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Case Study

Changes of heart rate variability and prefrontal oxygenation during Tai Chi practice versus arm ergometer cycling

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Abstract. [Purpose] Exercise has been shown to improve cardiovascular fitness and cognitive function. Whether the inclusion of mind over exercise would increase parasympathetic control of the heart and brain activities more than general exercise at a similar intensity is not known. The aim of this study was to compare the effects of Tai Chi (mind-body exercise) versus arm ergometer cycling (body-focused exercise) on the heart rate variability and prefrontal oxygenation level. [Subjects and Methods] A Tai Chi master was invited to perform Tai Chi and arm ergometer cycling with similar exercise intensity on two separate days. Heart rate variability and prefrontal oxyhemoglobin levels were measured continuously by a RR recorder and near-infrared spectroscopy, respectively. [Results] During Tai Chi exercise, spectral analysis of heart rate variability demonstrated a higher high-frequency power as well as a lower low-frequency/high-frequency ratio than during ergometer cycling, suggesting increased parasympathetic and decreased sympathetic control of the heart. Also, prefrontal oxyhemoglobin and total hemoglobin levels were higher than those during arm ergometer exercise. [Conclusion] These findings suggest that increased parasympathetic control of the heart and prefrontal activities may be associated with Tai Chi practice. Having a "mind" component in Tai Chi could be more beneficial for older adults' cardiac health and cognitive function than body-focused ergometer cycling.

Key words: Tai Chi, Heart rate variability, Prefrontal activity

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INTRODUCTION

Cardiovascular diseases in the older adults are often associated with perturbed autonomic balance, manifested by an increase in sympathetic modulation, a decrease in parasympathetic modulation or a combination of both[1)]. In aging, the autonomic control of the cardiovascular system favours heightened cardiac sympathetic tone with parasympathetic withdrawal, which can magnify the effects of concomitant cardiovascular disease[2)]. Studies have shown that parasympathetic control of the heart during exercise is important for cardiac health[3)], and long-term physical endurance training increases parasympathetic activity and decreases sympathetic activity in humans at rest[3)].

Aging is often associated with changes in cognitive functioning. These changes can be normal as in normal aging, or as a result of pathological modification in people with mild cognitive impairment or dementia[4)]. Much attention has been placed on interventions which attempt to reverse or slow down the progression of cognitive decline in older adults with and without cognitive impairment[5)]. Recent evidence has shown that exercise may protect older adults against cognitive impairments in

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aging[6]. One of the hypotheses is that exercise can induce angiogenesis. For example, 30 days of wheel-running exercise was found to increase blood flow in the cerebellum, motor cortex, and hippocampus of rats[7]. In older adults reaching their retirement age, regular exercise sustained their cerebral blood flow compared to inactive controls[8].

Tai Chi (TC) is regarded as a mind-body exercise, as its practice requires subjects to be “mindful” of the intrinsic energy from which she/he may ultimately perceive greater self-control and empowerment[9]. Like other mind-body exercises, such as yoga, qigong and aikido, TC involves meditation, imagery, concentration on the self and diaphragmatic breathing during its practice[10]. A question then naturally arises: Is there a difference in the autonomic control of the heart between a mind-body exercise such as TC and a body-focused exercise such as cycling? Therefore, the first objective of this study was to investigate the effects of TC versus arm ergometer cycling (EGO) on the autonomic control of cardiac activity. The effect of mind-body exercise on cerebral oxyhemoglobin level, especially in the prefrontal cortex, may be different from that of body-focused exercises such as EGO. Therefore, the second objective of this study was to compare the effects of TC and EGO on prefrontal cortex activity. To address these two objectives, measurements of heart and brain activities were conducted before, during, and immediately after exercise for comparison between TC and EGO.

SUBJECTS AND METHODS

A healthy TC master (age 65 years, 168 cm tall, weighing 56 kg) was invited to participate in this study. The TC master had been practicing and teaching TC for more than 20 years. She signed a written informed consent which was approved by the Department of Rehabilitation Sciences of the Hong Kong Polytechnic University.

The subject attended our laboratory on two separate afternoons at similar times to ensure consistent assessment conditions. She was asked to perform a 12-form *Yang* style TC routine[11] in a sitting position on the first day, and exercised with the arm ergometer (Monark Electric Ergometer Model 829E, Monark, AB, USA) in a similar sitting position on the other day. Measurement started with the subject sitting quietly for 10 min, followed by 12 min of exercise while sitting, and then another 10 min of quiet sitting. The intensity during EGO cycling was kept at the same level based on the calculated oxygen consumption during the TC practice. Both the heart rate variability and prefrontal oxygenation were measured throughout the 10-, 12-, and10-minute intervals as described as below.

Heart rate variability (HRV) was measured using an electrocardiogram, and the R-to-R peak intervals were continuously recorded using an RR recorder (Polar RS800, Polar Electro Ltd., Finland), attached around the chest, at a sampling frequency of 1,000 Hz. Pulse signals were transmitted to a Polar watch and stored for off-line spectral analysis. To standardize TC and EGO exercise intensities, breath-by-breath oxygen consumption, respiratory frequency and tidal volume during the two exercises were recorded with a metabolic cart (K4B2, COSMED, Pavona di Albano, Italy) which was calibrated prior to data collection. The turbine was calibrated using a 3-liter syringe.

Spectral analysis of HRV is a well-established method for assessing autonomic control of the heart. This method was introduced by Akselrod in 1981[12]. Power at high frequencies (HFs) is considered to indicate parasympathetic control, while power at low frequencies (LF) is considered to be an index of sympathetic control. Studies using this method have found that concentration and meditation have significant neuro-physiological effects on autonomic nervous control, causing an increase in parasympathetic tone and a decrease in sympathetic activity[13, 14].

The brain’s prefrontal cortex controls various cognitive functions, including motor planning and delayed response[15], as reflected by neuropsychological tests of its activation such as the Continuous Performance Test[16], and the Wisconsin Card Test[17]. Oxygenation of the prefrontal area during exercise can be investigated non-invasively using near-infrared spectroscopy (NIRS). It measures tissue oxygenation through comparing the light absorption spectra of oxygenated hemoglobin (O_2Hb) and deoxygenated hemoglobin (HHb) at their specific wavelengths based on the Lambert-Beer law[18]. NIRS was employed in this study to measure the prefrontal cerebral O_2Hb and HHb levels, and to infer total hemoglobin (cHb) (the sum of O_2Hb and HHb)[19]. A NIRO 200 spectroscope (Hamamatsu Photonics, Japan) was used with the sampling frequency set at 1 Hz. Two probes were attached to the subject’s forehead for measurement.

Analysis of HRV was performed using a short-time Fourier transformation (STFT) of the RR intervals during exercise. The RR interval signals were transmitted to a computer running Polar Protrainer 5 software (Polar Electro Ltd., Oulu, Finland) through an infrared USB adapter. Artifacts and extra data detected by the system were auto-corrected. Then the RR intervals were processed using MATLAB 7.1 software (The MathWorks Inc., Natick, USA) with a tailor-made program. Since the RR intervals were not constant during exercise, STFT was employed to calculate the frequency spectrum of the HRV[20, 21], instead of using the conventional fast Fourier transformation (FFT) spectrum analysis to generate the power spectral density in the HF range (between 0.15 and 0.4 Hz) and the LF range (0.04–0.15 Hz). The HF and LF power in normalized units (HF_{nu} and LF_{nu}) were also calculated, according to the methods recommended by the Task Force on Measurement Standards of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996)[22], as percentages of power with respect to total power minus very low frequency power. The two parameters emphasize controlled and balanced behavior of the two branches of the autonomic nervous system. The LF/HF ratio, which is commonly regarded as an indicator of sympatho-vagal balance[22], was also computed. For comparison, the parameters were averaged every 1 min during exercise and over 10 min in the rest and recovery periods.

Levels of O_2Hb and HHb were recorded over the 10 min of rest and then averaged. The average was used as the baseline

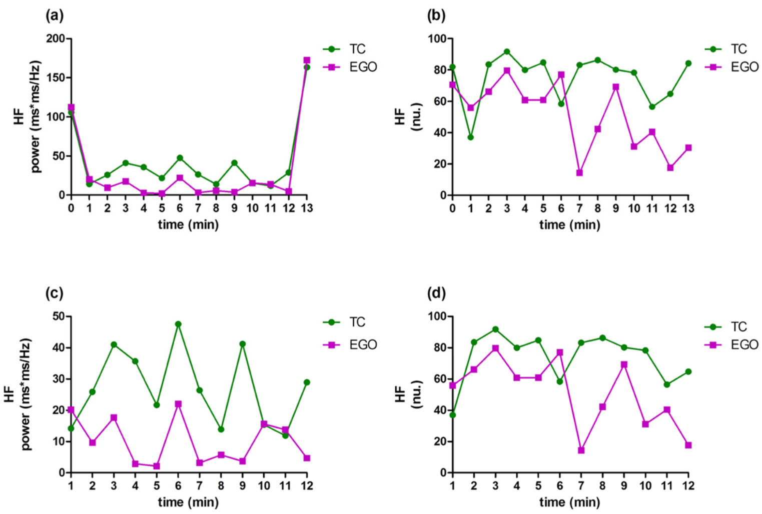

Fig. 1. HF power (a) and normalized HF power (b) during the two exercises
Time "0" represents the average value of the 10 min at rest, and "13" the 10-min recovery periods. HF power (c) and normalized HF power (d) during the two 12-min exercises.

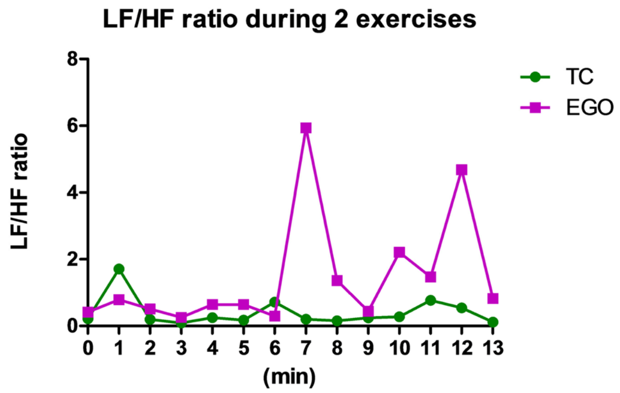

Fig. 2. LF/HF ratios during the two exercises
Time "0" represents the average value of the 10 min at rest, and "13" the 10-min recovery periods.

value to normalize the subsequent data recorded during the 12 min of exercise (averaged over each one minute), and during the 10 min recovery which followed.

RESULTS

The mean intensities were 2.6 METs for TC and 2.3 METs for EGO cycling. C statistic analysis[23)] of oxygen consumption between resting and exercise gave a Z value of 4.61 for Tai Chi and 4.63 for ergometer cycling. These values demonstrate that the exercise intensities of the two exercises were similar.

The spectral analysis of heart rate variability showed that the HF power spectrum decreased at the start of both exercises and increased in the recovery phase (Fig. 1a). The Z scores were 3.30 for TC and 3.46 for EGO. The between-exercises comparison showed that during TC, the decrease in HF power was less than during EGO. The overall display also shows that during TC, the HF power in normalized units was generally higher than during EGO (Fig. 1b).

Comparing the two exercise periods, HRV during TC had higher HF power than that during ergometer cycling, as shown in Fig. 1c and Fig.1d. The two figures show the changes during the 12-min exercise periods without the baseline and recovery periods.

The LF/HF ratio was higher in ergometer cycling than in TC, especially from the 7th minute onwards (Fig. 2).

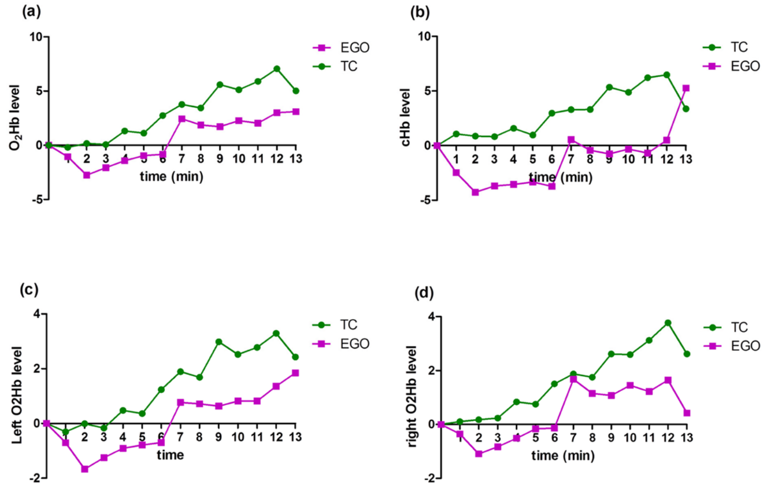

Fig. 3. O_2Hb (a) and cHb (b) during the two exercises. Left (c) and right (d) hemispheric O_2Hb activities during the two conditions
Time "0" represents the average value of the 10 min at rest, and "13" the 10-min recovery periods.

The O_2Hb and cHb levels gradually increased during the TC routine. However, both levels initially decreased, then increased in the later phases of EGO exercise (Fig. 3a, b). The Z values were 4.06 and 3.81 for TC and EGO, respectively, based on the C statistic. Both exercises showed overall increased oxygenation of the prefrontal area. The left /right hemisphere difference in O_2Hb during the two exercises is shown in Fig. 3c, d. The Figures clearly show that the difference between the exercises was more obvious in the left hemisphere.

DISCUSSION

In a cross-sectional study, Lu and Kuo[24)] observed that experienced Tai Chi practitioners had higher HF power and lower LF/HF ratios, implying more dominant parasympathetic control of the heart. Their protocol included 20 minutes of Tai Chi, 10 min of warm-up and 10 min of cooling down. However, they investigated HRV only before and after, not during Tai Chi practice. Therefore, the behaviors of the sympathetic and parasympathetic systems during Tai Chi exercise remained unclear. Also, there was no control (body-focused) exercise to compare the autonomic control of the heart with that of Tai Chi which has a mind-body component. In this study, the Tai Chi master displayed higher HF power and a lower LF/HF ratio in HRV during TC than during EGO performed at a similar exercise intensity, suggesting more parasympathetic control of the heart during TC than during cycling.

Dimsdale and Mills[25)] found that meditation could override a powerful adrenergic stimulus (iosproterenol) administered through blood infusion. We theorized that Tai Chi's mind component might similarly override the tendency of the exercise to tip the sympathetic-vagal balance towards more vagal mediation. A TC master, who exercises in a meditative manner resulting in relaxation, might raise parasympathetic control of the heart, to dominate that of sympathetic control, in contrast to cycling which has no meditative component. Our results do indeed show that during Tai Chi practice, the subject appeared to have had greater parasympathetic control of the heart than during cycling performed at a similar intensity.

Related to this, a previous study reported that experienced Tai Chi practitioners with an average of 6.7 years' experience had better arterial compliance than older control adults[26)]. A randomized clinical trial also found that older adults increased their large and small arterial compliances (26.2% and 17.9%, respectively) after performing Tai Chi training, three sessions per week, for 16 weeks[27)]. It is our suggestion that the improved arterial compliance after TC training could be due to increased parasympathetic control of the cardiovascular system. The findings of the present study, suggesting increased parasympathetic modulation of the heart during Tai Chi, are consistent with the hypothesis of improvement of arterial compliance proposed by previous studies. However, a prospective study with a large sample of subjects is needed before firm conclusions can be drawn.

Cranial O_2Hb is one of the valid parameters reflecting cortical activation during movement[19)]. Timinkul and colleagues[18)] showed that mild intensity exercise increased oxygenation of the prefrontal area in young subjects while they performed incremental exercise cycling. Their findings were similar to those of the present study. Furthermore, the intensity of only about 2.5 METs used in this study could be used to increase cerebral oxygenation in older subjects.

The prefrontal activity monitored in this study showed that TC and EGO elicited different oxygenation despite similar exercise intensities. The comparatively greater O_2Hb and cHb increases during TC may suggest that the subject had more prefrontal neuronal activation than when cycling. The physical intensities of both forms of exercise being similar, it could be argued that the additional prefrontal activation during TC resulted from the mental involvement during TC practice. Litscher and colleagues[28] found that during qigong, another mind-body exercise, there were increased O_2Hb and cHb levels in the practitioners' frontal area even while they were sitting without any physical movement. However, that study did not involve a physical component and did not use another body-focused exercise for comparison.

The present results demonstrate that, although differences were observed on both sides of the prefrontal cortex, the left prefrontal area showed a more obvious difference between TC and cycling (Fig. 3c, d). The left prefrontal area was activated more during TC than the right side, especially after the 7th minute (Fig. 3c). The TC in this study involved mainly upper limb activity, like the arm ergometer cycling performed in a similar sitting position. Both exercises were bimanual, so motor arousal could be presumed to be equally distributed on the two sides of the brain. Previous research has proposed that the right brain is responsible for sympathetic control of the heart, while the left side is related to parasympathetic control[29]. The present results which show more activation of the left prefrontal cortex during TC than during EGO cycling, may indicate greater parasympathetic control of the heart during TC, as also indicated by the higher HF power and lower LF/HF ratio. However, any direct connection between increased pre-frontal oxygenation during TC practice and dominant parasympathetic control of the heart could not be established in the present investigation.

The findings of the present case study will form the basis for larger scale investigation. If proven effective, mind-body practice could be conducted in different target populations, such as older adults with a history of falls, patients with Parkinson's disease, stroke survivors and subjects suffering from cardiopulmonary diseases. Subjects of those populations are often frail and often have cognitive impairment. Therefore, an exercise regime that enhances parasympathetic activities and simultaneously increases the oxygenation of the brain more than body-focused exercise would be a good choice for physical therapy rehabilitation. Also, Tai Chi can be practiced anytime and anywhere without the use of equipment. This might increase the sustainability of the exercise habit and is especially important for older adults in the community where rehabilitation services are often lacking.

This study had some limitations. First, there was only one female subject participating in this study and she was a master of TC. Therefore, our findings cannot be generalized to male subjects or to novice practitioners. Second, although the participant performed the exercises in a quite environment, her mental state was not controlled.

In conclusion, the present study compared the effects of TC and EGO on heart rate variability and concurrent prefrontal lobe activities during these two exercises. Our results suggest that both exercises increase the parasympathetic modulation of the autonomic nervous system and prefrontal lobe activities, with more activity being observed during TC practice. Confirmation these findings in a larger sample, preferably through a prospective study, would indicate TC, a mind-body exercise, may be a better choice than cycling for improving the cardiovascular health and cognitive function of older adults.

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