P3 component

to better cognitive performance after a brief mindfulness exercise; neuroelectric measures of cognitive processing are likely to be more sensitive to brief mindfulness effects on cognition than behavioral measures.

The present study is consistent with functional magnetic resonance imaging (fMRI) studies, which have demonstrated that mindfulness exercise has an impact on brain structure (Fox et al., 2014; Yang et al., 2019). For instance, cross-sectional studies showed that experienced meditators exhibited increased activation and stronger connectivity in and between ACC and PFC (Chételat et al., 2017; Hölzel et al., 2007; Tang et al., 2010). Further, weekly training has been shown to induce structural plasticity in gray matter (Tang et al., 2020). Moreover, Dickenson et al. (2013) provided evidence that one session of a very basic form of mindfulness exercise can modulate the attention network including parietal and prefrontal structures in non-meditators. These studies consistently provide evidence of a neural change as the effects of mindfulness exercises on cognitive control, just as the P3 change shown in the present study.

In summary, our research provided direct evidence of the transient effects of a brief mindfulness exercise on cognitive processing in healthy young adults. A brief mindfulness exercise enhanced cognitive control, indexed by a higher response accuracy and smaller P3 amplitude. These findings suggest that a brief mindfulness exercise may lead to more efficient cognitive processing. The present results exemplify the need for a mechanism-based approach to deepen our understanding of the association between mindfulness exercise and cognition. The present research also provides a basis for further exploration of mindfulness exercises as behavioral interventions for maintaining and enhancing cognitive health.

Limitations and Future Directions

Despite the current study sheds light on the transient effects of a brief mindfulness exercise on cognitive control in meditation-naïve young adults, there are some limitations to this work that should be noted. First, the method used for the control group in the present study is a matter of debate. We have utilized 20 min of seated rest, which might not be the best control protocol because it could lead to participant boredom and have a negative impact on participants' performance. Nevertheless, using an active control group, such as receiving relaxation exercises or other training, could also be problematic because it may draw a "placebo effect" depending on behavioral task measures (Enck & Zipfel, 2019), and may also induce other physiological confounding factors. In future studies, several pilot studies are encouraged to consider the most appropriate control condition for behavioral and neuroelectric measures. In addition, future studies are encouraged to compare the effects of brief mindfulness with other behavioral interventions, such as physical exercise, which have been shown to have significant transient effects, in order to determine their relative effectiveness in enhancing cognitive function. Further, it would be relevant to examine the potential synergistic effects of combining mindfulness with other interventions to maximize cognitive benefits. Second, although the current study fills the gap between behavioral and neuroelectric studies by providing new evidence that a brief mindfulness exercise resulted in more efficient stimulus processing and enhanced cognitive performance, further studies are needed to consider dose-response relationships, characteristics/types of exercise, individual differences, baseline performance, and aspects of cognitive control that are more likely to be affected. Third, this investigation has shed light on a potential neural mechanism underlying the effects of a brief mindfulness exercise through inference. However, in order to gain a more comprehensive understanding of how a brief mindfulness exercise can influence cognitive performance, it is crucial to investigate other neurobiological indicators such as BDNF and hormones. Recent evidence suggests that mindfulness training can upregulate BDNF (see Gomutbutra et al., 2020, for a review), highlighting the need for further examination of neurobiological mechanisms underlying the association between brief mindfulness exercises and cognitive control. Fourth, there is also a need for more fMRI studies in order to better understand brain regions that underlie the positive cognitive changes observed after brief mindfulness exercises. Lastly, our results should be interpreted with caution and not generalized as our sample consisted of healthy and meditation-naïve individuals. Therefore, further studies should explore the generalizability of these findings to different clinical and individual contexts.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12671-023-02120-9.

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Author Contribution Mohamed Aly: data curation, formal analysis, visualization, conceptualization, methodology, writing — original draft. Tomoko Ogasawara: conceptualization, data curation, methodology, visualization. Keita Kamijo: visualization, supervision, writing — review and editing. Haruyuki Kojima: conceptualization, data curation, funding acquisition, investigation, methodology, project administration, resources, supervision, visualization, writing — review and editing.

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Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethical Approval This study was approved by Research Ethics Committee, Institute of Human and Social Sciences, Kanazawa University.

Informed Consent The present study obtained informed consent from all participants.

Conflict of Interest The authors declare no competing interests.

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