The benefits of Tai Chi and brisk walking for cognitive function and fitness in older adults

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ABSTRACT

The purpose of this study was to investigate the benefits of exercises with different cognitive demands for cognitive functions (Executive and non-Executive) in healthy older adults. A cross-sectional design was adopted. In total, 84 healthy older adults were enrolled in the study. They were categorized into the Tai Chi group (TG), the brisk walking group (BG) or the control group (CG). Each participant performed the Stroop task and a digit comparison task. The Stroop task included the following three conditions: a naming condition, an inhibition condition and an executive condition. There were two experimental conditions in the digit comparison task: the non-delay condition and the delay condition. The results indicated that participants of the TG and BG revealed significant better performance than the CG in the executive condition of cognitive tasks and fitness. There was no significant difference of reaction time (RT) and accuracy rate in the inhibition and delay conditions of cognitive tasks and fitness between the TG and BG. The TG showed shorter reaction time in the naming and the executive conditions, and more accurate in the inhibition conditions than the BG. These findings demonstrated that regular participation in brisk walking and Tai Chi have significant beneficial effects on executive function and fitness. However, due to the high cognitive demands of the exercise, Tai Chi benefit cognitive functions (Executive and non-Executive) in older adults more than brisk walking does. Further studies should research the underlying mechanisms at the behavioural and neuroelectric levels, providing more evidence to explain the effect of high-cognitive demands exercise on different processing levels of cognition.

INTRODUCTION

The consequences of old age, including cognitive decline, has been an essential problem around the world (*Kurth, Cherbuin & Luders, 2017*). The decline in cognitive function, especially executive function, is impacted by ageing (*Colcombe & Kramer, 2003*). Executive function refers to an established higher-order cognitive process of control and coordination that allows for behavioural adaptation to complex or novel situations (*Diamond, 2012*). In particular, executive function consists of three sub-constructs: inhibition control, working memory, and task-switching (*Diamond, 2012*; *Miyake et al., 2000*).

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Research has indicated that a positive relationship exists between physical activity and executive function (*Salthouse, 2010*). Though most of previous exercise-cognition researches have focused on aerobic exercises (e.g., brisk walk, jogging and treadmill), later studies have demonstrated resistance exercise (*Chang et al., 2012*), dance (*Chuang et al., 2015*; *Kosmat & Vranic, 2016*) or coordination training (*Voelcker-Rehage & Niemann, 2013*) also could delay the decline of cognitive function. Many researchers have investigated the benefits of Tai Chi or aerobic exercises on cognitive decline, but limited studies have compared the benefits of aerobic exercises and Tai Chi on executive function. To our knowledge, few studies compared aerobic exercise and Tai Chi (*Fong et al., 2014*; *Taylor-Piliae et al., 2010*). *Taylor-Piliae et al. (2010)* revealed the results showed Tai Chi resulted in greater improvements in cognitive function compared to the attention-control groups and Western exercises, which included aerobic exercise, incorporated endurance, resistance/strength, and flexibility exercises. Conversely, another study by *Fong et al. (2014)* compared the task-switching aspect of executive function between participants undergoing aerobic exercises and Tai Chi participants. The results showed a positive relationship was observed regardless of the types of physical activity and task-switching (*Fong et al., 2014*). Some researchers suggested TC practice might have a similar pattern to the cortical morphology associated with aerobic exercise (*Wei et al., 2013*). In ERP studies, Tai Chi and aerobic exercise groups had a significantly larger P300 amplitude compared with sedentary group in cognitive tasks, but no difference was found between Tai Chi and endurance exercise groups (*Dai et al., 2013*; *Fong et al., 2014*). However, most of those studies did not assess the cardiorespiratory fitness or other physical fitness, so they did not control several confounding variables, which may affect cognition. Furthermore, the inhibition, working memory, and task-switching which are predominant sub-constructs of executive function need be reviewed. Only one of the sub-constructs was mentioned in previous studies. Therefore, this study should compare the effect on cardiorespiratory fitness and cognitive functions between Tai Chi and aerobic exercise.

Tai Chi, which is a moderate-intensity high demand activity that combines memorized, controlled physical postures and movements (*Miller & Taylor-Piliae, 2014*), is a high cognitive demand exercise. *Chang et al. (2010)* thought that the intensity of Tai Chi was similar to brisk walking and safe for older adults. Therefore, the difference between Tai Chi and brisk walking was the intensity of cognitive demand. Notably, studies found open-skill (i.e., table tennis and tennis) and closed-skill (i.e., jogging and swimming) exercises induced differential effects on executive functions. Results of studies supported that open-skill exercise may have a more beneficial effect on executive function in older adults (*Dai et al., 2013*; *Guo et al., 2016*; *Huang et al., 2014*). These studies found compared to closed-skill exercises, open-skill exercises is high cognitive demanded exercise that require a quick response to deal with complex environments, and more cognitive resources must be demanded to increase the efficiency of decision-making processes (*Dai et al., 2013*; *Guo et al., 2016*). In line with it, *Pesce (2012)* argued that future research should emphasize the qualitative aspects of exercise, such as exercise involving more physical and exercise-related cognitive features, rather than only targeting quantitative exercise characteristics such as exercise intensity, duration, and frequency. Therefore, cognition

demand of exercise may one of potential influential factors of the effect of exercise on cognitive function. However, these studies did not compare several confounding variables in different exercises, such as cardiorespiratory fitness, they could not prove the benefit of exercises with different cognitive demands on cognitive functions.

The type of cognition has been examined from basic information processing to higher levels of cognition (i.e., executive function). Some studies revealed that exercise has a different impact on different processing levels of tasks. Previous studies indicated that long-term exercise revealed the strongest effect on the executive function of older adults and formulated the selective improvement hypothesis (*Colcombe & Kramer, 2003*; *Kramer et al., 1999*). Later studies supported this theory, demonstrating aerobic exercise is more likely to benefit performance on tasks that involve higher rather than lower processing levels, especially in the executive function (*Dupuy et al., 2014*; *Mekari et al., 2015*). So, what is the effect of Tai Chi on different processing levels of task? In the reviews, Tai Chi improved executive function in older adults (*Zheng et al., 2015*). However, the results of different processing levels of tasks were inconsistent. For example, some studies revealed that Tai Chi could improve the performance in TMT-A and TMT-B tests (*Hung & Andreas, 2012*; *Reid-Arndt, Matsuda & Cox, 2012*). In contrast, *Matthews & Williams (2008)* found TC group improved in TMT-B, but no improvement in TMT-A. TMT-A and TMT-B tests could be classified into different processing levels of tasks, such as attention and executive function by domain (*Smith et al., 2010*). Thus, the conclusion that Tai Chi was more beneficial for tasks that relied on executive control processes was still open to debate. Other results revealed that Tai Chi can also improve cognition like attention and memory functions, and not only executive control (*Kim et al., 2016*; *Man, Tsang & Hui-Chan, 2010*). Taken together, the current study was to compare the performance on different tasks which can identify the different cognitive processing between Tai Chi and aerobic exercise. If different processing levels of tasks could be explicitly assessed, it would help researchers to normalize the measurement and facilitate the comparisons for future research. In these studies, only the TMT task was used to measure the different processing levels of cognitive function. Based on previous research, two types of tasks have been applied to assess the performance in different cognitive demand: an executive task and a non-executive task (*Dupuy et al., 2014*; *Gauthier et al., 2015*).

Accordingly, the main purpose of this study was to assess the benefits of exercises with different cognitive demands (Tai Chi and brisk walking) on cognitive functions (Executive and non-Executive) and fitness in healthy older adults. The classifications of these tasks according to their processing levels and their main brain regions were relevant. Therefore, the tasks involved higher mental functioning capacity by the frontal lobe and lower by the frontal lobe (*Voelcker-Rehage & Niemann, 2013*). We hypothesized that: (1) Tai Chi and brisk walking exercisers would show shorter RTs and more accurate in the executive function condition of the Stroop task and the digit comparison task than sedentary controls, (2) Tai Chi exercisers would show shorter RTs and more accurate in the non-executive function condition of the Stroop task and the digit comparison task than brisk walking exercisers and sedentary controls, and (3) Tai Chi exercisers would exhibit

similar cardiorespiratory fitness and dynamic balance ability as brisk walking exercisers, but better than sedentary controls.

METHODS

Ethical approval

The study was conducted ethically and received approval from the Ethics Committee of Shanghai University of Sport (No. 2017032).

Participants

Healthy older adults aged 60 to 72 years from a local community in Shanghai, China were recruited via advertisements placed throughout the community. The inclusion criteria were as follows: no history of major psychiatric illness (e.g., schizophrenia or bipolar disorder) or other serious neurological or musculoskeletal diagnoses; score ≥ 26 on the Mini-Mental Status Examination (MMSE); right-handedness; and normal or corrected-to-normal vision. Additionally, these participants met the following fitness criteria: no history of falling; the ability to walk without a cane or other assistive devices; body mass index (BMI) <25.0 and >18.5. All participants signed the written informed consent form provided by the Ethics Committee of Shanghai University of Sport.

A total of 84 older adults who met the requirements were recruited for the formal experiments. The eligible participants were assigned to three groups: the Tai Chi group (TG), the brisk walking group (BG), and the control group (CG). Each group included 28 participants. Potential subjects who engaged in both types of physical exercises or had practised for fewer than five years were excluded. Participants who had little or no exercise training for at least five years were assigned to the control group. The Tai Chi and brisk walking groups generally participated in Tai Chi (i.e., Tai Chi chuan or Qi Gong) or brisk walking exercises at least five times per week for 30 min per session for at least five years. The type-of-exercise questionnaire evaluated the specific type of exercise performed and the frequency per week, the duration per session and the number of years the participant had been practicing the specific type of exercise.

Experimental procedure

The participants visited the laboratory individually two times. At the first visit, the participants were given a general description of the study, signed the consent form, and completed various questionnaires (a health history and demographics questionnaire; the International Physical Activity Questionnaire (IPAQ), a type-of-exercise questionnaire; and the MMSE) under the instruction of the experimenter. After the participants' eligibility for participation in the study was confirmed, they completed the fitness tests. Within three days, the participants visited the laboratory again to complete the cognitive tests. Prior to each task, the participants performed 20 practice trials with feedback for each condition. They continued with the experiments only if their accuracy rate reached 75% in the practice trials. The order of the two tasks was counterbalanced within the groups.

Anthropometrics and fitness

Height (m) and body weight (kg) were evaluated to determine the BMI (kg/m^2). Hand-grip strength was measured with a hand-held dynamometer (Sammons Preston Rolyan; Jamar, Nottinghamshire, UK). The participants performed the hand-grip test twice with each hand, and the best results were used for the analysis. Physical activity levels were assessed with the Taiwan version of the IPAQ (*Liou et al., 2008*). The short version of the IPAQ is an 8-item scale that estimates the number of minutes spent engaging in vigorous and moderate intensity activity, walking, and sedentary behaviour during the previous seven days. The total amount of physical activity is calculated by adding the MET minutes and categorizing them as inactivity (i.e., fewer than 600 METs), moderate activity (i.e., 600–3,000 METs), and sufficient activity (i.e., >3,000 METs overall).

The 6-minute walk test (6MWT) is a simple test that is widely used in clinical settings to assess cardiorespiratory fitness (*Burr et al., 2011*; *Camarri et al., 2006*). Prior to the 6MWT evaluation, all participants completed a practice session. The 6MWT was performed over a 50-m-long straight course within an enclosed, level corridor. In both settings, each end of the 10-m walking course was marked on the floor using coloured tape. The participants were instructed to "cover as much distance as possible" during the test. The number of metres walked was recorded.

The timed up-and-go (TUG) test was used to evaluate dynamic balance ability (*Clark et al., 2010*; *Porciuncula, Rao & Mcisaac, 2016*). The participants were given verbal instructions to stand up from a seated position in a chair, walk a distance of 3 m as quickly and safely as possible, cross a mark on the floor, turn around, walk back to the chair and sit. The participants were allowed one TUG practice trial to familiarize themselves with the tasks. The study selected the following two conditions for the dual-task TUG: (1) in the mTUG task, the participants were asked to remember six random numbers while walking and to verbally repeat the correct numbers after sitting down, and (2) in the cTUG task, the participants were asked to cross a 17-cm-high (kerb height) obstacle while walking. The tests were completed three times, and the shortest duration was recorded for each task (*Shumway-Cook, Brauer & Woollacott, 2000*). The participants were instructed to walk as quickly as possible and to perform the secondary task as quickly and/or accurately as possible. For safety reasons, the participants practised all the tasks. Furthermore, the participants did not complete the test alone; an experimenter supervised the test throughout the experiment.

Cognitive test
Modified stroop task

The computerized modified Stroop task is based on the Stroop task and includes the following three conditions: a naming condition (non-executive), a inhibition condition, and an executive condition (*Bohnen, Twijnstra & Jolles, 1992*; *Olivier et al., 2015*). Each condition includes two blocks, and each block is composed of 30 trials, resulting in 180 trials for the three experimental conditions. All the experimental trials began with a fixation cross for 1,000 ms, and all visual stimuli appeared at the centre of the computer screen for a duration of 2,000 ms. The participants provided their responses by pressing the "F"
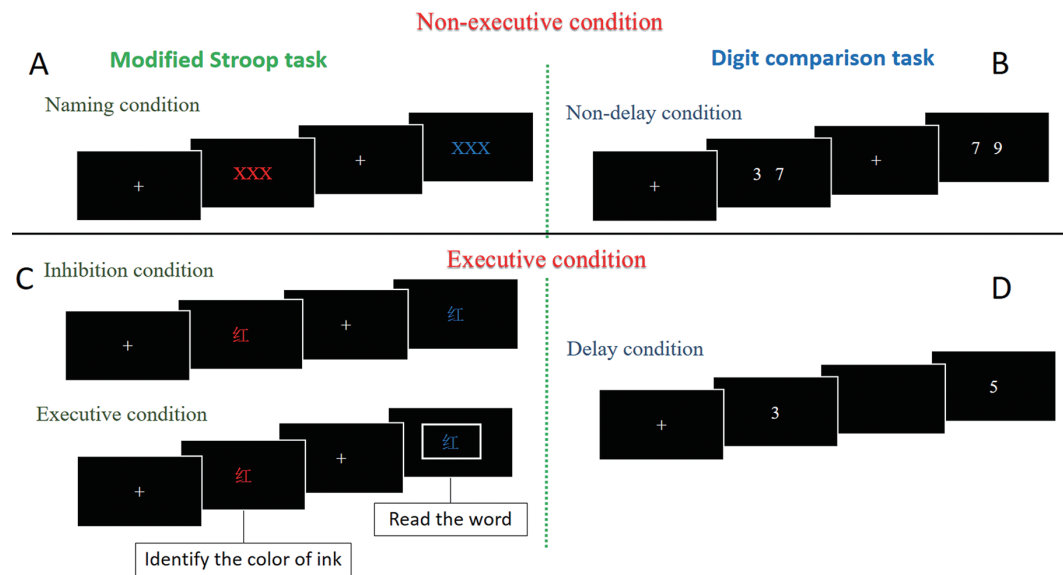
Figure 1 Illustration of the modified stroop task and digit comparison task. (A) The naming condition of the Modified Stroop task; (B) The non-delay condition of the digit comparison task; (C) The inhibition and executive conditions of the Modified Stroop task; (D) The non-delay condition of the digit comparison task.

button on a QWERTY keyboard with their left index finger if the testing stimulus was "Blue" and pressing the "J" button with their right index finger if it was "Red". In the naming condition, a visual stimulus (XXX) coloured red or in blue was presented, and the participants were asked to identify the colour of the writing by pressing a button. One block of the naming condition had 30 trials consisting of 15 red stimuli and 15 blue stimuli with mixed presentation. In the inhibition condition, the participants were presented with the word 蓝 in red or 红 in blue, and they had to restrain from reading the word and respond only to the text colour. One block of the inhibition condition had 30 trials consisting of 15 congruent and 15 incongruent trials. Two trial conditions were included in the executive condition task: inhibition and switch. Half of the trials were the same as those described for the inhibition condition. In the other trials, the words presented were surrounded by a rectangle (i.e., the word "蓝" was printed in red ink), and when a rectangle appeared around the word, the participants were instructed to change their response to read the word, ignore the colour of the writing, and respond to the word itself (i.e., 蓝). Thirty trials (20 inhibition and 10 switch) were included in one block of the executive condition (see Figs. 1A, 1C). The experimental blocks were interspersed with a 1-min condition called "Rest". The total Stroop task duration was approximately 15 min.

Modified digit comparison task

Working memory was evaluated using the modified digit comparison task. The participants were informed to indicate which number was larger by pressing the button. The number was represented by a pair of digits was ranging from 0 to 9 (e.g., "7" and "9"). There were

two experimental conditions: non-delay (non-executive) and delay (executive) (*Turner & Spreng, 2012*). Each run of the task involved two blocks of each condition composed of 30 trials in each block, resulting in 60 trials per experimental condition. In the non-delay condition trials, the visual stimulus set consisted of a pair of numbers that were simultaneously presented on the computer screen. The participants were required to press the "F" button on a QWERTY keyboard with their left index finger if the left number was larger and the press button "J" with their right index finger if the right number is larger. In the delay condition trials, there was a 1,500-ms delay between the digit pairs. Participants provided their responses by pressing the "F" button on a QWERTY keyboard with their left index finger if the first number was larger, and the "J" with their right index finger if the later number was larger. Experimental blocks where interspersed with a 1-min condition named Rest. Total digit comparison task duration was approximately 10 min (see Figs. 1B, 1D).

Statistical analyses

The statistical analyses were performed using SPSS version 22. One-way ANOVA was used to determine statistically significant differences in age, weight, height, BMI, the MMSE score, education, grip strength, 6MWT and the IPAQ score among the three groups. A mixed design 3 (Group: Tai Chi, brisk walking, and sedentary) × 3 (Condition: TUG, cTUG, and mTUG) ANOVA was used to analyse duration differences for the TUG test. RT and accuracy rate were used to evaluate the performance of cognitive tests. The RT data (i.e., the elapsed time from when the test stimuli were presented to when the keys were pressed) and accuracy rate data were collected using E-Prime (version 1.1) software. All error trials and trials with RTs more than three standard deviations from the individual mean were treated as outliers and were discarded prior to the analysis. Two mixed-design 3 (Group: Tai Chi, brisk walking, sedentary) × 3 (Condition: naming, inhibition, executive) ANOVAs were used to analyse differences in the RT and accuracy rates for the Stroop task. Two mixed-design 3 (Group: Tai Chi, brisk walking, and sedentary) × 2 (Condition: delay and non-delay) ANOVAs were used to analyse differences in the RT and accuracy rates for the digit comparison task. Post hoc comparisons were indicated using least significant difference tests. Effect size was expressed as partial eta-squared (η^2) to determine the magnitude of the effect when significant main and interaction effects were reached. The significance threshold was set at $p < 0.05$.

RESULTS

Anthropometrics and fitness

No significant differences were found in age ($F_{(2,81)} = 0.70$, $p = 0.50$), weight ($F_{(2,81)} = 0.54$, $p = 0.59$), height ($F_{(2,81)} = 0.62$, $p = 0.54$), BMI ($F_{(2,81)} = 0.57$, $p = 0.57$), MMSE score ($F_{(2,81)} = 0.08$, $p = 0.93$), or education ($F_{(2,81)} = 0.70$, $p = 0.51$) between the groups. There were significant differences in grip strength ($F_{(2,81)} = 3.57$, $p < 0.05$, $\eta^2 = 0.08$), 6MWT ($F_{(2,81)} = 165.72$, $p < 0.001$, $\eta^2 = 0.80$), and IPAQ scores ($F_{(2,81)} = 177.85$, $p < 0.001$, $\eta^2 = 0.82$). The post hoc comparison showed that the TG and BG had greater grip strength, longer 6 MWT and higher IPAQ scores than the CG, but no significant difference was found

Table 1 Participant characteristics.

	Tai Chi group (28)	Aerobic group (28)	Control group (28)
Age, years	66.14 ± 3.40	65.36 ± 4.06	65.04 ± 3.33
Gender (women, n)	18	19	19
Weight, kg	59.68 ± 5.29	57.75 ± 7.09	58.75 ± 8.24
Height, cm	163.29 ± 5.68	162.00 ± 6.53	161.43 ± 6.89
BMI	22.39 ± 1.76	21.95 ± 1.78	22.51 ± 2.62
MMSE score	27.93 ± 0.66	27.93 ± 0.94	27.86 ± 0.80
Education, years	11.11 ± 1.85	11.14 ± 1.76	10.64 ± 1.68
Muscle strength, kg	28.83 ± 6.51	28.47 ± 5.62	25.08 ± 5.16[*, #]
6MWT, m	573.41 ± 13.08	575.94 ± 14.12	516.09 ± 14.50[*, #]
IPAQ, METs	2453.39 ± 486.03	2415.88 ± 610.81	426.84 ± 159.71[*, #]
TUG, s	6.03 ± 0.45	6.26 ± 0.68	6.68 ± 0.58[**, ##]
cTUG, s	6.95 ± 0.54	6.96 ± 0.64	7.30 ± 0.67[*]
mTUG, s	6.29 ± 0.50	6.48 ± 0.55	7.03 ± 0.68[**, ##]

Notes.

BMI, body mass index; MMSE, min mental state exam; IPAQ, International physical activity questionnaire; METs, metabolic equivalents; 6MWT, six minute walk test; TUG, Time UP and GO; cTUG, TUG with crossing obstacle; mTUG, TUG with memory task.

[*]Represent the significant differences between the Tai Chi group and the control group, $p < 0.05$.
[**]Represent the significant differences between the Tai Chi group and the control group, ($p < 0.01$).
[#]Represent the significant differences between the brisk walking group and the control group, $p < 0.05$.
[##]Represent the significant differences between the brisk walking group and the control group, $p < 0.01$.

between the TG and BG. There were significant main effects of the task ($F_{(2,162)} = 114.18$, $p < 0.001$, $\eta^2 = 0.59$) and group ($F_{(2,81)} = 8.26$, $p < 0.001$, $\eta^2 = 0.17$). No significant interaction was found between the task and the group ($F_{(4,162)} = 1.824$, $p = 0.13$). The post hoc comparison revealed that TG and BG were shorter than CG regardless of conditions in TUG test. Table 1 shows the main characteristics of the subjects in the different groups.

Modified stroop task

Regarding the RT results, there were main effects for condition ($F_{(2,162)} = 624.07$, $p < 0.001$, $\eta^2 = 0.89$), and group ($F_{(2,81)} = 30.58$, $p < 0.01$, $\eta^2 = 0.44$). An interaction between condition and group was observed ($F_{(4,162)} = 10.58$, $p < 0.001$, $\eta^2 = 0.21$). The post hoc comparison of RT in two conditions showed that RT in the non-delay condition was shorter than that in the delay condition for three groups ($p < 0.05$). Moreover, regarding the groups, the TG had a shorter RT than the CG ($p < 0.001$) and the BG ($p < 0.05$) in the naming condition, but no significant difference was found between the BG and CG ($p = 0.11$). In the inhibition condition, the TG ($p < 0.001$) and BG ($p < 0.001$) had shorter RTs than the CG, but no significant difference was found between the TG and BG ($p = 0.10$). In the executive condition, the TG had a shorter RT than the BG ($p < 0.001$) and the CG ($p < 0.001$), and the BG had a shorter RT than the CG ($p < 0.001$).

For accuracy rate, there was a significant main effect of group ($F_{(2,162)} = 45.74$, $p < 0.001$, $\eta^2 = 0.36$), but no significant main effect of condition ($F_{(2,81)} = 0.92$, $p = 0.40$). No interaction between condition and group was observed ($F_{(4,162)} = 1.11$, $p = 0.35$). The post hoc comparison showed that accuracy rate in the non-delay condition was greater accuracy than that in the delay condition for three group ($p < 0.01$). For the effect of group, the
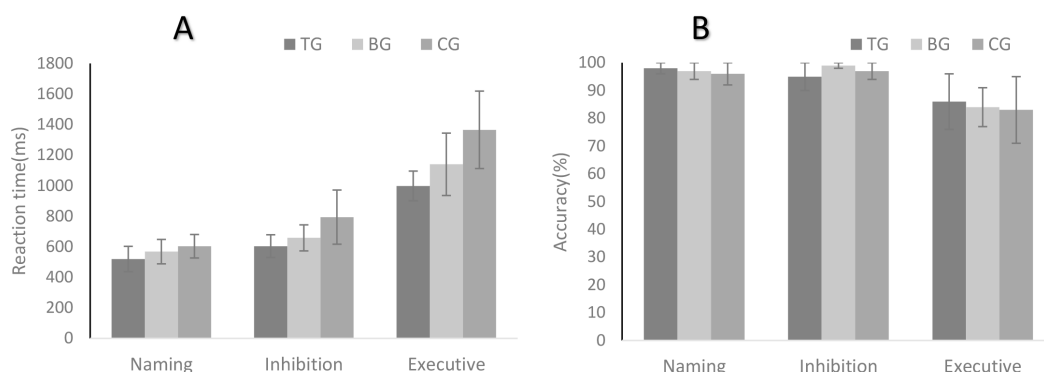
Figure 2 **Reaction time (A) and accuracy rates (B) in the modified Stroop task: the naming condition, the inhibition condition and the executive condition.** TG, Tai Chi group; BG, brisk walking group ; CG, control group.

TG exhibited greater accuracy than the CG ($p < 0.05$) in the naming condition, but no significant differences between the TG and the BG ($p = 0.56$) or between the BG and the CG ($p = 0.12$) were found. In the inhibition condition, the TG had greater accuracy than the BG ($p < 0.05$), but no significant differences were found between the TG and the CG ($p = 0.14$) or between the BG and the CG ($p = 0.27$). In the executive condition, there were no significant differences among the three groups. All results are presented in Fig. 2.

Modified digit comparison task

The results of the modified digit comparison task in the non-delay and delay conditions are presented in Fig. 2. There were significant main effects of condition ($F_{(1,81)} = 189.98$, $p < 0.001$, $\eta^2 = 0.70$) and group ($F_{(2,81)} = 189.98$, $p < 0.001$, $\eta^2 = 0.03$) and a significant interaction between condition and group ($F_{(2,81)} = 28.46$, $p < 0.001$, $\eta^2 = 0.41$). The post hoc comparisons of condition revealed that RT in the naming condition and inhibition condition was shorter than that in the executive condition for three groups ($p < 0.01$). There was no significant difference of the RT between the naming condition and inhibition condition in the BG and CG. In the TG, RT in the naming condition was shorter than that in the inhibition condition ($p < 0.05$). The results of group effects showed that the TG had a shorter RT than the BG ($p < 0.001$) and the CG ($p < 0.001$), and the BG had a shorter RT than the CG ($p < 0.05$). In the non-delay condition, no significant differences were found among the three groups.

There was a main effect of the accuracy rate of the conditions ($F_{(1,81)} = 39.86$, $p < 0.001$, $\eta^2 = 0.33$). There was no main effect of groups ($F_{(2,81)} = 0.67$, $p < 0.52$), and no significant interaction was observed between the conditions and the groups ($F_{(2,81)} = 0.57$, $p = 0.57$). Post hoc comparisons revealed that the higher accuracy rate was showed in non-delay condition ($p < 0.05$). All results are presented in Fig. 3.
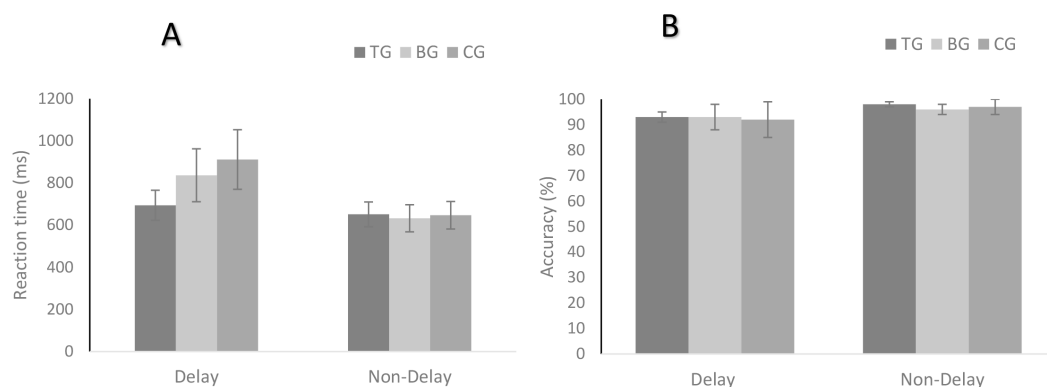
Figure 3 Reaction time (A) and accuracy (B) in the modified digit comparison task: the non-delay condition and the delay condition. TG, Tai Chi group; BG, brisk walking group; CG, control group.

DISCUSSION

This study aimed to compare the differences between the effects of Tai Chi and brisk walking on the cognitive functions of inhibition and working memory as well as the cardiorespiratory fitness and dynamic balance ability in healthy older adults. Consistent with previous studies, the older adults who engaged in exercise, regardless of the exercise type, showed shorter RT than the age-matched sedentary controls in executive condition. Due to the high cognitive demands of the exercise, the TG benefit cognition on both non-executive and executive condition of cognitive tasks more than the CG and the BG does. Additionally, the TG and BG showed better cardiorespiratory fitness and dynamic balance ability than the CG, but no significant difference was found between the TG and BG.

Based on previous research, we used cognitive tasks involving two processing levels: executive and non-executive (*Dupuy et al., 2014*; *Gauthier et al., 2015*). A significant main effect of condition was observed in terms of longer RTs for the executive function conditions than the non-executive function conditions of the Stroop and digit comparison tasks, replicating previous studies in which executive condition tasks required greater amounts of executive control. *Mekari et al. (2015)* concluded that the results for the naming condition of the Stroop task was similar to those for simple reactions that did not require a substantial executive control component. A previous functional magnetic resonance imaging study demonstrated the presence of different cerebrovascular reactivities between executive and non-executive (naming) condition of the Stroop task (*Gauthier et al., 2015*). The task-related regions in the frontal area of the brain exhibited significantly increased brain activity during the executive condition compared with the naming condition of the Stroop task (*Dupuy et al., 2014*).

The most important purpose of the present study was to indicate the relationship between the type of exercise and the executive function, especially for the Tai Chi and brisk walking groups. In the present study, the TG and BG exhibited significantly shorter RTs in the inhibition condition, the executive condition of the Stroop task and the delay condition of digit comparison task than the CG. Moreover, the older adults in the TG and BG

showed similar or greater accuracy rates compared with the CG, indicating that the shorter RTs could be attributed to the physical activity rather than to a speed-accuracy trade-off. The results are consistent with previous studies that both Tai Chi and aerobic exercise can improve inhibition and working memory (*Chang et al., 2013*; *Walsh et al., 2015*) in older adults. Previous meta-analyses have confirmed that Tai Chi has moderate effects on verbal working memory which was measured by Digit span test and the executive function which was measured by TMT (*Wu et al., 2013*). Furthermore, the BG was significantly correlated with shorter RTs in the executive condition but not in the non-executive condition. The present results supports the hypothesis that selective improvement due to long-term aerobic exercise is more beneficial for tasks that require executive control than for tasks that do not (*Colcombe & Kramer, 2003*; *Kramer et al., 1999*). In addition, fitness, a multi-faceted concept that includes physical (i.e., cardiovascular fitness and muscular strength) and motor fitness (i.e., flexibility, speed, balance and fine coordination) (*Brent, 2010*) have been proposed as potential factors that promote healthy cognitive aging (*Miller et al., 2012*). Researches suggested that a higher physical activity level and cardiorespiratory fitness are positively associated with executive function in older adults (*Fong et al., 2014*; *Huang et al., 2014*; *Voelcker-Rehage & Niemann, 2013*; *Zimmerman et al., 2014*). In current study, the TG and BG both had higher physical activity levels than the CG. Consistent with previous results, higher levels of physically activity were correlated with better executive function in older adults (*Chang et al., 2013*). Similarly, the results suggest that brisk walking and Tai Chi can both improve cardiorespiratory fitness and dynamic balance ability (*Van Iersel et al., 2008*), but no difference between the TG and BG. These results were consistent with the previous study indicated that higher cardiorespiratory fitness was associated with better performance on executive function tasks (*Dupuy et al., 2014*). Additionally, we sought to determine whether Tai Chi can improve cognitive function without sacrificing physiological functions. In the current study, the results showed that the TG and BG showed shorter reactive times than the sedentary older adults in the TUG and mTUG tests. This result also proved that TG and BG showed better cognitive function than CG because, especially in the mTUG test, a decreased gait ability during dual tasks could be due to a limited capacity to process attention or to competition for cognitive resources (*Mirelman et al., 2012*). The TG and BG may conserve their cognitive resources and pay more attention to walking. The results demonstrated that Tai Chi and brisk walking can produce greater dynamic balance ability and cognitive function, which was consistent with our hypothesis and previously published studies (*Hakim et al., 2004*; *Lee et al., 2012*; *Zhang et al., 2014*).

The interesting result was with the different effect on cognitive function between the TG and BG. In current study, older adults in the TG performed better in the naming condition and executive condition than BG. The reasons for these different effects on cognitive function between TG and BG are remain unclear. However, the different characteristics between Tai Chi and brisk walking provide evidence. Tai Chi and brisk walking are both moderate-intensity activities that offer cognitive benefits (*Chang et al., 2010*), but there are different cognitive demands between them. *Zheng et al. (2015)* reported that it involves learning and memorizing new skills and movement patterns and sustaining attention, which could be helpful for improving working memory, divided attention and

overall executive ability. Taken together, these elements suggest that, compared with brisk walking, the benefits of Tai Chi may be attributed to the increased cognitive demands of practising the exercise. *Lauenroth, Ioannidis & Teichmann (2016)* found that training that utilized combined cognitive exercise and aerobic training interventions improved attention, processing speed and executive function to a greater extent than aerobic exercise alone. The results were in accordance with studies of Tai Chi. *Kim et al. (2016)* noted that Tai Chi could improve attentional inhibition assessed by the Antisaccade task and mental attention measured using the Figural Intersections Task. Therefore, current results can support that Tai Chi could improve the performance in tests which examined from basic information processing to higher levels of cognition (*Hung & Andreas, 2012*; *Reid-Arndt, Matsuda & Cox, 2012*). A systematic review showed that Tai Chi exercise benefited attention, memory and perception in healthy adults (*Zheng et al., 2015*). In contrast, evidence from previous studies suggests that aerobic exercises that have little or no cognitive demand can have a beneficial effect on tasks that rely heavily on executive functions (*Fabre et al., 2002*; *Smiley-Oyen et al., 2008*). *Diamond (2011)* stated that older individuals should participate in exercises that have a higher cognitive demand rather than in a single, highly automated aerobic exercise (running on a treadmill, riding a stationary bike, or walking quickly) to improve their cognitive function. However, the results showed no difference of RT between TG and CG on non-executive of the digit comparison task. As an explanation, though the naming condition of the Stroop task and non-delay condition of the digit comparison task are both non-executive condition, they may apply to assess the different aspect of cognition. Additionally, the digit comparison task may rely on more school knowledge than the naming condition of the Stroop task. Due to the fact that no significant difference in years of education was found between the TG, BG and CG, the RT did not vary in all groups. The results implied that the "selective improvement" may exist not only between executive and non-executive function, but also in different aspect of cognitive function.

This study had some limitations that should be considered in future investigations. First, the sample sizes of the participant groups were small. Larger sample sizes may enhance our current findings. Second, the intensity of brisk walking and Tai Chi was measured using questionnaires in current study. Further studies could perform objective measurements using devices such as accelerometers. Third, the relationship between different exercise types and executive functions can be revealed in a cross-sectional design, but this design type could not explain the mechanisms underlying the improvement. Therefore, intervention studies are needed in the future to support the results. Lastly, although Tai Chi exercises have higher cognitive demands than highly automated types of exercise, the cognitive effort required differed across the participants. The amount of attentional resources devoted to the Tai Chi practice may affect the exercises benefits regarding executive function. This study contributes to the literature on the relationship between exercise types and executive function in older adults. The results suggest that future related research should consider that practice years and the automation levels of motor skills may influence the effects of exercise on cognition.

CONCLUSIONS

This study found that older adults who participated in either brisk walking or Tai Chi exhibited better executive function and fitness than sedentary older adults. Furthermore, Tai Chi was found to have a greater beneficial effect on cognitive functions (Executive and non-Executive) than brisk walking, a finding that may be related to the high cognitive demands of Tai Chi. The implication of this finding is that exercises with high cognitive demands provide greater benefits in terms of maintaining and improving cognitive function, although their effects on physical fitness levels were similar to the effects of aerobic exercise. Further studies should research the underlying mechanisms at the behavioural and neuroelectric levels, providing more evidence to explain the effect of high-cognitive demands exercise on different processing levels of cognition.

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The authors declare there are no competing interests.

Author Contributions
- Zhiguang Ji conceived and designed the experiments, performed the experiments, analyzed the data, contributed reagents/materials/analysis tools, wrote the paper, prepared figures and/or tables, reviewed drafts of the paper.
- Anmin Li conceived and designed the experiments, reviewed drafts of the paper.
- Tian Feng performed the experiments, analyzed the data, contributed reagents/materials/analysis tools, prepared figures and/or tables.
- Yihong You, Fanying Meng, Ruoqing Wang, Jialing Lu and Xiaolei Liu performed the experiments.
- Chunhua Zhang contributed reagents/materials/analysis tools.

Human Ethics
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REFERENCES

Bohnen N, Twijnstra A, Jolles J. 1992. Performance in the Stroop color word test in relationship to the persistence of symptoms following mild head injury. *Acta Neurologica Scandinavica* **85**:116–121 DOI 10.1111/j.1600-0404.1992.tb04009.x.

Brent SE. 2010. *ACSM's health-related physical fitness assessment manual.* Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins Health.

Burr JF, Bredin SS, Faktor MD, Warburton DE. 2011. The 6-min walk test as a predictor of objectively measured aerobic fitness in healthy working-aged adults. *The Physician and Sportsmedicine* **39**:133–139 DOI 10.3810/psm.2011.05.1904.

Camarri B, Eastwood PR, Cecins NM, Thompson PJ, Jenkins S. 2006. Six minute walk distance in healthy subjects aged 55–75 years. *Respiratory Medicine* **100**:658–665 DOI 10.1016/j.rmed.2005.08.003.

Chang YK, Huang CJ, Chen KF, Hung TM. 2013. Physical activity and working memory in healthy older adults: an ERP study. *Psychophysiology* **50**:1174–1182 DOI 10.1111/psyp.12089.

Chang YK, Nien YH, Tsai CL, Etnier JL. 2010. Physical activity and cognition in older adults: the potential of Tai Chi Chuan. *Journal of Aging & Physical Activity* **18**:451–472 DOI 10.1123/japa.18.4.451.

Chang YK, Pan CY, Chen FT, Tsai CL, Huang CC. 2012. Effect of resistance-exercise training on cognitive function in healthy older adults: a review. *Journal of Aging & Physical Activity* **20**:497–517 DOI 10.1123/japa.20.4.497.

Chuang LY, Hung HY, Huang CJ, Chang YK, Hung TM. 2015. A 3-month intervention of Dance Dance Revolution improves interference control in elderly females: a preliminary investigation. *Experimental Brain Research* **233**:1181–1188 DOI 10.1007/s00221-015-4196-x.

Clark RA, Bryant AL, Pua Y, Mccrory P, Bennell K, Hunt M. 2010. Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. *Gait & Posture* **31**:307–310 DOI 10.1016/j.gaitpost.2009.11.012.

Colcombe S, Kramer AF. 2003. Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychological Science* **14(2)**:125–130 DOI 10.1111/1467-9280.t01-1-01430.

Dai CT, Chang YK, Huang CJ, Hung TM. 2013. Exercise mode and executive function in older adults: an ERP study of task-switching. *Brain & Cognition* **83**:153–162 DOI 10.1016/j.bandc.2013.07.007.

Diamond A. 2011. Effects of physical exercise on executive functions: going beyond simply moving to moving with thought. *Annals of Sports Medicine & Research* **2**:Article 2011.

Diamond A. 2012. Executive functions. *Annual Review of Psychology* **64**:135–168.

Dupuy O, Gauthier CJ, Fraser SA, Desjardins-Crèpeau L, Desjardins M, Mekary S, Lesage F, Hoge RD, Pouliot P, Bherer L. 2014. Higher levels of cardiovascular fitness are associated with better executive function and prefrontal oxygenation in younger and older women. *Frontiers in Human Neuroscience* **9**:Article 66 DOI 10.3389/fnhum.2015.00066.

Fabre C, Chamari K, Mucci P, Massébiron J, Préfaut C. 2002. Improvement of cognitive function by mental and/or individualized aerobic training in healthy elderly subjects. *International Journal of Sports Medicine* **23**:415–421 DOI 10.1055/s-2002-33735.

Fong DY, Chi LK, Li F, Chang YK. 2014. The benefits of endurance exercise and Tai Chi Chuan for the task-switching aspect of executive function in older adults: an ERP study. *Frontiers in Aging Neuroscience* **6**:Article 295 DOI 10.3389/fnagi.2014.00295.

Gauthier CJ, Lefort M, Mekary S, Desjardins-Crépeau L, Skimminge A, Iversen P, Madjar C, Desjardins M, Lesage F, Garde E. 2015. Hearts and minds: linking vascular rigidity and aerobic fitness with cognitive aging. *Neurobiology of Aging* **36**:304–314 DOI 10.1016/j.neurobiolaging.2014.08.018.

Guo W, Wang B, Lu Y, Zhu Q, Shi Z, Ren J. 2016. The relationship between different exercise modes and visuospatial working memory in older adults: a cross-sectional study. *Peerj* **4**:e2254 DOI 10.7717/peerj.2254.

Hakim RM, DiCicco J, Burke J, Hoy T, Roberts E. 2004. Differences in balance related measures among older adults participating in Tai Chi, structured exercise, or no exercise. *Journal of Geriatric Physical Therapy* **27**:11–15.

Huang CJ, Lin PC, Hung CL, Chang YK, Hung TM. 2014. Type of physical exercise and inhibitory function in older adults: an event-related potential study. *Psychology of Sport & Exercise* **15**:205–211 DOI 10.1016/j.psychsport.2013.11.005.

Hung NM, Andreas K. 2012. A randomized controlled trial of Tai chi for balance, sleep quality and cognitive performance in elderly Vietnamese. *Clinical Interventions in Aging* **2012**:185–190 DOI 10.2147/CIA.S32600.

Kim TH, Pascualleone J, Johnson J, Tamim H. 2016. The mental-attention Tai Chi effect with older adults. *BMC Psychology* **4**:29 DOI 10.1186/s40359-016-0137-0.

Kosmat H, Vranic A. 2016. The efficacy of dance intervention as a cognitive training for old-old. *Journal of Aging & Physical Activity* **25**:32–40.

Kramer AF, Hahn S, Cohen NJ, Banich MT, Mcauley E, Harrison CR, Chason J, Vakil E, Bardell L, Boileau RA, Colcombe A. 1999. Ageing, fitness and neurocognitive function. *Nature* **400**:418–419 DOI 10.1038/22682.

Kurth F, Cherbuin N, Luders E. 2017. Aging mindfully to minimize cognitive decline. *Journal of Cognitive Enhancement* **1**:108–114.

Lauenroth A, Ioannidis AE, Teichmann B. 2016. Influence of combined physical and cognitive training on cognition: a systematic review. *BMC Geriatrics* **16**:141 DOI 10.1186/s12877-016-0315-1.

Lee HC, Chang KC, Tsauo JY, Hung JW, Huang YC, Lin SI, Fall Prevention Initiatives in Taiwan (FPIT) Investigators. 2012. Effects of a multifactorial fall prevention program on fall incidence and physical function in community-dwelling older adults with risk of falls. *Archives of Physical Medicine and Rehabilitation* **94**(4):606–615 DOI 10.1016/j.apmr.2012.11.037.

Liou YM, Jwo CJ, Yao KG, Chiang LC, Huang LH. 2008. Selection of appropriate Chinese terms to represent intensity and types of physical activity terms for use in the Taiwan version of IPAQ. *Journal of Nursing Research* **16**(4):252–263 DOI 10.1097/01.JNR.0000387313.20386.0a.

Man DW, Tsang WW, Hui-Chan CW. 2010. Do older T'ai Chi practitioners have better attention and memory function? *Journal of Alternative & Complementary Medicine* **16**:1259–1264 DOI 10.1089/acm.2009.0462.

Matthews MM, Williams HG. 2008. Can Tai chi enhance cognitive vitality? A preliminary study of cognitive executive control in older adults after A Tai chi intervention. *Journal of the South Carolina Medical Association* **104**:255–257.

Mekari S, Fraser S, Bosquet L, Bonnéry C, Labelle V, Pouliot P, Lesage F, Bherer L. 2015. The relationship between exercise intensity, cerebral oxygenation and cognitive performance in young adults. *European Journal of Applied Physiology* **115(10)**:2189–2197 DOI 10.1007/s00421-015-3199-4.

Miller DI, Taler V, Davidson PS, Messier C. 2012. Measuring the impact of exercise on cognitive aging: methodological issues. *Neurobiology of Aging* **33(3)**:622.e29–622.e43 DOI 10.1016/j.neurobiolaging.2011.

Miller SM, Taylor-Piliae RE. 2014. Effects of Tai Chi on cognitive function in community-dwelling older adults: a review. *Geriatric Nursing* **35**:9–19 DOI 10.1016/j.gerinurse.2013.10.013.

Mirelman A, Herman T, Brozgol M, Dorfman M, Sprecher E, Schweiger A, Giladi N, Hausdorff JM. 2012. Executive function and falls in older adults: new findings from a five-year prospective study link fall risk to cognition. *PLOS ONE* **7**:e40297 DOI 10.1371/journal.pone.0040297.

Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. 2000. The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology* **41**:49–100 DOI 10.1006/cogp.1999.0734.

Olivier D, Gauthier CJ, Fraser SA, Laurence DC, Michèle D, Said M, Frederic L, Hoge RD, Philippe P, Louis B. 2015. Higher levels of cardiovascular fitness are associated with better executive function and prefrontal oxygenation in younger and older women. *Frontiers in Human Neuroscience* **9**:Article 66 DOI 10.3389/fnhum.2015.00066.

Pesce C. 2012. Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of Sport & Exercise Psychology* **34**:766–786 DOI 10.1123/jsep.34.6.766.

Porciuncula FS, Rao AK, Mcisaac TL. 2016. Aging-related decrements during specific phases of the dual-task Timed Up-and-Go test. *Aging Clinical and Experimental Research* **28**:121–130 DOI 10.1007/s40520-015-0372-x.

Reid-Arndt SA, Matsuda S, Cox CR. 2012. Tai Chi effects on neuropsychological, emotional, and physical functioning following cancer treatment: a pilot study. *Complementary Therapies in Clinical Practice* **18**:26–30 DOI 10.1016/j.ctcp.2011.02.005.

Salthouse TA. 2010. Selective review of cognitive aging. *Journal of the International Neuropsychological Society* **16**:754–760 DOI 10.1017/S1355617710000706.

Shumway-Cook A, Brauer S, Woollacott M. 2000. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Physical Therapy* **80(9)**:896–903.

Smiley-Oyen AL, Lowry KA, Francois SJ, Kohut ML, Ekkekakis P. 2008. Exercise, fitness, and neurocognitive function in older adults: the ''selective improvement'' and ''cardiovascular fitness'' hypotheses. *Annals of Behavioral Medicine* **36**:280–291 DOI 10.1007/s12160-008-9064-5.

Smith PJ, Blumenthal JA, Hoffman BM, Cooper H, Strauman TA, Welsh-Bohmer K, Browndyke JN, Sherwood A. 2010. Aerobic exercise and neurocognitive performance: a meta-analytic review of randomized controlled trials. *Psychosomatic Medicine* **72**:239–252 DOI 10.1097/PSY.0b013e3181d14633.

Taylor-Piliae RE, Newell KA, Cherin R, Lee MJ, King AC, Haskell WL. 2010. Effects of Tai Chi and Western exercise on physical and cognitive functioning in healthy community-dwelling older adults. *Journal of Aging & Physical Activity* **18**:261–279 DOI 10.1123/japa.18.3.261.

Turner GR, Spreng RN. 2012. Executive functions and neurocognitive aging: dissociable patterns of brain activity. *Neurobiology of Aging* **33**:826.e821–826.e813.

Van Iersel MB, Kessels RP, Bloem BR, Verbeek AL, Olde Rikkert MG. 2008. Executive functions are associated with gait and balance in community-living elderly people. *Parkinsonism & Related Disorders* **14**:1344–1349.

Voelcker-Rehage C, Niemann C. 2013. Structural and functional brain changes related to different types of physical activity across the life span. *Neuroscience & Biobehavioral Reviews* **37**:2268–2295 DOI 10.1016/j.neubiorev.2013.01.028.

Walsh JN, Brad M, Jeffrey H, Vera N, Lewis L, Brian G, Macklin EA, Peng CK, Wayne PM. 2015. Impact of short- and long-term Tai Chi mind-body exercise training on cognitive function in healthy adults: results from a hybrid observational study and randomized trial. *Global Advances in Health & Medicine* **4**:38–48 DOI 10.7453/gahmj.2015.058.

Wei GX, Xu T, Fan FM, Dong HM, Jiang LL, Li HJ, Yang Z, Luo J, Zuo XN. 2013. Can Taichi reshape the brain? A brain morphometry study. *PLOS ONE* **8**:e61038 DOI 10.1371/journal.pone.0061038.

Wu Y, Wang Y, Burgess EO, Wu J. 2013. Effect of Tai Chi exercise on cognitive function in older adults: a meta-analysis. *Journal of Sport and Health Science* **2**:193–203 DOI 10.1016/j.jshs.2013.09.001.

Zhang L, Weng C, Liu M, Wang Q, Liu L, He Y. 2014. Effect of whole-body vibration exercise on mobility, balance ability and general health status in frail elderly patients: a pilot randomized controlled trial. *Clinical Rehabilitation* **28**:59–68 DOI 10.1177/0269215513492162.

Zheng G, Liu F, Li S, Huang M, Tao J, Chen L. 2015. Tai Chi and the protection of cognitive ability: a systematic review of prospective studies in healthy adults. *American Journal of Preventive Medicine* **49**:89–97 DOI 10.1016/j.amepre.2015.01.002.

Zimmerman B, Sutton BP, Low KA, Fletcher MA, Tan CH, Schneidergarces N, Li Y, Ouyang C, Maclin EL, Gratton G, Fabiani M. 2014. Cardiorespiratory fitness mediates the effects of aging on cerebral blood flow. *Frontiers in Aging Neuroscience* **6**:Article 59 DOI 10.3389/fnagi.2014.00059.