

Differential Effects of Long-Term Tai Chi Practice on Brain Networks in Young Adults: A Resting-State Fmri Study

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1. Abstract

1.1. Objective

Tai Chi has been found to modulate the intrinsic brain functions and structures, which has provided clues to reveal the mechanisms behind the clinical effects. The aim of the current study was to investigate the influence of long-term Tai Chi practice in young adults.

1.2. Methods

A total of 27 young adults with long-term Tai Chi experience and another 27 age and gender matched healthy control subjects were included in the current study. All the participants underwent trail making tests and brain structural and resting-state functional magnetic resonance imaging assessments.

1.3. Results

The demographic information and trail making tests showed no significant differences. fMRI results showed decreased functional connectivity in the left dorsolateral superior frontal gyrus in the Tai Chi group when comparing the changes of the default mode network with the control group. No increased changes in the default mode network and no significant differences in other brain networks were observed.

1.4. Conclusions

The current findings suggested decreased differential effects of long-term Tai Chi practice on brain networks in young adults. The

decreased results provided more understanding of the modulation effects as functional plasticity and functional specialization of brain networks in young adults with long-term Tai Chi experience.

2. Introduction

Tai Chi, also called Tai Chi Chuan or Taiji, is a famous intangible cultural heritage that has been practised as a martial art in China for centuries. Regarded as a mind-body exercise, Tai Chi combines physical movement and meditation to improve motor coordination, postural control, and cognitive function [1-3]. In the past decades, the favorable health values of Tai Chi on both physical and psychological conditions have been highly recognized with a substantial number of previous researches and reviews [4-6]. Although the clinical benefits of Tai Chi have been well documented, the underlying mechanisms interpreting the observed effects remain largely unknown in this field [7].

In the past decades, advances in functional magnetic resonance imaging (fMRI) techniques have opened a new window of human brain, offering new opportunities to investigate the neurological effects of different interventions [8]. As a special mind-body intervention, Tai Chi has been found to modulate the intrinsic brain functions and structures, which has provided clues to reveal the mechanisms behind the clinical effects of Tai Chi. It has been found that long-term Tai Chi practice could induce decreased fractional amplitude of low frequency fluctuations of the default mode network (DMN), the frontoparietal network, and the dor-

sal prefrontal-angular gyri network [9]. Apart from that, previous study also revealed decreased resting-state functional connectivity between the dorsolateral prefrontal cortex and the middle frontal gyrus [10], but increased gray matter volume in the thalamus and the hippocampus in elder long-term Tai Chi practitioners [11]. In a recent cross-section study, differences in the DMN, the sensory-motor network (SMN), and the visual network (VN) were observed in older women with long-term Tai Chi experience [12].

Given that long-term Tai Chi practice could induce different changes of brain networks in older adults, the aim of the current study was to investigate the influence of long-term Tai Chi practice in young adults, which may enlarge our understanding of the effects of Tai Chi on different populations. It was hypothesized that long-term Tai Chi practice could induce different changes on resting-state brain networks in young adults.

3. Materials and Methods

3.1. Subjects

The current study was approved by the Ethical Committee of Dongzhimen Hospital, the first affiliated hospital of Beijing University of Chinese Medicine. Written informed consent was obtained from all participants according to the Declaration of Helsinki. A total of 27 young adults with long-term Tai Chi experience and another 27 age and gender matched healthy control subjects were included in the current study. The inclusion criteria of the Tai Chi group were as follows: aged from 18 to 35 years old; right-handed; regular Tai Chi experience for more than 1 year; with a frequency of Tai Chi practice for more than 3 times per week and more than 30 minutes each time. The inclusion criteria of the control group were as follows: age and gender matched with the Tai Chi group; right-handed; with regular physical exercise (walking, jogging, stretching, et al); without previous experience of Tai Chi. The exclusion criteria of both groups were: history of balance or motor function abnormality; history of cerebral, mental, or psychological diseases; history of chronic pain problems; history of alcohol or drug dependency; history of sleep deprivation in the past three months; any other health problems or poor physical conditions that may influence the participation; females with plans of pregnancy in one year; participated in other researches during the past three months; any MRI contraindications.

3.2. Trail Making Test

All participants were asked to complete the Trail Making Test (TMT), a neuropsychological instrument that contains two task components, TMT-A and TMT-B, which is extensively used for the assessment of set-switching ability across a wide range of neurological conditions [13].

3.3. Imaging Acquisition

In order to obtain high quality imaging data, we set up the following rules for quality control during imaging acquisition. All scanning should be arranged three days in advance. Menstrual periods

should be avoided for female participants. All participants were told to maintain regular daily life and plenty of sleep prior to the scanning. All participants should stay rest for at least 20 minutes before scanning. All scanning should be arranged at least one hour away from meals. All scanning were operated by the same qualified doctor. Participants were instructed to stay still, think of nothing in particular, keep eyes closed, and not to fall asleep during the scanning. Earplugs were worn to attenuate scanner noise and foam head holders were immobilized to minimize head movements during each scanning.

Functional magnetic resonance images were acquired with a 3.0 Tesla MRI scanner (Siemens, Sonata Germany) at Dongzhimen Hospital, Beijing, China. For the functional scanning, resting-state fMRI data was collected using a single-shot, gradient-recalled echo-planar imaging sequence with the following parameters: repetition time = 2000 ms, echo time = 30 ms, flip angle = 90°, matrix = 64×64, field of view = 240mm², slice thickness = 3.5 mm, gap = 1 mm, 32 interleaved axial slices, and 180 volumes. The high-resolution structural information for anatomical localization was acquired using 3D MRI sequences with the following parameters: voxel size = 1 mm³, repetition time = 2530 ms, echo time = 3.4 ms, flip angle = 12°, matrix = 512×512, field of view = 240 mm×240 mm, slice thickness = 1 mm.

3.4. Data processing and Analysis

The structural data and the functional data were preprocessed separately to approach surface-based analysis. The resting-state functional data processing and analyzing were mainly carried out with the statistical parametric mapping toolbox (SPM12) and Analysis of Functional NeuroImages (AFNI). The structural data processing was mainly carried out with FreeSurfer software (<https://surfer.nmr.mgh.harvard.edu/>). Compared to the volume-based analysis, surface-based analysis may perform better in increasing statistical power. Due to the complex structure of our brain, some areas may be neighboring in volume-domain, but far away from each other in anatomy and play absolutely different roles in brain functional networks. Volume-based analysis is unable to avoid this kind of potential bias, while surface-based analysis can minimize the influence of other signals on gray matter signals and provide more reliable results.

A total of 170 volumes for each subject were corrected for slice timing after the starting 10 volumes were discarded for signal equilibrium. After that, the slice-timing was performed to correct acquisition time delay among different slices for remaining 170 volumes to the acquisition of the slice acquired in the middle time of each time repetition (TR). The slices of each participant were realigned by registering to the first image and then to the mean of the volume. None of the participants were excluded from further analysis due to excessive head motion (> 3mm or 3°). Then, we performed temporal band pass filtering (0.01-0.1 Hz) for each participant's time series after detrending the data to reduce possible

scanner influences.

Cortical segmentation and reconstruction were performed with the FreeSurfer image analysis suite. One assessor who was blind to participant characteristics followed the reconstruction procedures to check and correct any mistakes made by the FreeSurfer. We applied the AFNI Surface Mapper (SUMA) program to align reconstructed structural and functional data to the same template space. The functional data was smoothed with a full width half maximum of 8 mm. The brain networks of each participant were identified by using independent component analysis (ICA). Functional data were analyzed with the group ICA of fMRI toolbox. The procedures included the following steps: (i) applied ICA with Infomax algorithm as it is very suit for our spatial analysis, and (ii) back reconstructed into individual-level components. Finally, 30 independent components were auto-estimated through analysis. Group mean ICA maps were compared with published ICA templates identified via visual inspection. Following ICA, a back-reconstructed subject-specific time series for the networks were correlated with voxels' time series in a functional connectivity analysis by using the general linear model. The mean time

course for each functional network was calculated by averaging the time courses of all voxels within each network mask obtained from ICA analysis.

For the between-group comparison, we performed 2-sample t-test to identify significant differences. Both false discovery rate (FDR) and Monte Carlo Simulations correction were applied to do the multiple comparison correction ($P < 0.05$). We used REST toolbox to report the brain region with significant difference, and the result was displayed by using BrainVoyager QX software.

4. Results

4.1. Demographic Data and Behavioral Results

A total of 54 participants took part in the current study, including 27 long-term Tai Chi practitioners (age: 23.74 ± 2.92 years, 19 males and 8 females) and another 27 age and gender matched healthy subjects. The demographic information of the Tai Chi and control groups are shown in Table 1. There were no differences between the two groups in age, gender, body weight, height and educational level. The results of the trail making test also showed no significant differences (see Table 2).

Table 1: demographic information of the Tai Chi and control groups.

Items	Tai Chi group (n=27)	Control Group (n=27)	P
Age (year)	23.74 ± 2.92	23.74 ± 2.92	NA
Gender (Male/Female)	19/8	19/8	NA
Height (cm)	171.56 ± 8.58	172.07 ± 6.47	0.80
Weight (kg)	64.70 ± 13.59	66.04 ± 12.73	0.71
educational background (year)	16.70 ± 3.00	17.19 ± 2.29	0.51

Table 2: results of the trail making tests.

Items	Tai Chi group (n=27)	Control Group (n=27)	P
trail making test A (second)	19.21 ± 5.40	19.08 ± 6.79	0.94
trail making test B (second)	44.05 ± 14.50	43.66 ± 16.81	0.93

4.2. fMRI Results

We compared the resting state functional connectivity of the DMN, SMN, and VN between the Tai Chi and control groups. The results showed decreased functional connectivity in the left dorsolateral superior frontal gyrus in the Tai Chi group when comparing the

differences of the DMN with the control group. The specific cluster locations are shown in Table 3 and Figure 1. No brain regions with increased functional connectivity were detected in the Tai Chi group compared with the control group. No significant changes were observed in the SMN and VN between two groups.

Table 3: decreased functional connectivity in the Tai Chi group.

Region	Hem/BA	Talairach			t value	Area	Voxels
		X	Y	Z			
dorsolateral superior frontal gyrus	L/21 48	16	16	55	3.3451	15.5328	21

Note: Results from two-sample t-test, $p < 0.05$, corrected by Monte Carlo Simulations, iterated 1000 times, and cluster size $> 80 \text{ mm}^3$.

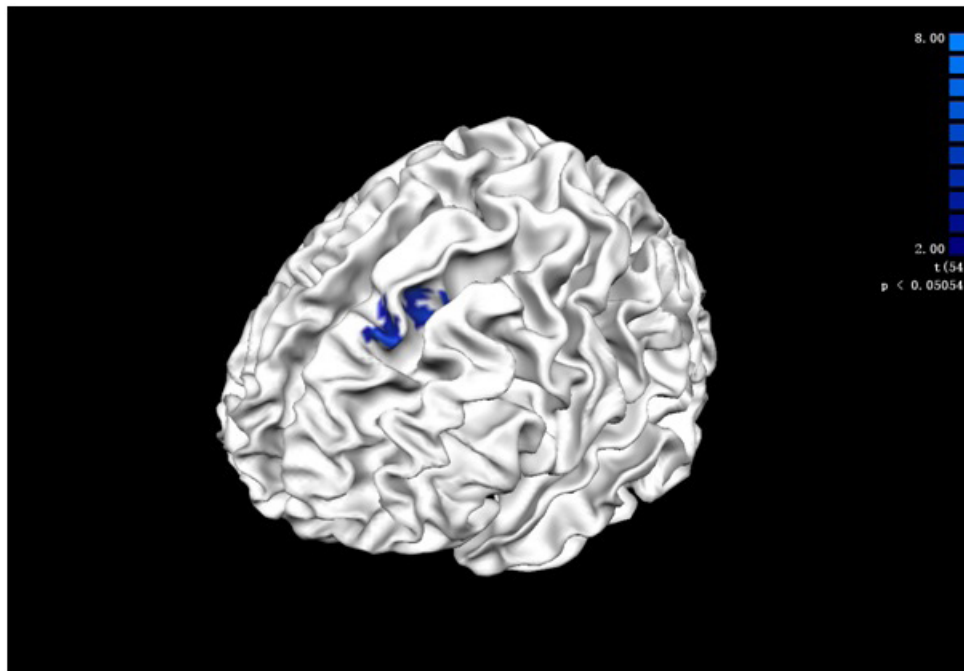


Figure 1: Decreased functional connectivity in the left dorsolateral superior frontal gyrus in the Tai Chi group when comparing the differences of the DMN with the control group. Results from two-sample t-test, $p < 0.05$, corrected by Monte Carlo Simulations, iterated 1000 times, and cluster size $> 80 \text{ mm}^3$.

5. Discussion

In this study we applied a cross-sectional design to investigate the effects of long-term Tai Chi practice on resting-state brain networks in young adults. We hypothesized that there might be a series of brain regions revealing increased or decreased functional connectivity among different brain networks, such as the DMN, SMN and VN. However, we only detected decreased functional connectivity in the left dorsolateral superior frontal gyrus in the Tai Chi group when comparing the changes of the DMN with the control group. No increased changes in the DMN and no significant differences in other brain networks were observed in our study. There were slight differences between the results of our study and previous studies focusing on the effects of long-term Tai Chi practice. We speculated that our results might provide further interpretations of the functional effects of long-term Tai Chi practice among different populations. It has been widely confirmed by previous fMRI studies that long-term Tai Chi practice can induce increased functional changes in older adults. The cross-section study conducted by Wei and her colleagues revealed significantly thicker cortex in a series of different brain regions of both hemispheres [14] and significantly greater functional homogeneity in the right post-central gyrus [15], which provided evidence for the functional plasticity and functional organization of the brain in long-term Tai Chi practitioners. Other cross-section studies detected larger gray matter volume [11] and similar improvements of white matter [16] in long-term Tai Chi practitioners, which suggested the protective effects of Tai Chi exercise at slowing gray and white matter atrophy in older adults. In another

cross-section study, Yue and his colleagues tried to compare the functional effects of long-term Tai Chi practice with walking in older women. Their results revealed significant increases of resting-state connectivity in the DMN, SMN and VN [12], as well as white and gray matter density and related network improvements including the hippocampus in the Tai Chi group [17, 18], which were consistent with the above mentioned study supporting the protective effects of Tai Chi in memory performance. In a cohort study, older adults received a six-week intervention that consisted of Tai Chi exercise, cognitive training, and group counseling, while the control group attended health knowledge lectures. The results showed increased resting-state connectivity between the medial prefrontal cortex and medial temporal lobe [19], and reorganized regional homogeneity of spontaneous fluctuations in the blood oxygen level-dependent signals in the superior and middle temporal gyrus and the cerebellum [20], as well as enhanced amplitude of low frequency fluctuations in the middle frontal gyrus, the superior frontal gyrus, and the anterior cerebellum lobe [21]. Taken together, the authors concluded that multimodal Tai Chi intervention can postpone the effects of aging by reorganizing the functions of brain regions affected by aging. Another cohort-study conducted by Tao and her colleagues compared the neural functional effects of 12-week Tai Chi and Baduanjin exercise with normal control. By applying different fMRI data analyzing techniques, this study revealed a series of evidences, such as increased hippocampus-medial prefrontal cortex resting-state functional connectivity [22], increased DMN resting-state connectivity in the medial prefrontal cortex [23], increased grey matter volume [24],

and increased low-frequency fluctuations in the frontal lobe [25], which supported the potential effects of Tai Chi practice in preventing memory decline during aging. The differential effects of long-term Tai Chi practice on brain networks in older adults have been well investigated by the above mentioned studies. There were converging evidences suggesting that long-term Tai Chi practice can induce increased functional changes in older adults. However, to the best of our knowledge, the potential effects of long-term Tai Chi practice on brain networks in young adults have not been well elucidated. In order to enlarge our understanding of the effects of Tai Chi on different populations, we conducted the current cross-section study with participants aged from 18 to 35 years old. In the beginning, we hypothesized that long-term Tai Chi practice could induce similar changes in young adults with that of the older adults. However, we only detected slightly decreased functional connectivity in the left dorsolateral superior frontal gyrus of the DMN in young adults, which were different from the significantly increased changes in older adults.

There are two possible explanations for the current decreased results. Firstly, our results have provided counterevidence supporting the theory that the brain functional networks, especially the cognition and memory functions, are declining during aging in older adults. That's the reason why previous studies detected comprehensively increased changes in older adults. When it comes to the young adults, whose brain functions are maintaining in the maturation period, the functional effects of long-term Tai Chi practice might be different from that of the older adults. Secondly, decreased functional changes also have been detected in previous studies investigating the effects of long-term Tai Chi practice in older adults. It has been reported in a previous cross-section study that long-term Tai Chi practice in older adults induced decreased functional homogeneity in the right dorsal lateral prefrontal cortex and the left anterior cingulate cortex [15], and decreased fractional amplitude of low frequency fluctuations in the bilateral frontoparietal network, the DMN, and the dorsal prefrontal-angular gyrus network [9]. Apart from that, older adults with long-term Tai Chi experience also revealed decreased middle frontal gyrus voxel-mirrored homotopic connectivity [26]. In another cross-section study, decreased resting-state functional connectivity between the dorsolateral prefrontal cortex and the middle frontal gyrus were found in older adults with long-term Tai Chi experience [10]. The cohort-study conducted by Tao and her colleagues detected similar decreases in resting-state functional connectivity between the dorsolateral prefrontal cortex and the left superior frontal gyrus [27]. Researchers of these studies proposed explanations of the decreased results as functional plasticity and functional specialization of brain networks which might be associated with higher-order cognitive ability in aging population. The dorsolateral superior frontal gyrus, which showed decreased functional connectivity in young adults with long-term Tai Chi experience in our study, coin-

cides with the results of previous studies focusing on older adults. As a key region of the DMN, the superior frontal gyrus plays an important role in the regulation of human cognition, memory, and behavior. Taken together, our findings might highlight more implications for the understanding of the modulation effects of long-term Tai Chi practice on brain networks in young adults as well as the older population. One limitation of the current study is that the interpretation should be taken with cautious because of the small sample size and poor Tai Chi homogeneity. And more behavior measurements are still in need to further determine relationships between functional effects and behavior changes.

6. Conclusions

In conclusion, our findings suggested decreased differential effects of long-term Tai Chi practice on brain networks in young adults. The decreased results provided more understanding of the modulation effects as functional plasticity and functional specialization of brain networks in young adults with long-term Tai Chi experience.

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