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Original Paper

Effects of Brief Focused Attention to Breathing on Perseverance and Prefrontal Activity: An fNIRS Study

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Key words: focused attention, breathing, perseverance, prefrontal activity, fNIRS

Abstract

Perseverance is an essential trait for maintaining efforts and achieving challenging goals. It is reported that focused attention to breathing, even briefly, can enhance cognitive functions. However, it is not yet clear whether brief attention to breathing also boosts perseverance. In our study, we investigated the effects of a brief period of focused attention to breathing on perseverance and brain activity in challenging situations, wherein failures could occur frequently. We conducted a "stopwatch task" where participants tried to stop a timer at 10 seconds within an acceptable range of deviation. As participants succeeded in trials, this allowable deviation range was progressively reduced, making the task increasingly difficult and leading to frequent failures. The participants in the experimental (BREATH) group were instructed to focus on their breathing during the task. We observed a significant increase in perseverance (the number of trials attempted before quitting) and a significant decrease in response deviation from 10 seconds in the BREATH group, but not in the control (CTRL) group. Brain scans revealed differential activation in the prefrontal cortex (PFC) between the BREATH and CTRL groups: increased activation in the ventral parts of the PFC in the CTRL group, and more activation in the right PFC in the BREATH group. Moreover, we found negative correlations between brain activity in the right ventral PFC and perseverance. These results suggest that focused attention to breathing, even briefly, can enhance perseverance and concentration in challenging situations, which is potentially associated with different activations in the PFC.

1. Introduction

Perseverance is a key attribute in achieving difficult goals. This trait refers to the capacity to maintain sustained effort in the face of long-term plans and challenges, playing a crucial role in an individual's academic, professional, and everyday life. Achieving difficult goals requires not only effort but also the maintenance of that effort over time, which necessitates perseverance. Psychological research indicates

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that there is significant individual variation in this trait, influenced by a person's mindset[1,2]. Since mindset influences perseverance, it is conceivable that this trait can be strengthened through postnatal experiences. High levels of perseverance not only increase the likelihood of success but also reflect a person's ability to cope with adversity. However, individual differences in perseverance are believed to be deeply influenced by psychological and physiological factors.

In this context, mindfulness meditation, specifically focusing on breathing, has gained attention. Focusing on one's breath is a fundamental practice in mindfulness, directly influencing the autonomic nervous system and promoting mental and physical relaxation[3,4]. It is thought that controlling breathing is key in managing negative emotions such as anger and anxiety. For instance, deep breathing can alleviate anxiety and pain sensation, and mindfulness meditation focused on breathing can reduce stress and prevent depression[4-7]. Since breathing control is relatively easy to implement, improving perseverance through this method could be beneficial to many people. By focusing on breathing, it is possible to suppress stress responses and achieve the psychological stability necessary for perseverance. Moreover, mindfulness meditation has been reported to enhance activity in the prefrontal cortex (PFC), thereby supporting self-regulation and the maintenance of conscious attention[8,9]. Recent reports suggest that even brief periods of focused attention to breathing (just a few minutes to several tens of minutes) can enhance concentration and cognitive abilities[10,11]. However, it remains unclear whether a brief focused attention to breathing would also enhance perseverance.

This study aims to explore the effects of a brief period of attention to breath on perseverance. Specifically, we intended to examine how brief attention to breathing, such as several tens of seconds, influences behavior under challenging circumstances. To experimentally create a challenging situation, we developed a stopwatch task wherein failures could occur repeatedly. Additionally, we investigated the effects of brief focused attention to breathing on PFC activity using functional near-infrared spectroscopy (fNIRS). The PFC is known to be involved not only in cognitive functions but also in attention and emotional control[12-14], and thus is hypothesized to play a significant role in perseverance.

2. Methods

2.1 Subjects

Twenty-five adults without a history of any neurological disorder participated in the experiments (6 males and 19 females; mean age, 24.2 ± 5.8 years; range, 20-34 years).

2.2 Behavioral task

We conducted a behavioral task called the stopwatch task. The task was designed such that the subjects experienced failures repeatedly. In this task, the subjects were instructed to press the start button of the timer, count seconds in their mind, and stop the timer at 10 s with an allowable range of time deviation. The subjects responded by clicking the mouse buttons. A subject was seated on a chair with a headrest to minimize body movement in a dimly lit room. We instructed the participants to minimize bodily movements as much as possible, except for mouse clicks, during the task. A 19-inch liquid crystal display (LCD) monitor (P1917S, Dell Computer, Round Rock, Texas, USA) was placed in front of each subject. The distance between the subject and the monitor was approximately 65 cm.

The time course of the task is shown in Figure 1A. First, the time condition (10 s ± allowable range of time deviation) and the choice options ("try" or "quit") were shown on the monitor. The subject chose either "try" or "quit" by clicking the left or right button of the mouse, respectively. If the subjects chose "quit", the experiment session ended. The subjects were instructed that they could continue the task as many times as they wanted even if they failed a trial and that they could discontinue the task whenever they wanted. If the subjects chose "try" (left button click), the message "when you click again, the timer will start" (in Japanese) was shown on the monitor. Then, the subject clicked the left button again to start the timer, counted 10 s in their mind, and clicked the left button again to stop the timer. When the subject stopped

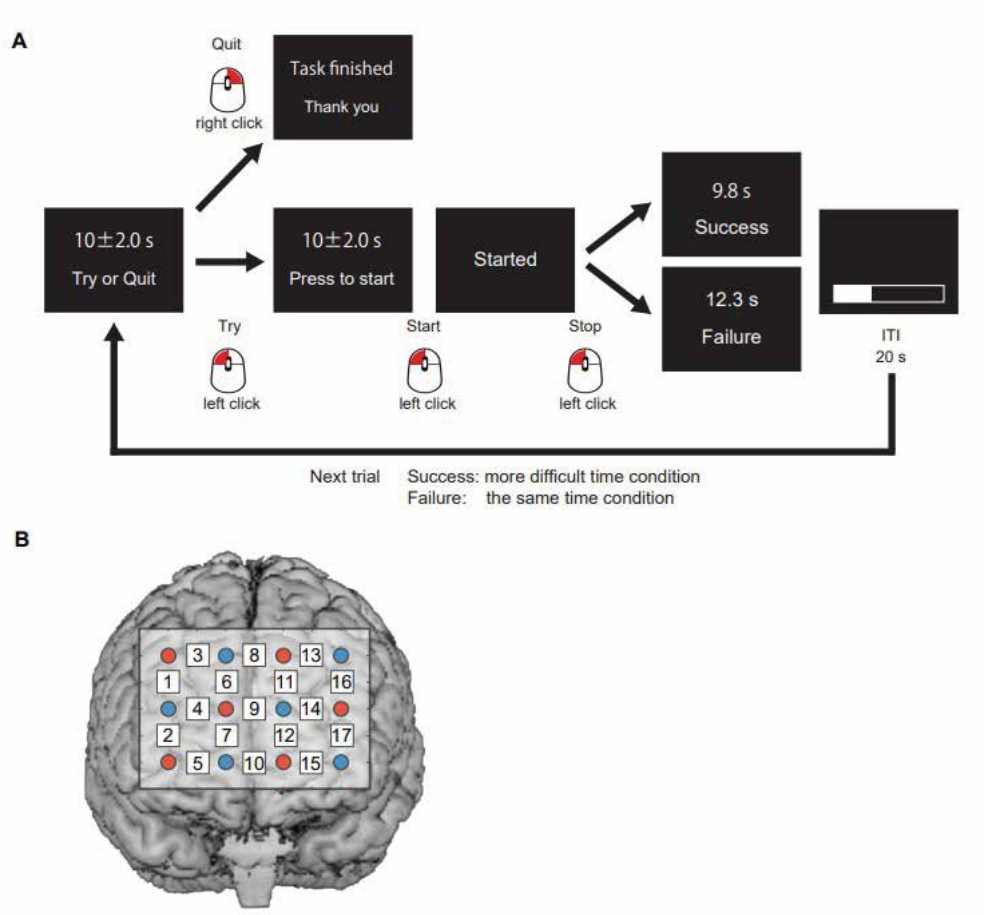

Figure 1

(A) Time sequence of the stopwatch task. (B) Schematic arrangement of fNIRS probes superimposed on a standard brain surface. Red and blue circles represent near-infrared emitters and detectors, respectively. Numbers refer to the recorded NIRS channels.

the timer, the response time and the result (success or failure) were shown on the monitor. If the response time was within the 10 s ± allowable time range, the trial was a success, otherwise a failure. Then, a 20-s intertrial interval (ITI) was introduced. During the ITI, the progress bar indicated the remaining waiting time. After the ITI, the next time condition was shown on the monitor. If the subject failed in the previous trial, the same time condition as the previous one was shown. If the subject succeeded in the previous trial, the time condition with a narrower allowable time deviation was shown (i.e., more difficult condition). The allowable time deviation increasingly narrowed from ± 2.0s to ± 0.1s, as the subject succeeded in the trials (Table 1). Thus, the task became increasingly more difficult, and the subjects tended to fail in the task repeatedly. Even when the subjects failed in the trial, they could continue the task as many times as they wanted. They could also discontinue the task any time.

When the allowable time deviation was ± 0.1 s, the task program judged the subject's response as a failure irrespective of how precise the subject had responded. When the subject's response time was within 10 s ± 0.1 s, the task program presented a spurious response time (slightly out of the allowable time deviation range) on the monitor. Thus, the subjects could never succeed in the trial when the allowable time deviation was ± 0.1 s. We call this type of trial "trick" trials. The subjects were not informed about the existence of "trick" trials. The number of "trick" trials that the subjects continued with was used as an index of perseverance. The maximum limit for "trick" trials was set at 20, and the experiment finished if

Table 1 Time condition

The allowable time deviation increasingly narrowed from ±2.0 s to ±0.1 s, as the subject succeeded in the trials.

Level	Time condition	Success range
1	10 ± 2.0	8.0 - 12.0
2	10 ± 1.8	8.2 - 11.8
3	10 ± 1.6	8.4 - 11.6
4	10 ± 1.4	8.6 - 11.4
5	10 ± 1.2	8.8 - 11.2
6	10 ± 1.0	9.0 - 11.0
7	10 ± 0.8	9.2 - 10.8
8	10 ± 0.6	9.4 - 10.6
9	10 ± 0.4	9.6 - 10.4
10	10 ± 0.2	9.8 - 10.2
11	10 ± 0.1	Never succeed

this number exceeded 20 trials.

2.3 Experiment schedule

All subjects performed two experimental sessions on different dates. In the first session, they practiced the stopwatch task for several trials and then performed the task. We considered the performance in the first session as their baseline performance. Then, we randomly assigned the subjects to either the experimental (BREATH) or control (CTRL) group.

Then, we instructed the subjects in the BREATH group on how to focus attention to their breathing by using a 10-min video of mindfulness meditation practice, with the purpose of familiarizing them with this practice. The video has been published on the web by the Mindfulness Meditation Association[15]. The training instruction was conducted under the guidance of a licensed psychologist who practices mindfulness meditation in her clinical practice. The instruction video included several natural scenes with background music and narration of the instruction on how to focus attention to their breathing, specifically the sensations of the breath on the nostrils and the feeling of expansion and contraction of the abdomen. We had the subjects in the BREATH group practice focusing on their breathing by watching the video every day at home for 1 week.

One week after the first session, the subjects participated in the second experimental session. The BREATH group was instructed to focus attention to their breathing during every ITI, keeping their eyes open. Moreover, the message "Please focus attention to breathing" was shown on the monitor during the ITI. On the other hand, the subjects of the CTRL group were given no instruction about breathing and performed the task in the same way as the first session, and no instruction about breathing was shown on the monitor during ITI. We recorded the hemodynamic response of the PFC with fNIRS in the second session.

2.4 Data acquisition

Cerebral oxygenation changes were measured using Spectratech OEG-17APD (Spectratech Inc., Yokohama, Japan) at a sampling frequency of 12.2 Hz. The Spectratech OEG-17APD employs two wavelengths of approximately 770 and 840 nm. Seventeen channels were measured with a 3 × 4 optode probe set consisting of six light emitters and six photodetectors (Figure 1B). The optodes were affixed to a

probe set at an inter-optode distance of 3 cm. The probe set was fastened to the subject's head with elastic straps. The NIRS probes were attached to the forehead in accordance with the international 10-10 electrode system, such that the center of the lowest probe line (i.e., channel 10) was positioned on Fpz (Figure 1B). Our measurement area covered Fp1, Fpz, Fp2, AF3, AFz, AF4, F3, F1, Fz, F2, and F4.

2.5 Data analysis

The raw data were converted into oxy-Hb and deoxy-Hb concentrations using the modified Beer-Lambert law. The data of oxy-Hb and deoxy-Hb from each channel was digitally processed with a 0.01-0.3 Hz band-pass filter to attenuate low-frequency drifts and cardiac oscillations. We then converted the data by the hemodynamic signal separation method described by Yamada et al.[16]. This method reduces the influence of systemic physiological signals by separating the hemodynamic signal into estimated functional and systemic components on the basis of the fact that the changes in oxy-Hb and deoxy-Hb concentrations are negatively correlated in the functional cerebral response, but positively correlated in the systemic fluctuations[16,17]. We used the functional component of oxy-Hb and deoxy-Hb in statistical analyses.

We defined the 5 s period before the subjects clicked the start button in each trial as the baseline period. We analyzed the hemodynamic response during the period that the subjects counted 10 s in their mind in each trial. However, since the hemodynamic response takes a few seconds to rise[18], we set a 1 s offset for the analysis period (i.e., we analyzed the data in 1-10s period after the start click). We calculated normalized brain activity (z-score) by subtracting the mean brain activity in the baseline period from that in the analysis period and then dividing the standard deviation of brain activity in the baseline period. Then, we analyzed whether or not the normalized brain activity was significantly different from zero by the one-sample t-test (the significance level was set at 0.05, uncorrected). Positive t-values indicate an increase in oxy-Hb/deoxy-Hb concentration, whereas negative t-values indicate a decrease in oxy-Hb/deoxy-Hb concentration. For the comparison of brain activity between the BREATH and CTRL groups, we compared the normalized brain activity between these groups by the two-sample t-test ($p < 0.05$, uncorrected).

3. Results

3.1 Effects of focused attention to breathing on perseverance

We first studied whether focused attention to breathing influenced perseverance in the stopwatch task. We considered the number of "trick" trials that the subjects continued with before giving up the task as an index of perseverance. One subject in the BREATH group gave up before reaching the trick trials (she gave up in trials with a ± 0.2 s allowance time deviation) in the first session. For this participant, we used the number of failed attempts in trials with a ± 0.2 s allowance time deviation before task abandonment. Another subject in the BREATH group completed all 20 trick trials in the first session; for this subject, we considered the number of trials conducted before giving up performing the task to be 20. Apart from these two subjects, all other subjects gave up performing the task during the trick trials.

Figure 2A shows the number of trials the subjects continued with before giving up the task in the first and second sessions. We did not find any significant differences in the number of trials in the first session between the CTRL and BREATH groups, confirming that the baseline performance was not different between the groups (t-test, $t = -0.34$, $p = 0.73$). Then, we compared the number of trials between the first and second sessions in each group and found significant increases in the number of trials in the BREATH group (t-test, $t = 2.26$, $p < 0.05$ uncorrected), but not in the CTRL group (t-test, $t = -0.20$, $p = 0.85$). These results suggest that the focused attention to breathing enhanced the subjects' perseverance in the stopwatch task.

3.2 Effects of focused attention to breathing on concentration

We then studied whether focused attention to breathing influenced the concentration during the stopwatch task. We considered the response deviation from 10 seconds as an index of concentration. For the data

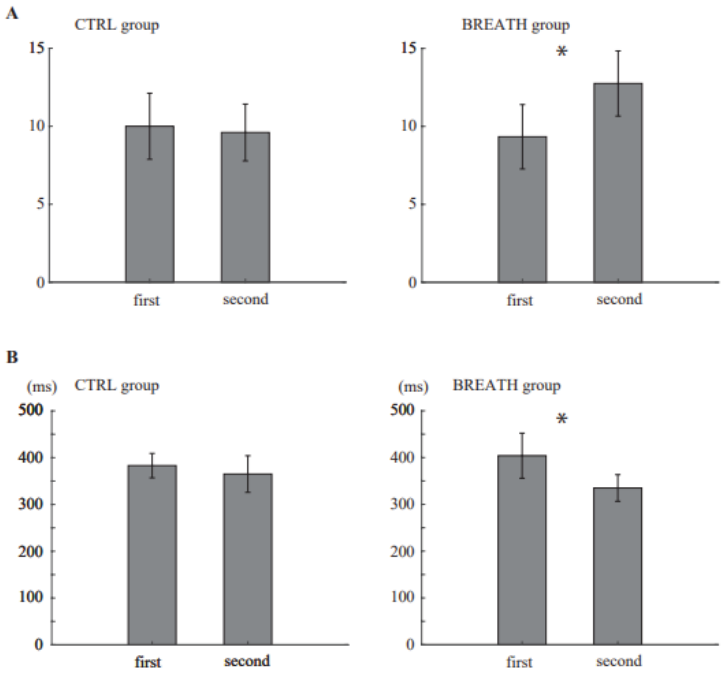

Figure 2

Behavioral performance in the stopwatch task
(A) Number of trials that the subjects retried before giving up the task. (B) Response deviation in the stopwatch task. The mean deviation from 10 s in the response time is shown.

in the trick trials, the actual response time, not the spurious shown time (see Methods), was used for the calculation. Figure 2B shows the response deviation of the subjects in the stopwatch task. We did not find significant differences in the response deviation in the first session between the CTRL and BREATH groups, confirming that the baseline performance was not different between the groups (t-test, $t = 1.65$, $p = 0.10$). Then, we compared the response deviation between the first and second sessions in each group and found a significant improvement of performance (reduction of deviation in response time) in the BREATH group (t-test, $t = 2.26$, $p < 0.05$ uncorrected), but not in the CTRL group (t-test, $t = -1.05$, $p = 0.30$). These results suggest that the focused attention to breathing increased the subjects' concentration.

3.3 Effects of focused attention to breathing on PFC activity

Next, we studied the effects of focused attention to breathing on brain activity. Initially, the data from each of the channels were visually inspected for saturation or extreme noise, which could happen due to poor optode-scalp contact, and the identified ones (7.7%) were eliminated from further analysis. Figure 3A shows the PFC activation in oxy-Hb while the subjects performed the stopwatch task in the second session. In the CTRL group, we found a significant increase in oxy-Hb concentration in wide areas of the PFC, especially the ventral parts of the PFC (channels 5, 7, 9, 10, 12, 14, 15, 16, and17). In the BREATH group, on the other hand, we found a significant increase in oxy-Hb concentration in the right hemisphere of the PFC (channels 1, 2, 3, and 5) and a significant decrease in oxy-Hb concentration in the center of the PFC (channels 7 and 9). The comparison of brain activity between the BREATH and CTRL groups revealed that the activity significantly increased in the right dorsolateral part of the PFC (channel 3) and significantly decreased in various parts of the PFC (channels 4, 7, 9, 10, 12, 13, 14, 15, and 16). These results suggest that focused attention to breathing activates the right PFC and inhibits the left PFC.

Figure 3B shows the PFC activation in deoxy-Hb while the subjects performed the stopwatch task in the

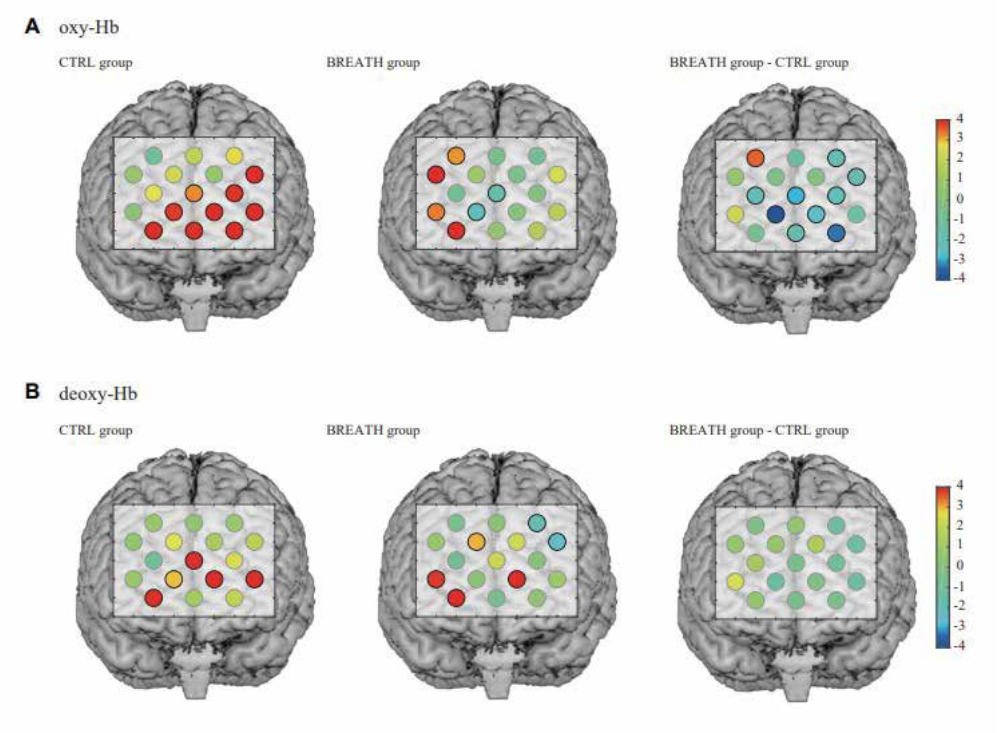

Figure 3

Topographical activation patterns of the PFC during the stopwatch task.
(A) Statistical maps (t-values) of oxy-Hb signals for the CTRL group (left), for the BREATH group (middle), and for the comparison between the BREATH and CTRL groups (right). In the CTRL group (left) and the BREATH group (middle), the red and blue circles indicate the increases and decreases in relative oxy-Hb concentration against zero, respectively. In the comparison between the CTRL and BREATH groups (right), the red and blue circles indicate the increases and decreases in oxy-Hb concentration in the BREATH group relative to the CTRL group, respectively. A channel with a significant difference is indicated by a thick black outline.
(B) Statistical maps (t-values) of deoxy-Hb signals for the CTRL group (left), for the BREATH group (middle), and for the comparison between the BREATH and CTRL groups (right). The configuration is the same as (A).

second session. In the CTRL group, we found a significant increase in deoxy-Hb concentration in channels 5, 7, 9, 12, and17. In the BREATH group, on the other hand, we found a significant increase in deoxy-Hb concentration in channels 2, 5, 6, and 12, and a significant decrease in deoxy-Hb concentration in channels 13 and 16. We did not find any significant difference in the brain activity in the comparison between the BREATH and CTRL groups (Figure 2B right).

3.4 Relationship between perseverance and PFC activity

Then, we studied whether the PFC activity was related to the perseverance of individual subjects. Figure 4 shows the relationship between normalized PFC activity and the number of trials attempted before giving up the task in each channel. We calculated the correlation between the PFC activity and the perseverance of each subject (Pearson correlation coefficient) and found significant negative correlations in channels 4 and 10 ($p < 0.05$, uncorrected). As shown above, we found a significantly different activity between the BREATH and CTRL groups in these channels. Also, we found a trend of negative correlation in channels 2 and 5, although it was not significant. These results indicate that the activity in the right ventral part of the PFC is related to the subjects' perseverance. We also conducted the same analysis for deoxy-Hb, but did not find any significant correlation in any channel.

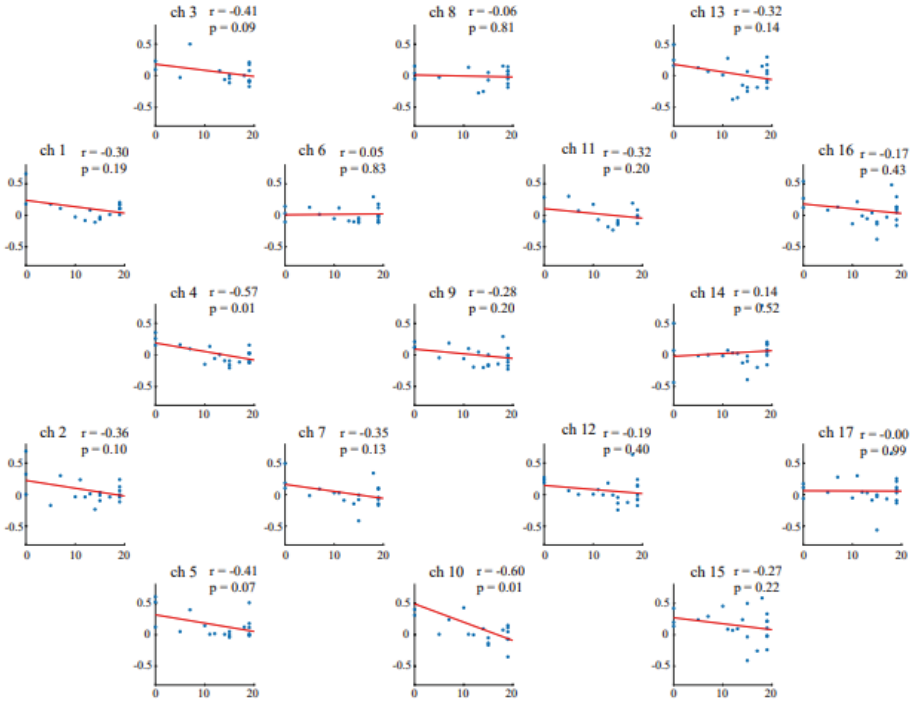

Figure 4

The correlation between brain activity and perseverance.
The y-axis represents the normalized brain activity (z-score). The x-axis represents the number of trials that the subjects retried before giving up the task. Each dot represents the data of an individual subject.

4. Discussion

In this study, we investigated the effects of a brief period of focused attention to breathing on perseverance and PFC activity in a challenging situation, wherein failures would occur repeatedly, using fNIRS. We found that perseverance and concentration increased in the subjects of the BREATH group, who focused attention to breathing during the ITI of the stopwatch task. We also found differential activation patterns of the PFC in oxy-Hb concentration depending on whether the subjects focused attention to breathing or not: the right PFC was activated in the BREATH group, and the ventral areas of the PFC were activated in the CTRL group. Furthermore, we found negative correlations between the brain activity and perseverance in the right ventral parts of PFC. These results suggest that a brief period of focused attention to breathing increased perseverance and concentration, and these effects were related to the specific activation patterns of the PFC.

Why does focused attention to breathing lead to increased perseverance and concentration in a challenging situation? When people experience failure, they often feel negative emotions. In such situations, their attention and thoughts are consumed by these emotions, leading them to ruminate on the negative events. This rumination triggers the sympathetic nervous system, creating a cycle where increased activation further intensifies negative emotions[19,20]. To endure challenging situations, it may be more important to divert attention away from negative emotions and maintain a sense of normalcy, rather than confronting the difficulties directly[21,22]. Our results suggest that focused attention to breathing, even for a brief period, is effective for distracting oneself from negative emotions caused by failure.

We found differential brain activation in the PFC between the BREATH and CTRL groups. The activation of the right dorsolateral PFC (DLPFC) (channel 3) was elevated in the BREATH group. Previous

studies reported that the DLPFC (especially the right DLPFC) was activated during meditation[8,23,24]. It is also known that the DLPFC is involved in attention control[12,25]. Since it is plausible that the subjects in the BREATH group were highly concentrated during the task, the elevated activation of the right DLPFC found in this study may be related to the attention control for achieving higher concentration.

On the other hand, the activation in the ventral areas of the PFC, especially the orbitofrontal areas, was elevated in the CTRL group. We also found significant negative correlations between the brain activity and the perseverance in the channels where there was significant differential brain activity between the BREATH and CTRL groups (channels 4 and 10, Figure 4). Given that there is a trend of negative correlation also in channels 2 and 5, the brain activity in the right ventral part of the PFC is negatively related to the subjects' perseverance. It is well known that the orbitofrontal cortex (OFC) is involved in emotion and value evaluation[26-28]. A previous study showed that the OFC is activated when the subjects feel regret[29,30]. The subjects in the CTRL group may have been more susceptible to being influenced by the positive and negative emotions stemming from their success or failure in the stopwatch task, compared to the subjects in the BREATH group. Furthermore, a previous study reported that ADHD patients display enhanced signaling of future rewards in the OFC[31], suggesting that a higher OFC activity may be related with distracted attention. Thus, the activation of the ventral parts of PFC found in this study may reflect emotions or less focused attention of the subjects of the CTRL group.

In conclusion, the results of our study suggest that focusing attention to breathing, even for a brief period, leads to an increase of activity in the right DLPFC and a suppression of activity in the ventral PFC, which in turn enhances perseverance and concentration.

5. Limitations

There are several limitations in this study. First, the sample size is small, and female subjects outnumbered male subjects. Thus, the results of this study may not be generalized across ages and genders. Second, we did not check the menstrual cycle status of female participants before the experiment. However, menstrual cycle is known to affect attention and premenstrual syndrome (PMS) causes abnormality in stress reactivity[32-34], and performance might be affected due to the menstrual cycle or PMS. Third, we recorded only PFC activity, but perseverance is probably related to other brain regions such as the cingulate cortex, parietal cortex, insula, amygdala, and basal ganglia[35-39]. Further studies are needed to investigate the effects of brief periods of focused attention to breathing on brain activity.

Ethical considerations

The experiments were conducted in accordance with the Declaration of Helsinki. This project was approved by the Ethical Committee of Kawasaki University of Medical Welfare (approved number: 19-064). All the subjects were informed of the content of the experiment, and written informed consent was obtained from them.

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