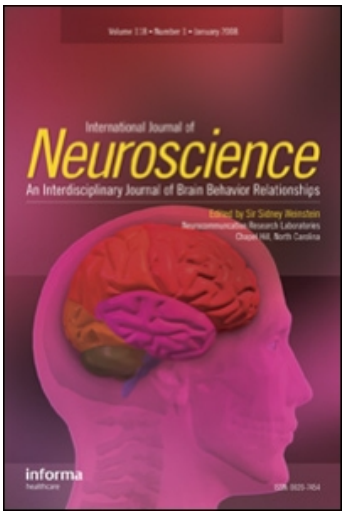

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A Forty-Five Year Follow-Up EEG Study of Qigong Practice

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A FORTY-FIVE YEAR FOLLOW-UP EEG STUDY OF QIGONG PRACTICE

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Afollow-up EEG study was conducted on a subject with 50 years of experiences in Qigong. Resting EEG at present showed frontally dominant alpha-1 as compared to occipitally dominant alpha-2 described in 1962. During the Qigong practice alph-1 enhanced quickly and became far more prominent than 50 years ago. Compared with baseline, these activities remained to be higher at rest after the Qigong practice. These results suggest that extended practice in meditation may change the EEG pattern and its underlying neurophysiology. It remains to be explored as to what biological significance and clinical relevance do these physiological changes might mean.

Keywords alpha-1, anterior frontal midline, EEG, meditation

Cahn and Polich (2006) have recently published a comprehensive review of electroencephalographic (EEG) studies of meditation since 1957. Increase in theta and alpha activities together with an overall slowing arising during practice of most forms of meditations are generally observed as short-term (state) changes in EEG. Changes in beta, gamma, and even delta bands during meditation practice have also been reported in a few studies using frequency spectrum analysis. In contrast, slower baseline EEG frequency and higher theta and alpha power at rest found in experienced meditators as compared with controls are considered to be long-term (trait) effect of meditation practice. However, the bias of self-selection could not be ruled out from these studies. To date no longitudinal study has ever evidenced the state changes in EEG during meditation practice do eventually lead to trait changes in the same subject.

Specific EEG changes during Qigong (QG) practice in a group of 12 subjects were documented in our earlier paper (Qin and Qu, 1962 in Chinese). Ms, the very subject with 5 year experiences of meditation whose EEG segments had been cited in that paper, was available for the present follow-up EEG study complemented with quantitative analysis. The main objective was to investigate whether there would be any long-term changes in EEG at rest and during meditation following forty-five more years of meditation practice.

METHODS

Subjects

The study subject (Ms) was a 76-year-old Chinese male, who had started regular Qigong exercise, a form of meditation commonly practiced in China, since late nineteen-fifties. The meditative technique involved focusing attention on breathing. Two Caucasian males (Ma1, Ma2) aged 76 and 72 years each, with 26 and 25 years of experience of meditation respectively, served as

meditator controls. The technique they used was to silently repeat a specifically chosen "mantra" to achieve a state of restful awareness. All three of them were amateur meditators. The non-meditator control group consisted of six Chinese septuagenarians (C1–6), 4 males and 2 females, who had no experiences in meditation or other like practices. All the subjects were right-handed, physically and mentally healthy, and did not use alcohol or medication that might affect their brain functions. Written informed consent was obtained from each subject.

Procedure. The participants were seated in a comfortable dental chair within a sound-proof and electrically shielded dark chamber, with eyes closed. The meditators were verbally instructed to begin and end the meditation. Five to ten minutes of eyes-closed rest EEG was recorded before and after a period of meditation for 30 minutes or longer. The subject was asked to make a sign on attaining the meditative state, i.e., a state of profound serenity, thoughtless awareness. For the non-meditator group, 20–30 minutes rest EEG with eyes closed was recorded for each subject.

EEG Recording Details. EEG was recorded from nineteen electrodes (F_{p1}, F_{p2}, F_7, F_3, F_Z, F_4, F_8, C_3, C_Z, C_4, T_3, T_4, P_3, P_Z, P_4, T_5, T_6, O_1, and O_2) with the Electro-Cap according to the 10–20 montage system referenced to linked earlobes. Impedance for each channel was kept at 5 kΩ. EEG signals were amplified and digitized using the Cadwell Easy II system with a band-pass filter set between 0.16 Hz and 70 Hz. Sampling rate was 200 point/sec through a 16-bit A/D converter. Digitized data were stored on a hard disk of an interfaced PC.

EEG Analysis Details. The raw data were inspected visually for the amplitude, spatial and temporal characteristics of the main frequencies, presence or absence of general or focal discharges or slowing. Significant ($> 3^\circ$ arc) eye movements or any other type of apparent artifacts were eliminated. The data were then analyzed quantitatively for each testing condition. One minute artifact-free epoch within the first four minutes of each condition was applied for a mean FFT calculation with 4,096 points per window to produce a power spectrum with 0.05 Hz frequency resolution. Power density presented was an integrated value across a bandwidth of 1 Hz around the peak frequency of interest. Similar calculation was also used to quantify the broad bands power densities in delta, theta, alpha, and beta. Alpha-1 (6.5–8.5 Hz) and alpha-2 (8.5–12.5 Hz) were identified to describe the unique effect of meditation on alpha EEG. These alpha activities were validated by showing the inhibitory

response to eyes opening. Mapping display was plotted using a squared 4 nearest point interpolation in a 21-point grid. Coherence was calculated for four coherence pairs at the peak alpha frequency: F_3- F_4, P_3- P_4, F_3- P_3, and F_4- P_4. Coherence function between signal $x(f)$ and signal $y(f)$ is defined as a normalized cross-spectral function $C_{xy}(f)$ with its coefficient varying between 0 and 1.

RESULTS

Routine EEG. Ms' raw EEG in the resting state (Figure 1) showed diffuse alpha activities at 8.5–9 Hz. Bilaterally synchronized low amplitude alpha bursts were seen in the occipital regions; some of them last for as long as 4 seconds. Intermittent slower activities at 8-Hz stood out in the anterior medial fronto-central regions every two to four seconds, with its maximum amplitude, located at F_{p1}, F_{p2}, one and a half times as high as the concomitant occipital alpha activities. Both frontal and occipital activities showed desynchronizing response to eyes opening.

Ms' EEG during meditative state (Figure 2) was apparently different from that at premeditation rest. The alpha activities were markedly enhanced in amplitude and duration in the oscillation envelope. Bilaterally synchronized, sharp contoured, 8- Hz alpha activities stood out in the anterior fronto-central midline region every one to two seconds, propagating to parieto-occipital areas, with its maximum amplitude located at F_Z.

The same phenomena were observed in the other two experienced meditators. There was progressive enhancement in the low frequency alpha activities in the anterior frontal midline during the entire period of meditation practice. All of the six control subjects showed stable parieto-occipital dominant alpha around 10-Hz.

Quantitative EEG

Frontal dominant alpha-1. The dominant rhythm of Ms' rest EEG has a peak frequency of 8.1-Hz located primarily at anterior frontal midline. Fig 3 displays sharply contrasted EEG topographic differences of alpha-1 and alpha-2 bands between Ms and C1 at eyes-closed rest. Ms had an anterior frontal midline dominant alpha-1 while C1 showed a typical occipital dominant alpha-2.

Frontal alpha, theta, beta power enhancement. The dynamic changes in Ms' qEEG mapping of delta, theta, alpha, and beta bands at different time

Figure 1. Routine EEG of Ms at rest. Record shows dominant and highly synchronized alpha activity across the entire scalp.

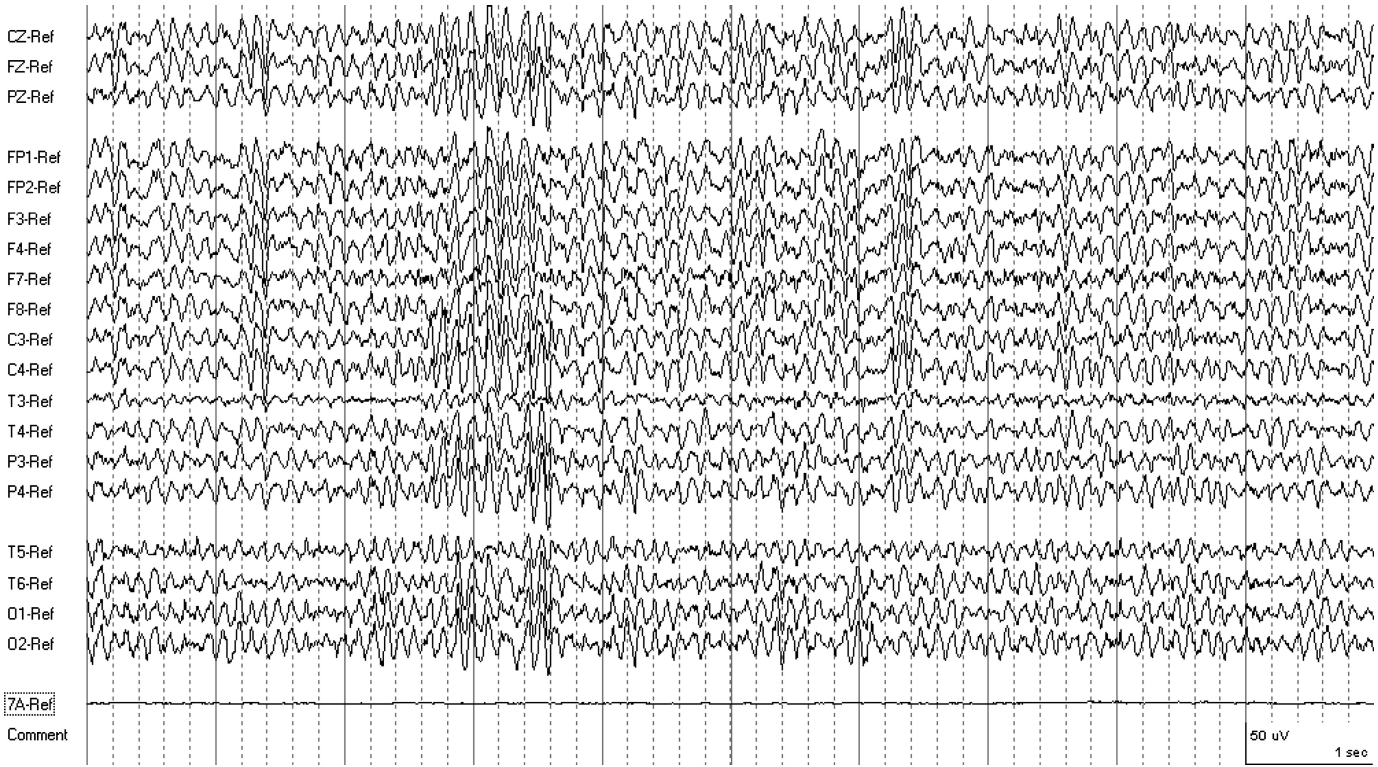

Figure 2. Routine EEG of Ms during Qigong practice. Record shows much enhanced alpha activity, especially in the frontal region.

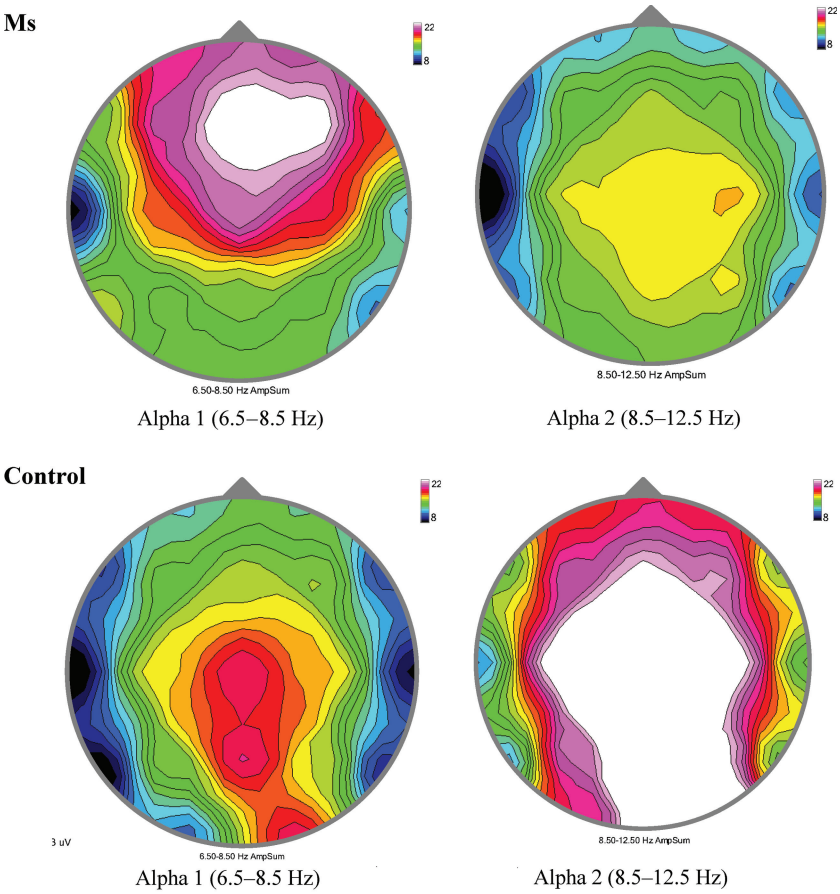

Figure 3. Topographic comparison of alpha EEG between Ms and nonmeditator control. Alpha-1 is an integrated power density calculated between 6.5 Hz and 8.5 Hz and alpha-2, between 8.5 Hz and 12.5 Hz. Ms' EEG was dominated with midline frontal alpha-1 dominance as compared with parietal occipital alpha-2 dominance in the control.

points from premeditation state across the entire period of meditation practice to the postmeditation rest are displayed in Figure 4.

The alpha EEG was the dominant component in the power spectrum throughout the whole session, with its maximum around the anterior frontal midline. Once QG was started, the dominant alpha-1 activities increased immediately from 3.1 μV^2 at premeditation baseline to 4.8 μV^2 (55% increment) within one minute. The power enhancing effect built up quickly

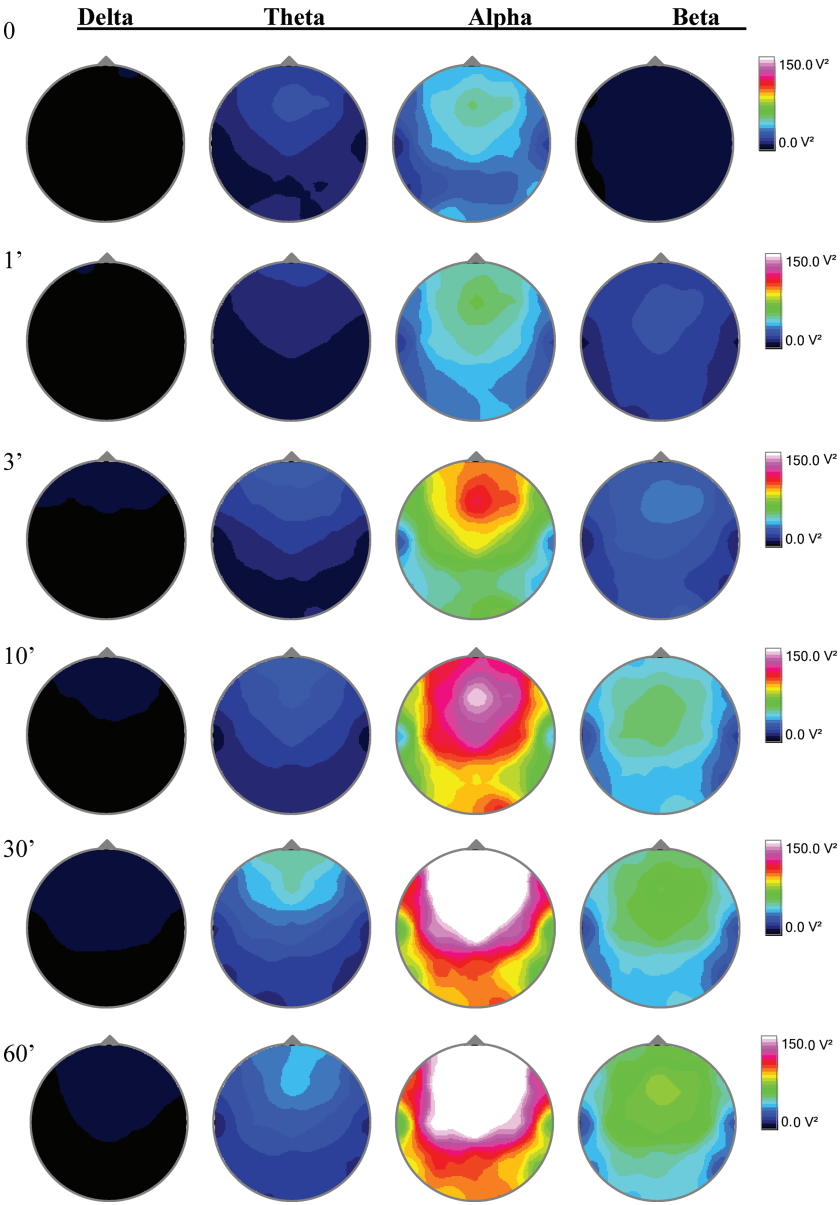

Figure 4. Topographic display of dynamic quantitative EEG changes during Qigong practice. Each map is calculated using the first minute EEG data at each stage. Delta is defined as 0.5–4.0 Hz, theta, 4.0–6.5 Hz, alpha, 6.5–12.5 Hz, and beta, 12.5–30.0 Hz. As the practice progress, EEG power increases in every frequency band except for delta. Alpha power has the most robust change during the practice and effect remains after the practice is stopped.

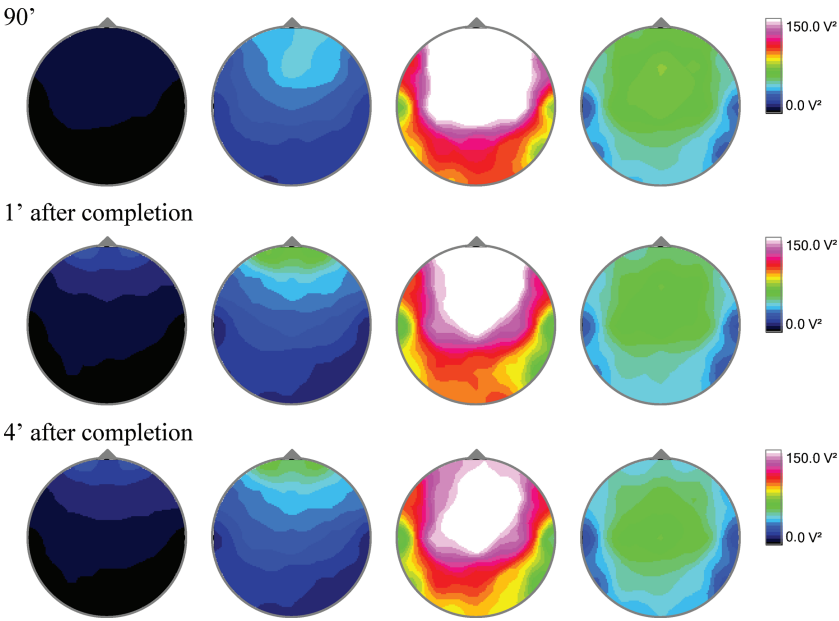

Figure 4. (*Continued.*)

and propagated bilaterally and backward over the period of exercise. When the subject signaled to denote his experiencing of meditative state at approximately 20 minutes into the exercise, the alpha-1 oscillations already covered the entire skull surface, reaching a plateau around 27.5 μV^2 (787% increment) at anterior frontal midline. The much enhanced anterior frontal midline low frequency alpha remained 21.8 μV^2 (603% increment) in power density at postmeditation rest (Figure 4).

The development of theta and beta bands followed the same pattern of the alpha activity in a lesser degree. Averaged anterior frontal midline theta power at baseline rest state was 1.8 μV^2 and beta, 0.6 μV^2. Thirty minutes after the start of meditation, both bands reached their maximal power enhancement at 2.7 μV^2 (50% increment) and 4.1 μV^2 (583% increment). They remained high at postmeditation rest. The delta band activities remained at extremely low level during the entire session (< 0.4 μV^2; Figure 4).

In contrast, the EEG power remained stable in nonmeditator controls during the entire recording period.

Increase in Alpha Coherence. During the meditation practice, the fronto-parietal intrahemispheric coherence at 8.1-Hz for the pairs of F_3-P_3 and F_4-P_4

increased markedly from 0.5 at premeditation rest to 0.8 during meditative state, and remained 0.7 after the practicing was stopped. As for the interhemispheric coherence, P_3-P_4 increased from 0.7 to 0.8 during meditative state, F_3-F_4 was already approaching maximal at rest and had little changes during meditation.

Ma1 but not Ma2 had the similar increase of peak alpha intrahemispheric coherence. The nonmeditator controls did not show changes of alpha coherence during EEG examination.

DISCUSSION

The dominant frontal alpha-1 EEG during eyes-closed rest is the most robust feature in Ms' and the other two meditators' EEG in the present study. Ms' resting EEG recorded 45 years ago clearly showed an occipital dominance of alpha rhythm at 10-Hz (Qin and Qu, 1962). In the present study, however, the dominant alpha activity has yielded to a frontal 8.1-Hz oscillation. This frontal dominant alpha-1 EEG pattern is observed in all the three long-term meditators but not in any of the 6 control subjects.

The alpha rhythm frequency was usually considered liable to decline in elderly individuals. However, an EEG study in 52 neuropsychiatrically normal septuagenarians found their alpha frequencies to be around 10-Hz with no focal or diffuse slowing (Katz & Horowitz, 1982). Quantitative EEG analysis in 68 carefully selected healthy elderly subjects and 20 young subjects did not find slow waves to increase with age and alpha band EEG power in the normal elderly remained almost unchanged. However intra-hemispheric coherence of all bands was found to decrease almost lineally with advancing age (Koyama, Hirasawa, Okubo, & Karasawa, 1997).

Higher F3- F4 coherence in the 6–12, 15–25 and 35–45 Hz bands was revealed in Transcendental Meditation (TM) groups during meditation as compared with normal controls during rest (Travis, Tecce, Arenander, & Wallace, 2002). Consistent with these findings, Ms' resting F3-F4 coherence at 8.1-Hz was also exceptionally high (0.96). Meanwhile, the longitudinal coherence at F3-P3 and F4-P4 was found to increase from 0.5 at eyes-closed rest to 0.8 during meditation. Similar chages in a lesser degree were also found in other experienced meditators but not in age matched control subjects. Therefore, the marked slowing of the alpha rhythm found in the study subject could not be ascribed to the aging process.

Alpha enhancement and frequency reduction during meditation was also reported by others (Banquet, 1973). Yamamoto, Kitamura, Yamada, Nakashima, and Kuroda (2006) showed that the mean frequency of alpha waves

in 8 TM practitioners decreased from 11.33 Hz before meditation practice to 9.66 Hz during TM, while no change was found in an age-matched control group during a mock meditation. Similar but more robust changes in alpha activities could be found in experienced meditators. Zhang, Li, and He (1988) demonstrated in 10 QG masters with 10–47 years experience that alpha EEG altered from occipitally dominant 10–12 Hz during eyes-closed rest to frontally dominant 8.5-Hz during meditative state. Augmentation of alpha, theta, and beta activities with frequency reduction in alpha rhythm, primarily at the frontal channels, were commonly found in subjects practicing meditation. The question is whether these state dependent electrophysiological changes would eventually become a neurophysiological trait of the meditator.

Stigsby, Bodenberg, and Moth (1981) showed that the EEG mean frequencies of 14 TM subjects at rest were 1-Hz slower than those of age-matched control subjects. Aftanas & Golocheikine (2001) found that the alpha mean frequendy in long-term (3–7 years) Sahaja Yoga meditators was approximately 0.8-Hz lower than unexperienced ($< \frac{1}{2}$ year) meditators of the same age. The authors further demonstrated that Sahaja Yoga meditators with 5–10 years of experience had higher power density than control individuals in the rest theta and alpha-1 frequency bands (Aftanas & Golocheikine, 2005), Lutz, Greischar, Rawlings, Ricard, and Davidson (2004) reported a significant correlation between the length of meditation training and the relative gamma power ($p < 0.02$) in a group of long-term Buddhist practitioners. A longitudinal study of TM effects on frontal interhemispheric broad band coherence revealed a significant linear trend in EEG coherence increase from baseline to the 2, 6, and 12 months posttest recordings during eyes-closed rest (Travis & Arenander, 2006). These findings suggest that EEG frequency, power density, and coherence may be affected by long-term meditation.

It is known that regular active performance of one task over time may lead to functional and anatomical reorganization of the involved structure. For instance, the cortical representation areas of the left hand digits of string players were found larger than controls while the analogous areas of the right hand digits were not different from the controls (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995). Using magnetic resonance imaging, Lazar et al. (2005) demonstrated that the prefrontal cortex and right anterior insular cortex were thicker in Insight meditation participants than age-matched controls, and that the cortical thickness was correlated with years of practice.

It is thus hypothesized that the cumulative effects of meditation practice may induce permanent changes in meditator's background EEG over time. In

our early study, Ms' occipital dominant 10-Hz alpha activity at baseline was found to turn into frontal dominant 8–8.5 Hz alpha acitivities during meditation practice and at postmeditation rest (Qin & Qu, 1962). Following 45 years of further practice, qEEG analysis showed his alpha rhythm at eyes-closed rest to be frontal dominant 8.1-Hz. The other two long-term meditators' rest EEGs also featured the same pattern. These changes appear to be different from age matched controls and therefore likely to be the result of decades-long meditation practice. The fact that their slowed resting alpha oscillations at anterior frontal midline become immediately enhanced on starting meditation practice and remain at postmeditation rest much higher than premeditation baseline also lends support to our contention.

Meditative states have been considered to be periods of drowsiness or a state between wakefulness and drowsiness by some authors (Stigsby et al., 1981). Some subjects might fall asleep during meditation practice, just like others undergoing EEG examination or sitting idly. However, EEG expression of drowsiness is characterized by "alpha dropout", i.e., trains of alpha waves become less and less continuous (Niedermeyer, 2005). And the "anterior slow alpha of drowsiness" recorded in a significant portion of subjects would quickly fragment and give way to a low-voltage pattern of mixed slow and fast frequencies (Broughton & Mullington, 2005). Furthermore, there is a decrease in alpha coherence during sleep (Cantero, Atienza, Salas, & Gomez, 1999). In contrast to drowsiness or sleep, increase in alpha and theta activities and coherence above baseline wakeful resting state are found during meditation (Aftanas & Golocheikine, 2003; Travis & Arenander, 2006). Experienced meditators could keep themselves fully awake during meditation in a state of physical immobility for a length of time impossible for nonmeditators. Ms was able to maintain the highly activated alpha-1 activity virtually unchanged for 30 to 90 minutes long during meditation practice without behaviorally falling dozy. Marked increase in 8.1-Hz alpha coherence was observed during Ms meditation practice and post meditation rest. So meditation practice should rather be considered a form of mental exercise performed during the waking state. The meditative state attained through meditation is not a transitional stage between wakefulness and drowsiness or sleep.

In Ms' EEG segments cited in our 1962 paper, the earliest changes during QG practice was the emergence of 7-Hz theta waves in the frontal region. They soon slowed to 6-Hz and lasted three to nine seconds long, while the alpha activites slowed down to 8-Hz in the frontal region. The 7-Hz theta and 8-Hz alpha activities remained in the frontal region at postmeditation period. In the present study, the similar alpha enhancement became much more robust and

dominant, while the theta enhancement were relatively less impressive during QG practice.

The topographic display of Ms' 8.1-Hz EEG activities during QG practice (Figure 4) looks the same as that of the alpha band mapping for a Qigong master (Figure 1B, Zhang et al., 1988). As compared with Sahaja Yoga meditators (Aftanas & Golocheikine, 2003), Ms' theta and alpha-1 power changes between eyes-closed rest and meditation conditions also had the similar anterior frontal midline dominance. However, the increase in alpha-1 power reached 7.9 times higher than baseline for Ms, as compared to 1.2 times increase for the Sahaja Yoga meditators with 3–7 years experience of practice. A highly accomplished Kundalini yoga meditator with 32 years experience of mediation produced a 5 fold increase in alpha during meditation practice (Arambula, Peper, Kawakami, & Gibney, 2001; Cahn and Polich, 2006). These data suggest categorically that the number of years committed to meditation practice may be reflected in alpha power increase during the practice.

The source of increased frontal and central alpha activity during meditation practice of 8 TM practitioners has been mapped to the medial prefrontal cortex and anterior cingulate cortex using magnetoencephalography and EEG simultaneously together with magnectic resonance imaigng (Yamamoto et al., 2006). These cortical regions were found on MRI to be thicker in Insight meditation subjects than sex/age-matched controls (Lazar et al., 2005). EEG studies on objectless meditation found the ratio of gamma-band activity (25–42 Hz) to slow rhythms (4–13 Hz) was higher over medial frontoparietal electrodes in long-term Buddhist practitioners than healthy controls. And this difference increased sharply during meditation and remained higher in the post-meditation period than the initial baseline (Lutz et al., 2004).

In the present study, we demonstrate that far more brain areas are involved in the process of meditation. During the progress of Ms' practice the 8.1-Hz EEG propergated laterally and posteriorly from the anterior frontal midline until the entire scalp surface was covered with the activity. For the whole length of each meditation session and also time beyond, this enhanced alpha rhythm might have served as a leitmotiv/reverberating "horizontally" in much more cortical areas and possibly "vertically" in those subcortical neural structures that have connections with those cortical areas.

Our study provides the first evidence that long term practice of meditation can modulate the resting EEG by functionally reorganizing cerebral neuronal networks. Corroborating results to the same effect from studies of more long term meditators are needed. In view of the beneficial effects of deep brain stimulation (DBS) in many medically intractable disorders, possibly

due to stimulation-induced modulation of pathological brain electrical activity (McIntyre, Savasta, Kerkerian-Le Goff, & Vitek, 2004; Schiff et al., 2007), meditation practice might be looked upon as an autogenous brain stimulation. It is thus worthwhile to explore meditation's potential therapeutic benefit for medically intractable diseases.

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