Measurement and Evaluation of Energy Metabolism of Bafa-Wubu Tai Chi

Shaojun Lyu*, Jianwei Zhang, Wen Yuan, Zaihao Chen, Tianming Gao, Yameng Li, Cuihan Li, Bo Song, Hongwei Wang, Meize Cui, Qiuyang Wei

Abstract

Background

The Bafa Wubu of Tai Chi (Eight Elements and Five Steps) is a novel tai chi form recently developed with the General Administration of Sport of China in order to promote Tai Chi in China and abroad. While this form has already been taught to thousands, no studies have been previously reported on its exercise physiology.

Objectives

To reveal the characteristics of respiration and energy metabolism of the Bafa Wubu of Tai Chi and lay a theoretical foundation for further scientific research on Tai Chi practice.

Methods

First, the baseline maximal exercise capacity of all the participants was measured. Then they received Bafa Wubu of Tai Chi training for three weeks to ensure that they gained proficiency. All participants then performed a single iteration of the Bafa Wubu Tai Chi form while their energy metabolism was measured dynamically, including maximal oxygen uptake (VO_2max), oxygen uptake/kg (VO_2/kg), metabolic equivalent (METs), heart rate (HR), respiratory quotient (RQ), tidal volume(TV), respiratory frequency, blood pressure, oxygen saturation and rate of perceived exertion (RPE).

Results

106 healthy individuals were recruited. After the 3-week practice, 100 (94%) individuals passed the assessment and were invited to participate in the physiologic testing. Prior to completing the study, 5 (5%) subjects withdrew. The 95 subjects who completed the study consisted of 63 men (aged 39.7 years±9.8) and 32 women (aged 36.9 years±11.1).

A single iteration of the Bafa Wubu Tai Chi form required approximately 3 minutes. During practice of Tai Chi, the average VO_2 for men was 0.72±0.16 (L/min), which was 26.17% ±6.77% of VO_2max; the average VO_2 for women was 0.67±0.19 (L/min), which was 30.25%±5.76% of VO_2max. Immediately after Bafa Wubu of Tai Chi exercise, SP increased by 17.3% ($p<0.01$) ; HR increased by 53.2% ($p<0.01$); and RPE increased by 76.4% ($p<0.01$); but there were no significant differences in DP and SpO_2, P=0.489, P=0.312. (3) The average METs was 2.21±0.44 METs, the average VO_2/kg was 13.81 ±4.24 ml/kg/min, the average HR was 104±16times /min, the average RQ was 0.80±0.08, the average respiratory frequency was 24 ±4 times / min; The average TV was 0.83 ±0.21L.

Conclusion

The Bafa Wubu of Tai Chi is a low intensity aerobic exercise, and energy consumption is mainly from the oxidation of fat. The Bafa Wubu of Tai Chi improves cardiopulmonary function demonstrated by improvement of pulmonary ventilatory function through increase of tidal volume during exercise.

Keywords

taijiquan, Taichi, Tai chi, tai ji, Bafa Wubu of Tai Chi; energy metabolism; exercise physiology; respiration

Funding

National Key R&D Program of China (2018YFC2000600), Finance Department of the State Administration of Traditional Chinese Medicine (GZY-GCS-2018-011), and the Wushu Research Institute of the General Administration of Sport of China (WSH2018A004).

J. of Int. Society of Chinese Health Practices
2020 Volume 1 Issue 1
Published online June 1, 2020

The authors' full names, academic degrees, and affiliations are listed in the Appendix.

Corresponding author

Prof. Shaojun Lyu. College of P.E. and Sports, Beijing Normal University. No.19 Xinjiekou wai street Haidian district, Beijing, China.100875.
Email: shaojunl@hotmail.com

Background and Significance

Tai Chi is a mind-body fitness routine which integrates martial arts, Qigong, daoyin and traditional Chinese medicine. Studies have shown that Tai Chi improves muscle strength[1-4], physical balance[5-7], cardiopulmonary functions[8-10] and mental health[11-13]. There are many styles and forms of Tai Chi, and the Yang 24 Form Tai Chi is the most popular one at present. However, the various Tai Chi routines have practical problems such as highly strenuous routines and complicated movement structures that are difficult to learn[14]. As a result, our team, at the request of the General Administration of Sport of China, created a new form, the Bafa Wubu of Tai Chi, that is simple enough to be readily learned even by novices while preserving tai chi's traditions and benefits. Our team has promoted its practice nationally and internationally since July 2018. In addition, the formulation of exercise prescriptions has become a hot spot, if Tai Chi exercise prescription is formulated, it is necessary to accurately measure the exercise intensity and energy metabolism characteristics of Tai Chi. Therefore, the General Administration of Sport of China has established the research of "Measurement and Evaluation of the Energy Metabolism of the Bafa Wubu of Tai Chi", in order to reveal the characteristics of energy metabolism of the Bafa Wubu of Tai Chi and lay a theoretical foundation for more scientific Tai Chi practice.

Methods

Participants

A total of 106 healthy individuals were recruited, after the 3-week practice, 100 (94%) individuals who passed the assessment were selected as participants. In the course of the study, 5 (5%) subjects withdrew, remaining 95 participants. The participants (63 men aged 39.7±9.8 and 32 women aged 36.9±11.1) were recruited from Beijing Normal University and the Central Institute of Ethnic Administrators (China). Inclusion criteria were as follows:

- Participants were interested in Tai Chi and they were Tai Chi beginners practicing Tai Chi for less than one month;
- Participants were healthy with no metabolic diseases;
- Participants signed the Informed Consent Form.
- In addition, those with movement dysfunction and long-term Tai Chi practitioners were excluded from the study.

Test for Maximal Exercise Capacity

Every participant received a baseline physical examination for collecting data about height, weight, blood pressure and oxygen saturation. High-intensity exercise, smoking, drinking alcohol and/or coffee were not allowed for at least 24 hours before the test. Their exercise capacities were measured following the Bruce Treadmill protocol on the cardiopulmonary exercise test machine (CORTEX Metal2, Germany). The load protocol starts at 2.7 miles per hour and a gradient of 10%, with an increase of 2% gradient and 1.3 miles per hour of speed every 3 minutes.

Methods of Bafa-Wuba Tai Chi Instruction

1. Type: Practicing the Bafa Wubu of Tai Chi[14], the core techniques of "eight elements and five steps". This style of Tai Chi consists of the "eight elements", which includes: Peng (warding off), Lu (rolling back), Ji (pressing), An (pushing), Cai (pulling down), Lie (splitting), Zhou (elbowing) and Kao (shouldering). The "five steps" include Jin (stepping forward), Tui (stepping backward), Gu (stepping to the left side), Pan (stepping to the right side) and Ding (maintaining central equilibrium);
2. Intensity: According to the ninth edition of the guidelines of the American College of Sports Medicine (ACSM), healthy adults have a moderate exercise range of 40%～59% of the reserve heart rate (HRR);
3. Time: The participants were required to attend a 60-minute class, consisting of 10 minutes of warm-up activities, 40 minutes of practice and 10 minutes of closing activities;
4. Frequency: This training class was held 5 times a week for a duration of the total of 3 weeks;
5. Progress: The major tasks in the first 2 weeks are to decompose technical movements, familiarize the core techniques, and form correct dynamic postures, so as to master elements of Tai Chi initially. The last week is to complete the whole set of routines, with 2-3 sets of movements as a group and 3-4 groups every day.
6. Selection: During the training period, the stability and coherence of movements, coordination between breathing and movements, as well as combination of mind, Qi and form are emphasized. After the 3-week practice, Tai Chi experts conduct assessment of all remaining participants and only those who passed the assessment will be selected for further testing. The experimental testers, Tai Chi instructors and

assessment experts were different people.

Energy Consumption Test

After Tai Chi training and passing the assessment, the energy consumption during a set of the Bafa Wubu of Tai Chi was tested by the MateMax3B portable cardiopulmonary tester (Cortex Gas Metabolizer, German Cortex). The tester produces indices such as oxygen uptake/kg (VO_2/kg), metabolic equivalent (METs), heart rate (HR), respiratory quotient (RQ), tidal volume (TV) and respiratory frequency. The Inbody 3.0 body composition analyzer (BIOSPACE, South Korea) was used to measure the height, weight, body fat ratio, and FFM.

The participants were instructed to avoid high-intensity exercises, smoking, alcohol and coffee for at least 24 hours prior to testing. Participants are not allowed to take part on an empty stomach, and the tests are scheduled for at least 30 minutes after meals. The participants first sat quietly for 10 minutes, and then resting heart rate, blood pressure and oxyhemoglobin saturation were measured after all the indices were maintained stable. Then, the participants were asked about weekly exercise, and appropriate breathing masks were selected for them, and then the test instrument corrects for the surrounding air. They would wear the heart rate strap and breathing mask sealed well after the air correction. Those participants began to rise for a Starting Posture by following the music for Tai Chi routines, and performed the set of Tai Chi exercise, in which the music is used to control the movement speed and rhythm. And the heart rate, blood pressure, oxyhemoglobin saturation and rating of perceived exertion (RPE) can be tested immediately after the practice. Each person was tested for three times in different periods, then the results of the three tests were compared, and the average values of the three tests were regarded as the final result.

Statistical Analysis:

The output data from the above tests are analyzed with Statistical tools SPSS21.0, with a sampling frequency of 60 times/min. For the sake of accuracy, the indices are presented by average value ± standard deviation with the unit of second, with a significant difference as $P<0.05$ regarding the significance level, and with a substantially significant difference as $P< 0.01$.

Results

Selection of Subjects and Baseline Characteristics

106 healthy individuals were recruited. After the 3-week practice, 100 (94%) individuals passed the assessment and were invited to participate in the physiologic testing. Prior to completing the entire study, 5 (5%) subjects withdrew. The 95 subjects who completed the study had the following demographics and body composition (Table 1).

Table 1 List of Basic Characteristics and Body Composition of the Participants（M±SD）

	Male (n=63)	Female (n=32)
Average Age	39.7±9.8	36.9±11.1
Height (cm)	174.4±7.0	162.9±5.4
Weight (kg)	72.6±8.2	55.3±6.1
Percentage of Fat (%)	20.2±4.94	24.0±3.82
Fat-free mass (FFM) (kg)	50.7±6.46	41.9±4.95

Exercise Intensity Measurement:

Exercise intensity can be expressed by VO_2max%, METs, HR, RPE and so on. Because of the difference between individuals with HR and RPE, the percentage of maximum oxygen uptake can eliminate the difference caused by the individual's physiological function. And the oxygen uptake of human body during exercise is closely related to the intensity of exercise. Therefore, this study uses VO_2max% to represent exercise intensity. The VO_2max was significantly correlated with gender, so this study was divided into male and female groups. The results were shown in Table 2.

Table 2 List of Oxygen Uptake Test Results of Participants (M ±SD)

	n	Age	VO_2（L/min）	VO_2max（L/min）	%VO_2max
Men	63	39.7±9.8	0.72±0.16	3.11±0.57	26.17±6.77
Women	32	36.9±11.1	0.67±0.19	2.20±0.24	30.25±5.76

Comparison of Physiological Indices at Rest and after Practicing Bafa-Wubu Tai Chi:

The comparison of energy metabolism indices before and after the Tai Chi exercise is shown in Table 3. The results show that SBP increased significantly by 17.3% ($P < 0.01$), HR increased significantly by 53.2% ($P < 0.01$), RPE significantly increased by 76.4% ($P < 0.01$), but there was no significant difference in DBP and SpO_2, immediately after exercise.

Table 3 Comparison of Physiological before and after the Practice of Tai Chi (M ±SD)

	n	Before practice	After practice	t	P
SBP（mmHg）	95	110.9±8.1	130.1±4.3	—16.8	0.000
DBP（mmHg）	95	69.6±5.8	70.2±5.8	—0.7	0.489
SpO_2（%）	95	96.7±1.2	96.8±1.3	—1.0	0.312
HR（time/min）	95	78±3	119±6	—41	0.000
RPE	95	6.1±0.4	11.3±1.1	—17.6	0.000

The Characteristics of Energy Metabolism during Tai Chi Exercise:

(1) METs:

The metabolic equivalent measured at rest was 1.10 ±0.14 METs, the average metabolic equivalent during exercise was 2.21 ±0.44 METs and the maximum was 3.51 METS. As shown in Figure 1, the change of METs in the whole set of Tai Chi practice has a rising trend and it was divided into two stages: the first stage, the rising trend is smooth from Starting Posture to the the 17th-posture Left Shoulder and METs was between 1.10 METs and 1.54 METs; the second stage was obvious from 18th-posture Advance, Ward off (L,R) to the 30th-posture Central Equilibrium(L,R) and METs was between 1.64 METs and 3.51 METs, which was restored to the quiet level within about 3 minutes after the exercise.

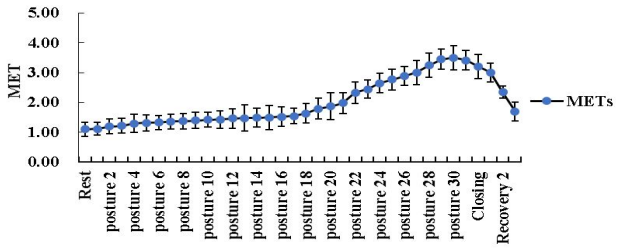

Figure 1 Chart of METs Change in the Bafa Wubu of Tai Chi Practice Process

(2) VO_2/kg:

VO_2/kg measured at rest was 6.68±2.07ml/kg/min, the average VO_2/kg during exercise was 13.81±4.24 ml/kg/min. As shown in Figure 2, the change of VO_2/kg in the whole set of Tai Chi practice has a rising trend and it was divided into two stages: the first stage, the rising trend was smooth from Starting Posture to the17th-posture Left Shoulder and VO_2/kg was between 6 ml/kg/min and 9 ml/kg/min; the second stage was obvious from 18th-posture Advance, Ward off (L,R) to the 31th-posture Cross Hands and VO_2/kg was between 10 ml/kg/min and 20 ml/kg/min, which was restored to the quiet level within about 3 minutes after the exercise.

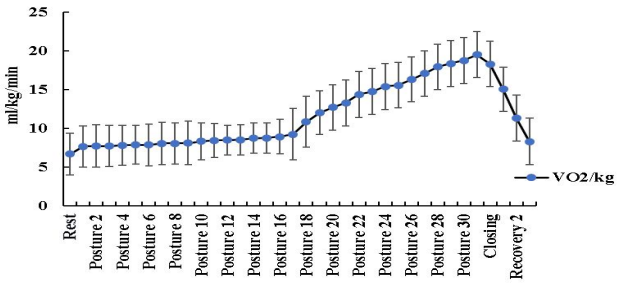

Figure 2 Chart of VO_2/kg Change in the Bafa Wubu of Tai Chi Practice Process

(3) HR:

HR measured at rest was 78±3 times/min the average HR during exercise was 104±16 times/min. As shown in Figure 3, the change of HR in the whole set of Tai Chi practice has a rising trend and it was divided into two stages: the first stage, the rising trend was smooth from Starting Posture to the16th-posture Right Elbow and HR was between 82 times/min and 104 times/min; the second stage was smooth from 17th-posture Left Shoulder to the 32th-posture Closing Posture and HR

was between 110 times/min and 119 times/min, which was restored to the quiet level within about 3 minutes after the exercise.

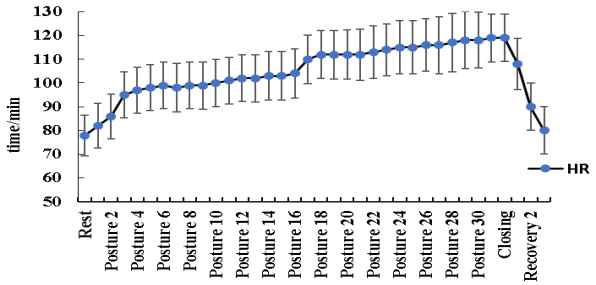

Figure 3 Chart of Heart Rate Change in the Bafa Wubu of Tai Chi Practice Process

(4) RQ:

RQ measured at rest was 0.76±0.07, the average RQ during exercise was 0.80±0.08. As shown in Figure 4, In the routine of the whole Bafa Wubu of Tai Chi movement, the change of RQ is relatively stable, between 0.70 and 0.90.

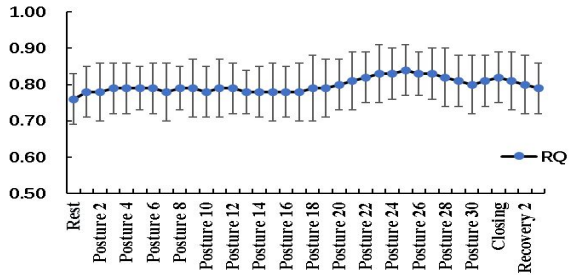

Figure 4 Chart of RQ Change in the Bafa Wubu of Tai Chi Practice Process

(5) Respiratory frequency:

Respiratory rate per minute measured at rest was 17±3times/min, and the average respiratory rate per minute during exercise was 24±4times/min. As shown in Figure 5, in the routine of the whole Bafa Wubu of Tai Chi movement, the change of respiratory frequency is increased smoothly, between 20 times/min and 27 times/min, which was restored to the quiet level within about 1 minutes after the exercise.

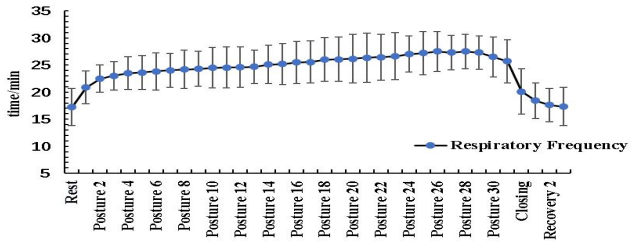

Figure 5 Chart of Respiratory Frequency Change in the Bafa Wubu of Tai Chi Practice Process

(6) TV:

TV measured at rest was 0.66±0.17 L, the average TV during exercise was 0.83±0.21L. As shown in Figure 6, in the routine of the whole Bafa Wubu of Tai Chi movement, the change of TV is increased smoothly, between 0.74 L and 0.98 L, which was restored to the quiet level within about 2 minutes after the exercise.

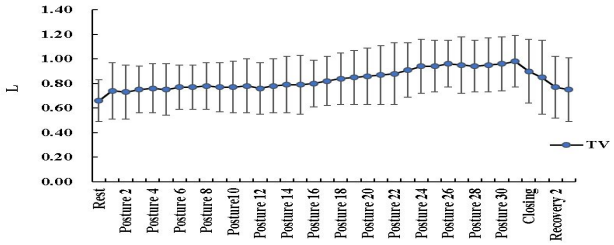

Figure 6 Chart of TV Change in the Bafa Wubu of Tai Chi Practice Process

Discussion

Analysis of the Bafa Wubu of Tai Chi Exercise Intensity

During the practice of the Bafa Wubu of Tai Chi, this study revealed the %VO_2max was 26.2% (men) and 30.3% (women). According to the model of Huang Yushan[15] for categorizing physical activity intensity according to $V0_2$max% (low-intensity exercise if $V0_2$max%<40, medium-intensity exercise if $V0_2$max% ranges 50-60, and high-intensity exercise if $V0_2$max% ranges 70-80), Bafa Wubu of Tai Chi is thus categorized as a low-intensity exercise. According to the model of Pate RR[16] to categorize physical activity intensity through energy metabolism (low-intensity exercise if METs < 3, medium-intensity exercise if METs ranges 3-6 and high-intensity exercise if METs > 6) Bafa Wubu of Tai Chi is also a low-intensity exercise. Zhuo, D[17] found that the average METs during the practice of Tai Chi was 4.1, which is higher than the results of this study. The form utilized by Zhuo, D was the 48 Form Yang style Tai Chi, which lasts a longer time, has more movements and is more difficult compared with the Bafa Wubu of Tai Chi. Thus, the energy consumption of various Tai Chi routines can differ significantly and thus stresses the importance of specifying the form used in tai chi research. The Bafa Wubu of Tai Chi is simple and easy to learn and has a range of energy expenditure within the parameters of safe exercise.

Analysis of the Bafa Wubu of Tai Chi Energy Expenditure

Because of different heights and weights of the participants, the relative oxygen uptake was used to

reflect the change of the supply of muscle oxygen and the consumption of oxygen. Figure 1, Figure 2 and Figure 3 show that the energy consumption varies in the form of a "ladder" during the practice of the Bafa Wubu of Tai Chi. This explanation for this is two-fold. The first reason is the purposeful organization of the movements. One iteration of the Bafa Wubu of Tai Chi lasts approximately 3 minutes and is divided into two stages. The first stage is to practice the first 17 postures for exercise in place, requiring that upper limbs employ the eight methods while keeping the lower limbs stationary. The second stage is to practice the last 15 postures where eight elements are combined with the five steps exercise. The organization of the movements determines that its energy consumption characteristics are presented in two stages and is progressive, which also ensures the safety of the exercise process. The second reason is the physiological mechanism. Tai Chi is a highly demanding exercise for lower limbs, the practitioner is required to lower the body's center of gravity during the marching exercise, so each leg has to bear the body weight for a long time. Compared with the first stage, the second stage will further stimulate the blood circulation and energy metabolism of muscles in legs, especially the quadriceps femoris and calf muscles[18-21]. In addition, as can be seen from Figure 4, in the routine of the whole Bafa Wubu of Tai Chi movement, the change of RQ is relatively stable, between 0.70 and 0.90. Therefore, the Bafa Wubu of Tai Chi practice is mainly based on the oxidation energy supply of fat.

Analysis of the Bafa Wubu of Tai Chi Respiratory Characteristics

As seen from Figure 5, in the routine of the whole Bafa Wubu of Tai Chi, the change of respiratory frequency is increased smoothly, the average respiratory frequency during exercise was 24±4. The three core elements of Tai Chi exercise, namely Xing (body), Qi (breath) and Yi (mind), are commonly referred to as "building Xing", "conveying Qi" and "using Yi" in the process of Tai Chi exercise. Tai Chi practice always emphasizes that "Conducting Qi through Yi, activating body through such statements as Qi" and "Not using force but Yi". If the practitioner breathes improperly, he can quickly go into oxygen debt. Thus, Bafa Wubu of Tai Chi practice requires deep and slow abdominal breathing. "Natural" abdominal respiration is a kind of respiratory movement dominated by diaphragm activity. When inhaling deeply, the diaphragm and external intercostal muscles (the primary inspiratory muscles)contract, and the accessory respiratory muscles also participate, which further expands the chest and then increases the inspiratory volume. When exhaling forcefully, the relaxation of inspiratory muscles combined with the contraction of intercostal and abdominal wall musculature further narrows the chest and deepens the respiration [22-25]. In addition, as can be seen from Figure 6, the TV increased smoothly from an average of 0.74 L to 0.98 L. Thus, because of the small increase in respiratory frequency, it reveals that Bafa Wubu of Tai Chi practice mainly increases lung ventilation volume through the increase of tidal volume.

When selecting the appropriate exercise regimen, differences in energy metabolism among regimens should be taken into consideration. For example, for patients with chronic illness or the elderly, practice with the Bafa Wubu of Tai Chi is suggested for improved safety given its low intensity and gradual increase in energy consumption.

Conclusion

The Bafa Wubu of Tai Chi is a low-intensity aerobic exercise. During the practice, the energy consumption varies in the form of "ladder" and its energy supply mode is mainly based on the oxidation of fat. Bafa Wubu of Tai Chi practice can be used as an introductory Tai Chi routine for improving cardiopulmonary function.

Acknowledgements

The authors thank Beijing Normal University, The Central Institute of Ethnic Administrators and Beijing Sport University for their help with recruitment of participants, training supervision and data collection.

Appendix

Authors
The authors' full names and affiliations are as follows:
Shaojun Lyu, College of Wushu, Beijing Sport University, Beijing, China
Jianwei Zhang, College of P.E. and Sports, Beijing Normal University, Beijing, China
Wen Yuan, Zaihao Chen, College of Wushu, Beijing Sport University, Beijing, China
Tianming Gao, Yameng Li, College of P.E. and Sports, Beijing Normal University, Beijing, China
Cuihan Li, College of Wushu, Beijing Sport University, Beijing, China
Bo Song, Hongwei Wang, Meize Cui, Qiuyang Wei, College of P.E. and Sports, Beijing Normal University, Beijing, China

Authors' contributions
L.S.J conceived and designed the study protocol. The individual interviews were conducted by Z.J.W., G.T.M., Y.W. and C.Z.H. Z.J.W., Y.W., C.Z.H., L.Y.M. and L.C.H. performed the translation and analysed the data. Z.J.W., Y.W., C.Z.H., G.T.M., S.B., W.H.W., C.M.Z. and W.Q.Y. guided and supervised the Tai Chi training. L.S.J. and Z.J.W. contributed to writing and reading the manuscript. All authors approved the final manuscript.

Abbreviations
ACSM: American College of Sports Medicine
RPE: rating of perceived exertion.

Ethics approval and consent to participate
This study was approved by the Ethics Committee of Sports Science Experiment, Beijing Sport University (NO.2018010H). All participants provided written informed consent and were assured confidentiality and anonymity.

Consent for publication
Not applicable.

Availability of data and materials
The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interest.

Funding
This work is financially supported by National Key R&D Program of China (2018YFC2000600), Finance Department of the State Administration of Traditional Chinese Medicine (GZY-GCS-2018-011), and the Wushu Research Institute of the General Administration of Sport of China (WSH2018A004).

References

1. Lan C, Lai J S, Chen S Y, et al. Tai Chi Chuan to improve muscular strength and endurance in elderly individuals: a pilot study. Arch Phys Med Rehabil, 2000. 81(5): 604-7.
2. Fong S S, Ng S S, Luk, W S, et al. Shoulder Mobility, Muscular Strength, and Quality of Life in Breast Cancer Survivors with and without Tai Chi Qigong Training. Evid Based Complement Alternat Med, 2013. 2013: 787169.
3. Su Z, Zhao J, Wang N, et al. Effects of Weighted Tai Chi on Leg Strength of Older Adults. J Am Geriatr Soc, 2015. 63(10): 2208-10.
4. Zhou M, Peng N, Dai Q, et al. Effect of Tai Chi on muscle strength of the lower extremities in the elderly. Chin J Integr Med, 2016. 22(11): 861-866.
5. Maciaszek J, Osinski W. Effect of Tai Chi on body balance: randomized controlled trial in elderly men with dizziness. Am J Chin Med, 2012. 40(2): 245-53.
6. Scianni A. Tai Chi improves balance and prevents falls in people with Parkinson's disease. J Physiother, 2015. 61(1): 44.
7. Zou L, Loprinzi P D, Yu, J J, et al. Superior Effects of Modified Chen-Style Tai Chi versus 24-Style Tai Chi on Cognitive Function, Fitness, and Balance Performance in Adults over 55. Brain Sci, 2019. 9(5).
8. Guo J B, Chen B L, Lu Y M, et al. Tai Chi for improving cardiopulmonary function and quality of life in patients with chronic obstructive pulmonary disease: a systematic review and meta-analysis. Clin Rehabil, 2016. 30(8): 750-64.
9. Yang Y L, Wang Y H, Wang S R, et al. The Effect of Tai Chi on Cardiorespiratory Fitness for Coronary Disease Rehabilitation: A Systematic Review and Meta-Analysis. Front Physiol, 2017. 8: 1091.
10. Jia X, Jiang C, Tao J, et al. Effects of core strength training combined with Tai Chi Chuan for the musculoskeletal system and cardiopulmonary function in older adults: A study protocol for a randomized controlled trial. Medicine (Baltimore), 2018. 97(35): p. e12024.
11. Wayne P M, Gagnon M M, Macklin E A, et al. The Mind Body-Wellness in Supportive Housing (Mi-WiSH) study: Design and rationale of a cluster randomized controlled trial of Tai Chi in senior housing. Contemp Clin Trials, 2017. 60: 96-104.
12. Tao J, Chen X, Liu J, et al. Tai Chi Chuan and Baduanjin Mind-Body Training Changes Resting-State Low-Frequency Fluctuations in the Frontal Lobe of Older Adults: A Resting-State fMRI Study. Front Hum Neurosci, 2017. 11: 514.
13. Osypiuk K, Thompson E, Wayne, P M. Can Tai Chi and Qigong Postures Shape Our Mood? Toward an Embodied Cognition Framework for Mind-Body Research. Front Hum Neurosci, 2018. 12: 174.
14. Shaojun Lyu. Bafa Wubu of Tai Chi. Beijing Sport University Press.2018
15. Huang Yushan. Theory and Application of Exercise Prescription[M]. Guangxi: Guangxi Normal University Press, 2005:27-28
16. Pate RR, Pratt M, Blair S N, et al. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. JAMA, 1995. 273(5): 402-7.
17. Zhuo D, Shephard R J, Plyley M J, et al. Cardiorespiratory and metabolic responses during Tai Chi Chuan exercise. Can J Appl Sport Sci, 1984. 9(1): 7-10.
18. Lin SF, Sung HC, Li TL, et al. The effects of Tai-Chi in conjunction with thera-band resistance exercise on functional fitness and muscle strength among community-based older people[J]. J Clin Nurs, 2015. 24(9-10): 1357-66.
19. Son NK, Ryu YU, Jeong HW, et al. Comparison of 2 Different Exercise Approaches: Tai Chi Versus Otago, in Community-Dwelling Older Women[J]. J Geriatr Phys Ther, 2016. 39(2): 51-7.
20. Glickmanl Simon R. Home-based Tai Chi Chuan May Reduce Fall Rate Compared to Lower Extremity Exercise Training in Older Adults with History of Falls[J]. Explore (NY), 2017. 13(1): 79-80.
21. Wu G. Age-related differences in Tai Chi gait kinematics and leg muscle electromyography: a pilot study[J]. Arch Phys Med Rehabil, 2008. 89(2): 351-7.
22. Holmes M L, Manor B, Hsieh W H, et al. Tai Chi training reduced coupling between respiration and postural control. Neurosci Lett, 2016. 610: 60-5.
23. Bosnak Guclu M, Bargi G, Katayifci N, et al. Comparison of functional and maximal exercise capacity, respiratory and peripheral muscle strength, dyspnea, and fatigue in patients with heart failure with pacemakers and healthy controls: a

cross-sectional study. Physiother Theory Pract, 2019: 1-12.
24. Dempsey J A. Respiratory Determinants of Exercise Limitation: Focus on Phrenic Afferents and the Lung Vasculature. Clin Chest Med, 2019. 40(2): 331-342.
25. Stocker F, Neidenbach R, Fritz C, et al. Oxygen Availability in Respiratory Muscles During Exercise in Children Following Fontan Operation. Front Pediatr, 2019. 7: 96.