

Construction of a meditation practice support leads to a good meditation state: an fNIRS study

Seika Fujii*

Satoru. Hiwa, Hiroshi. Furutani, Tomoyuki. Hiroyasu

Faculty of Life and Medical Sciences, Doshisha University, 1-3 Tatara Miyakodani
Kyotanabe-shi, Kyoto-fu 610-0394, Japan

tomo@is.doshisha.ac.jp

Abstract

In this study, we constructed a system to quantify a meditation state based on brain function information and feedback that is based on the functional near-infrared spectroscopy (fNIRS). In the system, the meditation state is fed back to the user in real time. The system informs the user via sound when it judges that a good meditation is being performed. The meditation experiment was conducted using this system. As a result, user's brain state at meditation were visualized.

Keywords: meditation, neurofeedback, real-time, dynamic functional connectivity analysis, fNIRS.

1. Introduction

Kabat-Zinn defined mindfulness as "to actively pay attention and consciousness without value judgment at this moment"¹. Meditation brings a person to a state of mindfulness, which typically has the effect of reducing stress and improving concentration². These effects have been neuroscientifically verified using non-invasive brain function imaging equipment such as functional magnetic resonance imaging (fMRI)^{3,4}. On the other hand, it is not easy for a novice who has just begun meditation to judge whether they are achieving a good or bad state of meditation, and it is thus difficult to experience those effects mentioned above. It would be beneficial if there were a system that could support novices' meditation practices and improve the effects of meditation. In this study, we constructed a system to quantify the meditation state based on brain function information and feedback that is based on functional near-infrared spectroscopy (fNIRS), which is one of the non-invasive brain function imaging devices used to study the effects of meditation. In our previous study, we defined the meditation meta-state as one that is peculiar to meditation. This meditation

meta-state is determined by measuring the time series obtained from multiple channels made by the fNIRS, obtaining the correlation of time series data between channels, and finally expressing it in a matrix. A meditation meta-state derived from the data of a practitioner is defined, the similarity is obtained by data of the brain state under meditation and real-time processing, and by definition that meditation is done better if the similarity is high, meditation state is fed back in real time. By doing this, users can objectively recognize their meditation state, and it becomes possible to experience the feeling of meditation. Features of the constructed system exist in this feedback method. The system alerts the user when the meditation is being performed well while the user is in the process of meditating. In other words, the system praises the user. Although this mechanism inhibits meditation, the act of returning from a wandering state to a mindful state is essential in mindfulness training. At the same time, by giving feedback to users immediately after a good meditation state, the motivation to continue with their practice is maintained. In the following sections, we explain the analysis method used to construct the system,

the creation method of the meditation meta-state, and the specifications of the proposed system.

2. Proposed System

2.1. Functional Connectivity Analysis

The fNIRS device measures changes in cerebral blood flow (CBF). If the changes in CBF between two regions are measured and found to be similar, it is considered that those regions are functionally coordinated and active. In this way, cooperative and active regions are nodes, and the cooperativeness of brain function connectivity can be represented as a network that has a thick line to connect regions with a high degree of cooperation. As shown in Fig. 1, the network representation can be put into the form of a matrix. This series of analyses is called functional connectivity (FC) analysis. In previous studies related to meditation, FC analysis is often used⁵. The FC analysis is summarized as follows. First, a correlation coefficient of the time series data between two regions is calculated and correlation coefficients are calculated for all measurement points, and a correlation coefficient matrix is created. The correlation coefficient indicates the degree of cooperation. Finally, thresholding is performed on this correlation coefficient matrix and a FC matrix that shows a stronger degree of cooperation is obtained. Furthermore, the brain state of the user during meditation changes from moment to moment⁴. Dynamic FC analysis is used to capture the changing brain state to construct the system. In dynamic FC analysis, a fixed-length window of time is used, and the FC analysis is performed on the amount of CBF that changes within that window⁶. Concerning the width of this window, a certain overlap is kept, and the FC analysis is similarly performed while moving the window on the time axis. As a result, a dynamic brain function network is observed.

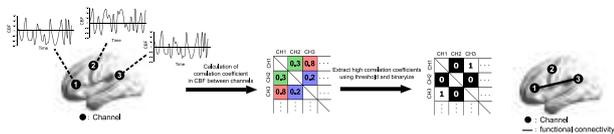


Fig. 1 Process of functional connectivity analysis

2.2. Definition of meditation meta state

To quantify the meditation state of a user, a reference indicator is necessary. In this study, the brain state peculiar to meditation is called the meditation meta-state,

and a corresponding matrix is created. The meditation meta-state is used as a reference indicator. The procedure for calculating the meditation meta-state is as follows. To measure brain activity, the amount of CBF change across 116 channels was measured using the ETG-7100 fNIRS system (Hitachi, Ltd.). Data for five meditation practitioners (45.6 ± 0.7 years old, cumulative practice time $3,910 \pm 2,228$ hours) were used for a meditation meta-state. The meta-state was constructed from changes in CBF during their five-minute meditation practice. Using dynamic FC analysis, the FC commonly seen among all five practitioners was defined as the meditation meta-state. A region with meta-state Fig. 2 was shown. From Fig. 2, it is suggested that the meditation meta-state indicates one's state during meditation.

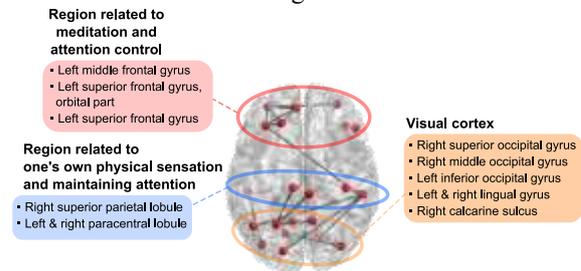


Fig. 2 Brain regions containing the meditation meta-state

2.3. Estimation of brain state during meditation

The change in the amount of CBF obtained using the fNIRS was analyzed and the meditation state of the user was determined. Fig. 3 shows the procedure used for estimating the state of the brain during meditation. A window of 60 seconds was used to analyze the change in the amount of CBF. First, physiological noise was removed by the moving average and FC matrix was calculated. Then, in the matrix, Fisher's Z transformation was performed so that the correlation coefficient became a normal distribution, and an edge density of 15% was set as a threshold value of the correlation coefficient. The number of connection was kept constant. This matrix is defined as the state of the brain during the meditation of a user, and the similarity between this matrix and the meta-state was calculated. The degree of similarity was set as a ratio (occurrence) so that the connection of the meta-state is included in the FC of a user.

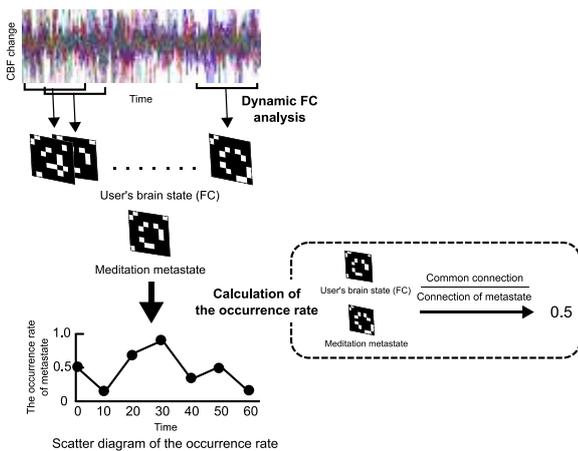


Fig. 3 The process of estimating the meditation state

2.4. Feedback

The system feeds information regarding the meditation state back to the user. Feedback is important in that it informs you when you are in an excellent meditation state. In other words, it praises the user. To realize this, feedback is made available to the user if the following conditions are simultaneously satisfied at the point that the meditation meta-state is attained:

- The current occurrence is larger than the one that was calculated immediately before.
- The current occurrence is 1st or 2nd is largest among the last five.

When the occurrence is higher than the one immediately preceding, it indicates that the meditation state is improved. Furthermore, within the most recent (5 times) occurrences, the taming with relatively high occurrence is calculated. When these conditions are met, it is judged that the user's meditating brain state has approached the target state and a sound is heard. The user is thus informed that their meditative state has improved.

2.5. Real-time system

We assumed that it is essential to provide feedback of the meditation state during the user's meditation practice. For that purpose, the changes in CBF are processed in real time and fed back to the user. In the constructed system, brain function is measured by the ETG-7100, and the processes of sections 2.3 and 2.4 are performed in real time. Feedback is given to the user according to the meditation state determined by the processing result of section 2.3.

Construction of a meditation

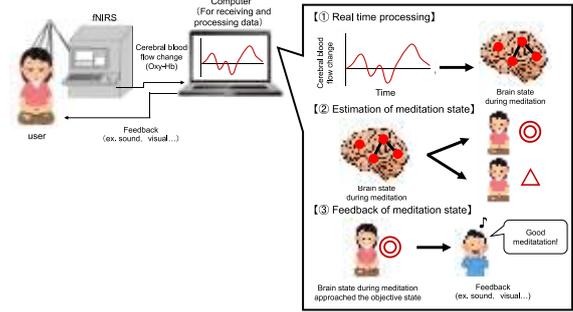


Fig. 4 System overview

3. Materials & Methods

3.1. Participants

The participants comprised four male (with a mean age of 23.0 years, SD 0.8 years) who were novices in meditation. Each subject was evaluated every three days for four days at a time (range 2018/6/13 - 6/25; 12: 00 - 17: 00). Furthermore, the subjects were randomly divided into two groups (two in each group). One group received feedback from the system based on changes in the amount of CBF, and one group received feedback at random moments (two each).

3.2. Protocol

The experimental design is shown in Fig. 5.

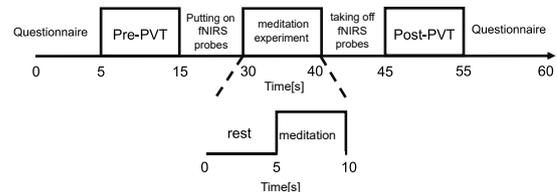


Fig. 5 Experiment protocol

Subjects responded to a questionnaire before and after the experiment. A psychomotor vigilance task (PVT) was also conducted before and after the meditation experiment to measure their attention control abilities. After the PVT, the meditation experiment was started. In the meditation experiment. Participants kept their eyes closed and the breath counting method was used. Counting one's breath is one of the meditation practices that novices can easily do. The feedback sound identified the state in which the last meditation was done, and participants were instructed to maintain that state.

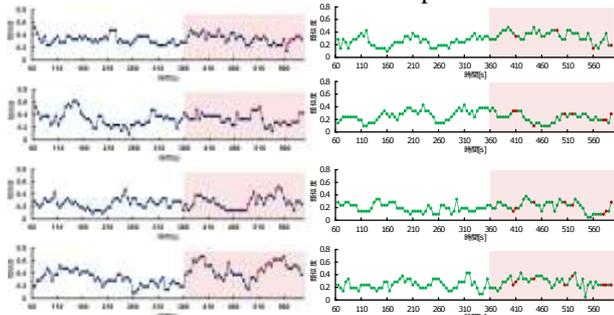
3.3. fNIRS data and behavioral acquisition

Changes in CBF across the whole brain 116 CH were measured using the ETG-7100. PVT was used for examining changes in the attention control abilities of participants with or without the system. When a white circle was displayed at the center of a screen, the participants were instructed to press a key quickly. Reaction time (RT) is the amount of time between the moments when a white ring is shown and when the participant presses the key.

4. Results & Discussion

4.1. Occurrence of meditation meta state

Fig. 6 shows a graph of the transition of occurrences in both the feedback group and the false feedback group within 10 minutes of the meditation experiment.



Subject A (Feedback group) Subject C False Feedback group)

Fig. 6 Changes in the occurrence of subject A and subject C: the first to fourth measurements

4.2. RT in the PVT

Fig. 7 shows the relationship between RT of each PVT. As shown in Fig. 7, there was no difference between the groups. Kaul et al. reported that RT in PVTs improved by doing meditation for 40 minutes⁷. In other words, attention control abilities may be enhanced by meditation with or without feedback.

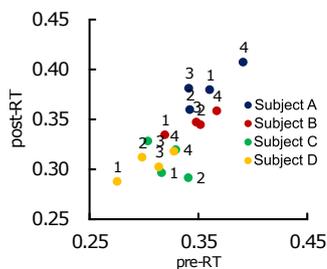


Fig. 7 The relationship between the RTs of pre- and post-PVT of all subjects

5. Conclusion

By practicing meditation, the effects of reduced stress and improved concentration are experienced. However, for a novice, it is difficult to recognize and affect one's state during meditation. Therefore, we constructed a system that feeds back the meditation state to the user in real time by using fNIRS. In the system, the state of brain function during meditation is expressed as a network by a dynamic FC analysis. The data of experts was used as a reference indicator of a good meditation state, and it was defined as the meditation meta-state. For the brain state of a user, the extent to which the meditation meta-state is contained was defined as an occurrence. By setting conditions on the occurrence, the reachability of the target state was evaluated. A feedback system was built to inform the user via an audible sound when it estimates that a good meditation is being performed. The meditation experiment was then conducted using the system. As a result, one's state at rest and one's state at meditation were visualized. In this experiment, there was no difference between the feedback group and the control group obtained. The system has been further modified, and new validation experiments need to be done.

References

1. M.A. Killingsworth and D.T. Gilbert, "A wandering mind is an unhappy mind," *Science*, vol. 330, no. 6006, pp. 932–932, 2010.
2. J. Smallwood and R.C. O'Connor, "Imprisoned by the past: unhappy moods lead to a retrospective bias to mind wandering," *Cognition & Emotion*, vol. 25, no. 8, pp. 1481–1490, 2011.
3. Kabat-Zinn, Jon and Hanh, Thich Nhat, "Full catastrophe living: Using the wisdom of your body and mind to face stress, pain, and illness," *Delta*, 2009.
4. Y.-Y. Tang, B.K. Hölzel and M.I. Posner, "The neuroscience of mindfulness meditation," *Nature Reviews Neuroscience*, vol. 16, no. 4, pp. 213–225, 2015.
5. W. Hasenkamp, C.D. Wilson-Mendenhall, E. Duncan and L.W. Barsalou, "Mind wandering and attention during focused meditation: a fine-grained temporal analysis of fluctuating cognitive states," *Neuroimage*, vol. 59, no. 1, pp. 750–760, 2012..
6. V.D. Calhoun, R. Miller, G. Pearlson and T. Adalı, "The chronnectome: time-varying connectivity networks as the next frontier in fMRI data discovery," *Neuron*, vol. 84, no. 2, pp. 262–274, 2014.
7. P. Kaul, J. Passafiume, R.C. Sargent and B.F. O'Hara, "Meditation acutely improves psychomotor vigilance, and may decrease sleep need," *Behavioral and brain Functions*, vol. 6, no.1, p.47, 2010.