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Behavioral and Electrophysiological Evidence for Enhanced Attention Network Efficiency Through Focused-Breathing and Body-Scan Mindfulness Practices

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Abstract

Objectives Focused-breathing and body-scan are mindfulness techniques that serve to focus attention. However, findings on their effects on attention networks have been inconsistent. The purpose of this study was to investigate the impact of a four-week mindfulness training on attention networks, utilizing behavioral measures as well as the CNV and N2 components of event-related potentials associated with the alerting, orienting, and executive control subsystems of attention.

Methods A longitudinal randomized controlled trial was conducted with 72 participants divided into three groups: focused-breathing, body-scan, and wait-list control (24 participants each). Behavioral and electrophysiological data were collected before and after training using attention network tests.

Results For the alerting network, both behavioral and EEG measures showed that the wait-list control group exhibited a significantly greater decrease in network efficiency than the focused-breathing group. For the orienting network, no significant differences in behavioral or EEG changes were found. For the executive control network, the focused-breathing group demonstrated significantly greater improvements in behavioral efficiency and larger reductions in N2 amplitude than the waiting-control group.

Conclusions Supported by behavioral and EEG data, the findings revealed that four weeks of focused-breathing training enhanced the alerting and executive control networks, whereas body-scan training showed no significant effects. These results highlight the superiority of focused-breathing for improving attentional network efficiency, demonstrating that these two forms of mindfulness training may be dissociable.

Preregistration This study is not preregistered.

Keywords Mindfulness · Attention network · Focused-breathing · Body-scan · Event-related potentials

Mindfulness is defined as a purposeful and non-judgmental attention to the present-moment experience (Kabat-Zinn, 2002). Given that the core component of mindfulness training is the cultivation of present-moment awareness (Hölzel et al., 2011; Shapiro et al., 2006), recent meta-analyses have demonstrated that mindfulness training is consistently associated with significant improvements in objective measures of attentional performance, which extended to trait mindfulness as well (Verhaeghen, 2021), suggesting that mindfulness may serve as a fundamental mechanism underlying these attentional enhancements. Researchers have categorized mindfulness into two primary types: focused attention and open monitoring (Lutz et al., 2008). Among these, focused-attention mindfulness has been shown to be associated with significant improvements in attentional performance (Chiesa et al., 2011). Specifically, both focused-breathing and body-scan are considered integral components of focused-attention mindfulness practices. Focused-breathing exercises involve directing

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attention to the physical sensations associated with the process of breathing (Kabat-Zinn et al., 1985). When teaching novice mindfulness practitioners, they are generally taught focused-breathing exercises first, and even practitioners with many years of experience often use focused-breathing to regulate their emotions in stressful situations (Kabat-Zinn et al., 1986). Body-scan requires practitioners to place their attention in an orderly fashion on various parts of the body, with the aim of cultivating non-judgmental attention to bodily sensations, cognitions, and emotions (Kabat-Zinn et al., 1985), with an emphasis on sensory-based, internalized embodied awareness, rather than merely a mental exercise that treats the body as an object (Dreeben et al., 2013).

Research has shown that mindfulness training can significantly improve attention, thus enhancing individual cognitive function (Tang et al., 2007). While these studies establish the general benefits of mindfulness on attention, recent research has begun to differentiate the effects of specific techniques on distinct attentional processes. For instance, a randomized controlled trial revealed differential effects of mindfulness techniques: body-scan meditation showed broad improvements in psychological outcomes (mindfulness, self-compassion, emotion regulation, life satisfaction), while focused-breathing had limited effects and loving-kindness meditation specifically enhanced concentration (Kropp & Sedlmeier, 2019). Neurophysiological evidence reveals further divergence: body-scan reduces delta and low-gamma band power during rest compared to focused-breathing (Ng et al., 2021). Dissociable neural mechanisms have also been identified: focused-breathing strengthens the salience network's connectivity with visual regions, while body-scan enhances its coupling with frontal and sensorimotor areas (Guu et al., 2023). However, the differential effects of focused-breathing and body-scan practices on attentional subsystems remain unclear, and elucidating these distinctions could substantiate their distributed yet dissociable neurocognitive mechanisms.

Posner and Petersen (1990) categorized attention into three attentional networks based on their different functions: the alerting network (achieving and maintaining a state of alertness), the orienting network (selecting information from sensory inputs), and the executive control network (resolving conflicts in responses). The Attention Network Test (ANT) measures these three attentional networks (Eriksen & Eriksen, 1974; Fan et al., 2002), and furthermore, the ANT paradigm provides a useful tool for clarifying differences in how focused-breathing and body-scan affect attentional networks. Previous studies investigating the effects of mindfulness on attentional networks have yielded inconsistent results, and they have been unable to effectively isolate the unique contributions of focused-breathing and body-scan practices. Elliott and colleagues (2014) demonstrated that a 7-day high-intensity meditation retreat improved executive attention and the alerting network, but not the orienting network. Tang and colleagues (2007) used an integrated set of practices combining traditional Chinese medicine, mindfulness, and other meditations and found that, compared to a control group, five consecutive days of mindfulness training improved the novice practitioners' executive control network, but did not improve their alerting network and orienting network. Eight weeks of focused-breathing training for college students with no mindfulness experience significantly improved orientation and executive control but did not alter alertness (Becerra et al., 2017). Kwak and colleagues (2020) found that four days of meditation training enhanced behavioral performance and neural activity in the executive control network, and although there were no significant improvements in behavioral data for the alertness and orientation, significant increases in activation of the corresponding brain regions were nevertheless detected (Kwak et al., 2020). The current findings on the effects of mindfulness on attentional networks are inconsistent, which may be related to the technique of mindfulness intervention and the duration of the intervention used by the researchers.

In addition, Jha and colleagues (2007) found that expert practitioners showed better alertness and executive control in an ANT task compared to novice practitioners and a control group, while orientation was better improved in novice practitioners compared to expert practitioners and a control group. Previous studies have intervened in a wide range of groups, with differences in intervention effects across groups, and in order to explore the purity effect of mindfulness training on attentional network effects, it is necessary to select participants with no mindfulness experience.

The ANT, a widely used paradigm for measuring attention, records both its behavioral and event-related potential (ERP) metrics. The contingent negative variation (CNV) is an event-related potential that appears between a warning and imperative stimulus, reflecting preparation for an upcoming action, and a larger CNV indicates a stronger state of active preparation and anticipatory attention (Mento, 2013; Walter et al., 1964). Brain regions where CNV is generated include the prefrontal cortex, the anterior cingulate cortex, and the basal ganglia, among others (Bares). In general, increased CNV negativity is associated with faster responses to target information (Fan et al., 2007; Linssen et al., 2011). CNV amplitude exhibits alerting and orienting effects, with the largest values observed at midline locations in the central and precentral zones, such as the CZ and FCZ (Williams et al., 2016). Shamatha breath-meditation (5 h/day, 3 months) sharpens perceptual discrimination and thereby reduces the vigilance decrement during sustained-attention tasks (Maclean et al., 2010). This improvement in sustained preparedness is paralleled by neurophysiological evidence: experienced meditators consistently show larger (more negative) CNV amplitudes over central scalp sites, indicating stronger anticipatory attentional engagement (Travis et al., 2000, 2002). The N2 component has been suggested to respond to the processes of conflict monitoring and inhibitory control, a response that may be produced in the anterior cingulate cortex, and a larger N2 indicates an increased need for conflict control (Donkers & van Boxtel, 2004; Gajewski et al., 2018; van Veen & Carter, 2002). Consistent with its role in conflict detection, three weeks of mindful breath awareness training strengthened conflict-monitoring capacity, as indexed by a selective increase in the centro-parietal N2 amplitude during No-Go trials (Pozuelos et al., 2019), and mindfulness training further enlarges the N2 at fronto-central sites, reflecting heightened conflict-related neural activation during conflict control (Malinowski et al., 2017). There is a paucity of research supporting the neural mechanisms by which mindfulness alters attention (Tang et al., 2015), and event-related potentials (ERPs) have fine temporal resolution to reflect specific neurocognitive processes (Kappenman & Luck, 2012); therefore, the use of electroencephalography to analyze the effects of focused-breathing and body-scan on attentional networks can further clarify the specific effects of focused-breathing and body-scan on attentional networks.

Owing to the distinct mechanistic pathways of the two focused-attention mindfulness trainings (Guu et al., 2023; Ng et al., 2021), the purpose of this study was to investigate the differences in the effects of focused-breathing and body-scan on attentional networks by recording pre- and post-test ANT behavioral and neurobiological data from three groups of participants—the focused-breathing, body-scan, and wait-list control groups—in a randomized controlled experiment. The meta-analysis found that there was no statistically significant difference between the results derived from the positive and negative control groups in the mindfulness intervention study, i.e., that mindfulness training per se was the key factor in producing attentional effects (Verhaeghen, 2021). In order to illustrate the effectiveness of focused-breathing and body-scan training in influencing the attentional network, a special wait-list control group was set up, which had no training task. Experienced meditation practitioners performed better on the orienting network of ANT, mainly in terms of reduction in reaction time (van den Hurk et al., 2010). Previous research has found that alertness can be improved by practicing breathing meditation during periods of sustained voluntary attention (Maclean et al., 2010). Repetitive engagement-detachment-movement practice is a specific manifestation of attentional orienting (Jha et al., 2007; Posner & Badgaiyan, 1998; Posner & Gilbert, 1999), and body-scan is more practiced than focused-breathing in the "engagement-detachment-movement" attentional processes. Based on previous research, we proposed the following hypotheses: (1) We hypothesized that both focused-breathing and body-scan interventions would improve overall mindfulness. (2) We predicted that focused-breathing would increase alertness, as demonstrated by enhanced alerting efficiency and greater CNV amplitude in the focused-breathing group compared to the wait-list control group. (3) We hypothesized that body-scan would more effectively improve orienting, leading to greater orienting efficiency and a larger CNV amplitude in the body-scan group compared to the control group. (4) Finally, we predicted that both interventions would strengthen executive control, resulting in improved executive control efficiency and an increased N2 amplitude in both meditation groups relative to the wait-list control group.

Method

Participants

A total of 90 university students with no experience in mindfulness practice were recruited from Nanjing University; all participants had normal visual acuity or corrected vision, were right-handed, and had no clinical history of reported psychological or psychiatric problems. As shown in Fig. 1, participants were randomly assigned to the focused-breathing group, body-scan group, or wait-list control group after stratified block randomization based on gender and baseline mindfulness scores. Since 18 participants were lost to follow-up, discontinued intervention, and had more than 20% electroencephalogram artifacts, data from 72 university students were finally analyzed: 24 in the focused-breathing group (mean age = 21.00 ± 2.06 years, 14 females); 24 in the body-scan group (mean age = 20.71 ± 2.16 years, 15 females); and 24 in the control group (mean age = 21.67 ± 1.99 years, 13 females). All participants signed an informed consent form and were paid accordingly after the experiment, and were informed of their right to stop participating at any time. The experimental procedures were approved by the Ethics Committee of the Department of Psychology at Nanjing University and were conducted in accordance with the approved guidelines.

Procedure

The study used a repeated measures ANOVA (within-between interaction) with G*Power (Faul et al., 2009) to estimate the required sample size, input effect size $f = 0.25$, α err prob = 0.05, power ($1 - \beta$ err prob) = 0.8, number of groups = 3, number of measurements = 2, and output total sample size = 42, so the experimental sample size for each group should be no less than 14.

The study followed a pre-test/post-test design. Before the intervention, all participants completed the five facets mindfulness questionnaire (FFMQ) and performed the Attention

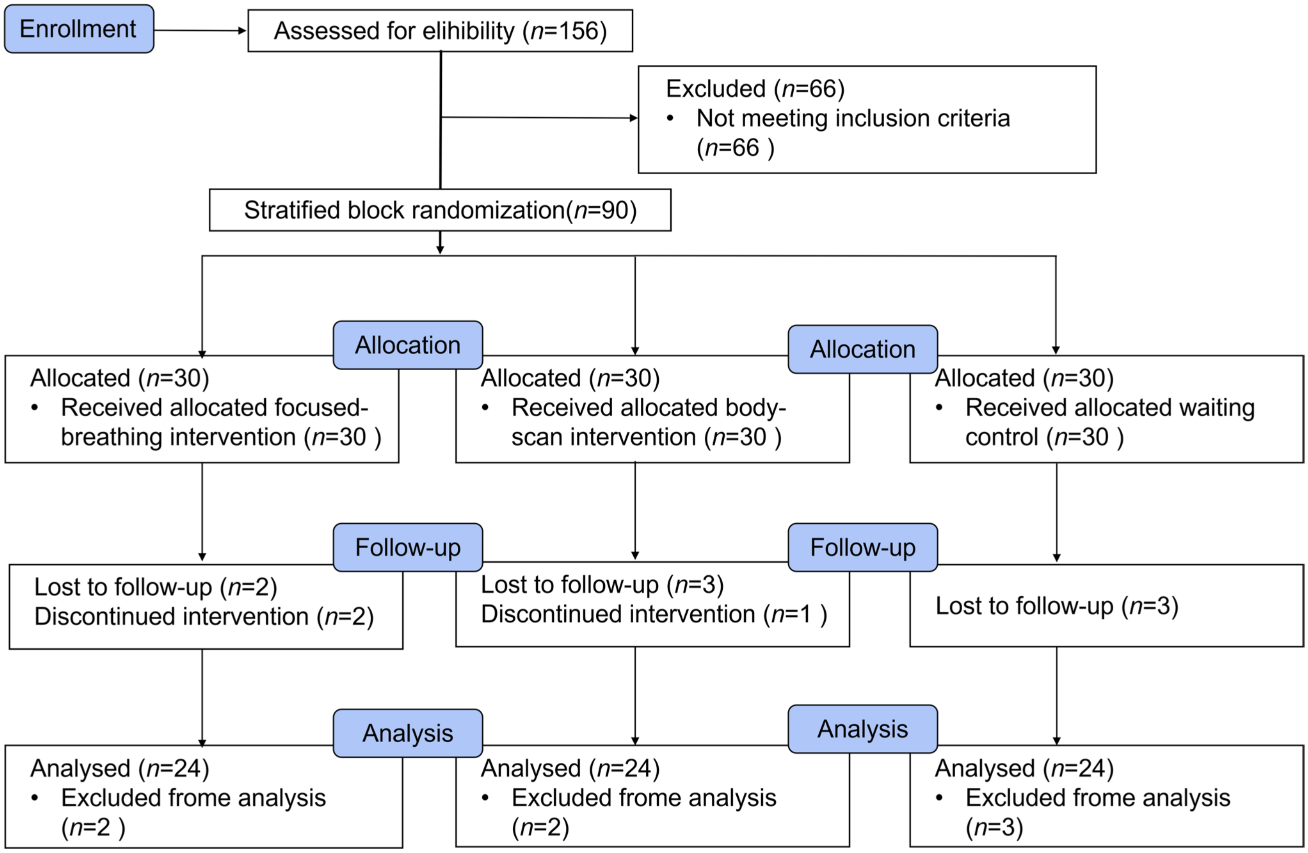

Fig. 1 CONSORT flow of participant enrollment, intervention implementation, and complete analysis procedures

Network Task (ANT) while their EEG activity was recorded. Following this initial assessment, the experimental groups underwent a four-week mindfulness training period, whereas the wait-list control group received no training. After the four weeks, all participants completed the FFMQ and the ANT a second time, with their EEG activity recorded again.

Both the focused-breathing and body-scan exercises were referenced to the practice instructions in mindfulness stress reduction therapy (Kabat-Zinn, 2002). To ensure that participants in the focused-breathing or body-scan groups received exactly the same mindfulness instructions for each exercise, audio recordings were used. For the focused-breathing group, a 30-min recording was used to guide practitioners to focus their attention on the breath, the rhythm of the breath, and the sensations in the body during the breath. For the body-scan group, a 30-min recording was used to guide the practitioners to focus attention on different areas of the body, noting the order of attention from the toes to the head. When attention is disturbed by internal or external stimuli, the focused-breathing practitioner is asked to consciously and gently shift attention to awareness of the breath, and the body-scan practitioner is asked to consciously and gently shift attention to awareness of the body. Both the focused-breathing and body-scan groups were conducted in a seated and quiet situation. The wait-list control group did not have any training tasks during the 4-week training period. After all participants completed the post-test experiment, the wait-list control group was given access to audio-recorded guided practice of mindfulness body-scan or focused-breathing.

The 4-week focused-breathing and body-scan interventions were structurally identical and consisted of weekly group training in a counselling group room for 60 min (30 min of training, 30 min of discussion), with the same leader for all groups; on non-training days, practitioners were required to practice on their own for 30 min each day and to record their daily practice.

Participants sat alone in a laboratory to complete the experiment. The ANT procedure was run using the E-Prime 2.0 software, and the monitor was located approximately 50 cm from the participants' eyes during the experiment. The ANT procedure is shown in Fig. 2. First, a fixed point "+" would appear in the centre of the screen (the presentation time was randomized between 400 and 1600 ms), and then a cue stimulus (presented for 100 ms) would appear, and there are four presentations of cue stimuli: above or below the fixed point, known as spatial cues; above and below the fixed point in both directions, known as dual cues; in the centre, known as central cues; or no cues appear,

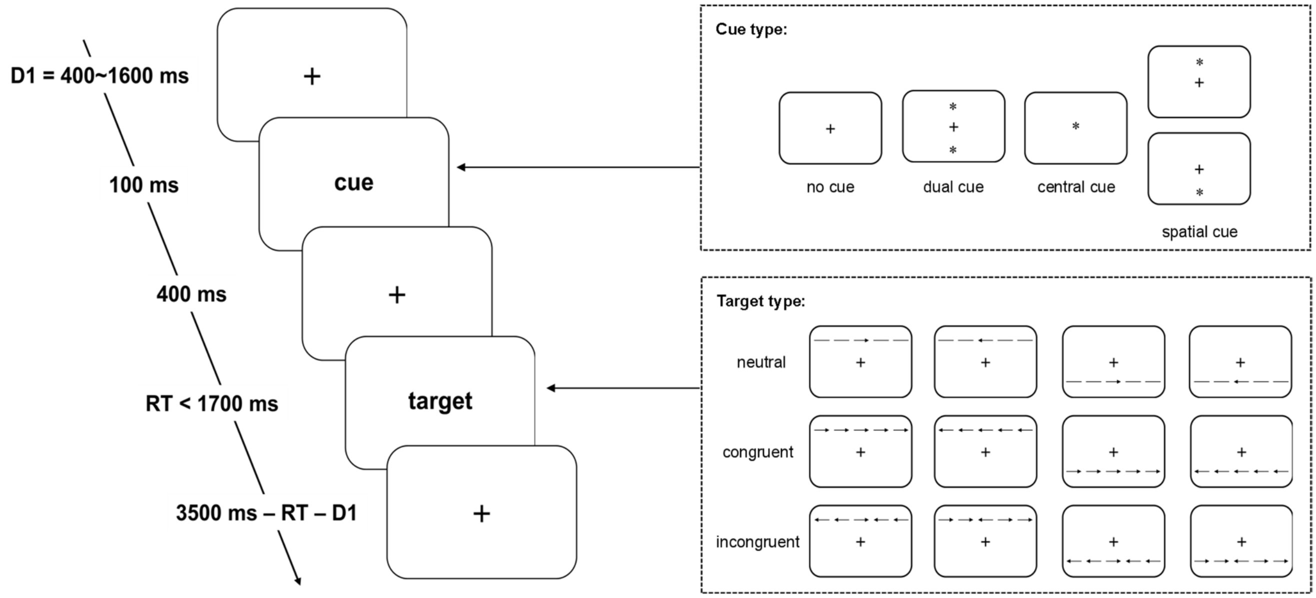

Fig. 2 Flowchart of the ANT experimental procedure. Reference and adaptation from the research of Fan et al. (2002)

known as no cues. Cues were always valid, with a 400-ms interval screen before the target appeared. The central and dual cues provided information about the timing of target stimulus appearance and were the alerting condition; the spatial cues indicated the location of the upcoming target stimulus and were the orienting condition. The target stimulus consisted of five horizontally aligned arrows or short lines appearing above or below the fixed point (maximum duration 1700 ms). By pressing the left and right mouse buttons, participants had to point to the direction of the central arrow, regardless of whether the bilateral arrow direction was a short line in the neutral condition, a congruently oriented arrow, or an incongruently oriented arrow. The total duration of each trial was 4000 ms, and the interval between trials was 4000 ms minus the sum of the time used before the response. There were 288 trials in total, each presented pseudo-randomly with no right-or-wrong feedback, and participants were required to respond as quickly and accurately as possible.

Measures

FFMQ consists of 39 items assessing five dimensions of mindfulness: observing, describing, not reacting, acting with awareness, and not judging. The higher the score, the higher the level of mindfulness (Baer et al., 2006; Deng et al., 2011). Mindfulness was measured using the Chinese version of the Five Facet Mindfulness Questionnaire (FFMQ), revised by Deng et al. (2011). The internal consistency of the FFMQ in this study was robust, with a Cronbach's alpha of 0.80 and a McDonald's omega of 0.82. The Cronbach's alpha (McDonald's omega) for the FFMQ subscales was 0.81 (0.82) for describing, 0.69 (0.71) for acting with awareness, 0.72 (0.72) for observing, 0.64 (0.65) for non-judging, and 0.58 (0.59) for non-reacting. A confirmatory factor analysis (CFA) was performed on the Chinese version of the FFMQ to assess its five-factor structure and provide evidence of its validity. The results showed a good model fit: $\chi^2/df = 4.28$, RMSEA = 0.06, CFI = 0.92, and TLI = 0.91.

Data Analyses

Behavioral Data Preprocessing

To ensure the validity of the behavioral data, trials with incorrect responses were excluded from the analysis of reaction times (RTs). Outlier RTs were identified and removed using a ± 3 standard deviation threshold from each participant's individual mean, following well-established procedures. The efficiency scores for each attentional network were then calculated based on the remaining RTs using subtraction formulas (Neuhaus et al., 2010). Specifically, the Alerting Network effect was determined by subtracting the RTs of the dual-cue condition from the no-cue condition; the Orienting Network effect was calculated by subtracting the RTs of the spatial-cue condition from the central-cue condition; and the Executive Control Network effect was obtained by subtracting the RTs of the congruent condition from the incongruent condition. For all network effects, smaller RT values reflect greater efficiency in attentional processing.

Electrophysiology Data Acquisition and Preprocessing

A NeuroScan 64-channel Ag–AgCl electrode EEG device was used, with electrode positioning in accordance with the international 10–20 system. Data were acquired using the left mastoid (M1) as a reference, while data from the right mastoid (M2) were recorded. The grounding electrode point was at the midpoint between Fpz and Fz. Electrodes were placed 1.5 cm above and below the left eye to record vertical EEG data, and 1.5 cm above and below the left and right outer corners of the eye to record horizontal EEG data. The EEG data were collected with a filter bandpass of 0.01–100 Hz, a sampling frequency of 1000 Hz for each lead, and an impedance of less than 5 kΩ between the scalp and the electrodes.

EEG data were analyzed and processed using the toolkits EEGLAB and ERPLAB (Delorme & Makeig, 2004; Lopez-Calderon & Luck, 2014) in the MATLAB 2019b (MathWorks, Natick, MA, USA) software package. For analyses, the sampling frequency was reduced to 500 Hz and the data were filtered using a bandpass filter from 0.1 to 30 Hz (24 dB/octave) (Luck, 2014). The mean values of M1 and M2 were used as a reference. Data were segmented according to stimulus onset time (300 ms before the cued stimulus to 800 ms after the target stimulus, with a 500 ms interval from the cued stimulus to the target stimulus included in between), and the data were corrected for time-locking with cue and target presentations, respectively, by using the 200 ms before cue stimulus presentation as the baseline. Electrooculogram components were removed using independent component analysis (ICA). Afterwards, signals with voltages exceeding ± 75 μV were excluded as artifacts, and data from participants with artifact rejection rates exceeding 20% were excluded. Finally, data from each electrode were averaged and the overall mean ERP for all participants in each experimental condition was calculated. Data with correct responses and free of artifacts were averaged by time (pre-test, post-test) × group (focused-breathing, body-scan, or wait-list control group) × condition (alertness: no cue, double cue; orientation: central cue, spatial cue; executive control: consistent, inconsistent) categorical overlay averaging.

Referring to previous related studies (Malinowski et al., 2013; Williams et al., 2016) and the topographic map activation areas after total averaging in the present experiment, the CZ electrode was selected to do the analysis for the CNV component, and the selected electrode, the FCz electrode, was selected to do the analysis for the N2 component. Referring to the peak values of the components after total averaging in this study and related studies on the time windows of the CNV and N2 components, the average of the signals in the time window of 250–500 ms after the cue was selected as the amplitude of the CNV, and the average of the signals in the time window of 270–370 ms after the target was selected as the amplitude of the N2.

The neural network effects were then calculated using subtraction formulas (Norris et al., 2018): the Alerting Network effect as the difference in CNV amplitude between the no-cue and dual-cue conditions; the Orienting Network effect as the difference in CNV amplitude between central-cue and spatial-cue conditions; and the Executive Control Network effect as the difference in N2 amplitude between incongruent and congruent conditions.

To analyze the FFMQ scores, a 2 (Time: pre-test vs. post-test) × 3 (Group: focused-breathing, body-scan, or wait-list control) mixed-design ANOVA was performed. A similar mixed-design ANOVA was also conducted on the behavioral reaction times (RTs) and ERP amplitudes to assess the attentional network effects. For post hoc pairwise comparisons, we provided the *p*-values corrected by Bonferroni to take multiple comparisons into consideration, and we applied Greenhouse–Geisser correction to the *p*-values that did not satisfy the sphericity assumption.

Results

Five Facet Mindfulness Questionnaire

A time (pre-test, post-test) × group (focused-breathing group, body-scan group, or wait-list control group) mixed-design ANOVA was performed on the FFMQ. The main effect of group was not significant, $F_{(2,69)} = 0.26$, $p = 0.78$, $\eta^2 = 0.007$. The main effect of time was significant, $F_{(1,69)} = 31.20$, $p < 0.001$, $\eta^2 = 0.31$, and post-test scores were significantly greater than the pre-test. The time and group interaction was significant, $F_{(2,69)} = 4.67$, $p = 0.013$, $\eta^2 = 0.12$. Within-subjects simple effects analyses revealed that, in the focused-breathing group, post-test scores were significantly greater than pre-test scores ($p < 0.001$), and similarly, in the body-scan group, post-test scores were significantly greater than pre-test scores ($p < 0.001$). In contrast, the wait-list control group showed no significant within-subjects difference between pre-test and post-test ($p = 0.47$).

Behavioral Data

The Attention Network Effect

Mixed-measures ANOVAs were conducted for the alerting, orienting, and executive control effects at different time points (pre-test and post-test) and for each group (focused-breathing, body-scan, or wait-list control).

For the alerting network effect, neither the time nor group main effects were significant, $F_{(1,69)} = 2.62$, $p = 0.11$, $\eta^2 = 0.04$; $F_{(2,69)} = 0.02$, $p = 0.98$, $\eta^2 = 0.01$. The time and

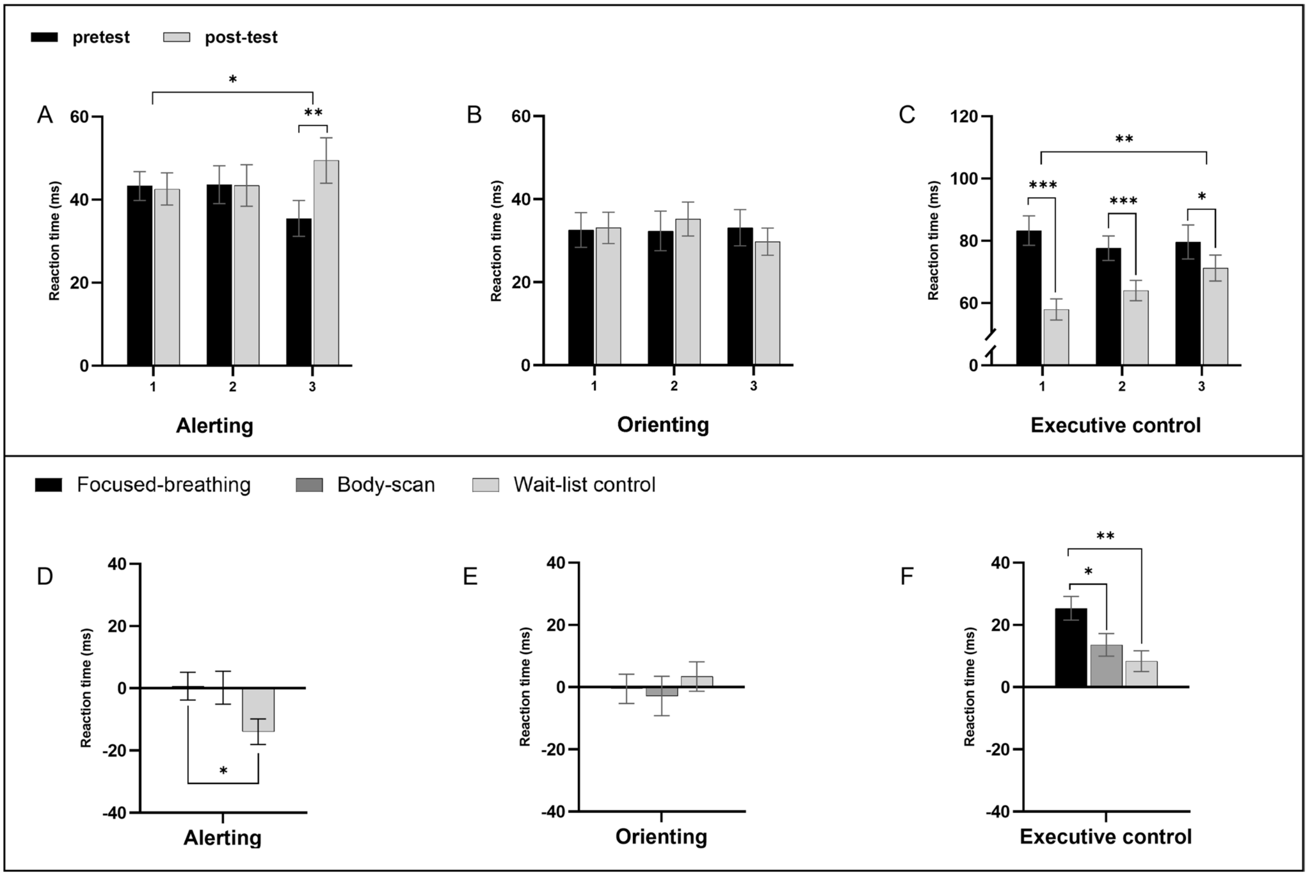

Fig. 3 Attention network effect of different groups. **A** Bar graphs of alerting network effects. **B** Bar graphs of orienting network effects. **C** Bar graphs of executive control network effects. **D** Bar graphs depicting the pre-test minus post-test differences in alerting network effects. **E** Bar graphs depicting the pre-test minus post-test differences in orienting network effects. **F** Bar graphs depicting the pre-test minus post-test differences in executive control network effects. *Note*: ***$p<0.001$; **$p<0.01$; *$p<0.05$. Group 1 represents the focused-breathing group, Group 2 represents the body-scan group, and Group 3 represents the wait-list control group

Table 1 Descriptive statistical analysis of attention network efficiency ($M \pm SD$)

	Alerting effect		Orienting effect		Executive control effect	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Focused-breathing	43.3 ± 16.57	42.59 ± 16.88	32.55 ± 20.38	33.06 ± 18.31	83.3 ± 20.32	57.96 ± 15.44
Body-scan	43.64 ± 21.85	43.42 ± 23.89	32.34 ± 22.96	35.19 ± 19.62	77.64 ± 18.87	64.04 ± 15.62
Wait-list control	35.49 ± 20.79	49.45 ± 26.26	33.14 ± 20.85	29.7 ± 15.81	79.63 ± 26.33	71.26 ± 20.01

group interaction was significant, $F_{(2,69)}=3.22$, $p=0.046$, $\eta^2=0.09$, and further simple effects analyses revealed that neither the focused-breathing group nor the body-scan group showed significant changes from pre-test to post-test ($p=0.88$ and $p=0.96$, respectively); however, in the wait-list control group, the alerting effect became larger ($p=0.004$), that is, less efficient, in the post-test compared to the pre-tests (see Fig. 3A).

For the orienting network effect, neither the main effects of time and group nor their interaction were significant, $F_{(1,69)}=0.001$, $p=0.95$, $\eta^2=0.001$; $F_{(2,69)}=0.14$, $p=0.87$, $\eta^2=0.004$; $F_{(2,69)}=0.36$, $p=0.70$, $\eta^2=0.01$ (see Fig. 3B).

For the executive control network effect, the main effect of group for executive control efficiency was not significant, $F_{(2,69)}=0.50$, $p=0.61$, $\eta^2=0.01$ (Table 1). The main effect of time was significant, $F_{(1,69)}=57.45$, $p<0.001$, $\eta^2=0.45$, and the post-test executive control effect became smaller, i.e., more efficient, compared to the pre-test. The time and group interaction was significant, $F_{(2,69)}=5.82$, $p=0.005$, $\eta^2=0.14$, and further simple effects analyses revealed that the focused-breathing ($p<0.001$), body-scan ($p=0.001$), and control groups ($p = 0.02$) all demonstrated a significant decrease in the reaction time difference score in the executive control effect, that is, more efficiently, on the post-test compared to the pre-test (see Fig. 3C). Furthermore, no significant differences were observed among the three groups at pre-test ($p_{Bonf} = 0.70$); however, at post-test, significant group differences emerged ($p_{Bonf} = 0.04$). Specifically, the focused-breathing group demonstrated significantly smaller executive control effect compared to the wait-list control group ($p_{Bonf} = 0.048$).

The Effect of Attention Networks on Pre-Test and Post-Test Differences

One-way ANOVAs were conducted to examine attention gains from mindfulness training, focusing on alerting, orienting, and executive control with the factor of group (focused-breathing, body-scan, and wait-list control).

For the alerting network, the results showed a main effect of group, $F_{(2,69)} = 3.22$, $p = 0.046$, $\eta^2 = 0.09$. Further pairwise comparisons based on the Bonferroni correction indicated that attention gains tended to be significantly greater for the focused-breathing group (0.71 ms) than for the wait-list control group (−13.76 ms), $t(23) = 2.23$, $p_{Bonf} = 0.041$, Cohen's $d = 0.64$ (see Fig. 3D).

For the orienting network, there was no significant main effect of group, $F_{(2,69)} = 0.36$, $p = 0.70$, $\eta^2 = 0.01$ (see Fig. 3E).

For the executive control network, there was a significant main effect of group, $F_{(2,69)} = 5.82$, $p = 0.005$, $\eta^2 = 0.14$. Further pairwise comparisons based on the Bonferroni correction indicated that attention gains tended to be significantly greater for the focused-breathing group (25.35 ms) than for the body-scan group (13.60 ms), $t(23) = 2.31$, $p_{Bonf} = 0.046$, Cohen's $d = 0.67$, and for the wait-list control group (8.37 ms), $t(23) = 3.33$, $p_{Bonf} = 0.004$, Cohen's $d = 0.96$ (see Fig. 3F).

ERP Data

The Attention Network Effect

As mentioned before, the alerting network effect is defined as the CNV amplitude in the no-cue condition minus that in the dual-cue condition; the orienting network effect as the CNV amplitude central-cue minus spatial-cue conditions; and the executive control network effect as the N2 amplitude incongruent minus congruent conditions.

For the alerting network, CNV difference waveforms for the different groups are shown in Fig. 4A--D. A mixed-measures ANOVA was conducted on the mean CNV waveform amplitude, with factors of time (pre-test, post-test), group (focused-breathing, body-scan, or wait-list control group). The results revealed a nonsignificant main effect of group, $F_{(2,69)} = 2.02$, $p = 0.141$, $\eta^2 = 0.04$. The main effect of time was not significant, $F_{(1,69)} = 3.35$, $p = 0.07$, $\eta^2 = 0.01$. The time and group interaction was significant, $F_{(2,69)} = 3.47$, $p = 0.037$, $\eta^2 = 0.03$, and further simple effects analyses revealed that, in the post-test, the wait-list control group (−2.43 μV) was significantly more negative than the focused-breathing group (0.72 μV), $t(23) = 3.48$, $p_{Bonf} = 0.045$, Cohen's $d = 0.56$.

For the orienting network, CNV difference ERP waveform plots for different groups are presented in Fig. 4E--H. A mixed-measures ANOVA was conducted on the mean CNV difference waveform amplitude, with factors of time (pre-test, post-test), group (focused-breathing, body-scan, or wait-list control group). None of the time, group main effects, or interactions were significant, $p > 0.1$.

For the executive control network, N2 difference ERP waveforms for different groups are presented in Fig. 4I--L. A mixed-measures ANOVA was conducted on the mean N2 waveform amplitude, with factors of time (pre-test, post-test), group (focused-breathing, body-scan, or wait-list control group). There was a significant main effect of group, $F_{(2,69)} = 4.47$, $p = 0.015$, $\eta^2 = 0.06$, with wait-list control group (−1.78 μV) being significantly smaller than the focused-breathing group (−0.60 μV), $t(23) = 2.97$, $p_{Bonf} = 0.012$, Cohen's $d = 0.62$. There was a significant main effect of time, $F_{(1,69)} = 12.09$, $p < 0.001$, $\eta^2 = 0.07$, and the pre-test (−1.70 μV) N2 mean difference amplitude was significantly more negative compared to the post-test (−0.60 μV). The time and group interaction was significant, $F_{(2,69)} = 3.32$, $p = 0.042$, $\eta^2 = 0.04$, and further simple effects analyses revealed that, in the post-test, with wait-list control group (−1.70 μV) being significantly more negative than the focused-breathing group (0.47 μV), $t(23) = 3.92$, $p_{Bonf} = 0.002$, Cohen's $d = 1.13$.

The Effect of Attention Networks on Pre-Test and Post-Test Differences

One-way ANOVAs were conducted, focusing on alerting, orienting, and executive control with the factor of group (focused-breathing, body-scan, and wait-list control).

For the alerting network, the results showed a main effect of group, $F_{(2,69)} = 3.47$, $p = 0.037$, $\eta^2 = 0.03$. Further pairwise comparisons based on the Bonferroni correction indicated that attention gains tended to be significantly greater for the focused-breathing group (−2.02 μV) than for the wait-list control group (0.91 μV), $t(23) = -2.45$, $p_{Bonf} = 0.05$, Cohen's $d = -0.71$ (see Fig. 5A).

For the orienting network, there was no significant main effect of group, $p > 0.6$ (see Fig. 5B).

For the executive control network, there was a significant main effect of group, $F_{(2,69)} = 3.32$, $p = 0.042$, $\eta^2 = 0.04$.

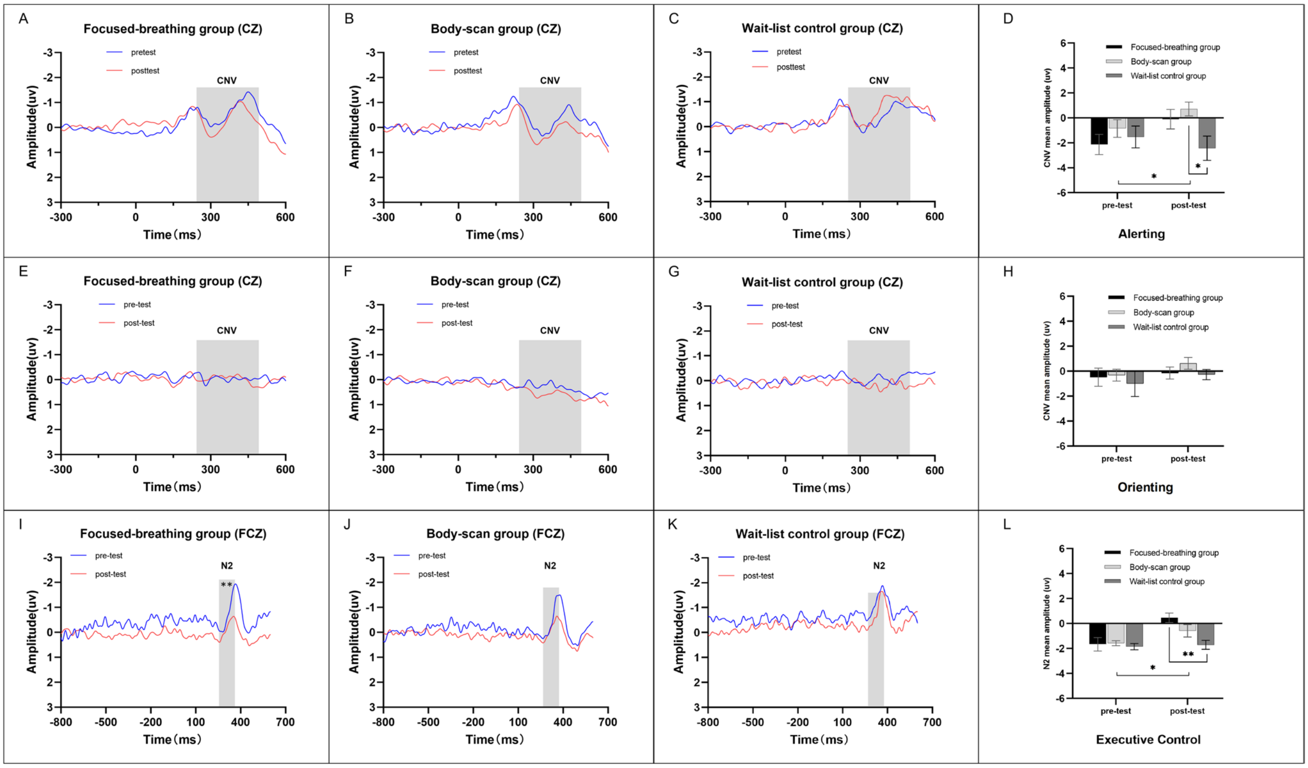

Fig. 4 Pre- vs. post-test ERP difference waveforms and mean amplitudes by group. This figure illustrates the pre- to post-test changes in event-related potential (ERP) for the three attention networks: alerting (**A**–**D**), orienting (**E**–**H**), and executive control (**I**–**L**). Panels **A**–**C**, **E**–**G**, and **I**–**K** show the average ERP difference waveforms. Specifically, panels **A**–**C** and **E**–**G** display waveforms at the Cz electrode, while panels **I**–**K** show waveforms at the FCz electrode. Panels **D**, **H**, and **L** display the mean amplitude differences. Panels **D** and **H** show the CNV mean amplitudes (250–500 ms post-cue), and panel **L** shows the N2 mean amplitudes (270–370 ms post-target)

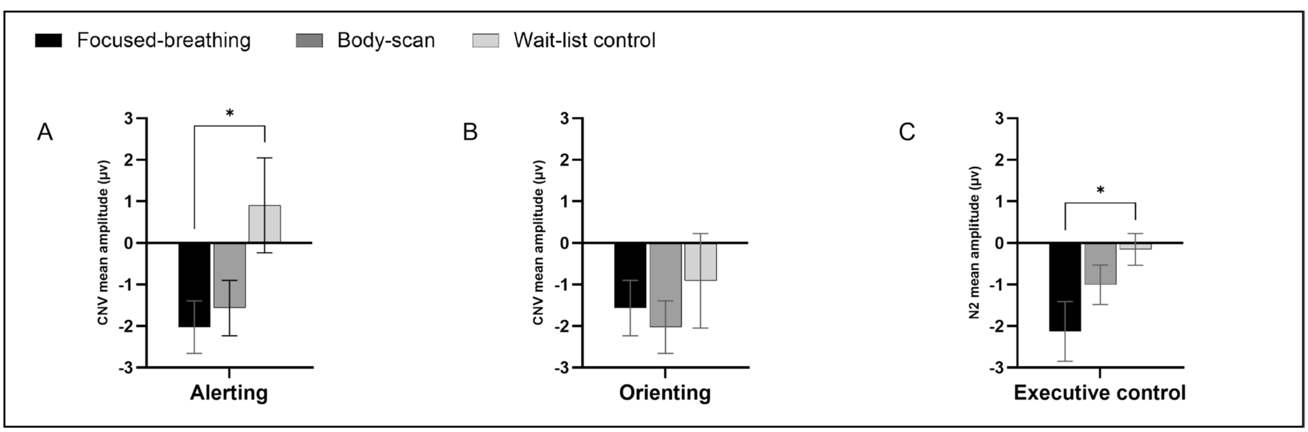

Fig. 5 Pre-Test minus Post-Test mean difference amplitudes by group. This figure illustrates the Pre-Test minus Post-Test for the three attention networks: alerting (**A**), orienting (**B**), and executive control (**C**)

Further pairwise comparisons based on the Bonferroni correction indicated that attention gains tended to be significantly more negative for the focused-breathing group (−2.13 μV) than for the wait-list control group (−0.15 μV), $t(23) = -2.57$, $p_{Bonf} = 0.037$, Cohen's $d = -0.74$ (see Fig. 5C).

Discussion

The current study found that compared to the pre-test, the total FFMQ scores of the post-test were significantly higher in the focused-breathing and body-scan groups.

This suggests that both focused-breathing and body-scan training may considerably improve mindfulness in beginner practitioners, implying that both methods of mindfulness training are beneficial. Comparisons of pre-test and post-test differences in attentional network effects among the three groups revealed that mindfulness training can change the efficiency of the attentional network. Specifically, only focused-breathing mindfulness training has an effect on the efficiency of the attentional network, including its alerting and executive control functions. The results suggest that focused-breathing and body-scan mindfulness have inconsistent effects on attentional network efficiency. This lack of consistency reveals a clear dissociation between the two types of mindfulness training.

According to behavioral data, the wait-list control group's post-test alerting network effect grew greater on the attentional alerting network, suggesting that it became less efficient. EEG data also found disparities in alerting network effects across groups. The wait-list control group showed no significant difference in pre-test to post-test CNV mean amplitude between the no-cue and dual-cue conditions. In contrast, the focused-breathing group exhibited a significantly more negative pre-test minus post-test CNV difference amplitude compared to the control group, suggesting that focused-breathing training enhances alerting efficiency. In contrast to previous research, our findings suggest that focused-breathing improves the alerting network, possibly because other studies' exclusion of extreme response times may have obscured a significant effect (Becerra et al., 2017).

One of the purposes of focused-breathing is to quiet the brain (Verhaeghen, 2021); hence, the smaller CNV amplitude in the focused-breathing group indicated a more relaxed brain state. Incagli and colleagues (2019) found that 8 weeks of focused-breathing stress-reducing meditation training resulted in participants exhibiting greater CNV amplitudes, reflecting greater use of active cognitive control after their training processes. Thus, the present findings support the hypothesis that focused-breathing mindfulness training promotes a more optimal form of attention by enhancing both attentional readiness (Brunia, 1999; Brunia & van Boxtel, 2001; Tecce, 1972) and motor preparation (Scheibe et al., 2009), allowing individuals to process information more fluidly and easily. This outcome is consistent with previous research, such as regular participation in mindfulness training helping to buffer the impairment of nurses' alerting attention over time (Wong et al., 2018).

While both techniques enhance attention, their mechanisms differ: focused-breathing primarily reduces mind-wandering by strengthening sustained attentional focus (Ju & Lien, 2016), whereas body-scan improves attentional performance through heightened somatic awareness and sensory integration (Adhikari et al., 2018), despite its guidance tending to emphasize sequential focus on bodily sensations rather than explicit instructions on attentional monitoring (e.g., redirecting attention after distraction) (Sauer-Zavala et al., 2012). Body-scan training, on the other hand, permits people to spend more attentional resources and actively prepare (Incagli et al., 2019). However, no significant improvement of alerting network efficiency by body-scan was found on the behavioral data and ERP data. It is possible that focused-breathing is more accessible to beginners than body-scan training. Research supports this, showing that even a short four-day meditation retreat with breathing exercises can boost activation in alerting network regions, including the left insula and medial frontal gyrus (Kwak et al., 2020).

Based on frontal-central CNV slow-wave measurements, previous research found that individuals with social anxiety exhibit a more negative CNV amplitude during the response preparation phase, indicating they invest greater cognitive effort to maintain task performance (Judah et al., 2013). In the current study, the smaller CNV amplitude difference (between the two cues) observed in the focused-breathing group during the post-test reflected an improvement in attentional efficiency. The consistent behavioral and EEG findings align with attentional control theory (Eysenck & Derakshan, 2011), which posits that mindfulness training can enhance top-down, goal-directed behavior without the need to prematurely invest attentional resources in pre-task preparation, thereby leaving more attentional resources available for subsequent task processing.

On behavioral and EEG outcomes, the attentional orienting networks of the three groups were not significantly different on the pre-tests and post-tests.

It has been found that 8 weeks of mindfulness stress reduction training reduced reaction times to spatial cues, thereby decreasing orienting network efficiency, possibly suggesting that mindfulness training improves the efficiency of the involvement component of the orienting system, especially on spatial cues (Jha et al., 2007). It has also been found that the higher efficiency of the orienting network in the ANT in experienced meditators compared to controls was due to a shortened reaction time to the central cue (van den Hurk et al., 2010). This finding contrasts with an earlier study using an 8-week mindfulness breath-training program, which is consistent with our method, that successfully enhanced the orienting network efficiency in inexperienced university students (Becerra et al., 2017). However, the present study was unable to replicate these findings and did not show that focused-attention mindfulness training improves the orienting network. This discrepancy may be related to our shorter training duration. It is worth noting that the efficiency of the orienting network appeared to show a trend toward a decrease after mindfulness training.

Several studies, in alignment with our findings, have also found that mindfulness training does not improve the efficiency of the orienting network. A 7-day meditation training primarily focused on breathing has been found to not improve the efficiency of the orienting network (Elliott et al., 2014). It follows that returning to the mindfulness object is primarily a matter of error monitoring, which is a process of reactivation with the relevant target that does not involve the attention orienting network (Zhong et al., 2024), and similar results have been found in previous studies (Baijal et al., 2011; Tang et al., 2007).

Based on a review of previous studies, it appeared that changes in orienting efficiency may depend on a longer training duration (e.g., 8 weeks) and a comprehensive training program that incorporates multiple techniques, rather than a single one.

In terms of behavioral outcomes, the executive control network effects became smaller in the post-test, especially in the focused-breathing post-test, suggesting that the efficiency of executive control was improved by focused-breathing mindfulness training. In the executive control ERP, only in the focused-breathing group was N2 mean difference amplitude significantly more negative than the wait-list control group.

Consistent with the majority of research showing that mindfulness training can significantly improve executive control efficiency (Becerra et al., 2017; Elliott et al., 2014; Kwak et al., 2020), our study found that focused-breathing similarly enhanced this ability. This is an expected finding. A more notable question, however, is why body-scan mindfulness training was not effective at improving executive control efficiency. Kropp and Sedlmeier (2019) demonstrated that the body-scan technique has mixed effects. While body-scan training can improve emotional regulation and attention, it was not the most effective technique for enhancing attentional performance. Specifically, compared to other techniques like focused-breathing and loving-kindness meditation, body-scan meditation leads to greater improvements in mindfulness dimensions such as acceptance, but results in a decline in the ability to remain present. In contrast, focused-breathing meditation had a more significant positive impact on attentional performance in the present research.

In ANT, frontal-central N2 is associated with executive control (Williams et al., 2016). One study found that 8 weeks of mindfulness stress reduction training increased N2 amplitude in a Stroop task in novice practitioners, and that this increase was independent of stimulus coherence (Moore et al., 2012). The current study found that focused-breathing increased the efficiency of the executive control network. However, the untrained wait-list control group also increased executive network efficiency at the post-test. This could be due to the exposure effect of the high sensitivity of the executive control task, meaning that the mindfulness training group's improvement was greater than that caused by simple task exposure. However, this improvement might have been obscured by a floor effect in RT performance (Jha et al., 2007), which was supported by the wait-list control group's EEG results showing no significant difference in N2 wave amplitude between the pre-test and post-test.

Consistent behavioral and EEG findings indicate that focused-breathing training enhances the efficiency of executive control. This enhancement was demonstrated through a reduced response time difference between incongruent and congruent targets and a corresponding decrease in the N2 amplitude difference between these targets. These results provided support for attentional control theory (Eysenck & Derakshan, 2011), suggesting that focused-breathing practice optimizes attentional efficiency while simultaneously minimizing the cognitive cost associated with conflict monitoring.

The current study revealed distinct effects of body-scan and focused-breathing training on the efficiency of attentional networks, with findings supported by both behavioral and EEG amplitude results. While four weeks of focused-breathing successfully enhanced the alerting and executive control networks, the same duration of body-scan training did not lead to a significant enhancement of any attention network. These results highlight focused-breathing as a more effective method for improving attentional network efficiency than body-scan, providing evidence that these two forms of mindfulness training may be dissociable.

Limitations and Future Directions

There are several drawbacks to the current study as well. First, the ANT paradigm used to measure three attentional networks simultaneously increases the complexity of results interpretation. In particular, the EEG results, such as the EEG component of attentional alerting mixed in the attention orienting condition, waited for the control group to have significantly smaller CNV amplitudes measured posteriorly in the central cue, suggesting that it is due to impairment of the alerting network over time. Second, the time interval between the cue and the target was fixed in the present study, and fixation intervals have been found to affect participants' expectations of the target and thus responses (Jepma et al., 2012), so this may have led to the existence of an expectation that participants would respond to the target. The alerting network may have interfered with the orienting and executive control networks because the no-cue condition did not provide temporal information about the target, but the time interval between the presentation of the target and the appearance of the central, dual, and spatial cues remained constant. Third, the results are restricted in terms of heuristic for clinical applications, and the patients were a non-clinical group. Prior research on mindfulness training to enhance attention has involved a number of groups and has shown that mindfulness can help children with sustained and selective attention (Janz et al., 2019), older adults with attentional system aging prevention (Malinowski et al., 2017), and people with attention deficit hyperactivity disorder (Thomas et al., 2015), while future research could add considerations for clinical applications.

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Data Availability All data, analysis code, and research materials are publicly available and can be accessed at https://osf.io/7a4m6.

Declarations

Ethical Approval The study was approved by the Ethics Committee of the Department of Psychology at Nanjing University.

Informed Consent The study obtained informed consent from all participants.

Conflict of interest The authors declare no competing interests.

AI Use Statement This work was completed without the use of AI-assisted tools.

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