論文の内容の要旨

論文題目 Meditators and Non-Meditators: EEG Source Imaging during Resting.

和訳　無課題安静閉眼時における、瞑想者と非瞑想者健常群の脳機能局在化画像の比較

指導教員　赤林　朗　教授

東京大学大学院医学系研究科

平成 16 年 4 月入学

医学博士課程

内科学　専攻

氏名　鄭　志誠

Meditation is known to achieve a particular class of altered states of consciousness. These states are experienced by the subject and are objectively measurable. Brain activity of meditation has been examined by EEG (electroencephalogram) for nearly 50 years, and various results are accumulated. Brain electric measurements reflect diverse subtle parameters of the working mechanisms of neural networks that constitute the different functional states of the brain.

Many meditation practices are designed to increase awareness towards occurring experiences by sustaining attention to the present moment in a detached manner. The meditation state itself is characterized by a detached monitoring of ongoing experience. Meditators claim that continuous meditation practice leads to a changed state of mind in everyday life. It is believed that long-term meditation training correlates to increased awareness and greater detachment. A detached attitude with reduced initial emotional evaluation of events is described. Indeed, meditation in general is practiced by many as a self-regulatory approach to emotion management. That is, non-engaging observation with no intent to analyze or judge or form expectations.

Several popular meditation exercises involve sustained attention. The exercises can be roughly divided into two categories depending on the focus of attention which can be on one single object or on no object. In ‘focused attention’ meditation, the focus of attention is kept on a single object (like the perception of one's own breathing, a mantra or a visualization); when a distracting thought occurs and is detected, the instruction is to move the focus of attention back to the primary object. In ‘open monitoring' meditation, there is no object of attention. The instruction is to keep an open awareness and non-reactively monitor all internal and external experiences. A common characteristic of focused attention and open monitoring meditation is the above described detachment. It is conceivable that prolonged meditation training carries detachment over into the everyday lives of meditators and becomes an integral part of it after some time.

The question arises whether physiological training effects of long-term meditation practice can be found in meditators during no-task resting. We hypothesized that the neuroplasticity effects of meditation, specifically increased awareness and detachment, would be detectable in a no-task, eyes-closed resting state. By probing for differences in the resting between meditators and controls, we expected to find physiological evidence for the described detachment in the form of inhibited appraisal systems as well as increased awareness of themselves and their surround in the brain of meditators.

Considering the reviewed reports of various affected brain regions by meditation, we used LORETA functional tomography (low resolution electromagnetic tomography) for the analysis of EEG data in order to obtain unambiguous brain localizations. This method does not simply ascribe brain electric signals from a given head site to directly underlying brain sources, but computes intracerebral distributions of source strength from the head surface-recorded multichannel EEG data. Moreover, in order to provide experimental settings that are less invasive and more natural to daily situations, portable EEG device was used. It had minimum restriction of subjects' postures and movements.

EEG was recorded during task-free resting in 8 Qigong meditators and 9 normal healthy controls. 19 EEG electrodes were applied at the positions of the international 10/20 system using a electrode cap. All subjects were self-declared right-handed. The meditators had an average meditation experience of 11.5 years, whereas the controls had no experience in meditation. The age, gender and education level of the two groups had no statistical significant difference. And all subjects reported to have had no previous or current psychiatric diagnosis, head trauma or drug usage, and did not use any central active medication. After complete information about the study design, the subjects gave their written consent. The study was approved by the ethics committee of the University of Tokyo (#1364).

Off-line, scalp EEG recordings were computed for intracortical source localizations by applying LORETA software. The manually selected epochs were firstly digitally filtered via Fourier Transformation into the seven independent frequency bands which is determined by factorial analyses: Delta (1.5-6 Hz), Theta (6.5-8 Hz), Alpha-1 (8.5-10 Hz), Alpha-2 (10.5-12 Hz), Beta-1 (12.5-18 Hz), Beta-2 (18.5-21 Hz), Beta-3 (21.5-30 Hz) and Gamma (35-44 Hz). And 3-dimensional electric neuronal distributions were linearly calculated by solving the inverse problem by finding maximal smoothness of all solutions. It means that LORETA assumes equivalent generator strength among neighboring voxels. And it represents electrical activities as power of current density. These generators have no restriction for number of dipoles, locations or orientations within the brain. It applies a three-shell spherical head model (scalp, skull, and brain compartments). The brain compartment is restricted to the cortical gray matter, co-registered to the Talairach probability brain atlas and digitized Montreal Neurological Institute MRI template. The solution space is sampled at 7 mm resolution, resulting in a total of 2394 voxels.

LORETA functional images were computed for each subject, separately in each of the 8 frequency bands. The LORETA functional images were scaled to unit average total power, i.e. the average of the power values over all voxels was scaled to unity (for each given subject and frequency band separately). Such a scaling procedure, commonly used in fMRI and PET imaging, has the effect of decreasing non-physiological sources of variance. The differences in brain electric activity between groups were assessed by exceedence proportion tests performed on LORETA images of t-statistics. These voxels were attributed to the corresponding Brodmann Areas (BAs), based on their MNI coordinates.

Comparing resting between meditators and controls, only the delta frequency band revealed significant differences in the exceedence proportion tests ($p<0.05$, corrected for multiple testing). Delta activity is known to correspond with functional inhibition. In meditators, parts of prefrontal cortex (BA 9, 10, 11, 44, 45, 46 & 47, preferably right lateralized) and anterior cingulate cortex (BA 32) showed inhibition (stronger delta activity), whereas motor, somatosensory (BA 4, 6 & 7) and visual association cortices (BA 18 & 19), left superior temporal gyrus (BA 22), left precuneus (BA 31), left temporo-parietal junction (BA 22, 39 & 40) and bilateral fusiform gyrus (BA 37), extending on the right to the parahippocampal gyrus (BA 30) showed stronger activation (less delta activity) compared to controls.

Thus, during resting, those brain areas involved in reflection about current experiences (BA 10), attending to subjective emotions (BA 32), emotion regulation (suppression of sadness: BA 11; reappraisal of sad film excerpts: BA 9, 10, 11, 32 & 47), anticipation (BA 11), expectation (BA 11), semantic searching and decision making (BA 32, 9 & 47) and analogical reasoning (BA 11) were all inhibited in meditators as compared to controls. This inhibition of appraisal systems in the brain is in line with a detachment from experience, defined by an attenuation of analysis, judgment and expectation, implying a lesser degree of processing of ongoing experience. Interestingly, in normal subjects, increased delta and theta EEG in the right but not left prefrontal cortex (BA 8, 9, 10 & 46) during pre-experimental resting correlated with greater propensity for later decreased cognitive control measured as risk-taking. This supports our conclusion that increased delta in the same areas indicates increased detachment in the meditators.

The areas with stronger activity (reduced delta activity) in meditators mostly comprised the unimodal sensory association cortices and the multimodal temporo-parietal junction and the secondary motor cortex, all part of a network known to be involved in the detection of changes in the sensory environment. In particular, the temporo-parietal junction has been related to the integration of multimodal sensory information about the own body and the body in space. The precuneus is an important part of the default mode network and is associated with monitoring the external world. Thus, the meditators keep those areas activated during resting that are involved in the detection and integration of internal and external sensory information: this suggests that they stay more aware of their internal and external sensory environment than controls.

In search for evidence of an effect of continued meditation practice, the hypotheses were supported by the results of LORETA functional tomography, suggesting a training effect of long-term meditation practice leading to a trait change in non-meditating states. The appraisal systems of the meditators were inhibited and the brain areas involved in the detection and integration of internal and external sensory information showed increased activation.

Two further points should be noted: Firstly, resting is not the same for meditators and non-meditators, because meditators often report an inability for non-meditative resting. After years of practice it apparently becomes quite impossible for them not to meditate. It has been proposed earlier that a lack of differences between meditation and resting in meditators could be due to this inability for ‘normal’ resting. The differences of resting state characteristics between meditators and non-meditators should be clarified by ratings of their subjective experiences in future studies. In which way this quasi-meditation resting state in meditators differs from actively engaged meditation states is another issue to be addressed in future studies. As discussed above, the observed EEG effects of long-term meditation when interpreted as possibly resulting from the trait change could well account for the meditators' inability for ‘normal’ resting. The observations give additional support to neuroplasticity effects in meditation in a growing body of findings as reviewed in the introduction. A second point that warrants caution in the interpretation of the observed differences is the possibility of trait differences between subject groups. Only a longitudinal study starting before the uptake of meditation practice could shed light on this issue.

In sum, the findings of differing brain-electric activation patterns during no-task eyes-closed resting between Qigong practitioners and normal controls reflect the subjective reports of experienced meditators of an acquired increased awareness and greater detachment from ongoing experience during non-meditation times in everyday life, suggesting a training effect of continued meditation practice.