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ORIGINAL PAPER

Meditators and Non-Meditators: EEG Source Imaging During Resting

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Abstract Many meditation exercises aim at increased awareness of ongoing experiences through sustained attention and at detachment, i.e., non-engaging observation of these ongoing experiences by the intent not to analyze, judge or expect anything. Long-term meditation practice is believed to generalize the ability of increased awareness and greater detachment into everyday life. We hypothesized that neuroplasticity effects of meditation (correlates of increased awareness and detachment) would be detectable in a no-task resting state. EEG recorded during resting was compared between Qigong meditators and controls. Using LORETA (low resolution electromagnetic tomography) to compute the intracerebral source locations, differences in brain activations between groups were found in the inhibitory delta EEG frequency band. In the meditators, appraisal systems were inhibited, while brain areas involved in the detection and integration of internal and external sensory information showed increased activation. This suggests that neuroplasticity effects of long-term meditation practice, subjectively described as increased awareness and greater detachment, are carried over into non-meditating states.

Keywords Meditation · Qigong · LORETA · Plasticity · EEG localization

Introduction

Meditators claim that continued meditation practice leads to a changed state of mind in everyday life. 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 (Takahashi et al. 2005). The meditation state itself is characterized by a detached observation of ongoing experience, exercised through the intent not to analyze, not to judge and not to expect anything (Maupin 1969; Cardoso et al. 2004). This reduced reactivity to and reduced engagement in observed experiences will be referred to as 'detachment' in this paper.

Many 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. Lutz et al. (2008) distinguished focused attention meditation and open monitoring meditation. 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. Similarly, Newberg and Iversen (2003) distinguished

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meditation exercices that focus attention on one object and those that have no special instruction other than to attempt the clearing of all thoughts from attention. Often focused attention meditation is done prior to open monitoring meditation to calm the mind and reduce the amount of thoughts.

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. Deikman (1963) already proposed a reduction in habitual cognition due to meditation. He described it as a "partial deautomatization of the psychic structures that organize and interpret perceptual stimuli" (p. 329).

The question arises whether physiological neuroplasticity effects of long-term meditation practice can be found in meditators during no-task resting. Evidence for such effects is accumulating. Lazar et al. (2005) reported increased cortical thickness in Buddhist Insight meditation practitioners in prefrontal cortex and right anterior insula, brain areas involved in attention, interoception, and sensory processing. In a longitudinal study, Slagter et al. (2007) found a reduced attentional-blink deficit after a 3-month period of intensive Vipassana meditation. Newberg et al. (2001) reported regional cerebral blood flow (rCBF) findings concerning a thalamic laterality index difference between Tibetan Buddhist meditators and controls at rest, with meditators showing relative higher rCBF right than controls. Practitioners of Transcendental Meditation showed a slowing of EEG (more theta power) during eyes-closed resting compared to a control group with no meditation experience (Tebecis 1975). Sahaja Yoga meditators showed under eyes-closed resting increased theta and alpha activity and lack of parieto-temporal asymmetry compared to controls (Aftanas and Golosheykin 2005). Lutz et al. (2004) described greater relative gamma power at medial fronto-parietal electrodes in long-term Buddhist practitioners compared to controls in baseline EEG before meditation. Wenk-Sormaz (2005) reported reduced habitual responding in non-meditators after attending to breath for 20 min. It was concluded that meditation leads to a higher flexibility to respond non-habitually, which would support Deikman's suggestion of deautomatization of response. Since the Stroop task was performed before and immediately after a 20-min period of meditation (in non-meditators), it is still an open question, whether long-term experience produces lasting effects of the kind reported by Wenk-Sormaz. Increases in relative left-sided anterior activation of the brain after an 8-week mindfulness meditation program have been reported by Davidson et al. (2003). A group of Zen meditators showed increased delta activity mainly in the medial prefrontal cortex during resting compared to controls (Faber et al. 2008); this was interpreted as an inhibition of the medial prefrontal cortex resulting in a reduction of emotional and cognitive engagement, described by the Zen meditators as detachment.

In search for plasticity effects of long-term meditation practice, we investigated the EEG during task-free resting in a group of experienced Qigong practitioners. In general, the exercises of Qigong can be seen as a practice of self-regulation. The regulation includes body (relaxation, posture, breathing) and mind (thinking, emotion) (Pan et al. 1994). Meditation exercises used daily by our group of Qigong meditators comprise both focused attention meditations (breath counting, and Qigong, i.e., slow breath-synchronized arm movements) and open monitoring meditation (thinking of nothing).

Considering the reviewed reports of various affected brain regions, we used LORETA functional tomography (low resolution electromagnetic tomography, Pascual-Marqui et al. 1994, 1999, 2002) 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 (often resulting in erroneous conclusions), but computes 3-dimensional intracerebral distributions of source strength from the head surface-recorded multichannel EEG data.

By probing for differences in the task-free, eyes-closed resting condition between meditators and controls, we expected to find physiological evidence for the described detachment in the form of inhibited appraisal systems in the brain of meditators. As Qigong practitioners exercise open awareness during meditation, we also expected to find neurophysiological evidence of increased awareness of themselves and their surround in task-free resting compared to controls.

These hypotheses were supported by the present results, suggesting that mechanisms of neuroplasticity reflect the effects of long-term meditation practice in non-meditating states. Noteworthy is the finding that the observed differences concerned the EEG delta frequency band that represents inhibiting functions.

Materials and Methods

Subjects

For this study, 10 Qigong meditators and 10 normal controls were recruited. Multichannel EEG was recorded from all subjects. The EEG of one meditator was removed from the data pool, because he reported a heavy headache during the recording. The EEG of another meditator and one control had to be discarded due to technical problems. Data analysis was finally carried out on the EEGs of a group of eight Qigong meditators (mean age: 41.5 years, SD = 10.4, range: 30–56, three males) and a group of nine normal controls (mean age: 37.1 years, SD = 5.9, range: 25–43, three males); the age difference was not significant ($P = .30$). All subjects were self-declared right-handed. The meditators had an average meditation experience of 11.5 years (SD = 8.8, range: 3–30, meditating for about 1 h each day), whereas the controls had no experience in meditation. The meditators were members of the Qigong group 'meimen' in Taipei, Taiwan. They volunteered to participate in the present study following an invitation by the Department of Stress Science and Psychosomatic Medicine, School of Medicine at The University of Tokyo. The control subjects were recruited at the Department of Health Science and Social Welfare of the Waseda University in Tokyo. The education level of the two groups was similar: high school (Qigong: $N = 2/8$; controls: $N = 1/9$); university (Qigong: $N = 6/8$, controls: $N = 8/9$). 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) and thus conforms to the ethical standards laid down in the 1964 Declaration of Helsinki.

Qigong Meditation Exercises

Our group of Qigong practitioners daily engages in three different meditation exercices which they describe as follows: During "Breath Counting" meditation, they count their breaths repeatedly from 1 up to 10 or until the moment when they experience an intruding thought. Whenever that happens, they immediately start again at one. The practitioners try to focus on the physical experience of their breathing, and mentally focus on the numbers. "Breath Counting" can be considered a focused attention meditation. During "Thinking of Nothing" meditation, the practitioners focus on trying not to think of anything or to feel anything—physically, to let their body relax, and mentally, to not get attached to thoughts and perceptions, with the goal to "dissolve into emptiness". This can be considered an open monitoring meditation. During the practice of "Qigong" meditation, the practitioners move their arms in synchrony with their breathing, at a very slow rate (down to about two per minute), focusing on the flow of Qi (i.e., energy) and thinking of nothing. This can basically be considered a focused attention meditation. A byproduct of this meditation is the reduction of spontaneous thoughts; this is true for "Breath Counting" as well. Both meditations lead to an emptying of the mind with a more and more effortless counting of the breath or moving of the arms in a slow, breath-synchronized way. "Breath Counting" and "Qigong" both might better be seen on the continuum from focused attention meditation to open monitoring meditation, similar to many other meditation exercises (Cahn and Polich 2006).

Recording Conditions

The EEG of all subjects was recorded during an "initial resting" condition that lasted 4 min: 20 s eyes open, 40 s eyes-closed, repeated four times. After this condition, both groups were recorded under some additional conditions. For the present report, only the "initial resting" condition was analyzed and compared between meditators and controls.

EEG Recording

Nineteen EEG electrodes were applied at the positions Fp1/2, F3/4, F7/8, Fz, T3/4, C3/4, Cz, T5/6, P3/4, Pz, O1/2 of the International 10/20 System (Jasper 1958) using a Neuroscan electrode cap. All impedances were kept below 5 kΩ. The EEG recording was done with a portable 24-channel EEG acquisition system (TEAC AP1000). The left ear was used as a reference. The EOG was recorded using two electrodes at the left outer canthus and under the right eye. The EMG was recorded from an electrode placed on the neck. Using a highpass filter of 0.05 Hz and a lowpass filter of 100 Hz, the EEG data were digitized at 200 samples/s/channel.

The EEG of the meditators was recorded during their short visit to Tokyo. Due to their tight schedule and the great distance to the university recording room, the recordings were done in a hotel room. All electrical devices (air conditioner, refrigerator, TV, lights) were unplugged to avoid electrical artifacts.

The EEG of the controls was recorded in a room of the Psychology Laboratory at Waseda University in Tokyo with the exact same technical equipment.

Data Conditioning

Off-line, the EEG data were carefully reviewed manually for eye-, muscle- and movement-artifacts. All artifact-free two-second epochs were selected for further analysis. An average of 66.2 s (SD = 34.6) of EEG data were available per subject for the "initial resting" condition.

All 2-second EEG data-epochs were recomputed to average reference (spatial DC rejection).

Data Analysis

To test differences between meditators and non-meditators in the "initial resting" condition, the original LORETA software (low resolution electromagnetic tomography; Pascual-Marqui et al. 1994, 1999, 2002) was used to compute 3-dimensional intracortical localizations of the brain electric activity measured on the scalp. LORETA solves the "inverse problem" by finding the smoothest of all solutions with no a priori assumptions about the number, location, or orientation of the generators. LORETA uses a three-shell spherical head model including scalp, skull, and brain compartments, registered to the digitized Montreal Neurological Institute (MNI305) MRI template (Talairach and Tournoux 1988). The solution space corresponds to cortical gray matter sampled at 7-mm resolution, resulting in a total of 2394 voxels.

The EEG was analyzed with LORETA in the seven independent frequency bands as determined by factorial analyses (Kubicki et al. 1979; Lopes da Silva 1981; Coppola and Herrmann 1987): 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), and Beta-3 (21.5–30 Hz). The Gamma frequency band has been reported to be of interest in meditation research (Lehmann et al. 2001; Lutz et al. 2004). Thus, an additional Gamma frequency band (35–44 Hz) was included in the analysis. The LORETA frequency band analysis was done after Frei et al. (2001). LORETA functional images were computed for each subject and condition separately in each of the eight frequency bands. The LORETA functional images were scaled to unit average total power, i.e., the average of the power values over all voxels (for each given subject and frequency band separately) was scaled to unity. Such a scaling procedure, commonly used in fMRI and PET imaging (Kiebel and Holmes 2004), 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, corrected for multiple testing (Friston et al. 1990, 1991). Significant voxels were attributed to the corresponding Brodmann areas (BAs), based on their MNI coordinates.

Results

Comparing "initial resting" between meditators and controls, only the delta frequency band revealed significant differences in the exceedence proportion tests ($P < 0.05$, *t*-threshold = 3.6). Table 1 contains *P*-values and *t*-thresholds for all frequency bands. Meditators had significantly stronger delta activity in prefrontal cortex (BAs 9, 10, 11, 44, 45, 46, and 47) and anterior cingulate cortex (BA 32). Meditators had significantly weaker delta activity in motor and somatosensory association cortices (BAs 4, 6, and 7), visual association cortex (BAs 18 and 19), left temporo-parietal junction (BA 22, 39, 40), left precuneus (BA 31), and bilateral fusiform gyrus and right parahippocampal gyrus (BA 30). Figure 1 shows the results in a series of transverse

Table 1 *P*-values and *t*-thresholds of the frequency band-wise exceedence proportion tests comparing "initial resting" data between meditators and controls

Frequency band	*P*-value	*t*-threshold
Delta	.05	3.60
Theta	.24	2.70
Alpha1	.11	3.00
Alpha2	.21	2.95
Beta1	.56	0.79
Beta2	.54	0.42
Beta3	.82	0.10
Gamma	.23	0.94

Listed are the lowest *P*-values down to the accepted significance level of $P = .05$

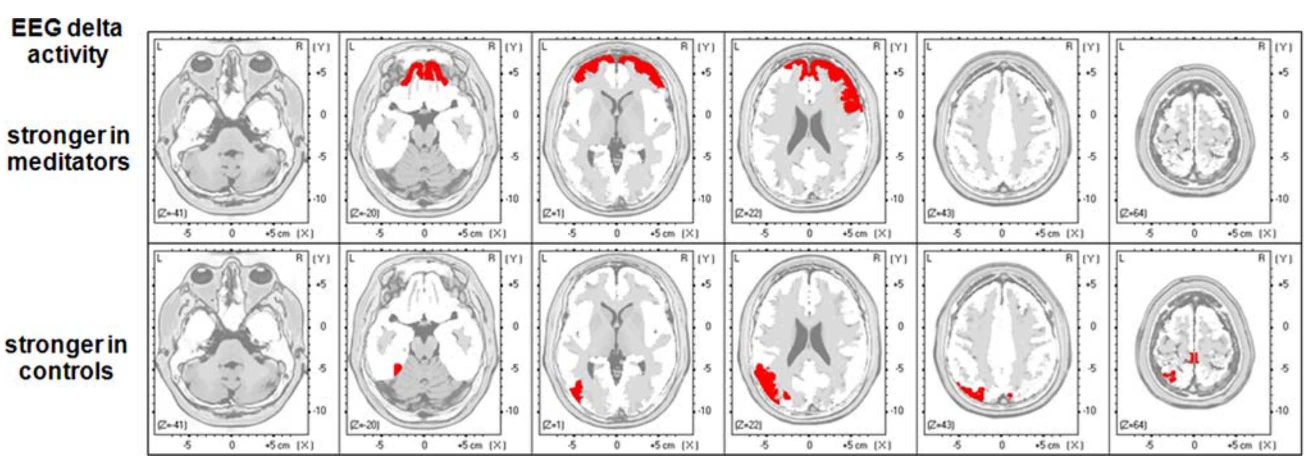

Fig. 1 LORETA functional tomography slices of EEG delta frequency band differences of source strength during "initial resting" between meditators and controls; shown are six transverse slices in steps of 21 mm from the most inferior level ($z = -41$) to the most superior level ($z = 64$) with significant voxels (at $P < 0.05$, corrected for multiple testing) marked in red. Coordinates are given in millimeters (Montreal Neurological Institute atlas), with the origin at the anterior commissure

Table 2 LORETA delta frequency band results of the comparison of "initial resting" between meditators and controls

Stronger delta activity in		Meditators		Controls	
Region	BA	LH	RH	LH	RH
Primary motor cortex	4	–	–	2	2
Secondary motor cortex	6	–	–	2	2
Somatosens. assoc.	7	–	–	10	2
Dorsolat. PFC	9	2	6	–	–
Medial PFC	10	46	68	–	–
Orbitifrontal	11	27	31	–	–
Visual association V2	18	–	–	4	2
Visual association V3	19	–	–	34	9
Superior temporal gyrus	22	–	–	3	–
Parahippocampal gyrus	30	–	–	–	1
Precuneus	31	–	–	2	–
Anterior cingulate	32	2	2	–	–
Fusiform gyrus	37	–	–	6	1
Wernicke	39	–	–	30	–
Wernicke	40	–	–	14	–
Lateral PFC	44	–	8	–	–
Dorsolat. PFC	45	–	11	–	–
Dorsolat. PFC	46	4	17	–	–
Ventrolat. PFC	47	2	3	–	–

Anatomy regions (*PFC* prefrontal cortex) with voxels at $P < 0.05$ (exceedence proportion test) and number of significant voxels in left (LH) and right hemisphere (RH)

LORETA slices. Table 2 lists the number of significant voxels for the involved BAs.

Discussion

In search for evidence of a neuroplasticity effect of continued meditation practice, EEG during no-task eyes-closed resting was compared between a group of Qigong meditators and a meditation-naive control group. We hypothesized physiological evidence of increased awareness and greater detachment in meditators. Both hypotheses were confirmed by the results of LORETA functional tomography. Significant differences between groups were found only in the inhibitory (Niedermeyer and Lopes da Silva 1993) delta EEG frequency band. Parts of prefrontal cortex and anterior cingulate cortex showed inhibition (stronger delta activity) in meditators, whereas motor, somatosensory and visual association cortices, left superior temporal gyrus, left precuneus, left temporo-parietal junction, and bilateral fusiform gyrus (extending on the right to the parahippocampal gyrus) showed stronger activation (less delta activity) compared to controls.

We appreciate that clinical tradition divides delta from theta frequencies at 3–4 Hz (e.g., Niedermeyer and Lopes da Silva 1993), contrary to the factor analysis-based border at 6 Hz utilized in this study (Kubicki et al. 1979; Lopes da Silva 1981; Coppola and Herrmann 1987). However, when we reanalyzed the data dividing the 1.5–6 Hz delta band into a low and high part (1.5–3.5 and 4–6 Hz, respectively), the low part showed clearly stronger results; for the $P = .05$ level, the low frequency sub-band fulfilled much higher statistical demands (t[threshold] = 4.0) than the high frequency sub-band (t[threshold] = 1.9). Hence, the present delta band results are predominantly driven by the lower delta frequencies.

Thus, during "initial resting", those brain areas involved in reflection about current experiences (BA 10; Lieberman 2007), attending to subjective emotions (BA 32; Lane et al. 1997), emotion regulation (suppression of sadness: BA 11: Lévesque et al. 2003, reappraisal of sad film excerpts: BA 9, 10, 11, 32, 47: Lévesque et al. 2004), anticipation (BA 11; Ernst et al. 2004), expectation (BA 11; Kufahl et al. 2008), semantic searching and decision making (BA 32, 9, 47; Gigi et al. 2007), and analogical reasoning (BA 11; Luo et al. 2003) 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 (Gianotti et al. 2009). 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 (Downar et al. 2000). 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 (Blanke and Arzy 2005). The precuneus is an important part of the default mode network (Raichle et al. 2001) and is associated with monitoring the external world (Corbetta et al. 2000; Gusnard et al. 2001). 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.

As hypothesized, the observed brain activation patterns reflect the subjective reports of the meditators: even while not meditating they stay more aware of themselves and their surround than controls, and at the same time stay more detached, doing less analyzing, judging, and expecting. Open awareness and a detached attitude are the main defining features of open monitoring meditation (Lutz et al. 2008). Our finding of brain electric correlates of increased awareness and detachment in the resting state of experienced meditators compared to controls suggests that the meditators' resting state is to some extent similar to an open monitoring meditation. Our Qigong practitioners regularly exercise both focused attention and open monitoring abilities, but, since the eyes-closed resting state that we analyzed here was completely task-free, no special focused attention abilities were needed. It appears plausible that we only find brain electric correlates of what is considered the main ingredient of open monitoring meditation, namely increased awareness and greater detachment.

We observed significant results solely in the delta frequency band, whereas past meditation research from early on mainly reported findings in the theta, alpha, beta, and gamma frequency bands (i.e., Das and Gastaut 1957; Banquet 1973; Hebert and Lehmann 1977; Lehmann et al. 2001; Lutz et al. 2004; for an overview see Cahn and Polich 2006). The observed neural plasticity that assumedly carries meditation effects into resting was addressed by several authors (Aftanas and Golosheykin 2005; Lutz et al. 2004; Tebecis 1975) who studied Yoga, Buddhist, and Transcendental Meditation practitioners. The reported EEG results differed between the studied meditation traditions, and differed from our present findings in Qigong. However, our earlier results in the delta frequency band of Zen meditators (Faber et al. 2008) are in line with the present findings. Some differences between findings might be accounted for by different methodologies, in particular by the source modeling technique that we used, but the question remains whether the exercises of the different meditation traditions may not produce different brain electric changes.

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: Itoh et al. (1996) noted a lack of spectral differences in Qigong meditators between meditation and resting and attributed this to the inability of the meditators to sustain a non-meditative resting state. 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, our observed EEG effects of long-term meditation when interpreted as resulting from neuroplasticity could well account for the meditators' inability for 'normal' resting. Our 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.

Conclusion

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

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