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Revealing the Neural Mechanisms Underlying the Beneficial Effects of Tai Chi: A Neuroimaging Perspective

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Abstract: Tai Chi Chuan (TCC), a traditional Chinese martial art, is well-documented to result in beneficial consequences in physical and mental health. TCC is regarded as a mind-body exercise that is comprised of physical exercise and meditation. Favorable effects of TCC on body balance, gait, bone mineral density, metabolic parameters, anxiety, depression, cognitive function, and sleep have been previously reported. However, the underlying mechanisms explaining the effects of TCC remain largely unclear. Recently, advances in

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neuroimaging technology have offered new investigative opportunities to reveal the effects of TCC on anatomical morphologies and neurological activities in different regions of the brain. These neuroimaging findings have provided new clues for revealing the mechanisms behind the observed effects of TCC. In this review paper, we discussed the possible effects of TCC-induced modulation of brain morphology, functional homogeneity and connectivity, regional activity and macro-scale network activity on health. Moreover, we identified possible links between the alterations in brain and beneficial effects of TCC, such as improved motor functions, pain perception, metabolic profile, cognitive functions, mental health and sleep quality. This paper aimed to stimulate further mechanistic neuroimaging studies in TCC and its effects on brain morphology, functional homogeneity and connectivity, regional activity and macro-scale network activity, which ultimately lead to a better understanding of the mechanisms responsible for the beneficial effects of TCC on human health.

Keywords: Traditional Chinese Exercise; Cognitive Function; Mood; Pain; Review.

Introduction

Tai Chi Chuan (TCC) is a traditional Chinese martial art that has been practiced in China for centuries. Deep diaphragmatic breathing, relaxation and the imperceptibly smooth flow of body postures are signature features of TCC (Wolf et al., 1997). Indeed, TCC has been considered to be a tenant of traditional wisdom and a powerful martial art in China, which was only taught to a limited population before the 1950s. This traditional martial art was then gradually simplified and made into a common sport in 1950s, aimed at promoting a healthy lifestyle among the general public of Mainland China. TCC has evolved into different styles during its development with Yang being one of the most popular. As a mind-body exercise, TCC requires practicing individuals to not only build their physical strength, but also to treat their body and mind as a whole in order to improve the mind-body control (Wolf et al., 1997). The health values of TCC have been highly recognized in recent researches. Although a number of the beneficial effects of TCC on human health have been identified, the underlying mechanisms mediating those effects remain largely unknown. In the current review, we summarized the beneficial effects of TCC on different populations and recent advances in neuroimaging findings on TCC-induced changes in brain morphology, functional homogeneity and connectivity, regional activity and macro-scale network activity.

Beneficial Effects of Tai Chi

TCC consists of training in both physical and mental components. A number of research studies have revealed the beneficial effects of TCC on both physical and psychiatric health in different populations. Previous systematic reviews have provided evidence that TCC is beneficial to a number of specific medical conditions, such as falls, Parkinson’s disease, depression, cognitive impairment and dementia, rehabilitations of stroke, cardiac disease and chronic obstructive pulmonary disease, by improving balance, muscle strength, aerobic capacity and general well-being (Del-Pino-Casado et al., 2016; Huston and McFarlane, 2016; Wolf et al., 1997).
The current review focuses on the potential mechanisms that mediate the effects of TCC through the modulation of brain morphology, functional homogeneity, activity and connectivity. The beneficial effects of TCC in different populations, together with the major outcomes and interventions employed, are briefly summarized in Table 1.

**Neuroimaging Findings on the Effects of Tai Chi Chuan on Brain Structure, Functional Homogeneity and Connectivity, Regional Activity and Macro-scale Network Activity**

Numerous studies have reported the beneficial effects of TCC on physical and mental health; however, the underlying mechanisms mediating those beneficial effects remain largely unknown. Fortunately, advances in neuroimaging technologies have provided some clues for understanding the neurological adaptation to TCC. A keyword search on the PubMed database was performed to access all the articles that were related to TCC-associated changes in brain, using the following terms: (1) “Tai Chi” or “Tai Chi Chih” or “Tai Chi Chuan” or “Tai Chi Quan” or “Taiji” or “Tai ji Quan” and (2) “magnetic resonance imaging” or “MRI” or “functional magnetic resonance imaging” or “fMRI” or “brain structure” or “neuroimaging”. Manual assessment was performed to filter out articles that were not related to TCC-induced alterations in brain. Until November 2017, there were a total of eight original studies that demonstrated changes in brain associated with TCC training or included intervention mechanisms that consisted of TCC. These eight articles were all included in this review. The changes in brain that associated with TCC are summarized in Table 2 and are briefly described as below.

TCC intervention has been found to bring several positive changes in brain function and structure. A study reported in 2012 has compared the normalized brain volume before and after the participants received TCC training (Mortimer et al., 2012). The intracranial volume of brains of the participants was increased by 47% after 40 weeks of TCC training (Mortimer et al., 2012), whereas significant change in brain volume was not observed in participants after receiving walking exercise intervention and in sedentary control subjects (Mortimer et al., 2012). Indeed, our previous study has also revealed that the cortical thickness of several parts of the brain, including right precentral gyrus, right middle frontal sulcus, right inferior segment of the circular sulcus of insula, left medial occipitotemporal sulcus, left lingual sulcus, and left superior temporal gyrus were larger in TCC practitioners compared with people who did not practice TCC (Wei et al., 2013). The changes in cortical thickness of those brain regions were correlated with the practicing hours of TCC training, while the increase in cortical thickness of superior temporal gyrus of Tai Chi practitioners was correlated with their shorter reaction time in an Attention Network Test (Wei et al., 2013).

Apart from the alterations of the brain morphology, TCC intervention has been demonstrated to modulate the functional homogeneity (i.e., temporal synchronizations of brain functional activity within a small region) in several sections of the brain. By using the technique of functional magnetic resonance imaging (fMRI), increased functional homogeneity of right postcentral gyrus, together with decreased functional homogeneity of anterior cingulate cortex and superior frontal cortex, were observed in participants with long-term TCC training (Wei et al., 2014). Notably, the changes in functional
### Table 1. Summary of the Beneficial Effects of Tai Chi

| Beneficial Effect | Studied Population                      | Outcome Indicator                                                                 | Intervention/Experience                        | Reference                        |
|-------------------|-----------------------------------------|------------------------------------------------------------------------------------|------------------------------------------------|----------------------------------|
| Flexibility       | Fall-pone older adults                  | Sit and reach test                                                                 | 60 min per section, 3 sections per week, 12 weeks | Choi et al. (2005)               |
|                   | College students                         | Sit and reach test                                                                 | 60 min per section, 3 sections per week, 12 weeks | Zheng et al. (2015a)             |
| Balance and Gait  | Fall-pone older adults                  | Single leg stand test                                                               | 35 min per section, 3 sections per week, 12 weeks | Choi et al. (2005)               |
|                   | Older adults with mobility disability    | CoP mediolateral displacement and velocity in locomotion phase                     | 60 min per section, 3 sections per week, 16 weeks | Vallabhajosula et al. (2014)     |
|                   | College students                         | Open eye perimeter and close eye perimeter in Pro-Kin system                       | 60 min per section, 3 sections per week, 12 weeks | Zheng et al. (2015a)             |
|                   | Elderly women                            | Comprehensive shake index                                                          | 40 min per section, 6 sections per week, 12 months | Song et al. (2014)               |
|                   | Female older adults with knee osteoarthritis | Single leg stand test with eyes closed                                            | 20 min per section, 3 sections per week, 12 weeks | Song et al. (2003)               |
|                   | Patients with stroke                     | Berg balance score                                                                 | Meta-analysis summary: A total of 8 studies on 704 subjects Mean difference (95%CI) = 11.85 [5.41, 18.3], P < 0.0001 | Chen et al. (2015)               |
|                   | Patients with Parkinson’s disease        | Berg balance score                                                                 | Meta-analysis summary: A total of 8 studies Berg balance score mean difference (95%CI) = 1.22 [0.8, 1.65], P < 0.0001 Timed up and go test mean difference (95% CI) = 1.06 [0.68, 1.44], P < 0.0001 | Yang et al. (2014)               |
| Beneficial Effect                      | Studied Population           | Outcome Indicator                                                                                      | Intervention/Experience                                      | Reference                      |
|---------------------------------------|------------------------------|--------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|--------------------------------|
| Patients with MS                      |                              | • Multiple balance and coordination tests includes single leg stand test and walk test in different situations | 90 min per section, 2 sections per week, 6 months            | Burschka et al. (2014)       |
| Patients with fibromyalgia            |                              | • Single leg stand test                                                                                | 90 min per section, 2 sections per week, 12 weeks, 8 forms of Yang style | Jones et al. (2012)          |
| Irradiated nasopharyngeal cancer survivors |                              | • Single leg stand test with eye closed                                                                 | Trained with 18 forms of Tai Chi Qigong for more than 6 months | Fong et al. (2014b)          |
| Female cancer survivors               |                              | • Single leg stand test                                                                                | 60 min per section, 2 sections per week, 10 weeks            | Reid-Arndt et al. (2012)     |
| Elderly                               |                              | • Single leg stand test                                                                                | 60 min per section, 3 sections per week, 24 weeks           | Li et al. (2004)             |
| Motor Function and Exercise Capacity   | Patients with COPD           | • 6-min walk test                                                                                      | 40 min per section, 3 sections per week, 6 months           | Niu et al. (2014)            |
|                                      | Patients with COPD           | • 6-min walk test                                                                                      | Meta-analysis summary: A total of 11 studies on 824 subjects Mean difference (95%CI) = 35.99 [15.63-56.35], P < 0.0005 | Wu et al. (2014)             |
| Patients with chronic systolic heart failure |                              | • Cardiac exercise self-efficacy instrument                                                            | 60 min per section, 2 sections per week, 12 weeks           | Yeh et al. (2011)            |
| Patients with chronic systolic heart failure |                              | • 6-min walk test                                                                                      | 50 min per section, 4 sections per week, 12 weeks, 10 forms of Yang style | Caminiti et al. (2011)       |
| Patients with MS                      |                              | • FSMC                                                                                                | 90 min per section, 2 sections per week, 6 months           | Burschka et al. (2014)       |
| Patients with fibromyalgia            |                              | • 6-min walk test                                                                                      | 60 min per section, 2 sections per week, 12 weeks, 10 forms of Yang style | Wang et al. (2010a)          |
| Patients with fibromyalgia            |                              | • Timed up and go test                                                                                 | 90 min per section, 2 sections per week, 12 weeks, 8 forms of Yang style | Jones et al. (2012)          |
| Beneficial Effect       | Studied Population                  | Outcome Indicator                            | Intervention/Experience                                                                 | Reference          |
|------------------------|-------------------------------------|----------------------------------------------|----------------------------------------------------------------------------------------|--------------------|
| Patients with peripheral neuropathy | Timed up and go test, 6-min walk test | 60 min per section, 3 sections per week, 24 weeks, 8 forms of Yang style | Li and Manor (2010) |
| Female postmenopausal breast cancer survivors | Fatigue symptom inventory | Two 60 min section and five 30 min sections per week for first 2 weeks, followed by one 60 min section and five 30 min sections per week for 10 weeks | Larkey et al. (2015) |
| Nasopharyngeal cancer survivors | 6-minute walk test | 90 min per section, 1 sections per week, 6 months, 18 forms Tai Chi Qigong | Fong et al. (2014c) |
| Female cancer survivors | Timed up and go test, Five times sit to stand test | 60 min per section, 2 sections per week, 10 weeks | Reid-Arndt et al. (2012) |
| Elderly | Timed chair rise test, 50-foot speed walk | 60 min per section, 3 sections per week, 24 weeks | Li et al. (2004) |
| Lung Function | Patients with COPD | Forced expiratory volume, Twitch oesophageal pressure, Twitch gastric pressure, Twitch transdiaphragmatic pressure | 40 min per section, 3 sections per week, 6 months | Niu et al. (2014) |
| Patients with COPD | Dyspnea, Forced expiratory volume in 1s, Forced vital capacity | Meta-analysis summary: A total of 8 studies on 544 subjects Dyspnea mean difference (95%CI) = −0.86 [−1.44, −0.28], P = 0.004 FEV1 mean difference (95%CI) = 0.07 [0.02,0.13], P = 0.01 FVC mean difference (95%CI) = 0.12 [0.00, 0.23], P = 0.04 | Yan et al. (2013) |
| Beneficial Effect     | Studied Population                        | Outcome Indicator                                      | Intervention/Experience                               | Reference |
|----------------------|-------------------------------------------|--------------------------------------------------------|------------------------------------------------------|-----------|
| Muscle Strength       | Elderly women                             | • Extension strength of hip and knee                    | 40 min per section, 6 sections per week, 12 months    | Song et al. (2014) |
|                      | Female older adults with knee osteoarthritis | • Abdominal strength by number of sit-ups performed in 30 s | 20 min per section, 3 sections per week, 12 weeks, 12 forms of Sun style | Song et al. (2003) |
|                      | Patients with chronic systolic heart failure | • Peak torque of the quadriceps muscles                  | 50 min per section, 4 sections per week, 12 weeks, 10 forms of Yang style | Caminiti et al. (2011) |
|                      | Patients with peripheral neuropathy        | • Knee extensor and flexor peak torque                   | 60 min per section, 3 sections per week, 24 weeks, 8 forms of Yang style | Li and Manor (2010) |
|                      | Central obese adults with depression       | • Number of stands in 30s                               | 60–90 min per section, 3 sections per week, 12 weeks, Kaimai style | Liu et al. (2015) |
| Pain Relieve         | Elderly with knee osteoarthritis           | • Verbal descriptor Scale                               | 20–40 min per section, 3 sections per week, 20 weeks, Sun style | Tsai et al. (2015) |
|                      | Female older adults with knee osteoarthritis | • K-WOMAC                                              | 20 min per section, 3 sections per week, 12 weeks, 12 forms of Sun style | Song et al. (2003) |
|                      | Patients with fibromyalgia                | • Visual-analogue scale                                 | 60 min per section, 2 sections per week, 12 weeks, 10 forms of Yang style | Wang et al. (2010a) |
|                      | Patients with fibromyalgia                | • FIQ pain                                             | 90 min per section, 2 sections per week, 12 weeks, 8 forms of Yang style | Jones et al. (2012) |
| Metabolic Abnormality | Inactive adults                           | • Waist circumference                                  | 30 min per section, 5 sections per week, 12 weeks, 32 forms of Sun style | Hui et al. (2015) |
| Beneficial Effect                  | Studied Population                  | Outcome Indicator                                      | Intervention/Experience                                      | Reference                      |
|-----------------------------------|-------------------------------------|--------------------------------------------------------|------------------------------------------------------------|-------------------------------|
|                                   | Adults with borderline hypertension | • Systolic blood pressure                               | 50 min per section, 3 sections per week, 12 weeks, 108 forms of Yang style | Tsai et al. (2003)           |
|                                   |                                     | • Diastolic blood pressure                              |                                                            |                               |
|                                   |                                     | • Blood HDL                                             |                                                            |                               |
|                                   | Patients with chronic systolic heart failure | • Systolic blood pressure                              | 50 min per section, 4 sections per week, 12 weeks, 10 forms of Yang style | Caminiti et al. (2011)     |
| Microcirculatory Function         | Inactive elderly men                | • Skin blood flow                                       | 54 min per section, 5.1 ± 1.8 sections per week, 11.2 ± 3.4 years, Yang style | Wang et al. (2001)        |
|                                   |                                     | • Cutaneous vascular conductance                        |                                                            |                               |
|                                   |                                     | • Skin temperature                                      |                                                            |                               |
|                                   |                                     | • VO₂ Max                                               |                                                            |                               |
| Cognitive Function                | Female cancer survivors             | • MASQ                                                  | 60 min per section, 2 sections per week, 10 weeks           | Reid-Arndt et al. (2012)   |
|                                   |                                     | • Rey Auditory Verbal Learning Test                     |                                                            |                               |
|                                   |                                     | • Trail Making Test A                                   |                                                            |                               |
|                                   |                                     | • Trail Making Test B                                   |                                                            |                               |
|                                   |                                     | • Stroop Test                                           |                                                            |                               |
|                                   |                                     | • Controlled Oral Word Association Test                 |                                                            |                               |
| Elderly with cognitive impairments|                                     | • MMSE                                                  | 20–40 min per section, 2 sections per week, 15 weeks, 12 forms of Sun style | Chang et al. (2011)           |
|                                   |                                     | • Digit Symbol-Coding Scores                            |                                                            |                               |
| Older adults                      |                                     | • Reaction time of task switching                       | 78.8 ± 15 min per section, 6.1 ± 1.2 sections per week, 13.6 ± 8.6 years, Yang style | Fong et al. (2014a)       |
|                                   |                                     | • P3 amplitude in brain                                 |                                                            |                               |
| Elderly                           |                                     | • Trail Making Test A                                   | 60 min per section, 2 sections per week, 6 months, 24 forms of Yang style | Nguyen and Kruse (2012)      |
|                                   |                                     | • Trail Making Test B                                   |                                                            |                               |
| Beneficial Effect       | Studied Population                | Outcome Indicator | Intervention/Experience                                                                 | Reference          |
|------------------------|----------------------------------|-------------------|--------------------------------------------------------------------------------------------|--------------------|
| Quality of Life         | Patients with COPD               | • SGRQ            | Meta-analysis summary: A total of 11 studies on 824 subjects SGRQ mean difference (95%CI) = −10.02 [−17.59, −2.45], \( P = 0.009 \) CRQ mean difference (95%CI) = 0.95 [0.22,1.67], \( P = 0.01 \) | Wu et al. (2014)   |
|                        |                                  | • CRQ             |                                                                                           |                    |
|                        | Patients with chronic systolic   | • MLHFQ           | 60 min per section, 2 sections per week, 12 weeks                                          | Yeh et al. (2011)  |
| heart failure           |                                  |                   |                                                                                           |                    |
|                        | Patients with MS                 | • Questionnaire of life satisfaction | 90 min per section, 2 sections per week, 6 months                                           | Burschka et al. (2014) |
|                        | Patients with fibromyalgia       | • SF-36           | 60 min per section, 2 sections per week, 12 weeks                                           | Wang et al. (2010a) |
|                        | Elderly with MDD under           | • SF-36           | 120 min per section, 1 sections per week, 10 weeks                                          | Lavretsky et al. (2011) |
| escitalopram treatment  |                                  |                   |                                                                                           |                    |
|                        | Patients with stable symptomatic | • MLHFQ           | 55 min per section, 2 sections per week, 16 weeks                                           | Barrow et al. (2007) |
| chronic heart failure   |                                  |                   |                                                                                           |                    |
|                        | Adults with functional class I   | • Vitality subscale of SF-36 | 60 min per section, 2 sections per week, 12 weeks, Yang style                             | Wang (2008)       |
| or II rheumatoid arthritis |                              |                   |                                                                                           |                    |
|                        | Elderly                          | • SF-12 physical score | 60 min per section, 3 sections per week, 24 weeks                                           | Li et al. (2004)  |
| Anxiety                | Adults with borderline hypertension | • State-trait anxiety inventory | 50 min per section, 3 sections per week, 12 weeks, 108 forms of Yang style                | Tsai et al. (2003) |
|                        | Central obese adults with        | • DASS anxiety score | 60–90 min per section, 3 sections per week, 12 weeks, Kaimai style                         | Liu et al. (2015)  |
| depression              |                                  |                   |                                                                                           |                    |
Table 1. (Continued)

| Beneficial Effect       | Studied Population               | Outcome Indicator                  | Intervention/Experience                                           | Reference   |
|-------------------------|----------------------------------|------------------------------------|------------------------------------------------------------------|-------------|
| Patients with stable symptomatic chronic heart failure | SCL-90-R anxiety                  | 55 min per section, 2 sections per week, 16 weeks                      | Barrow et al. (2007)                                           |
| Older adults with cerebral vascular disorder          | GHQ anxiety/insomnia              | 50 min per section, 1 sections per week, 12 weeks, Yang style            | Wang et al. (2010b)                                           |
| Depression                |                                   |                                    |                                                                  |             |
| Patients with MS           | CES-D                             | 90 min per section, 2 sections per week, 6 months                          | Burschka et al. (2014)                                         |
| Patients with fibromyalgia | CES-D                             | 60 min per section, 2 sections per week, 12 weeks, 10 forms of Yang style | Wang et al. (2010a)                                           |
| Female cancer survivors  | Impact of event scale-revised     | 60 min per section, 2 sections per week, 10 weeks                          | Reid-Arndt et al. (2012)                                       |
| Central obese adults with depression       | DASS depression score              | 60–90 min per section, 3 sections per week, Kaimai style                 | Liu et al. (2015)                                            |
| Elderly with MDD under escitalopram treatment | CES-D                             | 120 min per section, 1 sections per week, 10 weeks                        | Lavretsky et al. (2011)                                       |
| Patients with stable symptomatic chronic heart failure | SCL-90-R depression              | 55 min per section, 2 sections per week, 16 weeks                          | Barrow et al. (2007)                                         |
| Adults with functional class I or II rheumatoid arthritis | CES-D                             | 60 min per section, 2 sections per week, 12 weeks, Yang style             | Wang (2008)                                              |
| Older adults with cerebral vascular disorder          | severe depression                  | 50 min per section, 1 sections per week, 12 weeks, Yang style              | Wang et al. (2010b)                                          |
| Insomnia            | Patients with fibromyalgia         | PSQI                               | 60 min per section, 2 sections per week, 12 weeks, 10 forms of Yang style | Wang et al. (2010a)                                          |
| Beneficial Effect               | Studied Population                  | Outcome Indicator | Intervention/Experience                                                                 | Reference               |
|--------------------------------|-------------------------------------|-------------------|----------------------------------------------------------------------------------------|-------------------------|
| Patients with fibromyalgia    | PSQI                                | 90 min per section, 2 sections per week, 12 weeks, 8 forms of Yang style | Jones et al. (2012)                       |
| Old age adults with cerebral   | PSQI                                | 50 min per section, 1 sections per week, 12 weeks, Yang style | Wang et al. (2010b)                     |
| vascular disorder              | GHQ anxiety/insomnia                |                   |                                                                                        |                         |
| Elderly                        | PSQI, ESS                           | 60 min per section, 3 sections per week, 24 weeks | Li et al. (2004)                        |
| Elderly                        | PSQI                                | 40 min per section, 3 sections per week, 16 weeks | Irwin et al. (2008)                     |
| Elderly                        | PSQI                                | 60 min per section, 2 sections per week, 6 months, 24 forms of Yang style | Nguyen and Kruse (2012)                |
| Elderly                        | PSQI                                | 5 min per section in the first week, 5 min were added to each section per week until the fourth week, 25 min per section, 3 sections per week for the rest 8 weeks, 10 forms of Yang style | Hosseini et al. (2011) |

Notes: COPD = chronic obstructive pulmonary disease; MS = multiple sclerosis; K-WOMAC = Korean version of the Western Ontario-McMaster Universities OA index; FSMC = Fatigue Scale of Motor and Cognitive Functions; CES-D = Center for Epidemiological Studies Depression Scale; DASS = Depression Anxiety Stress Scale 21; HDL = high-density lipoprotein cholesterol; SGRQ = St. George’s Respiratory Questionnaire; CRQ = Chronic Respiratory Disease Questionnaire; MASQ = Multiple Abilities Self-Report Questionnaire; MLHFQ = Minnesota with Heart Failure Questionnaire; FIQ = Fibromyalgia Impact Questionnaire; ASEQ = Arthritis Self-Efficacy Questionnaire; SF-36 = Medical Outcome Study 36-item Short Form Health Survey; SF-12 = 12-item Short Form Health Survey MMSE = Mini Mental State Exam; MDD = unipolar major depressive disorder; SCL-90-R = Symptom CheckList-90-Revised; GHQ = General Health Questionnaire; PSQI = Pittsburgh Sleep Quality Index; ESS = Epworth Sleepiness Scale.
| Brain Region and Network | Function of this Region | Changes Induced by Tai Chi Intervention | Tai Chi Intervention/Experience | Possible Related Beneficial Effects | Neuroimaging Technology | References          |
|--------------------------|-------------------------|----------------------------------------|--------------------------------|-----------------------------------|-------------------------|---------------------|
| Total brain volume       | General brain function  | \(\uparrow\) Intracranial volume of brain (~47%) | 50 min per section, 3 sections per week, 40 weeks | Cognitive functions               | MRI                     | Mortimer et al. (2012) |
| Right precentral gyrus   | Coordinate and plan for the voluntary movements | \(\uparrow\) CT | 14 ± 8 years of Tai Chi experience, 11 ± 3 hours per week, with styles included Yang, Wu, Sun and modified Chan | Gait and balance               | MRI                     | Wei et al. (2013)     |
| Right middle frontal sulcus | Short-term memory, theory of mind, evaluate recency, plan, override automatics responses, calculation, analyze auditory information, infer intention and emotions of others, deducting information from spatial imagery | \(\uparrow\) CT | Cognitive functions | Cognitive functions | Cognitive functions |                     |
| Left medial occipito-temporal sulcus | Process color and word information, face and body recognition | \(\uparrow\) CT | Cognitive functions | Cognitive functions | Cognitive functions |                     |
| Left lingual sulcus      | Visual memory, maintain visuo-limbo connection | \(\uparrow\) CT | Cognitive functions | Cognitive functions | Cognitive functions |                     |
| Right inferior segment of the circular sulcus of insula | Sensory of emotions, sensory of inner body, generate appropriate body response to maintain homeostasis, pain sensation | \(\uparrow\) CT | Pain management, moods, cognitive functions | Pain management, moods, cognitive functions |                     |
| Brain Region and Network | Function of this Region                                                                 | Changes Induced by Tai Chi Intervention | Tai Chi Intervention/Experience | Possible Related Beneficial Effects                                                                 | Neuroimaging Technology | References |
|--------------------------|----------------------------------------------------------------------------------------|----------------------------------------|--------------------------------|---------------------------------------------------------------------------------------------------|-------------------------|------------|
| Left superior temporal gyrus | Social cognition, analyze face and auditory information, percept verbal and non-verbal information from others | ↑CT                                    | 14 ± 8 years of Tai-Chi experience, 11 ± 3 hours per week, with styles included Yang, Wa, Sun and modified Chan | Cognitive functions                                               | MRI                     | Wei *et al.* (2013) |
|                          |                                                                                        | ↑HGBOLD (~16%)                          |                                |                                                                                                   | fMRI                    | Zheng *et al.* (2015) |
| Right postcentral gyrus  | General body sensation                                                                  | ↑FH (Improved functional integration)  | 14.6 ± 8.6 years of Tai Chi experience, 11.9 ± 5.1 hours per week, | Gait and balance                                              | fMRI                    | Wei *et al.* (2014)  |
| Left anterior cingulate cortex | Cognitive regulation, pain management, emotional processing                             | ↑FH (Improved functional specialization) |                                | Cognitive functions, moods, pain management                                                      |                         |             |
| Brain Region and Network | Function of this Region | Changes Induced by Tai Chi Intervention | Tai Chi Intervention/Experience | Possible Related Beneficial Effects | Neuroimaging Technology | References |
|--------------------------|-------------------------|----------------------------------------|---------------------------------|-------------------------------------|------------------------|------------|
| Right superior frontal cortex | Self-awareness, working memory, executive function, | ↑FH (Improved functional specialization) | | Cognitive functions | | |
| Medial prefrontal cortex | Self-knowledge, familiar other-knowledge, social information processing, emotional processing, sadness suppression, morality | ↑Resting state-FC with bilateral hippocampus | 60 min per section, 5 sections per week, 12 weeks | Moods, cognitive functions | fMRI | Tao et al. (2017) |
| | | ↑Resting state-FC with medial temporal lobe | | | | |
| Bilateral hippocampus | Learning, regulation of emotion, stress and memory | ↑Resting state-FC with medial prefrontal cortex | 60 min per section, 5 sections per week, 12 weeks | Moods, cognitive functions | fMRI | Tao et al. (2017) |
| Medial temporal lobe | Information processing, emotion processing, recollection and familiarity, recognition memory | ↑Resting state-FC with medial prefrontal cortex | | Cognitive functions | | Li et al. (2014) |
| Brain Region and Network       | Function of this Region                                                                 | Changes Induced by Tai Chi Intervention | Tai Chi Intervention/Experience                                                                 | Possible Related Beneficial Effects | Neuroimaging Technology | References               |
|-------------------------------|----------------------------------------------------------------------------------------|-----------------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------|------------------------|--------------------------|
| Middle temporal gyri          | Face recognition, word processing                                                      | ↑HGBOLD (~7% for left side ~10% for right side) | Multiple interventions consist of 18 sections of 1 hour cognitive training, 18 sections of 1 hour Yang style 24-form Tai Chi training, 6 sections of 90 min group counseling | Cognitive functions               | fMRI                   | Zheng et al. (2015b)    |
| Posterior cerebellum lobe      | Coordination, precision and timing of motor functions                                   | ↑HGBOLD (~10%)                          |                                                                                                 | Gait and balance                  |                        |                          |
| Middle frontal gyrus          | Executive function, Short-term memory, theory of mind, evaluate recency, plan, override automatics responses, calculation, analyze auditory information, infer intention and emotions of others, deducting information from spatial imagery | ↑Resting state ALFF (~13%)              | Multiple interventions consist of 18 sections of 1 hour cognitive training, 18 sections of 1 hour Yang style 24-form Tai Chi training, 6 sections of 90 min group counseling | Cognitive functions               | fMRI                   | Yin et al. (2014)       |
| Brain Region and Network | Function of this Region                                                                 | Changes Induced by Tai Chi Intervention | Tai Chi Intervention/Experience | Possible Related Beneficial Effects | Neuroimaging Technology | References |
|-------------------------|----------------------------------------------------------------------------------------|----------------------------------------|---------------------------------|------------------------------------|------------------------|------------|
| Superior frontal gyrus  | Self-awareness, working memory, executive function                                     | ↑ Resting state ALFF (∼21%)             | Cognitive functions             |                                    |                        |            |
| Anterior cerebellum lobe| Coordination, precision and timing of motor function                                   | ↑ Resting state ALFF (∼13%)             | Gait and balance                |                                    |                        |            |
| Default mode network    | Self-generated cognition, social cognition, metalizing, memory retrieval.              | ↓ Resting state fALFF (∼10%)            | 14.6 ± 8.6 years of Tai Chi experience, 11.9 ± 5.1 hours per week, Cognitive functions, moods | fMRI                | Wei et al. (2017) |            |
| Right lateralized fronto-parietal network | Visual attention, visual capacity, attention control via the selection between spatial and non-spatial information, integration and control of cognitive representation | ↓ Resting state fALFF (∼10%)            | Cognitive functions             |                                    |                        |            |
| Left lateralized fronto-parietal network | Visual attention, visual capacity, attention control via the selection between spatial and non-spatial information, integration and control of cognitive representation | ↓ Resting state fALFF (∼12%)            | Cognitive functions             |                                    |                        |            |

Notes: CT = Cortex thickness; FH = functional homogeneity; FC = functional connectivity; HGBOLD = regional homogeneity of spontaneous fluctuations in the blood oxygen level-dependent signals; ALFF = amplitude of low frequency fluctuations; fALFF = fractional amplitude of low frequency fluctuations; ↑ indicates increased; ↓ indicates decreased.
Homogeneities of postcentral gyrus and anterior cingulate cortex were correlated with the practical hours of Tai Chi training (Wei et al., 2014). The decrease in the functional homogeneity of anterior cingulate cortex was negatively correlated with the log-transformed accuracy in the Attention Network Test. Other studies have also demonstrated that psychological-physical intervention, which consisted of TCC training, cognitive training and group counseling, altered the neurological activities in several brain regions (Li et al., 2014; Yin et al., 2014, Zheng et al., 2015b). It has been demonstrated that the regional homogeneity of spontaneous fluctuations in the blood oxygen level-dependent signals (HGBOLD) in particular parts of the brain regions including left superior temporal gyri (increased by 16%), middle temporal gyri (decreased by 7% for left side and 10% for right side), and the posterior lobe of the cerebellum (increased by 10%) were altered after the psychological-physical intervention (Zheng et al., 2015b). Furthermore, the psychological-physical intervention has been demonstrated to increase the resting state amplitude of the low frequency fluctuations (ALFF) in middle frontal gyrus (increased by 13%), superior frontal gyrus (increased by 21%) and anterior cerebellum lobe (increased by 13%) in elderly subjects (Yin et al., 2014). These data suggested that TCC training might contribute to the increases in resting neurological activities in these brain regions and, hence, aid in improving the cognitive functioning and well-being of elders (Yin et al., 2014). The functional connectivity between the medial prefrontal cortex and the parahippocampal cortex of the medial temporal lobe has been demonstrated to improved from 0.036 to 0.201 in healthy elders after receiving TCC-consisted psychological-physical intervention (Li et al., 2014). Another recent study has demonstrated that 12 weeks of TCC training increased the resting state functional connectivity of bilateral hippocampus and medial prefrontal cortex (Tao et al., 2017). The observations on the increased functional connectivities among these brain regions were associated with individual improvements in cognitive performance (Li et al., 2014; Tao et al., 2017).

Although it is well known that each brain region has its specified functions, it has been demonstrated that multiple brain regions, rather than a particular region, work coherently to perform a task (Wei et al., 2017). Those brain regions that work coherently for task performance are regarded as a macro-scale brain network. Recent advancement in neuroimaging technology allows researchers to investigate macro-scale networks of the brain. Multiple networks in the human brain and their functions have been identified. A recent study has demonstrated that TCC training altered the resting state fractional amplitude of the low frequency fluctuations (fALFF) of the default mode network and the bilateralized frontoparietal network (Wei et al., 2017). The resting state, fALFF, in the default mode network was shown to be 10% lower in people with long-term TCC training, compared with those who have never received TCC training (Wei et al., 2017). The fALFF of left lateralized frontoparietal network and right lateralized frontoparietal network in experienced TCC practitioners were observed to be 12% and 10% lower, respectively, compared with the people who had not practiced TCC (Wei et al., 2017). Intriguingly, the TCC-induced change in fALFF of left lateralized frontoparietal network has been shown to be correlated with the performance of cognitive function (Wei et al., 2017).
Potential Mechanisms Responsible for the Effects of Tai Chi Chuan through the Modulation of Brain Morphology, Functional Homogeneity and Connectivity, Regional Activity and Macro-scale Network Activity

Alterations of brain morphology, functional homogeneity and connectivity, regional activity and macro-scale network activity caused by TCC training might contribute to the underlying mechanisms of the observed beneficial effects of TCC on health consequences. In this section, we attempted to identify the possible links between the alterations in brain and beneficial effects of TCC.

Balance and Gait Performance

A systematic review has concluded that TCC intervention significantly improves flexibility and balance function in older adults (Huang and Liu, 2015). Increased cortical thickness of right precentral gyrus (Wei et al., 2013) and elevated homogeneity of postcentral gyrus have been observed in long time TCC practicers (Wei et al., 2014). Right precentral gyrus is the primary motor cortex that is responsible for coordinating and planning for voluntary movements of skeletal muscle, whereas the postcentral gyrus is the main sensory receptive brain area for the sense of touch. The coordination of timing and the amplitude of muscle responses to postural perturbations and the abilities of re-organizing sensory inputs and subsequently modify postural responses are two important aspects of balance control (Woollacott et al., 1986). Improvement of the sensation of touch can thus provide more concise information to the brain in how to react and how to coordinate the muscles for better balance control. The TCC-associated increase in the cortical thickness of the right precentral gyrus (Wei et al., 2013) and functional homogeneity of postcentral gyrus (Wei et al., 2014) might be a possible mechanism to strengthen the coordination and planning of voluntary movement of brain. The cerebellum might be another brain region that is involved in the mechanism behind TCC-induced improvement in balance and gait. The cerebellum is known to be responsible for coordination, precision, and timing of motor functions. The increases in the basal activities of anterior cerebellum lobe (Yin et al., 2014) and posterior cerebellum lobe (Zheng et al., 2015b) after TCC-consisted psychological-physical intervention might lead to better functioning of cerebellum, and thus contribute to the better performance of balance and gait in TCC practicers. Further research is needed to confirm the involvement of these alterations in the brain in terms of the beneficial effects of TCC on balance and gait.

Metabolic Parameters

Metabolic syndrome refers to a sub-healthy condition consisting of a cluster of metabolic abnormalities including high blood pressure, central obesity, reduced blood high-density lipoprotein (HDL) cholesterol, elevated fasting blood glucose, and high blood triglyceride (Alberti and Zimmet, 1998). People with metabolic syndrome are more susceptible to the development of cardiovascular diseases, diabetes mellitus, and some cancers (Alberti and
TCC could be a possible intervention to prevent metabolic syndrome as it could elicit cardiorespiratory responses and energy expenditure to the level of moderate-intensity activity, which is associated with a reduced risk of developing metabolic syndrome. Previous studies have demonstrated that TCC intervention decreased systolic and diastolic blood pressure, blood triglyceride, low-density lipoprotein (LDL) cholesterol, postprandial blood glucose, fasting blood glucose, and increased HDL cholesterol (Hui et al., 2015; Tsai et al., 2003). However, it is known that TCC is an exercise with slow movement and moderate intensity, which might not be sufficient to dramatically alter metabolic rate. Thus, it is speculated that TCC might improve the metabolic parameters by an alternative mechanism. It has been demonstrated that the cortex of the inferior segment of the circular sulcus of insula is thickened in people with long-term TCC training (Wei et al., 2013). The insular lobe is related to the sensory function of inner body (de Araujo et al., 2012). It integrates information related to bodily states and instructs the body to generate appropriate responses such as food intake, blood pressure changes, and autonomic function, to maintain the homeostasis of the body (de Araujo et al., 2012). Alteration in the thickness of inferior segment of the circular sulcus of insula might be a part of behind mechanism of TCC to improve the metabolic parameters. The thickening of the inferior segment of the circular sulcus of insula induced by TCC might result in improvement of the recognition of inner body status, and serves as a possible mechanism of how TCC adjusts metabolic parameters. Nonetheless, additional research studies are needed to confirm the link between TCC and metabolic adaptation via the modulation of circular sulcus of insula.

Pain Relief

Knee arthritis and low back pain can be caused by prolonged inappropriate posture and exertion habits. TCC has been reported to relieve pain in patients with knee osteoarthritis and chronic low back pain (Song et al., 2003; Tsai et al., 2015). Apart from the fact that TCC training corrects the exertion posture and strengthens the muscles of practitioners in order to relieve pain, it is possible that the pain-relieving effect of TCC is attributed to the alteration of the brain activity induced by TCC training. Anterior cingulate cortex is a multi-functional brain region with registration on physical pain as one of the functions (Gu et al., 2015). Moreover, the insular cortex has been demonstrated to be involved in the sensory processing of pain information, and is involved in modulating cognitive-evaluative, affective and sensory discriminative dimensions of pain by utilizing the cognitive information provided by other brain regions (Starr et al., 2009). Increase in cortical thickness of the inferior segment of the circular sulcus of insula (Wei et al., 2013), together with a decrease in functional homogeneity of the left anterior cingulate cortex has been observed in people under long-term TCC training (Wei et al., 2014). The alterations of these brain regions might be involved in the mechanism behind TCC-mediated pain management. A previous study has suggested that inhibition of anterior cingulate cortex might help to relieve chronic pain (Gu et al., 2015). It is possible that the improved functional specialization of anterior cingulate cortex after TCC training might contribute to better pain management and thus accounts for the pain-relieving effects of TCC.
insular cortex has been reported to be involved in pain perception, modulation and
chronification (Lu et al., 2016). The increase in cortical thickness of insula observed in
long-term TCC practicers might also aid in improving pain management and relieving pain
via a better processing of pain-related cognitive information. Further research on the direct
correlation between perceived pain and the TCC-mediated changes on these brain regions
is needed to unmask the mechanism behind the TCC-mediated pain alleviation.

**Insomnia**

Sleep complaints including difficulties in falling asleep, waking up during the sleeping
period, awaking too early, and chronic insomnia are common sleep problems found in
older adults (Foley et al., 1995). It is estimated that sleep complaints exist in more than
50% of elders around the world (Foley et al., 1995). About 20–40% of the elders
worldwide have been diagnosed with chronic insomnia (Schubert et al., 2002). The high
morbidity of sleep impairments is an alarming public health issue since sleep disorder has
been shown to be associated with impaired cognitive function and memory, reduction of
attention span, increase in response time, anxiety, depression, risks of falls, hypertension,
and heart diseases (Schubert et al., 2002). TCC has been demonstrated to be beneficial in
alleviating sleep complaints (Irwin et al., 2008). Research studies have been conducted to
reveal the differences in the brain structures of healthy controls and insomniac patients. The
volume of the hippocampus (Riemann et al., 2007) and the grey matter concentration in
orbital frontal cortex have been shown to be decreased in patients with chronic insomnia
when compared to non-insomniac people (Joo et al., 2013). In contrast, the volume of
rostral anterior cingulate cortex has been shown to be increased in patients with chronic
insomnia (Winkelman et al., 2013). There is currently no direct measurement reporting that
TCC improves sleep, or alleviates sleep complaints and insomnia by altering the structure
of the brain, however the brain regions that are involved in mindfulness meditation-induced
improvement in insomnia have been reported. As meditation is regarded as an essential part
of TCC training, those brain regions that are altered by meditation might provide clues to
unmask the mechanisms behind the effects of TCC on improving sleep. It has been
reported that mindfulness meditation increased the volume of hippocampus (Holzel et al.,
2011) and the grey matter concentration in orbital frontal cortex (Luders et al., 2009). It is
possible that TCC might improve insomnia by inducing similar changes in the brain.
Indeed, several studies have reported that alterations of brain regions related to insomnia
have been observed in people received TCC training. The decrease in the homogeneity of
anterior cingulate cortex has been observed in long-term TCC practicers (Wei et al., 2014).
A recent study has demonstrated that the resting functional connectivity between bilateral
hippocampus and prefrontal cortex was significantly increased after TCC training (Tao
et al., 2017). Although the alterations caused by TCC on those brain regions were not
directly opposing the changes in brain observed in insomniac patients, alteration of those
insomnia-related brain regions induced by TCC might be the possible mechanism that
contributes to the sleep improvement.
Apart from the changes in morphology and activity, an altered pattern of functional connectivity in sub-regions of default mode network has been observed in insomniac patients’ brains (Nie et al., 2015). The functional connectivity between prefrontal cortex and right medial temporal lobe, and between left medial temporal lobe and left inferior parietal cortices have been demonstrated to be decreased in insomniac patients (Nie et al., 2015). A previous study has shown that TCC-consisted psychological-physical intervention significantly increased the functional connectivity between medial prefrontal cortex and medial temporal lobe (Li et al., 2014). The opposing change in the functional connectivity between prefrontal cortex and medial temporal lobe observed in insomniac patients and people trained with TCC-consisted psychological-physical intervention might imply that the modulation of functional connectivity between these two brain regions could be parts of the possible mechanisms for TCC to improve sleep. Of note, different diseases — Alzheimer’s disease, depression, and schizophrenia — are related to decreased or disrupted functional connectivity. TCC might be a possible intervention for normalizing the resting functional connectivity in these diseases, as well as, insomnia. However, further research is needed to identify the involvement of brain alteration induced by TCC in alleviating sleep complaints.

Cognitive Function

Cognitive function includes a range of functionalities such as memory, information processing, learning ability, speech, and reading. Cognitive impairment is a common problem that affects the self-care ability and quality of life of elderly population (Leroi et al., 2012). Elders with cognitive impairment might have impaired memory, unreasonable action, and fluctuated emotion, which generate a lot of stress to their caregivers (Leroi et al., 2012). TCC has been demonstrated to prevent the decline in cognitive function as reflected by the findings that TCC practitioners have a higher score in Mini Mental State Exam and Digit Symbol-Coding Score (Chang et al., 2011), a shorter task-switching reaction time (Fong et al., 2014a), and better immediate memory, attention and verbal fluency (Reid-Arndt et al., 2012).

In fact, a number of the brain regions that are related to cognitive functions have been demonstrated to be responsive to TCC training. Increases in cortical thickness in several brain regions that contribute to cognitive function, including middle frontal sulcus, inferior segment of the circular sulcus of insula, superior temporal gyrus, middle frontal sulcus, occipitotemporal sulcus and lingual gyrus, have been observed in long-term TCC practitioners (Wei et al., 2013). Middle frontal sulcus is responsible for internal thought processing including short-term memory, recognition, theory of mind, evaluating recency, planning, overriding automatics responses, and calculation. It is also involved in the analysis of auditory information by controlling and sustaining auditory verbal attention for auditory stimuli. Insula cortex is involved in generating emotional senses (Starr et al., 2009). Besides insula and middle frontal sulcus, superior temporal gyrus is another region of the brain that processes information of emotion from facial stimuli and analyzes the changeable characteristics in face and auditory stimuli to perceive both verbal and non-verbal
information from other individuals. Right middle frontal sulcus infers the intention and emotions of others, and deducts information from spatial imagery. The occipitotemporal sulcus processes color and word information and is also involved in face and body recognition. Lingual gyrus is involved in processing vision information for face and word recognition. Previous study has demonstrated that damage in lingual gyrus can lead to visual memory dysfunction and visuo-limbo disconnection, resulting in the impairment of motivation, memory, learning ability, and emotional control. The reported thickening of these aforementioned cortices in the brain regions induced by TCC might possibly strengthen the functionality of those regions and resulted in the observed improvements in memory, calculation, emotion sensory, theory of mind, auditory processing, recognition, and social cognition.

Apart from causing morphological changes in the brain, the functional connectivity between prefrontal cortex and medial temporal lobe has been observed to be increased after TCC-consisted psychological-physical intervention (Li et al., 2014), while the functional connectivity between prefrontal cortex and bilateral hippocampus was increased after 12 weeks of TCC training (Tao et al., 2017). Importantly, the increases in functional connectivity of these regions are associated with the improvement of cognitive function. Prefrontal cortex is involved in cognitive control processes including decision-making, memory, performance monitoring and response inhibition while medial temporal lobe is associated with information processing, emotion processing, storage and retrieval of long term memories (Simons and Spiers, 2003). It has been suggested that the prefrontal cortex and temporal lobe work together in the remembering process (Simons and Spiers, 2003). Therefore, increase in functional connectivity between prefrontal cortex and medial temporal lobe might possibly imply a better performance in memory. The major role in conducting cognitive processes, including spatial information processing, temporal sequencing, formulation of the relationships between objects in the environment, learning, regulation of memory, emotion and stress, has made hippocampus an important brain region for cognitive function. The increase in the functional connectivity between prefrontal cortex and bilateral hippocampus might improve cognitive function by facilitating the logic processing and decision-making. Taken together, the modulation of the functional connectivity between these brain regions might be a possible mechanism of TCC that strengthens the cognitive function of the practicers. Apart from considering specific regions with specialized function, it has been demonstrated that the interplay between different brain regions might also contribute to the improved functional performance of the brain (Wei et al., 2017). A recent study has demonstrated that fALFF in default mode network and bilateral frontoparietal network of experienced Tai Chi practicers are significantly lower compared with people without experience in mind-body exercise (Weible et al., 2017). The default mode network consists of brain regions that relate to self-generated cognition, social cognition, mentalizing (Andrews-Hanna et al., 2014), while the bilateral frontoparietal network consists of regions for visual attention and attention control (Scolari et al., 2015). Notably, association between cognitive control function and alteration of fALFF of left frontoparietal network has been demonstrated (Weible et al., 2017). In light of the alterations in activities of the macro-scale network that related to cognitive functions,
it is speculated that TCC-induced modulation of the activity of macro-scale brain networks might be a part of behind mechanism of improving cognitive function.

Mood

As a traditional martial art, TCC requires practicers to relax their body in order to achieve fast reaction and quick movement for combating. It is mentioned in the traditional TCC literature that mental relaxation is a critical step for achieving the relaxation status of the body. Current researches have reviewed that mental relaxation and improvement in anxiety and depression can be achieved by mindfulness meditation intervention (Hofmann et al., 2010). Thus, meditation, as an essential component of TCC, is believed to be a major contributor to the TCC favorable effects on alleviating anxiety, depression and mood disorder in different populations (Huston and McFarlane, 2016). The insula, thalamus, striatum, anterior cingulate cortex and amygdala are the brain regions that relate to anxiety (Gold et al., 2015). The ventral hippocampus is also reported to be involved in emotional memory and anxiety due to its connection to the amygdala, hypothalamus and prefrontal cortex (Leuner and Gould, 2010). A previous study has demonstrated the role of insular cortex, anterior cingulate cortex and medial prefrontal cortex in emotional processing (Critchley et al., 2004; Etkin et al., 2011). Insula generates emotionally relevant contexts, such as emotional pain, happiness and sadness (Critchley et al., 2004). The medial prefrontal cortex plays a role in increasing the attention of positive emotions and suppressing sadness, while both anterior cingulate cortex and medial prefrontal cortex have been suggested to be involved in emotional processing, especially in fear and anxiety (Etkin et al., 2011). Both anterior cingulate cortex and medial prefrontal cortex work together to process fear memory and emotional conflict (Etkin et al., 2011). Meditation has been previously reported to alleviate depression and anxiety via the modulation of functional connectivity between dorsal anterior cingulate cortex and insular cortex (Yang et al., 2016). A recent study has employed an optogenetic technique to mimic meditation intervention on animals and has demonstrated that alleviation of anxiety can be achieved by modulating the activity of anterior cingulate cortex (Weible et al., 2017). It is possible that TCC might share a similar mechanism (i.e., alteration of brain structure, activity and homogeneity) to achieve the reported favorable effects on mood. Indeed, previous studies have shown that TCC intervention altered the cortex thickness and function connectivity of some aforementioned emotion-related brain regions. Increased thickness of the right inferior segment of the circular sulcus of insula (Wei et al., 2013) and improved functional specialization in anterior cingulate cortex are observed in experienced TCC practicers (Wei et al., 2014). The thickening of the cortex of inferior segment of the circular sulcus of insula and improved functional specialization in anterior cingulate cortex might associate with a better emotional processing, recognition and adjustment and thus alleviate the mood disorders. However, further research is needed to confirm the association of the alleviation of mood disorders and the TCC-induced alterations in brain. In addition, the resting-state functional connectivity between medial prefrontal cortex and bilateral hippocampus has been shown to be increased after TCC training (Tao et al., 2017). As mentioned in the
above section, prefrontal cortex is involved in the regulation of memory (Simons and Spiers, 2003), while hippocampus is involved in regulation of both memory and emotion. The increase in the functional connectivity among these brain regions might improve the emotion processing by linking up the current emotion with previous events. These alterations in the brain caused by TCC might improve the ability of the practicers in dealing with negative emotion, and thus alleviate the moods disorders. Further investigation is needed to confirm whether these TCC-mediated alterations on brain are associated with the alleviation of mood disorders.

Limitation, Future Perspectives and Conclusion

TCC is a traditional Chinese martial art that is comprised of meditation and physical conditioning. The health favoring effects of TCC have been widely recognized. The exercise intensity of TCC is moderate and this makes it very accessible to different populations especially elderly individuals. There are numbers of studies demonstrating the beneficial effects of TCC exercise on various health aspects in a wide range of different populations. Altering brain morphologies and neural activities probably contribute to the underlying mechanisms of the beneficial effects of TCC on health. With the advanced technology of neuroimaging, the effects of TCC on the brain have been preliminarily investigated and revealed. In this review, we attempted to explore the possible mechanisms underlying the beneficial effects of TCC by matching the effects of TCC with the neurological changes in the brain as revealed by neuroimaging technology. However, it should be noticed that there are several limitations in this review. Firstly, although the number of TCC studies related to changes in brain morphology and neural activity has been increasing, the relatively small amount of studies may limit our discussion. Secondly, all of the available studies demonstrating the effects of TCC on brain are conducted in a relatively small scale (i.e., ~20 participants in each intervention group). Large-scale randomized control trials are warranted to confirm the effects of TCC on the brain morphology, connectivity and activity of particular regions and macro-networks, and the association between the TCC-induced changes in brain and the beneficial effects. It should also be noted that three of the eight available studies demonstrating the effects of TCC on brain were using a TCC-consisted psychological-physical intervention protocol rather than TCC-alone intervention. It is possible that the non-TCC element (i.e., cognitive training or group counseling) in TCC-consisted psychological-physical intervention protocol may have contributed to the discussed morphological changes of the brain.

In the future, the effects of TCC on the prevention of neurodegeneration and the promotion of neuroprotection and the cellular activities in different parts of the brain involved in these effects should be comprehensively investigated. Data collected from multiple levels by using different techniques including functional neuroimaging, molecular biology techniques, neuropsychological tests and physiological measurements should be a promising strategy to fully uncover the mechanisms and the effects of TCC on the human brain and health.
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