Available online at www.sciencedirect.com

ScienceDirect

Journal of Sport and Health Science 3 (2014) 36–42

www.jshs.org.cn

Review

Tai Ji Quan, the brain, and cognition in older adults

Yu-Kai Chang [a,*], Yu-Hsiang Nien [b], Ai-Guo Chen [c], Jun Yan [c]

[a] *Graduate Institute of Athletics and Coaching Science, National Taiwan Sport University, Taoyuan County 333, Taiwan, China*
[b] *Department of Sport Performing Arts, University of Taipei, Taipei 10048, Taiwan, China*
[c] *College of Physical Education, Yangzhou University, Yangzhou 225009, China*

Received 16 April 2013; revised 8 September 2013; accepted 9 September 2013

Abstract

The relationship between physical activity (PA) and cognition has received much attention recently. While evidence of improved cognition following PA has consistently been observed, the majority of studies have spotlighted aerobic exercise and the effects of other modes of PA, such as Tai Ji Quan, on cognition have received limited attention. This article provides a brief review of the literature concerning the influence of Tai Ji Quan on cognition in older adults, including those with intact cognition and those with cognitive impairment. In addition, this review proposes potential mechanisms (cardiovascular fitness, motor fitness, movement coordination, social interaction, and meditation statuses as well brain structure and function) evaluated from a neuroimaging perspective that may explain the Tai Ji Quan–cognition relationship. Finally, we present suggestions for future research. In conclusion, Tai Ji Quan, with its multi-faceted characteristics, shows promise as a mode of PA for enhancing cognition, as well as brain health, in older adults. Based on the findings in this review, further exploration of the effects of Tai Ji Quan on cognition in older adults is warranted.

Keywords: Brain plasticity; Dementia; Executive function; Physical activity; Tai Ji Quan

1. Introduction

With increased age, adults frequently experience deterioration in cognitive performance with respect to response speed and accuracy on tasks involving information processing speed, reasoning, memory, spatial orientation, and spatial visualization.[1] The aging process also reduces specific brain area volumes, such as in the caudate nucleus, lateral prefrontal cortex, cerebellar hemispheres, and hippocampus[2] which has been linked to cognitive impairment and age-related neurological pathologies such as dementia and Alzheimer's disease.

While cognitive ailments and brain decay with aging have been generally observed, the rate of deterioration is moderated by individual differences (e.g., education and cardiovascular fitness) as well as by several lifestyle factors (e.g., physical activity (PA), intellectual engagement, social interaction, and nutrition).[3] Among these factors, the effects of PA, particularly cardiovascular fitness, on cognition in older adults has received much attention. A large number of prospective studies have demonstrated that higher levels of participation in PA are positively associated with cognitive function and a lower incidence of cognitive impairment.[4,5] Research into the relationship between cardiovascular fitness and cognition has been strengthened by the development of using neuroimaging techniques. Using cross-sectional and longitudinal designs these experimental studies have revealed that older adults with

* Corresponding author.
E-mail address: yukaichangnew@gmail.com (Y.-K. Chang)
Peer review under responsibility of Shanghai University of Sport

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jshs.2013.09.003

higher cardiovascular fitness levels display better cognitive performance as well as more gray and white matter[6] and larger hippocampal volumes.[7,8]

Although a few recent studies have focused on the influence of resistance exercise modes on cognition,[9–11] the majority of studies regarding PA and cognition emphasize aerobic exercise; thus, the effects of other modes of PA on cognition remain mostly unexplored. Herein, the current review examines the literature focusing on the relationship between Tai Ji Quan (also known as Tai Chi Chuan, Taijiquan, and Taiji), a popular ancient Chinese PA regimen, and cognition in older adults with intact cognition, and on those with cognitive impairment. In addition, based on neuroimaging data we propose potential mechanisms underlying this relationship and suggest several directions for further studies on the effects of Tai Ji Quan on cognition in older adults.

2. Older adults with intact cognition

A few recent studies have examined the relationship between Tai Ji Quan and cognitive performance in terms of attention, memory, and eye–hand coordination. With a cross-sectional design, Man et al.[12] compared the performance of older adults who regularly participated in Tai Ji Quan on attention and memory tests to those with and without regular PA habits. While the researchers observed better performance in the physically active older adults rather than those who were sedentary, the Tai Ji Quan group performed better in sustained and divided attention as well as in everyday memory, encoding memory, and recall memory, compared with those in the regular PA group, which suggests that Tai Ji Quan provides additional beneficial effects on cognition. Another study reported a similar influence of Tai Ji Quan on cognition by examining the age effect. Hall et al.[13] compared cognitive performance on a Rapid Index Finger-Pointing task among young adults, older adults with Tai Ji Quan experience, and older adults who were physically inactive. The results indicated that although older adults displayed worse performance in terms of reaction time, movement time, and response accuracy than younger adults, reflecting age-related cognitive decline, older adults with Tai Ji Quan experience displayed a shorter movement time than their inactive counterparts, suggesting that Tai Ji Quan positively affects eye–hand coordination tasks that involve greater cognitive demand.

The apparent beneficial effects of Tai Ji Quan on cognition that requires higher cognitive processing demonstrated by Hall et al.[13] raises a question about whether Tai Ji Quan would benefit higher-order cognitive functioning, namely executive function. Indeed, meta-analysis has indicated that aerobic exercise not only benefits cognition in general (i.e., speed, spatial, and controlled aspects of cognition) but facilitates executive function to a greater degree,[14] which suggests that the effects of exercise on cognition are disproportional. For example, using a pre–post-experimental design, Matthews and Williams[15] determined that older adults who participated in a Tai Ji Quan intervention three times per week over 10 weeks improved executive function performance on the Trail Making Test B and Clock Drawing test, but not the Trail Making Test A or Digit Symbol test, which are indices of basic information processing tasks. Taylor-Piliae et al.[16] additionally examined long-term Tai Ji Quan intervention (5 times per week for 12 months) to compare cognition alteration in attention control and treatment control groups. Similar to Matthews and Williams,[15] Taylor-Piliae et al.[16] observed that older adults in the Tai Ji Quan group demonstrated better executive function performances with regard to Digits Backward, but not the basic cognitive performance measured by Digits Forward. In contrast, when compared with a 5.5-month motor training program of Tai Ji Quan, fall prevention, and contemporary dance, only adults that participated in the contemporary dance intervention demonstrated better performance in the switch aspect of executive function.[17] Notably, no significant differences were observed in the setting or suppressing attention aspects of executive function, which suggests that Tai Ji Quan might not be sensitive to these aspects of executive function. This disproportionate facilitation of executive function by Tai Ji Quan was discussed in a recent commentary by Etnier and Chang,[18] who argued that the variation in effect on these specific aspects of executive functioning from exercise training warrant further investigation.

In contrast to examining cognitive performance by using the cognitive tasks described above, three studies have examined the effects of Tai Ji Quan intervention on cognition using the Mini Mental State Examination (MMSE) in older adults with intact cognition. However, no effects on the MMSE were found following Tai Ji Quan after 8 weeks,[19] 24 weeks,[20] or 24 months.[21] Although these findings appear contradictory, it should be noted that the MMSE is a popular screening test for cognitive impairment and might be less sensitive in respect of older adults with normal cognition.[22,23]

3. Older adults with cognitive impairment

Beyond emphasizing cognitive function in older adults with intact cognition, a small number of recent studies have focused on the influence of Tai Ji Quan on cognitive functions in older adults with cognitive impairment. Using a pre–post experiential design, Chang et al.[24] indicated that, although post-test MMSE and Digit Symbol scores improved after a Tai Ji Quan program of twice per week for 15 weeks, compared to the pre-test, the differences in cognitive variables did not reach statistical significance. However, when analyzing the dose–response relationship of Tai Ji Quan session attendance (i.e., attending fewer sessions/low-dose group versus regular attendance/high-dose group), the high-dose group had significantly better MMSE and Digit Symbol scores than the low-dose group, which suggests that the beneficial effects of Tai Ji Quan on cognitive performance could be extended to older adults with cognitive impairment if participation reaches an efficacy threshold.

Stronger evidence of the effects of Tai Ji Quan was provided by recent studies that focused on older adults with mild cognitive impairment (MCI).[25,26] MCI is an intermediate stage between normal age-related cognitive decline and dementia[27] and is of particular interest because adults with MCI are at

high risk for developing dementia. Within a quasi-experimental design, older adults involved in a Tai Ji Quan program twice per week for 6 months demonstrated better performance in memory, as assessed by both the Subjective Memory Complaint Scale and the Rivermead Behavioral Memory Test (RBMT), compared with a control treatment. In addition, a better Tai Ji Quan Learning Test score was also significantly associated with an improved RBMT score, further confirming the positive relationship between Tai Ji Quan and specific types of cognition. More recently, Lam et al.[26] used a randomized controlled trial design to examine the effects of a long-term Tai Ji Quan program on the incidence of dementia as well as cognitive function. Older adults with MCI were randomly assigned to either one year of Tai Ji Quan intervention or a stretching and toning exercise intervention. Neuropsychiatric and cognitive performances were assessed at baseline and at 5, 9, and 12 months. Participants in the Tai Ji Quan group had better delay recall as well as a lower risk for developing dementia at the 12-month time point, suggesting that extended Tai Ji Quan involvement has greater benefits in preventing cognitive decline.

The positive influence of Tai Ji Quan on cognition has also been demonstrated in older adults with severe cognitive impairment, namely dementia. Using a randomized controlled trail design, Burgener et al.[28] examined the effects of a Tai Ji Quan program of three times per week for 40 weeks on the MMSE in older adults diagnosed with dementia. The MMSE was assessed at baseline, and at 20 and 40 weeks. While older adults in Tai Ji Quan displayed improved MMSE scores compared with two attention control groups at 20 weeks, there was no difference in MMSE scores between 20 and 40 weeks, indicating that 20 weeks of intervention may be adequate for obtaining improved cognition in this population.

It has been speculated that the effects of Tai Ji Quan could be similar to interventions that require more cognitive engagement in older adults with dementia. For example, Cheng et al.[29] indicated that both participants in Mahjong (i.e., a type of Chinese chess game) and Tai Ji Quan displayed significantly better MMSE and Digit Span Forward scores than a control group after 6 months. In addition, the facilitation was enhanced as time progressed and after 9 months of treatment, the MMSE scores had increased by 4.5 and 3.7 points from baseline in the Mahjong and Tai Ji Quan interventions, respectively, implying that the effects of Tai Ji Quan are comparable to activities featuring greater cognitive demand.

4. Potential mechanisms based on neuroimaging research

To provide a rationale for the link between Tai Ji Quan and cognition, Chang et al.[30] proposed a Tai Ji Quan−Cognition Mediational Model which contained three categories of mediators through which Tai Ji Quan may affect cognition: physical resources (e.g., increased sleep effectiveness), disease states (e.g., decreased cardiovascular disease, hypertension), and mental resources (e.g., enhanced self-efficacy or reduced depression). We now shift our attention to another perspective by proposing potential mechanisms influencing the effects of Tai Ji Quan on cognition based on the studies of PA/exercise and cognition, as well as the status of specific brain structures and their function, as have recently been elucidated, in particular, by using techniques from neuroimaging (Fig. 1).

4.1. The brain and cognition

With the emergence of cognitive neuroscience, researchers have been able to apply non-invasive and high spatial resolution techniques, such as magnetic resonance imaging (MRI), to explore brain structure and cognition. While the brain structure changes that appear with aged-related cognitive decline are still under debate, meta-analysis conducted by Demakis[31] has indicated an association between frontal lobe size and the executive function aspects of cognition. Furthermore, several brain regions, including the hippocampus[32] and cerebral cortex[33] have displayed decay in association with decreased cognitive performance, which implies that these brain regions play an essential role in cognitive aging.

An alternative approach for examining the brain and cognition is through investigation of brain activation, such as with single functional MRI (fMRI) and event-related potential

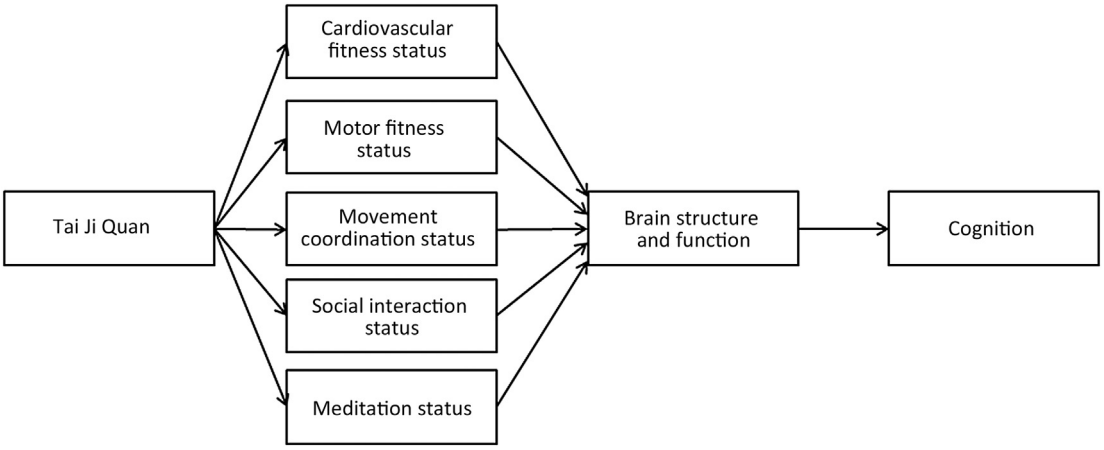

Fig. 1. A potential mechanism model among Tai Ji Quan, the brain, and cognition.

(ERP) techniques. Typically, studies using these approaches detect brain activation during administration of a cognitive task. These approaches have reliably demonstrated differences in brain activity during multiple cognitive functions[34] in older and younger adults. Generally speaking, older adults demonstrate two distinct neural activations, which has resulted in several interpretations. Specifically, aged-related deceased brain activity is typically thought to represent a cognitive deficit in older adults, whereas aged-related increased brain activity has been interpreted as either compensatory recruitment or more diffuse recruitment of neural resources for a given task (dedifferentiation) in an older population.[35] Obviously, neuroimaging studies provide an in-depth approach to examining the underlying mechanism between Tai Ji Quan and cognition via the role of brain function.

4.2. Cardiovascular fitness status

The level of cardiovascular fitness has been linked to brain structure. Using an MRI technique, a pioneering study by Colcombe et al.[36] observed that older adults with a higher fitness level displayed greater mass in prefrontal, superior parietal, and temporal cortices as well as greater anterior tracts compared to their counterparts. A similar positive association between cardiovascular fitness and these and other brain regions[37,38] (e.g., hippocampus[7,8]) has also been observed. A positive influence of cardiovascular fitness on the medial temporal and parietal cortices, a brain region related to Alzheimer's disease, has also been observed, suggesting that the beneficial effects of PA on cognition could be extended to adults with dementia.[39] These positive relationships between cardiovascular fitness and cognition were still observed even after controlling for confounders (e.g., education, smoking, alcohol use, self-rated health, and chronic conditions), suggesting an independent role of cardiovascular fitness in facilitating cognition.

Studies regarding Tai Ji Quan training have utilized different styles of Tai Ji Quan, with performance ranging from 30 to 75 min. Given that moderate exercise for 20−60 min can increase cardiovascular fitness,[40] Tai Ji Quan intervention should enhance fitness. Indeed, a meta-analysis of cross-sectional studies detected a large and significant positive effect of Tai Ji Quan on cardiovascular fitness.[41] Therefore, although studies that simultaneously examine Tai Ji Quan, cardiovascular fitness, cognition, and brain structure have been limited, the beneficial effects of Tai Ji Quan on cognition may be due to enhanced cardiovascular fitness.

4.3. Motor fitness status

In addition to continuous and routine movements, Tai Ji Quan is characterized by slow, complicated, graceful, balanced, and flexible movements. To perform Tai Ji Quan appropriately, an individual needs strong muscles to maintain and adjust his/her postures. Therefore, in addition to cardiovascular fitness, Tai Ji Quan has been recognized as increasing other physical and motor fitness levels, such as muscle strength, muscle endurance, flexibility, and balance.[42−44] The enhancement of motor fitness by Tai Ji Quan has also been extended to patients with neurodegenerative disease. Similar to improved leg muscle strength and reduced fall incidence from resistance training, Tai Ji Quan training has been shown to positively benefit muscle control, leg flexibility, and functional test performances compared with resistance and stretching groups in patients with Parkinson's disease.[45]

Notably, a high motor fitness level has recently been linked to better cognitive performance and a more efficient brain network. Voelcker-Rehage et al.[46] indicated that while cardiovascular fitness is possibly associated with executive function, motor fitness is positively correlated with both executive function and perceptual speed tasks. In addition, fMRI data revealed significant brain differences. Specifically, individuals with high cardiovascular fitness had active middle frontal, superior temporal, and inferior frontal gyri, whereas those with high motor fitness had an active supramarginal gyrus and inferior parietal lobe. These findings suggested that the type of fitness corresponds with different neural networks engaged during cognitive performance. Collectively, while the effects of cardiovascular and motor fitness on cognition and the brain have only been preliminarily examined, Tai Ji Quan can enhance both types of fitness and may affect multiple brain resources that influence cognition.

4.4. Movement coordination status

In additional to the cardiovascular fitness and motor fitness demands of Tai Ji Quan, it also involves coordination, conscious control, and low intensity, which should lead to overall improved movement coordination. Indeed, during Tai Ji Quan, particularly movements that require forward and backward shifting, coordination is necessarily involved, leading to substantial postural control in the lower extremities (e.g., hip, knee, and ankle joints).[47] Emerging evidence in studies in children and adolescents indicates a relationship between coordination of movements, better cognition[48] and brain activation.[49] For example, Chang et al.[49] separated individuals into a moderate or low intensity soccer course that emphasized coordination in movement training. Participants demonstrated faster reaction times and higher response accuracy in cognitive performance in both exercise intensity groups compared with a baseline group, suggesting that light exercise that is not sufficient to enhance fitness could nevertheless improve cognition. In addition, following coordination training, both groups exhibited a greater P3 amplitude and a shorter P3 latency in neuroelectrical indices, which indicate that the coordinative exercise itself increases the allocation of attentional resources and the efficiency of neurocognitive processing during the performance of a cognitive task. The findings of Chang et al.[49] provided a potential explanation for improved cognition following mild intensity Tai Ji Quan training; however, whether the positive relationship between movement coordination and brain activation could extend to older adults requires further examination.

4.5. Social interaction status

During Tai Ji Quan class, instructors and students experience substantial psychosocial interaction. Although Wayne and Kaptchuk[50] noted that they did not find any studies that focused on isolating the social effects of Tai Ji Quan (i.e., examining conditions with and without social support) in their review, they argued that Tai Ji Quan should be recognized as an intervention with significant potential for community-based social support. Interestingly, a recent study proposed by Mortimer et al.[51] has identified the association between Tai Ji Quan and social interaction, and this positive linkage has even extended to brain function. Following four groups (i.e., Tai Ji Quan, walking, social interaction, and control groups) over 40 weeks of intervention revealed significant improvements in dementia scales and neuropsychological assessments that measured basic information processes (e.g., Trail Making Test A), learning (e.g., Auditory Verbal Learning Test), and executive function (e.g., Trail Making Test B) in both Tai Ji Quan and social interaction groups but not in the walking or control groups, suggesting that social interaction within Tai Ji Quan may play an essential role in facilitating cognitive performance. Beneficial effects were also identified by MRI measurement, which found Tai Ji Quan and social interaction groups had significant mean percentage changes in normalized whole brain volume. These recent findings not only imply a potential relationship among Tai Ji Quan, social interaction, brain structure, and cognition, but also provide a foundation for further investigations.

4.6. Meditation status

Meditation may be the most unique dimension of Tai Ji Quan investigated compared to standard modes of PA. In Tai Ji Quan training, practitioners engage in a fundamental exercise, “chan-chuang/zhan-zhuang”, which literally means “standing like a post or standing meditation”. Requiring standing with a low or comfortable posture for an extended period of time, the main purpose of chan-chuang is not to enhance physical abilities (e.g., muscle strength) but to cultivate heightened perception through experiencing tranquility, awareness, relaxation, and the oneness of nature and humanity. Thus, it is theorized that Tai Ji Quan enhances cognition by promoting brain activation through meditation. Using an MRI technique, Luders et al.[52] found that individuals with long-term meditation experience had up to 15% greater right and left hippocampal volumes compared to their control counterparts. They also examined the meditation effect using diffusion tensor imaging (DTI), an approach to demark axonal tracts within the white matter *in vivo*, in 27 long-term meditation practitioners which showed a larger fractional anisotropy in the corticospinal tract, the temporal component of the superior longitudinal fasciculus, and uncinate fasciculus, suggesting that these individuals had better brain connectivity compared to matched controls.[53] Similarly enhanced white matter has also been observed in adults who participate in an integrative body-mind process with mindfulness meditation for 4 weeks, further supporting the potential of meditation to influence brain communication efficiency.[54]

4.7. Summary

Based upon this model, Tai Ji Quan could produce beneficial effects in cognition through multiple pathways, including cardiovascular fitness, motor fitness, movement coordination, social interaction, and meditation, given that the changes in these characteristics have been linked to better brain structure and function and brain health has been recognized as an essential factor in cognition based upon recent neuroimaging evidence. Nevertheless it should be noted that this is a preliminary model based upon neuroimaging studies emphasizing the relationship between PA/exercise−cognition and brain status and function. That being said, direct investigations of Tai Ji Quan’s influence upon cognition have been limited. This potential model is therefore presented as a guide for developing research to advance our understanding of the mechanisms driving the relationship between Tai Ji Quan and cognition.

5. Conclusions and future research directions

As reviewed above, a number of studies have provided intriguing evidence for the facilitative effects of Tai Ji Quan on cognitive functions in older adults with and without cognitive impairment. Furthermore, potential biological mechanisms linking Tai Ji Quan and cognition based on neuroimaging research have been proposed. However, it is important to acknowledge several methodological concerns that could limit our positive interpretations. For example, while the duration, frequency, and style of Tai Ji Quan were usually described quantitatively, previous studies have not always specified exercise intensity, which is a central component in exercise prescription. Exercise intensity is difficult to control because it fluctuates with the height of the posture, the duration of practice, and the style of Tai Ji Quan performed by the individual.[55] To address these limitations, Chang et al.[30] advocated that future research might consider assessing participant heart rates with a heart rate monitor, or use of a simple self-report (e.g., Ratings of Perceived Exertion) during Tai Ji Quan practice.

Individual differences likely moderate the relationship between Tai Ji Quan and cognition in older adults as well. Variables including education, social economic status, gender, intellectual ability, and health status have been linked to cognitive performance and therefore should be controlled as confounders. While a few previous studies have applied a randomized controlled trial design, the majority of studies of Tai Ji Quan and cognition have utilized only pre-experimental and quasi-experimental designs. Thus, firm conclusions about the effects of Tai Ji Quan on cognition cannot be reached due to the absence of appropriate control groups. Furthermore, the type of cognitive assessment and the level of cognitive impairment in various studies could affect the observed influence of Tai Ji Quan on cognition. For example, the MMSE

may be more sensitive to detecting the effects of Tai Ji Quan in older adults with cognitive impairment[24,28,29] than in those with intact cognition.[19–21] Additionally, few studies have focused on patients diagnosed with clinical dementia, and none of these studies have differentiated the sub-types of dementia, such as Alzheimer's disease or vascular dementia, as indicated in a review that examined PA and dementia.[56] Thus, the effects of Tai Ji Quan on cognition across specific types of dementia remains unclear.

Future research of the Tai Ji Quan–cognition relationship must address these unresolved issues. For example, studies that examined the effects of exercise on cognition have consistently observed a disproportionate influence on specific cognition; in other words, exercise has an especially positive effect on executive function.[14,57,58] However, given the comprehensive representation of executive function, Etnier and Chang[18] argued that the sub-types of executive function and appropriate measurements (i.e., neuropsychological assessments) should be considered when examining the effects of PA on cognition. Because the specific aspects of cognition that are influenced by Tai Ji Quan have yet to be investigated, further studies in this area are encouraged. Moreover, cross-disciplinary collaborations are necessary to advance our understanding, and these approaches, particularly through MRI, fMRI, and neuroelectrical techniques, have rapidly developed in the study of PA and cognition over last decade.[7,8,36–38,46] However, clear understanding of the relationship between Tai Ji Quan, the brain, and cognition has been limited. Finally, while Tai Ji Quan shares characteristics with standard modes of PA, it is also characterized by its social interaction, meditation, mindfulness, and imagery components. Along with recent research examining the psychosocial characteristics of Tai Ji Quan, these "mind" perspectives are intriguing directions for further exploration.

In conclusion, while research regarding the relationship between Tai Ji Quan and cognition in older adults is still in its infancy, we argue that Tai Ji Quan can moderate undesirable cognitive decline and/or improve cognitive function in later life. In addition, compared to aerobic exercise, which typically increases only cardiovascular fitness, Tai Ji Quan involves multifaceted physical improvements that could lead to additional impact on brain structure and function; therefore, Tai Ji Quan is recommended for older adults who are subject to normal and clinical cognitive decline.

Acknowledgment

We would like to express appreciation for support from partial grants from the National Science Council, Taiwan, China (NSC 101-2628-H-179-002, NSC 102-2420-H-179-001-MY3 to Yu-Kai Chang), during the preparation of this review.

References

1. Salthouse TA. When does age-related cognitive decline begin? *Neurobiol Aging* 2009;**30**:507–14.
2. Park DC, Reuter-Lorenz P. The adaptive brain: aging and neurocognitive scaffolding. *Annu Rev Psychol* 2009;**60**:173–96.
3. Kramer AF, Erickson KI, Colcombe SJ. Exercise, cognition, and the aging brain. *J Appl Physiol* 2006;**101**:1237–42.
4. Etgen T, Sander D, Huntgeburth U, Poppert H, Forstl H, Bickel H. Physical activity and incident cognitive impairment in elderly persons: the INVADE study. *Arch Int Med* 2010;**170**:186–93.
5. Middleton LE, Barnes DE, Lui LY, Yaffe K. Physical activity over the life course and its association with cognitive performance and impairment in old age. *J Am Geriatr Soc* 2010;**58**:1322–6.
6. Colcombe SJ, Erickson KI, Scalf P, Kim J, Prakash R, McAuley E, et al. Aerobic exercise training increases brain volume in aging humans. *J Gerontol A Biol Sci Med Sci* 2006;**61**:1166–70.
7. Erickson KI, Prakash RS, Voss MW, Chaddock L, Hu L, Morris KS, et al. Aerobic fitness is associated with hippocampal volume in elderly humans. *Hippocampus* 2009;**19**:1030–9.
8. Erickson KI, Voss MW, Prakash RS, Basak C, Szabo A, Chaddock L, et al. Exercise training increases size of hippocampus and improves memory. *Proc Natl Acad Sci U S A* 2011;**108**:3017–22.
9. Chang YK, Chu IH, Chen FT, Wang CC. Dose-response effect of acute resistance exercise on Tower of London in middle-aged adults. *J Sport Exerc Psychol* 2011;**33**:866–83.
10. Chang YK, Ku PW, Tomporowski PD, Chen FT, Huang CC. The effects of acute resistance exercise on late-middle-aged adults' goal planning. *Med Sci Sports Exerc* 2012;**44**:1773–9.
11. Chang YK, Pan CY, Chen FT, Tsai CL, Huang CC. Effect of resistance exercise training on cognitive function in healthy older adults: a review. *J Aging Phys Act* 2012;**20**:497–516.
12. Man DW, Tsang WW, Hui-Chan CW. Do older t'ai chi practitioners have better attention and memory function? *J Altern Complement Med* 2010;**16**:1259–64.
13. Hall CD, Miszko T, Wolf SL. Effects of Tai Chi intervention on dual-task ability in older adults: a pilot study. *Arch Phys Med Rehabil* 2009;**90**:525–9.
14. Colcombe SJ, Kramer AF. Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci* 2003;**14**:125–30.
15. Matthews MM, Williams HG. Can Tai Chi enhance cognitive vitality? A preliminary study of cognitive executive control in older adults after a Tai Chi intervention. *J S C Med Assoc* 2008;**104**:255–7.
16. Taylor-Piliae RE, Newell KA, Cherin R, Lee MJ, King AC, Haskell WH. Effects of Tai Chi and western exercise on physical and cognitive functioning in healthy community-dwelling older adults. *J Aging Phys Act* 2010;**18**:261–79.
17. Coubard OA, Duretz S, Lefebvre V, Lapalus P, Ferrufino L. Practice of contemporary dance improves cognitive flexibility in aging. *Front Aging Neurosci* 2011;**3**:13.
18. Etnier JL, Chang YK. The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature. *J Sport Exerc Psychol* 2009;**31**:469–83.
19. Kwok TCY, Lam K, Wong P, Chau W, Yuen KSL, Ting K, et al. Effectiveness of coordination exercise in improving cognitive function in older adults: a prospective study. *Clin Interv Aging* 2011;**6**:261–7.
20. Deschamps A, Onifade C, Decamps A, Bourdel-Marchasson I. Health-related quality of life in frail institutionalized elderly: effects of a cognition-action intervention and Tai Chi. *J Aging Phys Act* 2009;**17**:236–48.
21. Nowalk MP, Prendergast JM, Bayles CM, D'Amico FJ, Colvin GC. A randomized trial of exercise programs among older individuals living in two long-term care facilities: the FallsFREE program. *J Am Geriatr Soc* 2001;**49**:859–65.
22. Brucki SMD, Mansur LL, Carthery-Goulart MT, Nitrini R. Formal education, health literacy and mini-mental state examination. *Dement Neuropsychol* 2011;**5**:26–30.
23. Watfa G, Husson N, Buatois S, Laurain M, Miget P, Benetos A. Study of mini-mental state exam evolution in community-dwelling subjects aged over 60 years without dementia. *J Nutr Health Aging* 2011;**15**:901–4.
24. Chang JY, Tsai PF, Beck C, Hagen JL, Huff DC, Anand KJ, et al. The effect of tai chi on cognition in elders with cognitive impairment. *Medsurg Nurs* 2011;**20**:63–9. quiz 70.

25. Kasai JYT, Busse AL, Magaldi RM, Soci MA, de Moraes Rosa P, Curiati JAE, et al. Effects of Tai Chi Chuan on cognition of elderly women with mild cognitive impairment. *Einstein* 2010;**8**:40−5.
26. Lam LC, Chau RC, Wong BM, Fung AW, Tam CW, Leung GT, et al. A 1-year randomized controlled trial comparing mind body exercise (Tai Chi) with stretching and toning exercise on cognitive function in older Chinese adults at risk of cognitive decline. *J Am Med Dir Assoc* 2012;**13**(568):e15−20.
27. Petersen RC, Roberts RO, Knopman DS, Boeve BF, Geda YE, Ivnik RJ, et al. Mild cognitive impairment. *Arch Neurol* 2009;**66**:1447−55.
28. Burgener SC, Yang Y, Gilbert R, Marsh-Yant S. The effects of a multimodal intervention on outcomes of persons with early-stage dementia. *Am J Alzheimers Dis Other Demen* 2008;**23**:382−94.
29. Cheng ST, Chow PK, Song YQ, Yu EC, Chan AC, Lee TM, et al. Mental and physical activities delay cognitive decline in older persons with dementia. *Am J Geriatr Psychiatry* 2014;**22**:63−74.
30. Chang YK, Nien YH, Tsai CL, Etnier JL. Physical activity and cognition in older adults: the potential of Tai Chi Chuan. *J Aging Phys Act* 2010;**18**:451−72.
31. Demakis GJ. Frontal lobe damage and tests of executive processing: a meta-analysis of the category test, stroop test, and trail-making test. *J Clin Exp Neuropsychol* 2004;**26**:441−50.
32. Jack C, Petersen R, Xu Y, O'brien P, Smith G, Ivnik R, et al. Rates of hippocampal atrophy correlate with change in clinical status in aging and AD. *Neurology* 2000;**55**:484−90.
33. DeCarli C, Massaro J, Harvey D, Hald J, Tullberg M, Au R, et al. Measures of brain morphology and infarction in the Framingham Heart Study: establishing what is normal. *Neurobiol Aging* 2005;**26**:491−510.
34. Spreng RN, Wojtowicz M, Grady CL. Reliable differences in brain activity between young and old adults: a quantitative meta-analysis across multiple cognitive domains. *Neurosci Biobehav Rev* 2010;**34**:1178−94.
35. Grady C. The cognitive neuroscience of ageing. *Nat Rev Neurosci* 2012;**13**:491−505.
36. Colcombe SJ, Erickson KI, Raz N, Webb AG, Cohen NJ, McAuley E, et al. Aerobic fitness reduces brain tissue loss in aging humans. *J Gerontol A Biol Sci Med Sci* 2003;**58**:176−80.
37. Gordon BA, Rykhlevskaia EI, Brumback CR, Lee Y, Elavsky S, Konopack JF, et al. Neuroanatomical correlates of aging, cardiopulmonary fitness level, and education. *Psychophysiology* 2008;**45**:825−38.
38. Weinstein AM, Voss MW, Prakash RS, Chaddock L, Szabo A, White SM, et al. The association between aerobic fitness and executive function is mediated by prefrontal cortex volume. *Brain Behav Immun* 2012;**26**:811−9.
39. Honea R, Thomas GP, Harsha A, Anderson HS, Donnelly JE, Brooks WM, et al. Cardiorespiratory fitness and preserved medial temporal lobe volume in Alzheimer's disease. *Alzheimer Dis Assoc Disord* 2009;**23**:188−97.
40. American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription*. 9th ed. New York: Lippincott Williams and Wilkins; 2013.
41. Taylor-Piliae RE. The effectiveness of Tai Chi exercise in improving aerobic capacity: an updated meta-analysis. *Med Sport Sci* 2008;**52**:40−53.
42. Chen YS, Crowley Z, Zhou S, Cartwright C. Effects of 12-week Tai Chi training on soleus H-reflex and muscle strength in older adults: a pilot study. *Eur J Appl Physiol* 2012;**112**:2363−8.
43. Li JX, Xu DQ, Hong Y. Changes in muscle strength, endurance, and reaction of the lower extremities with Tai Chi intervention. *J Biomech* 2009;**42**:967−71.
44. Lu X, Hui-Chan CW, Tsang WW. Tai Chi, arterial compliance, and muscle strength in older adults. *Eur J Prev Cardiol* 2013;**20**:613−9.
45. Tsang WW. Tai Chi training is effective in reducing balance impairments and falls in patients with Parkinson's disease. *J Physiother* 2013;**59**:55.
46. Voelcker-Rehage C, Godde B, Staudinger UM. Physical and motor fitness are both related to cognition in old age. *Eur J Neurosci* 2010;**31**:167−76.
47. Wang LH, Lo KC, Lin CJ, Su FC. Multijoint coordination of lower extremity in Tai Chi exercise. *J Mech Med Biol* 2010;**10**:479−93.
48. Budde H, Voelcker-Rehage C, Pietrabyk-Kendziorra S, Ribeiro P, Tidow G. Acute coordinative exercise improves attentional performance in adolescents. *Neurosci Lett* 2008;**441**:219−23.
49. Chang YK, Tsai YJ, Chen TT, Hung TM. The Impacts of coordinative exercise on executive function in kindergarten children: an ERP study. *Exp Brain Res* 2013;**225**:187−96.
50. Wayne PM, Kaptchuk TJ. Challenges inherent to t'ai ci research: part I-t'ai chi as a complex multicomponent intervention. *J Altern Complement Med* 2008;**14**:95−102.
51. Mortimer JA, Ding D, Borenstein AR, DeCarli C, Guo Q, Wu Y, et al. Changes in brain volume and cognition in a randomized trial of exercise and social interaction in a community-based sample of non-demented Chinese elders. *J Alzheimers Dis* 2012;**30**:757−66.
52. Luders E, Thompson PM, Kurth F, Hong JY, Phillips OR, Wang Y, et al. Global and regional alterations of hippocampal anatomy in long-term meditation practitioners. *Hum Brain Mapp* 2013;**34**:3369−75.
53. Luders E, Clark K, Narr KL, Toga AW. Enhanced brain connectivity in long-term meditation practitioners. *Neuroimage* 2011;**57**:1308−16.
54. Tang YY, Lu Q, Fan M, Yang Y, Posner MI. Mechanisms of white matter changes induced by meditation. *Proc Natl Acad Sci U S A* 2012;**109**:10570−4.
55. Lan C, Lai JS, Chen SY. Tai Chi Chuan: an ancient wisdom on exercise and health promotion. *Sports Med* 2002;**32**:217−24.
56. Forbes D, Forbes S, Morgan Debra G, Markle-Reid M, Wood J, Culum I. Physical activity programs for persons with dementia. *Cochrane Database Syst Rev* 2008:CD006489. http://dx.doi.org/10.1002/14651858.CD006489.pub2.
57. Themanson JR, Hillman CH. Cardiorespiratory fitness and acute aerobic exercise effects on neuroelectric and behaviorla measures of action monitoring. *Neuroscience* 2006;**141**:757−67.
58. Pontifex MB, Raine LB, Johnson CR, Chaddock L, Voss MW, Cohen NJ, et al. Cardiorespiratory fitness and the flexible modulation of cognitive control in preadolescent children. *J Cogn Neurosci* 2011;**23**:1332−45.