Physiological Investigation on EEG Coherency during Yoga Meditation and Qigong Exercise

Tadashi KATO¹ and Kimiko KAWANO²

¹Department of Behavioral Science, College of Liberal Arts, Fairmont State University (WV, USA)
²Institute for Living Body Measurements, International Research Institute (Chiba, Japan)

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Abstract: Inner-brain functional synchronicity was investigated during TM (yoga meditation) and Qigong exercise, along with a control group that listened to a piece of relaxing music. Group 1 consisted of TM practitioners (N=8, 30.38 ± 4.37 y), Group 2 consisted of Qigong practitioners (N=8, 43.00 ± 13.09 y), and Group 3 consisted of healthy university students with no experience in TM or Qigong (N=8, 25.13 ± 3.18 y). Electroencephalograms (EEGs) were measured throughout the three stages of the experiment that consisted of: 1) pre-treatment-rest; 2) treatment; and 3) post-treatment-rest. The hemispheric (C3-C4) as well as frontal-parietal (Fz-Pz) coherences were computed and contrasted. Results demonstrated that TM produced increased coherences in both C3-C4 and Fz-Pz during and after meditation (that is, the treatment) in the TM group, while these coherences increased only after the treatment (Qigong) in the Qigong group. There was no significant change in the control group. These results suggested that TM enhanced the functional correlation in the brain, while Qigong enhanced it only during the rest period after the Qigong, and thereby implying a differential physiological mechanism. Different uses of yoga meditation and Qigong exercise as forms of alternative medicine were suggested as a potential clinical application.

Keywords: electroencephalogram (EEG), coherence, music, yoga meditation, transcendental meditation, TM, Qigong

1. Introduction

There have been many research studies conducted on the brain physiological effects of meditation ¹⁻¹² as well as those of Qigong exercise ¹³⁻¹⁷, both of which are considered as candidates for effective alternative medicine and stress reduction techniques. However, there have not been many comparative studies between meditation and Qigong exercise within the same experimental contexts. The present study investigated the brain physiological contrast between yoga meditation and Qigong exercise through analyses of EEG coherences.

A. Brain Physiological Research on Yoga Meditation

One of the earliest studies on yoga meditation was conducted by Wallace ¹². In his physiological study on the practitioners of transcendental meditation (TM), he discovered an increased power in the EEG alpha frequency band and a decrease in the peak alpha frequency. Banquet ³ reported significantly different powers in EEG alpha and beta activities during TM in comparison to simple resting states. Hebert and Lehmann ⁶ reported increased theta power in frontal lobe during TM while Stigsby et al. ¹⁰ suggested that mean EEG frequency of TM practitioners is slower by an average of 1 Hz compared to normal controls. Moreover, Levine et al. ¹⁰ reported increased hemispheric coherence as well as frontal-occipital coherence. Further, Arambula et al. ² reported increased alpha EEG activity during Kundalini yoga meditation and also increased theta EEG activity immediately following meditation. Lagopoulos et al. ¹⁸ reported significantly increased theta power as well as alpha power during the meditation condition when averaged across all brain regions. Among Sahaja Yoga meditators, Aftanas and Golosheykin ¹ reported increased theta 1 (4-6 Hz), theta-2 (6-8 Hz), and alpha-1 (8-10 Hz) in the closed-eyes condition, and increased theta-2 alpha-1 power in the open-eyes condition. Huang and Lo ⁷ sug-
gested there was increased frontal alpha-1 among meditators, while Cahn and Polich 4) summarized the overall consensus on the theta and alpha activation related to proficient meditation practices based on a meta-analysis. The most recent trend in EEG research on the effects of meditation has started focusing on not only spectral powers but also EEG coherences. For example, Travis et al. 11) suggested not only EEG alpha power but also increased coherencies in the alpha band occurred among TM practitioners.

**B. Brain Physiological Research on Qigong**

There has been increasing numbers of reports on the brain physiological effects of Qigong exercise, ranging from simple reports on results of EEG spectral analyses through EEG coherence analyses in more recent years. As a report on EEG spectral analyses, from a case study, Qin et al. 15) suggested that 50 years of Qigong practice done by a long-term Qigong practitioner had resulted in the shift from the occipitally dominant alpha-2 to the frontally dominant alpha-1. As a report on EEG coherency analyses, Sun 16) reported increased coherency values between frontal and occipital areas, along with increased alpha power at the frontal region. Moreover, Chan et al. 13) reported enhanced intra- and inter-hemispheric theta coherence among Shaolin Dan Tian Breathing practitioners, which is a form of Qigong breathing. They defined enhanced hemispheric theta coherence as an index of attention and alertness.

**C. Research on EEG Coherences**

The present study investigated EEG coherences, both in yoga meditation and in Qigong exercise by comparison and contrast. For this reason, it was imperative that the meaning and implications of EEG coherency analyses be established first. The earliest research on EEG coherence was conducted by Galbraith 19), and he suggested that fluctuations observed in the amplitude of evoked potential were a function of the fluctuation of EEG coherences that reflected the background activities. Further, Busk and Galbraith 20) suggested that higher inter-neural connectivity in the cerebral cortex was associated with higher EEG coherencies. These early studies established that higher EEG coherences reflected the higher structural and/or functional connectivity of neuronal activities within the cerebral cortex.

This notion of higher internal connectivity within the cerebral cortex as associated with higher EEG inter-channel coherencies has been further verified and strengthened by more recent studies 21-24).

Given this established association between higher EEG coherencies and stronger internal connectivity within the cerebral cortex, higher EEG coherencies found in meditation 9) as well as Qigong 16, 17) in previous studies appeared to imply the increased structural and/or functional associations of neuronal activities during these practices.

In the present study, EEG coherencies between right and left hemispheres as well as between frontal and occipital regions were compared and contrasted between TM (yoga-based-meditation) and Qigong exercise.

**II. Subjects**

Twenty-four healthy adult males were assigned to three groups as follows, after giving informed consent.

- **Group 1: TM** (N=8; age, 30.38 ± 4.37 y)
- **Group 2: Qigong Exercise** (N=8; age, 43.00 ± 13.09 y)
- **Group 3: Music-Listening Control** (N=8; age, 25.13 ± 3.18 y)

Due to the fact that it takes several years to learn to practice TM or Qigong correctly, subjects who were assigned to the TM group were experienced TM practitioners with over 3 years of practice and subjects who were assigned to the Qigong group were all experienced Qigong instructor with over 10 years of teaching experience. The control group consisted of healthy university students without any experience in yoga meditation or in Qigong exercise.

**III. Procedure**

The experimental room was shielded and its temperature was kept at 65.6 ± 1.69 °F (20.00 ± 0.97 °C). Subjects were asked to sleep well the night before the experiment and also to wash their hair and scalp prior to the measurement. Due to the fact that there was only one set of electrodes for the 16-channel-electroencephalography and it takes a few hours for the electrodes to dry after use, only one subject participated in the experiment per day.

Upon arrival at the experimental room, each subject was told to sit in a comfortable reclining chair with a mild shielding function. Sixteen active glass and silver-disc-shaped EEG electrodes filled with conductive paste were applied to the skin surface of the subject’s head, by following the guideline of the International 10-20 Method. Following the calibration at 50µV and 10 Hz, EEG data were monitored using the electroencephalograph IA97 (San-Ei Instrument Co., Ltd.) with the time-constant of 0.3 s.

**A. Group 1: Transcendental Meditation**

TM is a well-documented yoga-based-meditation technique that is based on the repetition of auditory images
in the mind. Following attachment of the electrodes, subjects in the TM group were told to remain resting with the eyes closed for 10 minutes (pre-treatment-rest), followed by a 20-minute-long meditation (treatment). Further, they were told to remain in the state of simple rest with the eyes closed for an additional 10 minutes (post-treatment-rest). Sixteen channel EEGs were monitored throughout these three stages.

B. Group 2: Qigong Exercise Group
Qigong is a traditional Chinese exercise that often-times combines breathing, imagery, and movements, and its positive effects on the nervous system and the cardiovascular system have been reported, though its effects on mental health have not been investigated much, which led to the present authors’ interest on including Qigong as a condition to contrast with yoga-based-meditation. Following attachment of the electrodes, subjects in the Qigong group were instructed to remain resting with the eyes closed for 10 minutes, followed by a 20-minute-long Qigong exercise which could be done while sitting in the chair with the eyes closed. Further, they were also told to remain in the state of simple rest with the eyes closed for an additional 10 minutes. Sixteen channel EEGs were monitored throughout these three stages.

C. Group 3: Music-Listening Control Group
Following attachment of the electrodes, subjects in the control group were instructed to remain resting with the eyes closed for 10 minutes. Subsequently, they listened to the same classical music piece that had been reported as ‘relaxing’ by multiple individuals in a pilot study (a violin sonata by Beethoven). This music-listening lasted for 20 minutes. Afterwards, they remained resting with eyes closed for an additional 10 minutes. Sixteen channel EEGs were monitored throughout these three stages.

IV. Analyses

A. Signal Processing
Sixteen channel EEGs were transmitted to a global band front amplifier with the highest limit of 40 Hz and sampling time of 0.125 Hz /5 ms. Subsequent to the A/D conversion, fast Fourier analysis was applied. Each 30-second-long time-series EEG was divided into six parts (5 minutes each) and weighted means were computed using these six parts. Following this computation, the peak alpha was computed for each 30-second time-series data set. Further, the auto power spectrum and cross power spectrum were computed based on the above-mentioned weighted mean. Moreover, a transmission function was calculated and the coherences between C3 and C4 and between Fz and Pz were computed, based on the following formula.

\[ \text{Coh}^2 = \frac{|C_{xy}|^2}{C_{xx} C_{yy}} \]

\[ C_{xy} = \text{cross power spectrum} \]
\[ C_{xx} = \text{spectrum at X(t)} \]
\[ C_{yy} = \text{spectrum at Y(t)} \]

The cross power spectrum was computed as the Fourier transformation of the intercorrelation function, which is based on the following formula.

\[ G_{xy} = \frac{1}{2\pi} \int C_{xy}(\tau) e^{-i\omega\tau} d\tau \]

Coherence between C3 and C4 as well as between Fz and Pz at each frequency band (theta, alpha I, alpha II, beta) were computed. The mean coherences were computed for each frequency band: theta band (4-8 Hz); alpha I band (8-10 Hz); alpha II band (10-13 Hz); and the beta band (13-30 Hz).

Further, coherence between two sets of signals at each peak alpha were computed in accordance with the calculation for the 30-second-long time-series data set from the 16 channels as previously described. The coherences between C3 and C4 were recognized as the indices of the functional correlations between the right and left hemispheres. On the other hand, coherences between Fz and Pz were recognized as the indices of the functional correlation between the frontal and occipital lobes.

B. Statistical Analysis

B.1 Within group comparison
Within group comparison for the TM group was conducted by using each frequency band (theta, alpha I, alpha II, beta) as well as the coherence at peak alpha as dependent variables. There were recordings of the experiment, and still photos were also taken for the Repeated Measures MANOVA for the three stages of the experiment (pre-treatment-rest, treatment and post-treatment-rest) and the within group factor and multiple variables were taken as dependent variables. These dependent variables included the coherency values for both comparisons. Overall, the Repeated Measures MANOVA was used (Table 1).
Table 1: Transition of Coherences in TM Group (Within Group MANOVA)

<table>
<thead>
<tr>
<th></th>
<th>C3-C4</th>
<th>pre-treatment-rest</th>
<th>TM treatment</th>
<th>post-treatment-rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>theta</td>
<td>0.81 (0.01)</td>
<td>0.81 (0.05)</td>
<td>0.82 (0.03)</td>
<td></td>
</tr>
<tr>
<td>alpha I</td>
<td>0.83 (0.05)</td>
<td>0.94 (0.04)**</td>
<td>0.89 (0.05)**</td>
<td></td>
</tr>
<tr>
<td>alpha II</td>
<td>0.79 (0.07)</td>
<td>0.91 (0.05)**</td>
<td>0.85 (0.05)*</td>
<td></td>
</tr>
<tr>
<td>beta</td>
<td>0.82 (0.05)</td>
<td>0.82 (0.02)</td>
<td>0.82 (0.02)</td>
<td></td>
</tr>
<tr>
<td>peak alpha</td>
<td>0.80 (0.03)</td>
<td>0.94 (0.02)**</td>
<td>0.89 (0.03)**</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Transition of Coherences in Qigong Group (Within Group MANOVA)

<table>
<thead>
<tr>
<th></th>
<th>C3-C4</th>
<th>pre-treatment-rest</th>
<th>Qigong treatment</th>
<th>post-treatment-rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>theta</td>
<td>0.76 (0.02)</td>
<td>0.77 (0.06)</td>
<td>0.77 (0.04)</td>
<td></td>
</tr>
<tr>
<td>alpha I</td>
<td>0.84 (0.04)</td>
<td>0.77 (0.07) ++</td>
<td>0.89 (0.05)**</td>
<td></td>
</tr>
<tr>
<td>alpha II</td>
<td>0.76 (0.07)</td>
<td>0.72 (0.06)</td>
<td>0.82 (0.06)*</td>
<td></td>
</tr>
<tr>
<td>beta</td>
<td>0.78 (0.01)</td>
<td>0.78 (0.05)</td>
<td>0.78 (0.03)</td>
<td></td>
</tr>
<tr>
<td>peak alpha</td>
<td>0.84 (0.03)</td>
<td>0.81 (0.03)</td>
<td>0.91 (0.03)**</td>
<td></td>
</tr>
</tbody>
</table>

Coherence Values = Mean (S.D.)
* Significantly larger than the value during pre-treatment-rest (p<.05)
** Significantly larger than the value during pre-treatment-rest (p<.01)
++ Significantly smaller than the value during pre-treatment-rest (p<.01)
Table 3: Transition of Coherences in Control Group (Within Group MANOVA)

<table>
<thead>
<tr>
<th></th>
<th>pre-treatment-rest</th>
<th>Music-Listing</th>
<th>post-treatment-rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>theta</td>
<td>0.77 (0.05)</td>
<td>0.77 (0.04)</td>
<td>0.77 (0.06)</td>
</tr>
<tr>
<td>alpha I</td>
<td>0.70 (0.08)</td>
<td>0.69 (0.08)</td>
<td>0.70 (0.07)</td>
</tr>
<tr>
<td>alpha II</td>
<td>0.75 (0.08)</td>
<td>0.75 (0.07)</td>
<td>0.76 (0.06)</td>
</tr>
<tr>
<td>beta</td>
<td>0.78 (0.06)</td>
<td>0.79 (0.05)</td>
<td>0.78 (0.05)</td>
</tr>
<tr>
<td>peak alpha</td>
<td>0.72 (0.05)</td>
<td>0.74 (0.06)</td>
<td>0.73 (0.07)</td>
</tr>
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</table>

C3-C4

<table>
<thead>
<tr>
<th></th>
<th>Fz-Pz</th>
</tr>
</thead>
<tbody>
<tr>
<td>theta</td>
<td>0.70 (0.06)</td>
</tr>
<tr>
<td>alpha I</td>
<td>0.65 (0.05)</td>
</tr>
<tr>
<td>alpha II</td>
<td>0.69 (0.04)</td>
</tr>
<tr>
<td>beta</td>
<td>0.72 (0.04)</td>
</tr>
<tr>
<td>peak alpha</td>
<td>0.65 (0.02)</td>
</tr>
</tbody>
</table>

| peak alpha (Hz) | 9.85 (0.41) | 10.60 (0.56)** | 10.01 (0.28) |

Coherence Values = Mean (S.D.)
** Significantly larger than the value during pre-treatment-rest (p<.01)

Within group comparison for the Qigong group was conducted by using each frequency band (theta, alpha I, alpha II, beta) as well as the coherence at peak alpha as dependent variables. There were recordings of the experiment, and still photos were also taken for the Repeated Measures MANOVA for the stages of the experiment (pre-treatment-rest, treatment and post-treatment-rest) and the within group factor and multiple variables were taken as dependent variables. These dependent variables included the coherency values for both comparisons. Overall, the Repeated Measures MANOVA was used (Table 2).

Within group comparison for the control group was conducted by using each frequency band (theta, alpha I, alpha II, beta) as well as the coherence at peak alpha as dependent variables. There were recordings of the experiment, and still photos were taken for the Repeated Measures MANOVA for the stages of the experiment (pre-treatment-rest, treatment and post-treatment-rest) and the within group factor and multiple variables were taken as dependent variables. These dependent variables included the coherency values for both comparisons. Overall, the Repeated Measures MANOVA was used (Table 3).

B.2 Between group comparison

Between group comparison for the pre-treatment rest was conducted for the three groups (TM group, Qigong group, and control group) as between independent variable and multiple coherence values (theta, alpha I, alpha II, beta for C3-C4 coherence as well as Fz-Pz coherence) as dependent variables. Therefore, the adopted statistical analysis was the Between Group MANOVA (Table 4).

Between group comparison during the treatment (TM, Qigong, or Music-Listening) was conducted for the three groups (TM group, Qigong group, and control group) as between independent variable and multiple coherence values (theta, alpha I, alpha II, beta for C3-C4 coherence as well as Fz-Pz coherence) as dependent variables. Therefore, the adopted statistical analysis was the Between Group MANOVA (Table 5).

Between group comparison for the post-treatment-rest was conducted by using three groups (TM group, Qigong group, and control group) as between independent variable and multiple coherence values (theta, alpha I, alpha II, beta for C3-C4 coherence as well as Fz-Pz coherence) as dependent variables. Therefore, the adopted statistical analysis was Between Group MANOVA (Table 6).
**V. Results**

**A. Within Group Comparison**

**A.1 TM group**

Repeated Measures of MANOVA for the TM group demonstrated a significant treatment effect (p < .01). Repeated Measures ANOVA for each dependent variable was subsequently applied, followed by post-hoc t-tests with Bonferroni correction.

**<Coherence between C3 and C4>**

C3-C4 coherence in the TM group was significantly higher during the meditation than before it (pre-treatment-rest) at alpha I band (p < .01), at alpha II band (p < .01), and at the peak alpha (p < .01). Moreover, C3-C4 coherence was also significantly higher during the post-treatment-rest than pre-treatment-rest at alpha I band (p < .05), at alpha II band (p < .05), and at the peak alpha (p < .01) (Table 1; Fig. 1).

**<Coherence between Fz and Pz>**

Fz-Pz coherence in TM group was significantly higher during meditation than the pre-treatment-rest at alpha I (p

<table>
<thead>
<tr>
<th>Table 4: Intergroup Contrast of Coherence during Pre-Treatment-Rest (Between Group MANOVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C3-C4</strong></td>
</tr>
<tr>
<td>theta</td>
</tr>
<tr>
<td>alpha I</td>
</tr>
<tr>
<td>alpha II</td>
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<tr>
<td>beta</td>
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<tr>
<td>peak alpha</td>
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<tr>
<td><strong>Fz-Pz</strong></td>
</tr>
<tr>
<td>theta</td>
</tr>
<tr>
<td>alpha I</td>
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<tr>
<td>alpha II</td>
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<tr>
<td>beta</td>
</tr>
<tr>
<td>peak alpha</td>
</tr>
<tr>
<td>peak alpha (Hz)</td>
</tr>
</tbody>
</table>

Coherence Values = Mean (S.D.)

**...Significantly larger than the values of control group (p<.01)**

***...Significantly larger than the values of TM group (p<.05)**

###...Significantly larger than the values of TM group (p<.01)

###...Significantly smaller than the values of TM group (p<.01)

<table>
<thead>
<tr>
<th>Table 5: Intergroup Contrast of Coherence during the Treatments (Between Group MANOVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C3-C4</strong></td>
</tr>
<tr>
<td>theta</td>
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<tr>
<td>alpha I</td>
</tr>
<tr>
<td>alpha II</td>
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<tr>
<td>beta</td>
</tr>
<tr>
<td>peak alpha</td>
</tr>
<tr>
<td><strong>Fz-Pz</strong></td>
</tr>
<tr>
<td>theta</td>
</tr>
<tr>
<td>alpha I</td>
</tr>
<tr>
<td>alpha II</td>
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<tr>
<td>beta</td>
</tr>
<tr>
<td>peak alpha</td>
</tr>
<tr>
<td>peak alpha (Hz)</td>
</tr>
</tbody>
</table>

Coherence Values = Mean (S.D.)

**...Significantly larger than the values of control group (p<.01)**

###...Significantly smaller than the values of control group (p<.01)

+++...Significantly smaller than the value of TM group (p<.01)

<table>
<thead>
<tr>
<th>Table 6: Intergroup Contrast of Coherence during Post-Treatment-Rest (Between Group MANOVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C3-C4</strong></td>
</tr>
<tr>
<td>theta</td>
</tr>
<tr>
<td>alpha I</td>
</tr>
<tr>
<td>alpha II</td>
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<tr>
<td>beta</td>
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<tr>
<td>peak alpha</td>
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<tr>
<td><strong>Fz-Pz</strong></td>
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<td>theta</td>
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<td>alpha I</td>
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<tr>
<td>alpha II</td>
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<tr>
<td>beta</td>
</tr>
<tr>
<td>peak alpha</td>
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<tr>
<td>peak alpha (Hz)</td>
</tr>
</tbody>
</table>

Coherence Values = Mean (S.D.)

**...Significantly larger than the values of control group (p<.05)**

**...Significantly larger than the values of control group (p<.01)**

###...Significantly larger than the values of TM group (p<.05)

###...Significantly larger than the values of TM group (p<.01)

+++...Significantly smaller than the value of TM group (p<.01)
<.01), alpha II (p < .01), and at peak alpha (p < .01). Moreover, Fz-Pz coherence was also significantly higher during the post-treatment-rest than the pre-treatment-rest at alpha I (p < .01), alpha II (p < .01), and at peak alpha (p < .01) (Table 1; Fig. 1).

A.2 Qigong group
Repeated Measures of MANOVA for the Qigong group demonstrated a significant treatment effect (p < .01). Post-hoc-ANOVA for each dependent variable was conducted, followed by post-hoc-t-tests with Bonferroni correction when ANOVAs were significant.

<Coherence between C3 and C4>
C3-C4 coherence was significantly higher during the post-treatment-rest than during the pre-treatment-rest in the Qigong group at alpha I (p < .01), alpha II (p < .05), and at peak alpha (p < .01). However, during the Qigong exercise, C3-C4 coherence was significantly lower than pre-treatment-rest at alpha I band (p < .01) (Table 2; Fig. 2).

<Coherence between Fz and Pz>
Fz-Pz coherence was significantly higher during the post-treatment-rest than during the pre-treatment-rest at alpha I band (p < .01), alpha II band (p < .01), and at peak alpha (p < .01). There was no significant difference in coherence between the pre-treatment-rest and during the Qigong exercise or between post-treatment-rest and during the Qigong exercise (Table 2; Fig. 2).

A.3 Control group
Repeated Measures MANOVA for the control group did not show any significant treatment effect (Table 3; Fig. 3).

B. Within Group Comparison
B.1 Pre-treatment comparison
Between Group MANOVA of pre-treatment comparison demonstrated a significant treatment effect (p < .01). In order to identify the sources of significance, Between Group ANOVAs were conducted for each dependent variable (theta, alpha I, alpha II, beta, and peak alpha powers in C3-C4 coherence as well as in Fz-Pz coherence), followed by post-hoc-t-tests with Bonferroni corrections when applicable.

<Coherence between C3 and C4>
In regards to the C3-C4 coherence, the TM group showed significantly higher coherence than the control group at alpha I band (p < .01) as well as at the peak alpha (p < .01). The Qigong group showed significantly higher coherence than the control group at the alpha I band (p < .01) and at the peak alpha (p < .01). In terms of the contrast between TM and Qigong groups, the TM group showed significantly higher coherence than the Qigong group at theta band (p < .01) as well as at the beta band (p < .01) while the Qigong group showed significantly higher coherence than the TM group at peak alpha (p < .05) (Table 4).

<Coherence between Fz and Pz>
The Qigong group showed significantly higher Fz-Pz coherence than the control group at the peak alpha (p < .01) and also significantly higher Fz-Pz coherence than TM group at the beta band (p < .05) as well as peak alpha (p < .01) (Table 4).

B.2 Comparison during the treatment
Between Group MANOVA for the comparison during the treatment demonstrated a significant treatment effect (p < .01). In order to identify the sources of significance, Between Group ANOVAs were conducted for each dependent variable (theta, alpha I, alpha II, beta, and peak alpha powers in C3-C4 coherence as well as in Fz-Pz coherence), followed by post-hoc-t-tests with Bonferroni corrections when applicable.

<Coherence between C3 and C4>
The TM group showed significantly higher C3-C4 coherence than the Control group at the alpha I band (p < .01), alpha II band (p < .01), and at the peak alpha (p < .01). Moreover, the TM group also showed significantly higher coherence than the Qigong group at alpha I band (p < .01), alpha II band (p < .01), and peak alpha (p < .01) (Table 5).

<Coherence between Fz and Pz>
The TM group showed significantly higher Fz-Pz coherence than the control group at the peak alpha (p < .01) and also significantly higher Fz-Pz coherence than TM group at the beta band (p < .05) as well as peak alpha (p < .01) (Table 5).

B.3 Post-treatment comparison
<Coherence between C3 and C4>
In regards to the C3-C4 coherence, the TM group showed significantly higher coherence than the control group at alpha I band (p < .01) as well as at the peak alpha (p < .01). The Qigong group showed significantly higher coherence than the control group at the alpha I band (p < .01) and at the peak alpha (p < .01). In terms of the contrast between TM and Qigong groups, the TM group showed significantly higher coherence than the Qigong group at theta band (p < .01) as well as at the beta band (p < .01) while the Qigong group showed significantly higher coherence than the TM group at peak alpha (p < .05) (Table 4).
by post-hoc t-tests with Bonferroni corrections when applicable.

The TM group showed significantly higher C3-C4 coherence than the control group at the alpha I (p < .01), alpha II band (p < .01), and beta band (p < .01). The Qigong group also showed significantly higher C3-C4 coherence than the control group at the theta band (p < .05), alpha I band (p < .01), and peak alpha (p < .01). However, when TM and Qigong groups were contrasted, the TM group had significantly higher C3-C4 coherence than the Qigong group at alpha I band (p < .01) and alpha II band (p < .01) (Table 6).

**<Coherence between Fz and Pz>**

The TM group showed significantly higher Fz-Pz coherence than the control group at alpha I (p < .01) and peak alpha (p < .01). Moreover, the Qigong group showed significantly higher Fz-Pz coherence than the control group at alpha I (p < .01), alpha II (p < .01), and peak alpha (p < .01). When TM and Qigong groups were contrasted, the Qigong group had higher Fz-Pz coherence than the TM group at beta band (p < .05) and peak alpha (p < .01) (Table 6).

VI. Discussion

**A. Between Group Comparison**

The present study suggested there were physiological differences among TM (yoga meditation), Qigong exercise, and music-listening conditions.

TM produced increased hemispheric as well as frontal-occipital coherences during and after the meditation. Qigong produced increased hemispheric as well as frontal-occipital coherences only after the exercise. Listening to music was not effective in the enhancement of inner-brain coherences.

Although listening to music did not effectively change the hemispheric EEG coherence (C3-C4) nor frontal-occipital EEG coherence (Fz-Pz), significant results for TM as well as Qigong exercise need to be examined further.

In terms of the difference between TM and Qigong, TM caused increased coherence both during and after the meditation, Qigong resulted in increased coherences only after the Qigong exercise. Two explanations to this notable difference between TM and Qigong are offered below.

**B. Difference in Measurement Conditions**

Due to the nature of the practice itself, participants in the TM group were engaged in meditation with the eyes closed during the experiment. To the contrary, Qigong practitioners did their Qigong with the eyes opened. Generally speaking, it is well known that alpha power typically increases at the occipital lobe when the eyes are closed. Therefore, the open or closed condition of the eyes would significantly influence the alpha power in the occipital lobe and thus influence the frontal-occipital coherence. Second, TM meditation was practiced in a seated position while Qigong was practiced in a standing position with some simple motions. In some instances, Qigong practitioners were moving only one arm during a given time. Movement of only one arm is expected to produce a hemispheric difference and thus decrease the hemispheric coherence. By considering the differences in these conditions (conditions of the eyes and physical movements), it is expected that TM and Qigong would produce different coherences during their practice.

On the other hand, increased coherences in the Qigong group (post-treatment-coherences) are notable as they resemble the post-treatment-coherence in the TM group. In other words, the results suggested that the state of the brain after the Qigong practice is similar to the state of the brain after meditation.

**C. Underlying Mechanism**

According to Galbraith 19, increased inner-brain coherences imply increased functional correlation in the brain. Therefore, it can safely be argued that TM meditation had produced an augmentation in the functional correlation within the brain. Since most of the increased coherences centered around the alpha band, it appears worthwhile to examine the significance in coherences in alpha band. With respect to the generative origin of the alpha wave, one of the commonly accepted explanations is that the alpha wave has its specific origin of generation between the thalamus and the cortex. In terms of the beta wave, however, its origin is considered as the accumulation of excitatory postsynaptic potential at the dendrites of pyramidal cells. The results of the present study appear to suggest that TM meditation amplified the inner-brain vibration associated with the alpha wave that has its specific origin and further expanded its effect to wider areas of the brain, including the frontal lobe, parietal lobe, and both hemispheres, while suppressing the excitatory post-synaptic potential at the dendrites, resulting in the enhanced functional synchronicity of electrical activities of the cerebral cortex.

In regards to the Qigong exercise, a similar physiological process was observed in the study, that is, the increased hemispheric as well as frontal-occipital coherences. Therefore, it appears safe to assume that the post-exercise-brain in Qigong resembles the post-meditation-brain in TM.
However, it should also be noted that the inner-brain coherences in the Qigong group were not only higher than the control group after the treatment but also before the treatment. These results appear to suggest that it may be more meaningful to study the general coherences among long-term Qigong-practitioners in the resting states than to study the real-time or immediate effect of Qigong exercise as it pertains to the inner-brain functional synchronicity.

D. Clinical Implications

Subjective reports among TM practitioners indicate that they typically experience a calmer mind with a comfortable level of alertness during a successful meditation. The present study indicates that such a meditative state, that is the combination of relaxation, along with an appropriate amount of alertness, corresponds to the increased inner-brain synchronicity as measured by the increased EEG coherences. Therefore, if it is possible to identify any technique that would produce the same effect, that is, the increased EEG coherences, it should be possible to produce similar meditative effects. This also implies the potential usefulness of EEG coherence feedback as an effective method for the coaching of relaxation with a proper level of alertness for athletes as well as for the general public who can benefit from such a state of mind.

References


ヨガ瞑想および気功鍛錬中の脳波コヒーレンスにおける
生理学的研究
(Physiological Investigation on EEG Coherency during Yoga Meditation and Qigong Exercise)

加藤正¹、河野貴美子²
(Tadashi KATO¹ and Kimiko KAWANO²)

¹Dept. of Behavioral Science, College of Liberal Arts, Fairmont State University (WV, USA)
²国際総合研究機構(IRI) 生体計測研究所（日本、千葉）

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要旨：TM（ヨガ瞑想）並びに気功鍛錬中の脳内の機能的な同期性について、リラックス音楽静聴時の
コントロールグループと比較し、検討した。グループ1：TM実践者（N=8、30.38±4.37歳）、グループ
2：気功実践者（N=8、43.00±13.09歳）、グループ3：健常対照群（N=8、25.13±3.18歳）であ
る。脳波（EEG）は、1）各課題実施前安静、2）実施中、3）実施後の安静、の3状態を通して計測し、
前頭中央-頭頂間（Fz-Pz）、並びに左右頭頂間（C3-C4）のコヒーレンスを計算して比較した。その結
果、TMでは瞑想中および瞑想後にC3-C4およびFz-Pzの双方でコヒーレンスが増加したが、気功群で
は気功法実施後にのみ増加した。対照群に有意な変化はみられなかった。これらの結果から、TM（ヨ
ガ瞑想）は脳内の機能相関を高め、気功は気功後の休息期間中に機能強化が行われるという異なる生
理学的メカニズムが示唆された。代替医療的な側面におけるヨガ瞑想と気功鍛錬の用い方の違いとし
て、臨床的な応用の可能性が考えられた。

キーワード：脳波(EEG)、コヒーレンス、音楽、ヨガ瞑想(TM)、気功