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Tai Chi practice on prefrontal oxygenation levels in older adults: A pilot study

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ABSTRACT

Objective: The role of exercise in preventing or delaying age-related cognitive decline is an important focus of rehabilitation. Tai Chi (TC) is a traditional Chinese exercise that has been found to improve cognitive function. However, the mechanism underlying this improvement is still unknown. We compared the effects of TC practice (mind-body exercise) and arm ergometry (AE; body focused exercise) on prefrontal cortex activity between TC practitioners and non-practitioners.

Design: This cross-sectional study included 16 older female subjects (8 TC practitioners and 8 non-practitioners). The practitioners had each practiced TC for at least 7 years. Prefrontal cortex activity was measured using the prefrontal oxygenation level obtained with near-infrared spectroscopy. During the spectroscopy measurement, the participants performed TC, after watching a video of 12-form seated Yang Style TC, and AE in a subsequent session.

Results: We found significantly greater changes in the levels of oxyhemoglobin (HbO2; $p = 0.022$) and total hemoglobin (cHb; $p = 0.002$) in the TC condition compared with the AE condition in all participants. In the TC practitioner group, a similar trend was shown in the change of HbO2 ($p = 0.117$) and cHb ($p = 0.051$) when practicing TC versus AE. However, in the non-practitioner group, we found a statistically greater change in cHb ($p = 0.005$) but not in HbO2 ($p = 0.056$).

Conclusion: The older adults had higher brain activity when practicing TC compared with AE, and a significant effect was observed in the non-practitioner group. These pilot results may provide insight into the underlying mechanism of the effectiveness of TC practice in preventing cognitive decline in older adults.

1. Introduction

Aging is commonly associated with progressive degeneration in multiple systems.[1] Decreases in cerebrovascular plasticity and cerebral hypoperfusion are consequences of aging, and these changes aggravate cognitive dysfunction.[2] Questions have been raised about the best way to slow down the effect of aging on cognition. Recently, researchers have explored the potential of mind-body exercise to preserve cognitive function in older adults. A number of studies have suggested that mind-body exercises play a positive role in preventing age-related cognitive deficits[3,4] and preserving executive function, language learning and memory.[5]

Among many different types of mind-body exercise, Tai Chi (TC) is a traditional Chinese martial art that has been practiced in China for a long time and has become popular in the West over the last 60 years.[6] The practice of TC elicits a meditative effect. It incorporates slow but deep diaphragmatic breathing with mental concentration and slow gentle circular movements that are recognized as the "mind" components of the exercise.[7] Studies have shown that TC practice, similar to other mind-body exercises when practiced as an intervention, is associated with a reduction in the rate of cognitive decline and with the preservation of cognitive function.[8–11] However, the majority of the available evidence has focused on the treatment effect of TC by measuring the neural activity pre- and post-TC practice; studies have seldom investigated real-time neural activity during TC practice.[4] In the literature, there is only one case study that has attempted to record the prefrontal cortex activity of a 65 year-old female TC practitioner during practice.[12] This case study reported a higher prefrontal oxygenation

Abbreviations: AE, Arm ergometry; cHb, Total hemoglobin; dHB, Deoxygenated hemoglobin; Hb, Hemoglobin; HbO2, Oxyhemoglobin; NIRS, Near-infrared spectroscopy; TC, Tai Chi

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during TC compared with arm ergometry (AE), which is regarded as a body-focused exercise.[12] This finding suggests that TC practice induced additional prefrontal neuronal activation. Given the positive result of a case study involving one female TC practitioner, it is worthwhile to extend the protocol to a larger population and to use more advanced technology. In addition, by including both TC practitioners and non-practitioners in the study, the effect of mind-body exercise experience can be evaluated.

The aim of this study was to compare the effects of mind-body and body-focused exercise on prefrontal activity in older adults. Only female subjects were recruited for this pilot study to control for gender differences that might have confounded the effects of movement on brain activity. We also sought to investigate the effect of TC experience on prefrontal activity by comparing TC practitioners with at least seven years of experience with non-practitioners. We hypothesized that prefrontal oxygenation levels in older adults would be higher during TC than body-focused exercise. We also expected the changes in prefrontal oxygenation levels during TC and body-focused exercises to differ between practitioners and non-practitioners. The findings regarding the differences in exercise type and experiences of mind-body practice may contribute to a better understanding of how TC practice delays cognitive decline and provide a scientific basis for prescribing mind-body exercise in older adults.

2. Methods

2.1. Subjects

The subjects were community-dwelling older females. Potential subjects were recruited by a poster displayed on The Hong Kong Polytechnic University campus. Prior to the experiment, a screening test was conducted.[9] The subjects were invited to participate in the experiment if they were aged between 60 to 75 and had either no experience of TC (for the non-practitioner group) or more than seven years of TC (in the practitioner group). Subjects were excluded if they met the following criteria: 1) history of neurological or cardiovascular disorders; 2) uncontrolled hypertension (i.e., systolic blood pressure ≥180 mmHg and/or diastolic blood pressure ≥105 mmHg); 3) active musculoskeletal problems in the upper limbs that would interfere with the measurement (e.g., pain or fracture); 4) Hong Kong Montreal Cognitive Assessment (HK-MoCA) score < 22 indicating cognitive impairment; or 5) complained of dizziness or feeling unwell on the day of the experiment. The study was approved by the Ethics Committee of The Hong Kong Polytechnic University. All subjects were given an information sheet, assured of confidentiality and the right to withdraw from the study at any time. All subjects provided written informed consent.

2.2. Study design

This was a cross-sectional study, and all subjects were required to attend two sessions in the laboratory at The Hong Kong Polytechnic University. After the collection of demographic data (Table 1), all subjects were required to watch a video of 12-form Yang Style TC, which lasted for 2 min and 33 s, and then to perform two sets of TC (Fig. 1). This procedure ensured that all participants could perform the TC movements. During the data collection phase, all subjects were instructed to take a 5 min rest, followed by a 9 min exercise period and a 10 min rest at the end. The oxygen consumption and prefrontal oxygenation level were recorded during the process. This protocol was based on a previous study[12] in which the two aforementioned parameters were closely monitored throughout the experiment. The findings of this previous work showed that the physical and mental status of the subject became stable before and after exercise. The current experiment was conducted in a quiet and dim room to avoid environmental disturbances. During the exercise period, the subjects were required to perform 12-form Yang Style TC for 9 min. after watching the video from the first session. They were also required to perform the AE exercise in the second session with the same 5 min rest period before the exercise and 10 min rest after exercise. The measured oxygen consumption during the AE exercises was similar to the oxygen consumption recorded in the first session.

Table 1
Demographics of participants.

	All participants (n = 16)	TC non-practitioner (n = 8)	TC practitioner (n = 8)	p value
Age (years)	65.9 ± 4.2	67.3 ± 4.0	64.6 ± 4.1	0.217
Height (cm)	154.4 ± 6.0	154.5 ± 6.2	154.3 ± 6.3	0.937
Weight (kg)	56.4 ± 7.3	58.3 ± 7.3	54.6 ± 7.4	0.340
HK-MoCA	25.6 ± 2.3	25.1 ± 2.6	26.1 ± 1.9	0.398
Time-Up-and-Go Test (s)	9.92 ± 1.14	9.97 ± 1.40	9.87 ± 0.89	0.862
Heart Rate (bpm)	68.0 ± 6.2	66.6 ± 6.3	69.4 ± 6.2	0.391
Systolic Blood Pressure (mm Hg)	134.8 ± 8.1	131.8 ± 5.3	137.9 ± 9.5	0.135
Diastolic Blood Pressure (mm Hg)	78.7 ± 4.3	76.5 ± 4.5	81.7 ± 0.8	0.017*

HK-MoCA = Hong Kong Montreal Cognitive Assessment.
* Denotes a difference at the significance level of $p < 0.05$.

2.3. Instrumentation

The prefrontal oxygenation level was measured using near-infrared spectroscopy (NIRS).[13,14] NIRS is a non-invasive measurement of hemodynamic signals related to brain activation and is based on the highly transparent properties of human tissue in the near-infrared range.[15] Recent work has provided evidence for the validity of prefrontal NIRS-Hb signals that are comparable to the blood oxygenation level dependent signal measured with functional magnetic resonance imaging (fMRI).[16]

We used a NIRSport 88 (NIRX Medizintechnik GmbH, Germany) for the measurements. Fifteen probes were attached to the prefrontal area according to the montage "Prefrontal_8 × 8" in NIRStar 14.1 (NIRx Medical Technologies LLC, USA), and the sampling frequency was set at 7.81 Hz. Ultrasound gel was used to increase the conductivity. The prefrontal oxygenation level was measured by comparing the light absorption spectra of oxygenated hemoglobin (HbO2) and deoxygenated hemoglobin (dHb). The HbO2 levels and total hemoglobin (cHb) levels were measured to determine the prefrontal oxygenation.[12]

The data were measured from a pre-exercise resting period to a post-exercise resting period. NIRSport 88 was calibrated using NIRStar 14.1 before the pre-exercise resting period, and the prefrontal oxygenation level at that moment was set as the baseline. The data collected during the pre-exercise resting period, exercise, and the post-exercise resting period from the 15 probes were averaged for analysis. To ensure a similar exercise intensity between the TC and AE, a metabolic cart (K4B2, COSMED, Pavona di Albano, Italy) calibrated with a 3-liter syringe was used to record the oxygen consumption during exercise.

2.4. Statistical analyses

Statistical analyses were performed using the SPSS statistical software package (IBM, Version 23). The homogeneity of the variance and the normality of the data were checked using the Levene's test and Shapiro-Wilk test, respectively. We first analyzed data from all participants to investigate the effect of exercise types on prefrontal oxygenation level. Specifically, we compared TC versus AE using a paired *t*-test. We next examined the interaction effect of the group X exercise type on prefrontal oxygenation level using a two-way repeated

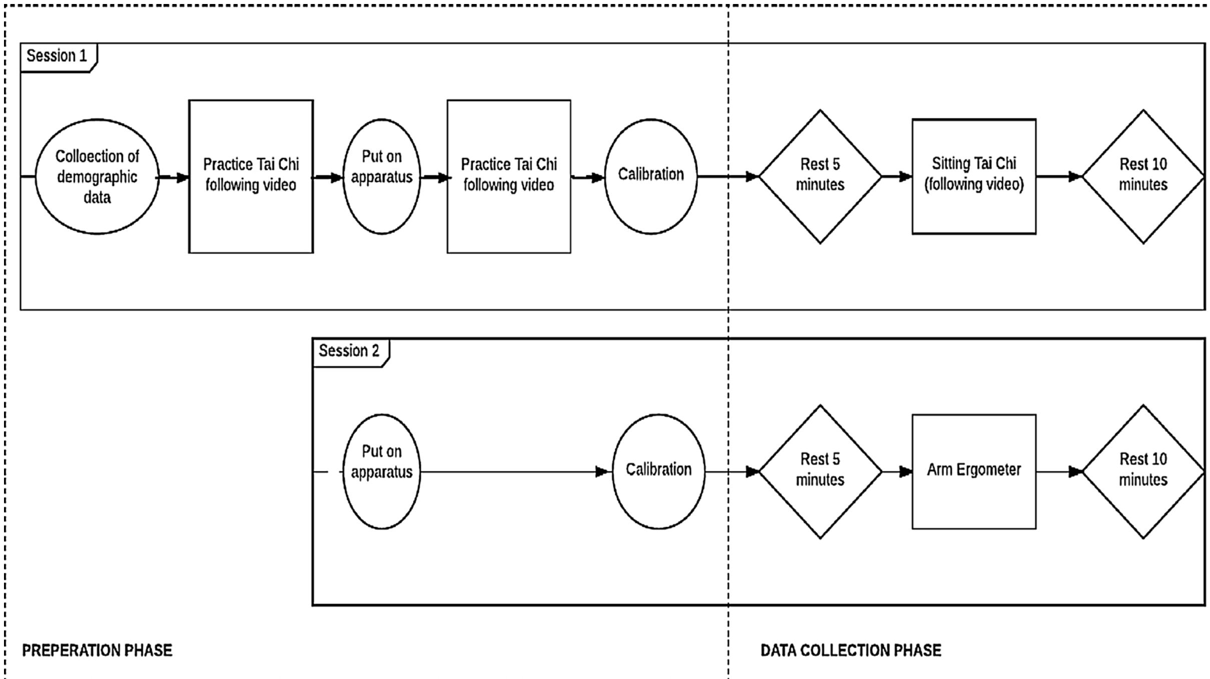

Fig. 1. Flowchart of protocol.

measures (mixed-design) analysis of variance. Lastly, we performed subgroup analysis to investigate the effect of exercise type on the prefrontal oxygenation of either the TC practitioner or non-practitioner groups using either a paired *t*-test or Wilcoxon signed-rank test, depending on whether the criterion of the normality of the data was met. The confidence level was set at 95% ($p < 0.05$) in all of the statistical analyses. All data are presented as mean ± standard deviation.

3. Results

Of the 25 recruited subjects, 2 chose to terminate the study after the first session for personal reasons, and 7 were excluded based on the exclusion criteria. Sixteen older adults completed the experiment: 8 were TC practitioners, and 8 were non-practitioners. The demographics of the subjects are shown in Table 1. No statistically significant differences were found in any of the demographic items except for diastolic blood pressure ($p = 0.017$). The subjects had a mean age of 65.9 years and did not suffer from cognitive impairment (> 22 of the HK-MoCA assessment). The Time-Up-and-Go Test results showed that these older adults were not classified as fallers (mean = 9.92 s). Their systolic blood pressure was slightly higher than that of their younger counterparts, with a mean of 134.8 mm Hg. Therefore, the subjects were a comparatively healthy sample of community-dwelling older adults.

We found no statistically significant differences in exercise intensity with exercise type in any of the participants ($p = 0.562$) or within the subgroups (TC practitioners: $p = 0.505$; non-practitioners: $p = 0.990$). These results demonstrate that any difference in the prefrontal oxygenation level was not attributable to the intensity level of the type of exercise. There was also no significant difference between the two groups during TC practice ($p = 0.941$).

The level of prefrontal oxygenation did not differ between groups or by exercise type during the pre-exercise resting period (all $p > 0.05$). We did find statistically significant differences in the change of HbO2 ($p = 0.022$; an average 452.2% increase) and cHb ($p = 0.002$; an average 1670.0% increase) between the exercise conditions (Table 2).

No statistically significant interaction for group X exercise type was found for either HbO2 or cHb. In the TC practitioner group, there were no differences in either HbO2 or cHb between the exercise conditions.

Table 2
Changes in prefrontal oxygenation for all participants during TC and AE practice.

	AE	TC	p-value
Change of HbO2 during exercise (×10^-6 mmol/L)	1.259 ± 2.944	5.694 ± 6.807	0.022*
Change of cHb during exercise (×10^-6 mmol/L)	0.401 ± 2.935	6.697 ± 6.668	0.002*

HbO2 = oxyhemoglobin; cHb = total hemoglobin.
* Denotes a difference at the significance level of $p < 0.05$.

In the non-practitioner group, there was a statistically significant difference in cHb ($p = 0.005$) between the exercise conditions but no statistically significant difference in HbO2 (Table 3).

4. Discussion

TC practice elicited greater prefrontal activity than AE, although exercise intensity was similar. There was a significantly greater increase in HbO2 and cHb levels from TC compared with AE. This result may have important implications for addressing the underlying mechanisms as to why TC practice has been shown to prevent degenerative cognitive deficits in older adults.[8–10] We suggest two possible explanations for how TC is protective against cognitive decline.

First, the significantly greater HbO2 and cHb levels found in TC compared to AE suggest an increase in neuronal activation of the prefrontal cortex during TC practice. Optimizing oxygenation in the prefrontal cortex can increase aerobic metabolism in the tissue, which is a prerequisite of cell activity.[17] These findings suggest that TC practice may promote prefrontal neuronal activity and hence reduce cognitive degeneration.

Second, a recent animal study has suggested a close relationship between regional blood volume of the brain and cerebral angiogenesis.[18] Pereira et al.[19] observed that when cerebral blood volume increased with exercise in mice, there was a positive correlation with newly born cells. Therefore, the significant increase in HbO2 and cHb could indicate a beneficial effect of TC on the cerebral vasculature and by extension could promote neurogenesis. This study could explain why

Table 3
Group changes in prefrontal oxygenation during exercise.

	TC non-practitioner			TC practitioner			Interaction
	AE	TC	p value	AE	TC	p value	
Change in HbO2 during exercise (×10^-6 mmol/L)	2.326 ± 0.615	8.138 ± 8.756	0.056	0.325 ± 3.857	3.521 ± 2.996	0.117	0.339
Change in cHb during exercise (×10^-6 mmol/L)	0.924 ± 1.579	8.549 ± 8.680	0.005*	−0.12 ± 3.917	4.846 ± 3.479	0.051	0.305

HbO2 = oxyhemoglobin; cHb = total hemoglobin.
* Denotes a within-group difference at the significance level of $p < 0.05$.

TC can help reduce the risk of developing age-related cognitive deficits. How increases in prefrontal oxygenation levels during TC practice correlate with cerebral angiogenesis and cognitive function requires further investigation.

The changes in HbO2 and cHb levels were higher during TC in both the practitioner and non-practitioner subgroups. However, a statistically significant difference for the within-group comparisons was only found in the cHb levels in the non-practitioners. A possible explanation could be the difference in the stage of motor learning and cortical activation between practitioners and non-practitioners. At the early stage of motor skill learning, more attention is required, and the prefrontal-parietal pathway is recruited, which increases prefrontal activity. With training, the automaticity increased and the striatal-cerebellum pathway become involved.[20,21] This theory could apply to our current findings. Non-practitioners might have to use more attention to learn TC movements and thus showed higher prefrontal activity. Conversely, the practitioners have already entered the autonomous stage, requiring less prefrontal activation. The small sample size could be another possible explanation. The HbO2 levels in non-practitioners ($p = 0.056$) and cHb level in practitioners ($p = 0.051$) were at the trend level. It is possible that the small sample size did not provide sufficient statistical power to detect significant differences.

Sun et al.[22] have found that a 3 month intervention of TC practice with healthy older adults significantly improved cognition. Ji et al.[23] have also demonstrated the beneficial effect of TC practice on executive function in older adults. Given that the prefrontal cortex is involved in both cognitive behavior and executive functions, the findings from this study could provide an explanation of the benefits of TC practice on cognition.

There are also similarities between the results in this study and those reported by Lu et al.[12] a case study that used a similar protocol with a female TC practitioner. Significantly higher levels of HbO2 and cHb during TC were observed in their study. We found higher HbO2 levels during TC in our practitioners. Also, the cHb levels in the current study trended higher in TC compared to AE ($p = 0.051$), with an effect size of 0.831. In addition, we used 15 probes used during NIRS, and it is possible that the 15 probes captured a more complete picture of the prefrontal oxygenation levels than the 2 probes used by Lu et al. To investigate the regional differences in brain activity during TC practice, future analyses of data from different probes can be performed based on prefrontal cortex subregions.

Compared with other mind-body studies, this study delineated the "mind" component of exercise by comparing a mind-body to a body-focused exercise. There have been other studies suggesting the effects of mind-body exercise can protect older adults against degenerative brain changes.[3,4] Additional studies have also suggested that physical exercise alone can improve cognition in older adults.[24] However, it has remained unknown whether a mind-body exercise can provide additional benefits to cognition compared with only physical exercise. Therefore, the use of body-focused exercise of similar intensity to mind-body exercise as a control is a strength of our study. The findings from this study likely suggest that the increased brain activity during TC is due to the "mind component" in TC practice.

5. Limitations

A number of limitations of the current study should be considered when interpreting the results. First, we assumed the older adults were practicing TC with the "mind" component, but we did not monitor the "mind" component of the exercise. Second, watching the video could have contributed the results, but the use of a video as instruction was necessary to standardize the form of TC and ensure fluency during TC practice. The video watching effect was minimized by requiring the participants to practice twice before the protocol started. Future studies should consider including a control group in which the subjects only watch the TC video. Third, the TC exercise was limited to a sitting form due to the instrumental constraints of the NIRS technique. These results might not generalize to the traditional standing forms of TC, which are a more complex form of mind-body exercise. Future research should consider extending the study to standing forms of TC. Also, the relatively small sample size due to our strict exclusion criteria is another limitation of the study. All our subjects were female volunteers and were within a narrow age range of between 60–72 years. Therefore, the results might not generalize, and further studies should be extended to include male subjects and older adults in different age groups. In addition, the cross-sectional design in the present pilot study is incapable of determining causal relationships, and future studies using randomized clinical trial designs are warranted.

6. Clinical implications

This study provides a foundation for healthcare professionals to prescribe mind-body exercise such as TC for older adults to counteract cognitive decline. The practice of TC has been shown to have a beneficial effect and might also apply to people without experience of mind-body exercise.

7. Conclusion

Older adult females had increased brain activity when practicing TC than when practicing AE, and a significant effect was observed in the non-practitioner group in this pilot study. These results provide an understanding of the mechanism underlying the effectiveness of TC practice on preventing cognitive decline in older adults. Mind-body exercises like TC practice, even in the early learning stages of the discipline, could be a good option for older adults to preserve cognition. However, randomized clinical trials with larger sample sizes are warranted.

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