


# Intensity level and cardiorespiratory responses to *Baduanjin* exercise in patients with chronic heart failure

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## Abstract

**Aims** *Baduanjin* (eight silken movements), a traditional Chinese exercise, is an alternative to the most common cardiac rehabilitation programmes due to their scarcity and unaffordability in China. The aim of this study was to measure the intensity and energy expenditure during *Baduanjin* and to determine the relative oxygen consumption (VO<sub>2</sub>) and heart rate (HR) responses of *Baduanjin* compared with maximal capacity in patients with chronic heart failure.

**Methods and results** Twenty participants (age: 65 ± 10 years, male: *n* = 17) with New York Heart Association II–III volunteered for this study. Participants were examined during two separate sessions, with 1–2 weeks between sessions. During session one, a symptom-limited cardiopulmonary exercise testing was performed on a cycle ergometer for measurement of maximal exercise capacity. Additionally, participants were taught *Baduanjin* exercise from a professional coach and were required to do it at home until the second session when their technique was confirmed by the coach. During session two, participants performed one 9 min round of *Baduanjin* with continuous measurement of VO<sub>2</sub> and HR. Measurements obtained during the *Baduanjin* were compared with data obtained during cardiopulmonary exercise testing. While performing *Baduanjin*, the mean VO<sub>2</sub> and HR were 7.1 ± 1.2 mL/kg/min and 86.1 ± 15.2 b.p.m., respectively. Compared with the cardiopulmonary exercise test, the VO<sub>2</sub> was 44% of their VO<sub>2max</sub> and 67% of their HR<sub>max</sub>, categorizing *Baduanjin* as a moderate-intensity exercise. The average energy expenditure during *Baduanjin* was 23.3 ± 4.4 kcal. Additionally, the VO<sub>2</sub> and HR responses during *Baduanjin* both exhibited a bimodal pattern.

**Conclusions** The results suggest that *Baduanjin* is a moderate-intensity aerobic exercise that could be an effective and safe exercise modality for home-based cardiac rehabilitation.

**Keywords** *Baduanjin*; Chronic heart failure; Exercise intensity; Oxygen consumption; Heart rate

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## Introduction

*Baduanjin*, translated as eight silken movements, is one of the most common forms of *Qigong* exercise.<sup>1</sup> *Qigong* is an ancient martial art, and it covers a spectrum of exercises: *Daoyinshu* (physical and breathing exercises), *Wuqinxi* (five

animals play), *Baduanjin* (eight silken movements), *Yijinjing* (changing tendons exercises), and *Tai Chi*. Although each type of *Qigong* exercise uses different practice postures or techniques of its own, they all share a unique methodology and theoretical system adopting key ideas of classical Chinese philosophy.<sup>2</sup> Commonly regarded as beneficial to health,<sup>3,4</sup>

*Baduanjin* have been practiced for over 1000 years, and now, it is a community exercise throughout mainland China.

*Baduanjin* is easy to learn, with minimal physical or cognitive demands, as it only entails eight simple movements based on traditional Chinese medicine theory. Moreover, it is an adaptable form of exercise that can be practiced at any place, any time, and without special equipment and minimal time investment. Hence, it is easily incorporated into daily routines and could easily be integrated into a comprehensive cardiac rehabilitation programme.

*Baduanjin* is characterized by slow movements (physical training) synchronized with meditation (mindfulness-based training) and regulated breathing (respiratory training) to achieve a harmonious flow of energy (*qi*) in the body.<sup>4</sup> From the perspective of Western thought and exercise science, *Baduanjin* is usually referred to as a light-intensity exercise, regardless of the individual's fitness level. However, for particularly deconditioned patients such as those with chronic heart failure (CHF), it may be considered a moderate-intensity or even high-intensity aerobic exercise depending on their age and exercise capacity.<sup>5</sup>

In clinical settings, the F.I.T.T. principle describes the four components of exercise prescription: frequency, intensity, time (duration), and type of exercise, which constitute the exercise 'dose'. Of these, exercise intensity is arguably the most critical component for cardiorespiratory fitness.<sup>6</sup> The gold standard for determining exercise intensity is the measurement of oxygen consumption ( $\text{VO}_2$ ).<sup>5</sup> To date, however, there is a lack of evidence on intensity levels for *Baduanjin* among CHF patients. In addition, no published studies have reported cardiopulmonary responses, such as  $\text{VO}_2$ , heart rate (HR), and other important parameters, during *Baduanjin* practice among patients with CHF. This shortcoming may exclude *Baduanjin* from the clinician's toolbox and incorporation into clinical practice. Therefore, the purpose of this study was to (i) measure the intensity and energy expenditure during *Baduanjin* and (ii) determine the relative cardiopulmonary response of *Baduanjin* compared with maximal capacity in patients with CHF.

## Methods

### Participants

This study was conducted as part of a project entitled the 'BESMILE-HF study' testing the efficacy and safety of *Baduanjin*.<sup>7</sup> The primary study is a randomized controlled trial where data on participants' maximal exercise capacities and cardiopulmonary responses during *Baduanjin* were collected at baseline. In the present study, individuals were included if they had data for the maximal exercise test and the *Baduanjin* intensity test.<sup>8,9</sup> The study was conducted in accordance with

the Declaration of Helsinki, and the BESMILE-HF study has been approved by the Ethics Committee of the Guangdong Provincial Hospital of Chinese Medicine (number: B2016–202-01). Study procedures were explained in full to all participants, and written informed consent was obtained.

### Data collection

#### *Procedures, equipment, and requirements*

Each participant came to the hospital on two separate sessions. During the first session, a maximal exercise test was conducted to determine individual maximal exercise capacity. On the same day, participants were required to learn how to practice *Baduanjin* until they had mastered it. The standing form of *Baduanjin* from China's General Administration of Sport<sup>10</sup> was used in this study. It has been standardized as a set of eight sequential movements for limbs, body trunk, and eye movements (*Figure 1*). One professional coach with over 5 years of teaching experience taught and confirmed participants' technique. Patients were then required to practice on their own at home for 1–2 weeks following the instructions of a video with verbal hints. Therefore, a period of at least 7 days separated the two visits, and all experimental procedures were completed within 2 weeks. On the second visit, a *Baduanjin* intensity test evaluated the cardiopulmonary responses during *Baduanjin*.

An ergospirometry platform (CARDIOVIT, CS-200; SCHILLER, Baar, Zug, Switzerland) was used for all tests. Respiratory gas analysis was performed on a breath-by-breath basis with a metabolic cart (PowerCube; Ganshorn, Niederlauer, Germany) and LF8 software (CARDIOVIT, CS-200 ergospirometry; SCHILLER). The maximal exercise test used an electronically calibrated upright bicycle (ERG 911S; SCHILLER). All tests were conducted in an air-conditioned laboratory with a temperature of 20–23°C, barometric pressure of 994–1042 mmHg, and relative humidity of 50–65%. Before each test, the gas analyser was calibrated with gases of a known concentration [15% of oxygen ( $\text{O}_2$ ) and 6% of carbon dioxide ( $\text{CO}_2$ )], and the flow metre was calibrated with a 3 L calibration syringe (SCHILLER).

The experiments were carried out in both morning and afternoon. However, for each participant, the maximal exercise test and *Baduanjin* test were conducted at the same time of the day. All tests were conducted by the same examiner to avoid inter-examiner variability. The examiner was both trained in and experienced with the tools. All participants were instructed to refrain from eating 2 h before these two visits and to abstain from caffeine, alcohol, and strenuous physical activity on each test day. Water intake was allowed.

#### *Maximal exercise test*

Prior to the maximal exercise test, spirometry was conducted according to the American Thoracic Society and European

**Figure 1** A 9 min *Baduanjin* exercise training session, including eight postures, involved muscle groups, and their corresponding durations.

Postures	1	2	3	4	5	6	7	8	
Time (min)	0	1.0	1.5	3.5	4.5	5.5	7.0	8.0	9.0
Name of postures and involved muscle groups									Duration
<b>1</b>	<b>Holding the hands high with palms up to regulate the internal organs</b>							<b>60 secs</b>	
	Muscles: Chest (Pectorals), Back (Latissimus Dorsi, Trapezius), Abs (External Obliques, Rectus Abdominis), Shoulders (Deltoids), Arms (Biceps, Triceps), Forearms								
<b>2</b>	<b>Posing as an archer shooting both left- and right- handed</b>							<b>90 secs</b>	
	Muscles: Gluteals, Quadriceps, Hamstrings, Calves (Gastrocnemius, Soleus), Chest (Pectorals), Back (Latissimus Dorsi), Sternocleidomastoid, Shoulders (Deltoids), Arms (Biceps, Triceps), Forearms								
<b>3</b>	<b>Holding one arm aloft to regulate the functions of the spleen and stomach</b>							<b>60 secs</b>	
	Muscles: Chest (Pectorals), Back (Latissimus Dorsi, Trapezius), Abs (Obliques, Rectus Abdominis), Shoulders (Deltoids), Arms (Biceps, Triceps), Forearms								
<b>4</b>	<b>Looking backwards to prevent sickness and strain</b>							<b>60 secs</b>	
	Muscles: Sternocleidomastoid, Shoulders (Deltoids), Chest (Pectorals), Back (Latissimus Dorsi), Abs (Rectus Abdominis, External Obliques, Internal Obliques, Transversus Abdominis)								
<b>5</b>	<b>Swinging the head while lowering the body to relieve stress</b>							<b>60 secs</b>	
	Muscles: Gluteals, Quadriceps, Hamstrings, Calves (Gastrocnemius, Soleus), Back (Latissimus Dorsi, Trapezius, Erector Spinae), Abs (Rectus Abdominis, External Obliques, Transversus Abdominis)								
<b>6</b>	<b>Moving the hands down the back-legs-feet to strengthen the kidneys</b>							<b>90 secs</b>	
	Muscles: Shoulders (Deltoids), Chest (Pectorals), Back (Latissimus Dorsi, Trapezius, Erector Spinae), Gluteals, Hamstrings, Calves (Gastrocnemius, Soleus)								
<b>7</b>	<b>Thrusting the fists and glaring the eyes to enhance strength</b>							<b>60 secs</b>	
	Muscles: Gluteals, Quadriceps, Hamstrings, Calves (Gastrocnemius, Soleus), Sternocleidomastoid, Shoulders (Deltoids), Back (Trapezius), Arms (Biceps, Triceps), Forearms								
<b>8</b>	<b>Raising and lowering the heels to cure disease</b>							<b>60 secs</b>	
	Muscles: Back (Erector Spinae), Gluteals, Hamstrings, Calves (Gastrocnemius, Soleus)								

Respiratory Society.<sup>11</sup> Participants were then instructed to lie down and rest in a supine position for 30–40 min before the maximal exercise test. Meanwhile, all subjects read a

standardized script of the testing procedures and received an explanation of the Borg 6–20 Rating of Perceived Exertion Scale.

On completion of these preliminary procedures, the maximum exercise test was conducted according to the American Thoracic Society/American College of Chest Physicians Statement on Cardiopulmonary Exercise Testing.<sup>12</sup> This was a symptom-limited exercise test using a bicycle ramp protocol: initial work rate of 0 W with 10% predicted maximum work rate increments every minute. Participants were verbally encouraged to maintain the desired pedal rate of 60 rpms and to exercise until exhaustion or fatigue. However, the examiner would stop the test according to the established criteria.<sup>13</sup> Perceived exertion was measured using the 6–20 Borg Scale (every 2–3 min) throughout the test.

The exercise test time ranged from 8 to 12 min. HR and rhythm were continuously monitored by 12 lead electrocardiogram. Peripheral oxygen saturation was continuously monitored, and blood pressure was measured at rest and every 3 min until test termination. The following data were collected automatically from the system for each participant (averaged over 10 s): HR (b.p.m.),  $\text{VO}_2$  (mL/kg/min), carbon dioxide production ( $\text{VCO}_2$ , L/min), respiratory rate (brpm), minute ventilation ( $V_E$ , L/min), end-tidal carbon dioxide partial pressure ( $P_{\text{ETCO}_2}$ , mmHg), ventilatory equivalents for carbon dioxide ( $V_E/\text{VCO}_2$  slope), and the ratio of  $\text{VO}_2$  change to work rate change ( $\Delta\text{VO}_2/\Delta\text{WR}$ ). The ventilatory threshold was assessed by the examiner and confirmed by an independent examiner using established criteria.<sup>13</sup> Both of them were experienced and certified physicians who received training before entering the study. If agreement could not be reached, a third physician was to be invited to discuss, and the final ventilatory threshold was determined by consensus.

### *Baduanjin intensity test*

*Baduanjin* intensity test was conducted on the second visit. Prior to the test, all subjects were instructed to lie down and rest in a supine position for 30 min.

During the test, participants were required to practice one round of *Baduanjin* lasting 9 min under the instruction of a video with verbal hints on technique to ensure that the same posture, pace, and sequence were followed. A 3 min and a 2 min breathing adjustment before and after practice was also included in the test. Thus, the total test time was 14 min.

The  $\text{VO}_2$  and  $\text{VCO}_2$  were measured simultaneously while breathing room air through a face mask covering the nose and mouth. Inhaled and exhaled gases were analysed in real time with a metabolic cart. HR, rhythm, and peripheral  $\text{O}_2$  saturation were continuously monitored. The same cardiopulmonary data as was collected during the maximal cardiopulmonary exercise test were collected automatically from the system for each participant and averaged over 10 s. Blood pressure was measured at rest and every 3 min until test termination.

## Statistical analysis

Data from the maximal exercise test and the average cardiorespiratory parameters obtained during *Baduanjin* were summarized as mean and standard deviation (SD). The mean  $\text{VO}_2$  and HR collected during *Baduanjin* were compared with individual maximal exercise capacity as determined by the cardiopulmonary exercise test and reported as a percentage (expressed as  $\% \text{VO}_{2\text{max}}$  and  $\% \text{HR}_{\text{max}}$ ). In order to categorize the *Baduanjin* exercise intensity, we referred to a position statement on exercise intensity terminology.<sup>5</sup> This position statement proposes the use of five categories to reflect clusters of activities that place similar relative physiological stress (within a category) on the exercising individual. The descriptors and cut-offs for the five categories based on  $\% \text{VO}_{2\text{max}}$  and  $\% \text{HR}_{\text{max}}$  were (i) 'sedentary':  $<20\% \text{VO}_{2\text{max}}$  or  $<40\% \text{HR}_{\text{max}}$ ; (ii) 'light':  $20 < 40\% \text{VO}_{2\text{max}}$  or  $40 < 55\% \text{HR}_{\text{max}}$ ; (iii) 'moderate':  $40 < 60\% \text{VO}_{2\text{max}}$  or  $55 < 70\% \text{HR}_{\text{max}}$ ; (iv) 'vigorous':  $60 < 85\% \text{VO}_{2\text{max}}$  or  $70 < 90\% \text{HR}_{\text{max}}$ ; and (v) 'high':  $\geq 85\% \text{VO}_{2\text{max}}$  or  $\geq 90\% \text{HR}_{\text{max}}$ . Moreover, in order to explore the cardiopulmonary response patterns throughout the session, all cardiopulmonary parameters, including  $\text{VO}_2$ , HR, blood pressure,  $\text{O}_2$  pulse,  $V_E$ , respiratory rate, and the  $P_{\text{ETCO}_2}$ , were summarized at 10 s intervals as mean  $\pm$  SD and plotted over time. No power calculation has been done because only descriptive data and no inferential statistics were provided in this study. All statistical procedures were performed with SPSS (version 18.0, Chicago, IL, USA).

## Results

Participants ( $n = 20$ , 17 male and 3 female, ages  $65 \pm 10$  years) had a clinical history of heart failure for  $4 \pm 3.5$  years and classified as either New York Heart Association (NYHA) II ( $n = 17$ ) or NYHA III ( $n = 3$ ). The mean left ventricular ejection fraction (LVEF) was  $46.7 \pm 12.1\%$ , and they were either with reduced LVEF (heart failure with reduced ejection fraction,  $n = 6$ ), perceived LVEF (heart failure with perceived ejection fraction,  $n = 8$ ), or middle ranged LVEF (heart failure with middle ranged ejection fraction,  $n = 6$ ). In addition, 75% of participants ( $n = 15$ ) had been taking beta-blockers. Details of demographic and anthropometrical characteristics, medical history, heart failure status, and co-morbidities are presented in *Table 1*.

Results of the maximum exercise test are shown in *Table 2*. Nineteen out of 20 participants attained respiratory exchange ratio  $> 1.1$ , with the other participant achieving a respiratory exchange ratio of 0.97 due to symptom limitation. All of the participants stopped the test due to leg fatigue. Ventilatory threshold was detected in all cases. Participants had an impaired exercise capacity with a mean  $\text{VO}_{2\text{max}}$  of  $17.6 \pm 4.9$  mL/kg/min, corresponding with a mean  $\text{HR}_{\text{max}}$  of

**Table 1** Participants' demographic and anthropometrical characteristics, heart failure status, and co-morbidities ( $n = 20$ )

Characteristic	Mean $\pm$ SD or number (%)
Demographic and anthropometrical characteristics	
Male	17 (85)
Age, years	64.6 $\pm$ 9.9
BMI	24.5 $\pm$ 3.6
Weight, kg	67.5 $\pm$ 11.5
Smokers	12 (60)
Heart failure characteristics	
Heart failure history, years	3.8 $\pm$ 3.5
NYHA classification	
NYHA II	17 (85)
NYHA III	3 (15)
LVEF classification	
HFrEF	6 (30)
HFmrEF	6 (30)
HFpEF	8 (40)
HR, b.p.m.	78 $\pm$ 14
SBP, mmHg	134 $\pm$ 17
DBP, mmHg	79 $\pm$ 12
NT-proBNP, pg/mL	1116.2 $\pm$ 2335.8
LVEF (Simpson), %	46.7 $\pm$ 12.1
PASP, mmHg	27.1 $\pm$ 7.0
Beta-blocker users	15 (75)
Co-morbidities	
Coronary heart disease	15 (75)
Previous myocardial infarction	7 (35)
Atrial fibrillation	4 (20)
Hypertension	10 (50)
Type 2 diabetes	6 (30)
Hyperlipidaemia	8 (40)
Chronic kidney disease	2 (10)
Stroke	3 (15)
Peripheral vascular disease	12 (60)

BMI, body mass index; b.p.m., beats per minute; DBP, diastolic blood pressure; HFmrEF, heart failure with middle ranged ejection fraction; HFpEF, heart failure with perceived ejection fraction; HFrEF, heart failure with reduced ejection fraction; HR, heart rate; LVEF, left ventricular ejection fraction; NT-proBNP, N-terminal B-type natriuretic peptide; NYHA, New York Heart Association; PASP, pulmonary artery systolic pressure; SBP, systolic blood pressure; SD, standard deviation.

**Table 2** Cardiorespiratory parameters obtained by maximal exercise test at the ventilatory threshold and at the maximal threshold from 20 participants with chronic heart failure

	Ventilatory threshold	Maximal intensity
	Mean $\pm$ SD	Mean $\pm$ SD
RER	1.3 $\pm$ 1.8	1.2 $\pm$ 0.1
WR (W)	54.9 $\pm$ 22.5	93.1 $\pm$ 33.3
VO <sub>2</sub> /kg (mL/kg/min)	11.9 $\pm$ 2.7	17.6 $\pm$ 4.9
HR (b.p.m.)	101.6 $\pm$ 17.0	131.6 $\pm$ 18.0
METs	3.4 $\pm$ 0.8	5.0 $\pm$ 1.4
SBP (mmHg)	151.3 $\pm$ 25.6	176.2 $\pm$ 31.4
DBP (mmHg)	85.7 $\pm$ 13.4	109.9 $\pm$ 69.6
O <sub>2</sub> pulse (mL/beat)	8.1 $\pm$ 2.5	9.2 $\pm$ 3.2
RR (breathes/min)	25 $\pm$ 5	33.5 $\pm$ 4.9
V <sub>E</sub> (L/min)	26.5 $\pm$ 4.6	50.1 $\pm$ 12.3
P <sub>ET</sub> CO <sub>2</sub> (mmHg)	34.9 $\pm$ 5.4	32.6 $\pm$ 7.4

b.p.m., beats per minute; DBP, diastolic blood pressure; HR, heart rate; METs, metabolic equivalents; O<sub>2</sub> pulse, oxygen pulse (the ratio of oxygen consumption to heart rate); P<sub>ET</sub>CO<sub>2</sub>, end-tidal carbon dioxide partial pressure; RER, respiratory exchange ratio; RR, respiratory rate; SBP, systolic blood pressure; SD, standard deviation; V<sub>E</sub>, minute ventilation; VO<sub>2</sub>, oxygen consumption; WR, work rate.

131.6  $\pm$  18.0 b.p.m. Participants also demonstrated an elevated V<sub>E</sub>/VCO<sub>2</sub> slope (34.0  $\pm$  8.4) and impaired aerobic efficiency measured by the  $\Delta$ VO<sub>2</sub>/ $\Delta$ WR ratio (10.3  $\pm$  2.1). Spirometry showed that 55% ( $n = 11$ ) of participants had normal lung function, and 30% ( $n = 6$ ) and 15% ( $n = 3$ ) demonstrated restrictive and obstructive patterns, respectively.

The exercise intensity and energy expenditure for all 20 participants during *Baduanjin* are shown in Table 3. During *Baduanjin*, the mean VO<sub>2</sub> was 7.1  $\pm$  1.2 mL/kg/min, 44% of VO<sub>2max</sub> (SD: 18%), categorizing *Baduanjin* as a moderate-intensity exercise (40–60% of VO<sub>2max</sub>).<sup>5</sup> The mean HR was 86.1  $\pm$  15.2 b.p.m., which was 67% of HR<sub>max</sub> (SD: 12%). This also categorized *Baduanjin* as a moderate-intensity exercise (55–70% of HR<sub>max</sub>).<sup>5</sup> However, the mean metabolic equivalent (MET) (2.0  $\pm$  0.4 METs) categorized *Baduanjin* as a light-intensity aerobic exercise (1.6–3 METs).<sup>5</sup> The mean energy expenditure was 155.4  $\pm$  29.6 kcal/h. Therefore, average energy expenditure was estimated to be 23.3  $\pm$  4.4 kcal for one 9 min *Baduanjin* session.

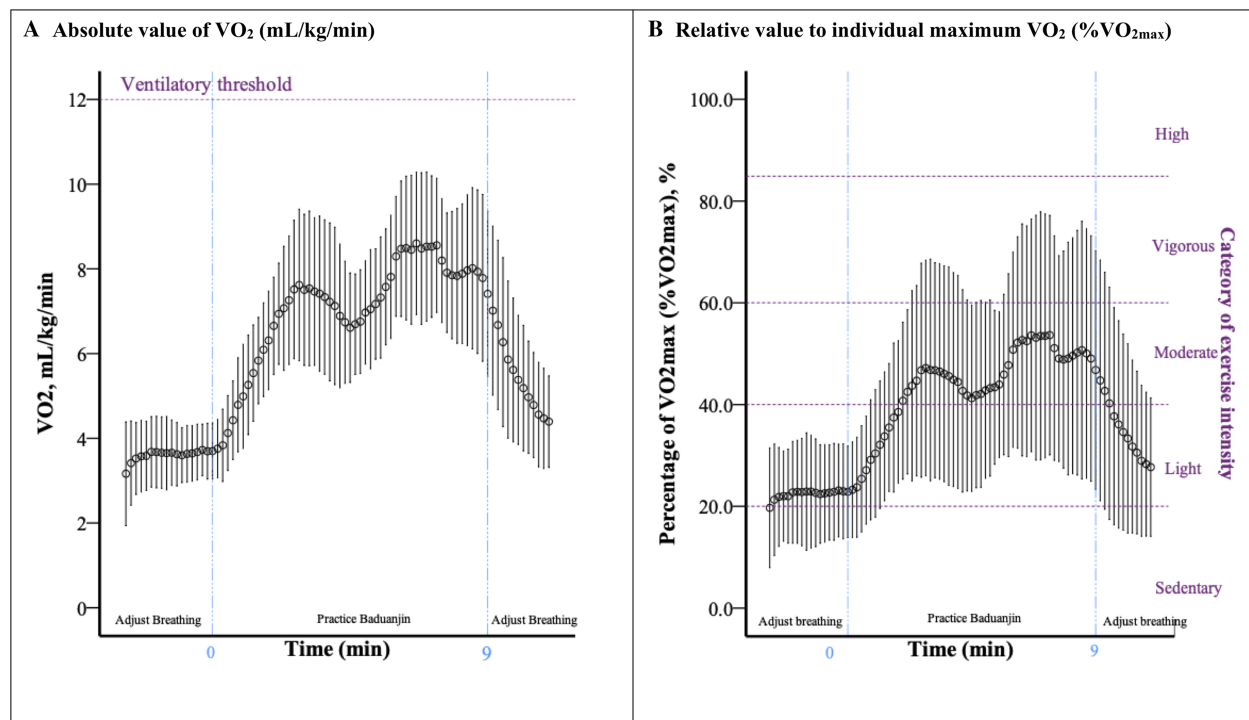
The VO<sub>2</sub> responses exhibited a bimodal distribution during *Baduanjin* (Figure 2). The VO<sub>2</sub> increased from 3.8 (23%VO<sub>2max</sub>) to 7.5 mL/kg/min (47%VO<sub>2max</sub>) during the first 3 min when a hemi-squat posture was involved (second posture), followed by a small drop in VO<sub>2</sub> after transition to the third posture. The intensity reached the second peak of 8.5 mL/kg/min (54%VO<sub>2max</sub>) at the 7th minute during an additional two hemi-squat postures (5th and 7th). It then dropped to 7.4 mL/kg/min (47%VO<sub>2max</sub>) at the end of the session (9th minute). Overall, the absolute VO<sub>2</sub> response remained under the ventilatory threshold (Figure 2A), and the %VO<sub>2max</sub> response indicating exercise intensity line remained mostly within the moderate-intensity area (Figure 2B).

**Table 3** Cardiorespiratory parameters obtained during *Baduanjin* from 20 participants

	Mean $\pm$ SD	Range
VO <sub>2</sub> /kg (mL/kg/min)	7.1 $\pm$ 1.2	(4–9)
VO <sub>2</sub> /VO <sub>2max</sub> (%)	44 $\pm$ 18	(21–82)
HR (b.p.m.)	86.1 $\pm$ 15.2	(64–120)
HR/HR <sub>max</sub> (%)	67 $\pm$ 12	(54–105)
METs	2.0 $\pm$ 0.4	(1–3)
EE (kcal/h)	155.4 $\pm$ 29.6	(101–211)
SBP (mmHg)	155 $\pm$ 22	(114–200)
DBP (mmHg)	92 $\pm$ 13	(71–119)
O <sub>2</sub> pulse (mL/beat)	5.7 $\pm$ 1.5	(3–9)
RR (brpm)	19.8 $\pm$ 3.6	(13–27)
V <sub>E</sub> (L/min)	15.9 $\pm$ 3.8	(9–23)
P <sub>ET</sub> CO <sub>2</sub> (mmHg)	31.1 $\pm$ 3.2	(25–36)

b.p.m., beats per minute; brpm, breathes per minute; DBP, diastolic blood pressure; EE, energy expenditure; HR, heart rate; METs, metabolic equivalents; O<sub>2</sub> pulse, oxygen pulse (the ratio of oxygen consumption to heart rate); P<sub>ET</sub>CO<sub>2</sub>, end-tidal carbon dioxide partial pressure; RR, respiratory rate; SBP, systolic blood pressure; SD, standard deviation; VO<sub>2</sub>, oxygen consumption; VO<sub>2max</sub>, maximum oxygen consumption; V<sub>E</sub>, minute ventilation.

**Figure 2** Mean oxygen consumption ( $\text{VO}_2$ , mL/kg/min) response during a 9 min *Baduanjin* session with a 3 min and a 2 min breathing adjustment before and after practice with chronic heart failure ( $n = 20$ ). During *Baduanjin*, the mean  $\text{VO}_2$  was  $7.1 \pm 1.2$  mL/kg/min, 44% of  $\text{VO}_{2\text{max}}$  (SD: 18%), categorizing *Baduanjin* as a moderate-intensity exercise (40–60% of  $\text{VO}_{2\text{max}}$ ). The  $\text{VO}_2$  responses exhibit a bimodal distribution during *Baduanjin*. Overall, (A) the absolute  $\text{VO}_2$  response remained under the ventilatory threshold and (B) the % $\text{VO}_{2\text{max}}$  response indicating exercise intensity line remained mostly within the moderate-intensity area.



Similar to the  $\text{VO}_2$  response, the HR response also exhibited a bimodal distribution with smaller magnitudes during *Baduanjin* (Figure 3). The HR increased from 76 (59%  $\text{HR}_{\text{max}}$ ) to 89 b.p.m. (69%  $\text{HR}_{\text{max}}$ ) with a small drop soon after; it then increased again to 95 b.p.m. (74%  $\text{HR}_{\text{max}}$ ) with a small drop to 84 b.p.m. (64%  $\text{HR}_{\text{max}}$ ) at the end of *Baduanjin*. Overall, the absolute HR response line remained under the equivalent HR for ventilatory threshold (Figure 3A), and the % $\text{HR}_{\text{max}}$  response line remained within the moderate-intensity area (Figure 3B).

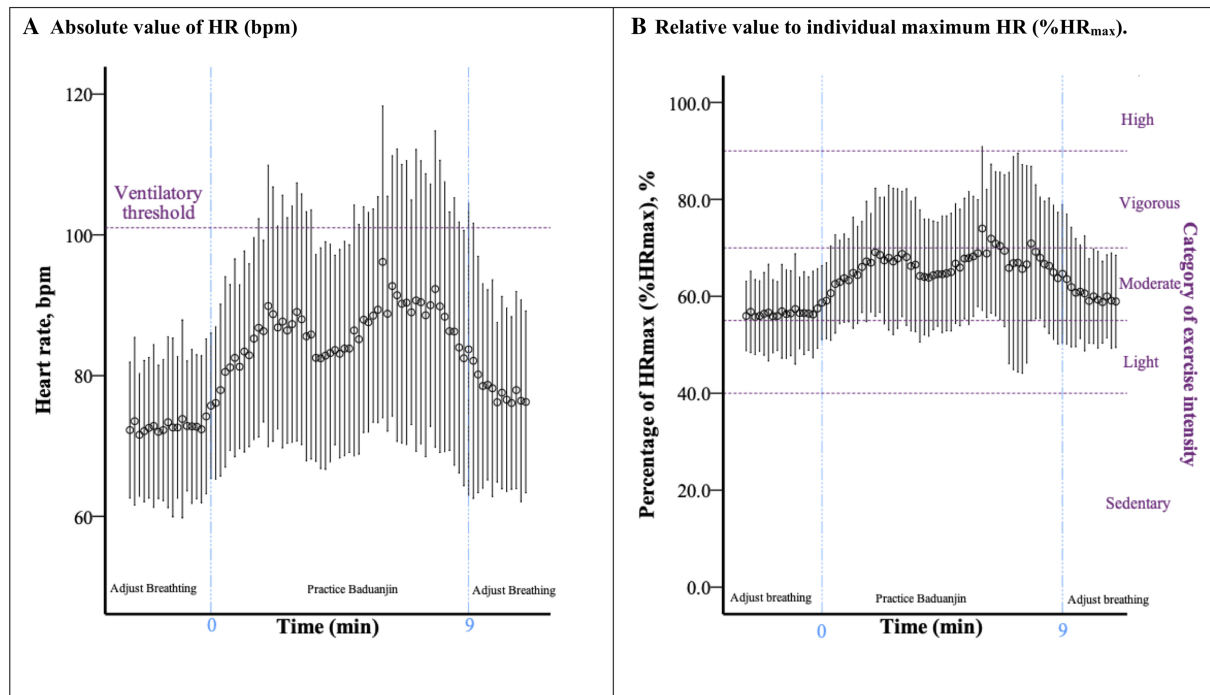
Figure 4 shows the participants ventilatory responses including respiratory rate (Figure 4A),  $V_E$  (Figure 4B), and  $P_{\text{ET}}\text{CO}_2$  (Figure 4C) during *Baduanjin*. The ventilatory responses demonstrated a pattern similar to  $\text{VO}_2$  and HR.

## Discussion

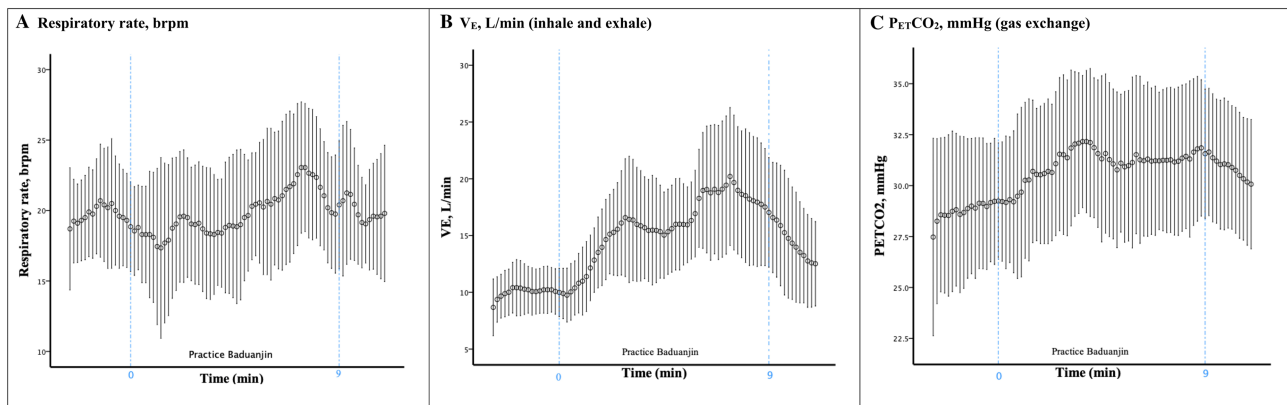
This is the first study to investigate *Baduanjin* intensity based on  $\text{VO}_2$  and HR, as well as cardiopulmonary responses during *Baduanjin* among CHF patients. Our results suggest that *Baduanjin*'s moderate intensity makes it suitable for improving exercise capacity in CHF patients. In addition, the  $\text{VO}_2$  and

HR responses both exhibited a bimodal pattern during the exercise session. Further, the average energy expenditure was estimated as 23.3 kcal for a 9 min *Baduanjin* session. Our findings on *Baduanjin* intensity are strengthened by comparison with maximal cardiopulmonary exercise testing (% $\text{VO}_{2\text{max}}$  and % $\text{HR}_{\text{max}}$  responses). In this light, exercise intensity can be expressed as either an absolute, for example, HR or MET, or as a relative measure, such as % $\text{VO}_{2\text{max}}$  or % $\text{HR}_{\text{max}}$ , allowing for comparison with other forms of exercise. A challenge when categorizing exercise intensity using absolute measurements is inter-individual variability with regard to functional capacity. Compared with those who are physically healthy and of similar age,<sup>3</sup> our participants demonstrate an impaired exercise capacity measured by the gold standard  $\text{VO}_{2\text{max}}$  ( $17.6 \pm 5$  mL/kg/min). Hence, the intensity of one exercise may differ across the population and may exceed the capabilities of some individuals.<sup>5</sup> In our study, the individual absolute intensity was  $2.0 \pm 0.4$  METs (ranging from 1 to 3 METs). This categorized *Baduanjin* exercise as a light-intensity activity (1.6–3 METs) if it is practiced by healthy individuals. However, both measures of relative intensity as measured in this study, % $\text{VO}_{2\text{max}}$  and % $\text{HR}_{\text{max}}$ , categorize *Baduanjin* as a moderate-intensity exercise. Moreover, both of the response lines were mostly located

**Figure 3** Mean heart rate (HR) response during a 9 min *Baduanjin* session with a 3 min and a 2 min breathing adjustment before and after practice in patients with chronic heart failure ( $n = 20$ ). During *Baduanjin*, the mean HR was  $86.1 \pm 15.2$  b.p.m., which was 67% of  $HR_{max}$  (SD: 12%), categorizing *Baduanjin* as a moderate-intensity exercise (55–70% of  $HR_{max}$ ). Similar to the  $VO_2$  response lines, the HR response also exhibited a bimodal distribution with smaller magnitudes during *Baduanjin*. Overall, (A) the absolute HR response line remained under the equivalent HR at ventilatory threshold and (B) the % $HR_{max}$  response line remained within the moderate-intensity area.



**Figure 4** Pulmonary responses during a 9 min *Baduanjin* session with a 3 min and a 2 min breathing adjustment before and after practice in patients with chronic heart failure ( $n = 20$ ). (A) respiratory rate, (B)  $V_E$ , (C)  $P_{ET}CO_2$ . The ventilatory responses demonstrated a pattern similar to  $VO_2$  and HR. SD, standard deviation; brpm, breathes per minute;  $V_E$ , minute ventilation;  $P_{ET}CO_2$ , end-tidal carbon dioxide partial pressure (mmHg), indicating gas exchange.



within the recommended moderate-intensity zones. Therefore, we believe that continuous monitoring of % $VO_{2max}$  and % $HR_{max}$  responses is an appropriate way to provide a composite gauge of exercise intensity, with priority given to % $VO_{2max}$  due to HR modulating impact of pharmacotherapies often prescribed for CHF patients (e.g. beta-blockers).

Our findings provide further evidence that *Baduanjin*'s eight simple postures are not only accessible and learner-friendly but also suitable in terms of their exercise intensity for CHF patients. Firstly, the *Baduanjin* training intensity fulfilled American College of Sports Medicine's recommendations to stimulate the body, causing physiologically

oriented outcomes.<sup>6</sup> It has been recommended that the exercise intensity should be set at 40–50% of  $VO_{2max}$  or 50–60% of  $HR_{max}$  at the starting point when initiating an exercise-based rehabilitation programme for CHF patients.<sup>14,15</sup> Moreover, *Baduanjin* intensity level is similar to that of general exercises that are used in rehabilitation programmes for CHF. A recently published Cochrane Systematic Review of exercise-based cardiac rehabilitation (EBCR) for heart failure shows that most EBCR programmes use moderate-intensity training at 40–80% of  $HR_{max}$  or 50–85% of  $VO_{2max}$ .<sup>16</sup> Therefore, the benefits of exercise capacity should be expected from continuous practice, and previous studies have reported that *Baduanjin* improves exercise capacity.<sup>17–22</sup>

Secondly, *Baduanjin* is a safe exercise for CHF patients, which can be practiced in a home-based setting. Both *Baduanjin*'s averaged and instant intensity levels are under or close to the ventilatory threshold, which fulfil the requirement of current clinical practice guidelines. It has also been proposed to be particularly suitable for elderly individuals and thus relevant for patients with CHF who are often older.<sup>23,24</sup> In addition, patients with CHF typically demonstrate an excessive ventilatory response to exercise.<sup>25</sup> In the present study, steady exercise-induced respiratory rates were observed during *Baduanjin*. The key element of *Baduanjin*, mindful breathing, emphasizes the coordination of breathing and physical movements, relaxation, focused self-awareness, and imagery. This decreases cardiac sympathovagal tone and ventricular workload,<sup>26</sup> decreasing the training burden on patients. Therefore, the likelihood of significant adverse arrhythmia, ischaemia, and/or other adverse cardiovascular events is proportionally reduced.

Thirdly, *Baduanjin* could facilitate initiation of exercise, long-term exercise adoption, and maintenance. Our results show that the average  $VO_2$  during *Baduanjin* was 44% of participants  $VO_{2max}$ , and the average HR was 67% of subject's  $HR_{max}$ . Moreover, a bimodal pattern response related to semi-squat postures was observed for  $VO_2$  and HR. These findings indicate that patients can achieve a suitable level of intensity during training by adjusting their postures, such as modifying the height of the semi-squat posture. Prior studies have shown that exercise efficacy is more likely to be achieved with a regimen that can provide effective low-intensity options, particularly as exercise is initiated, but that can also intensify as tolerated or facilitate intermittent intervals of higher intensity.<sup>23,27,28</sup> In this respect, *Baduanjin*, which is inherently less strenuous but easily modified to tailor intensity, may address tolerability and accessibility.

Our findings regarding the energy expenditure have implication for the personalization and standardization of exercise-based rehabilitation programmes using *Baduanjin* for CHF patients. A meta-regression analysis reports that the total energy expenditure (product of training intensity, session duration, session frequency, and programme length)

of a training programme appears to be the only training characteristic with a significant effect on exercise capacity.<sup>29</sup> This study reported a clinical importance improvement in peak  $VO_2$  of 1 mL/kg/min with each 80 kcal/kg increase in total energy expenditure. Together with our finding that energy expenditure averaged 23.3 kcal for one 9 min *Baduanjin* session, a personalized and goal-oriented *Baduanjin* exercise prescription can be made. For example, if a patient weighing 50 kg wants to increase 1 mL/min/kg after a 12 week *Baduanjin* exercise programme, this means the patient would need a total energy expenditure of 40 000 kcal (80 kcal/kg \* 50 kg). This would require at least 172 sessions (4000 kcal/23.3 kcal per session) of *Baduanjin* in total or ~2 daily sessions over 12 weeks to reach the goal.

As with all studies, there are potential limitations to note. Firstly, the interpretability and generalizability of the results were limited by the clinical characteristics of the analysed population. Our study population only included NYHA II and III CHF patients who are young and suffer from heart failure of mild severity. Therefore, our findings are specific to the population studied. Secondly, our population was relatively homogenous and had limited female participation. Additional studies focused on enrollment of female participants is encouraged. Thirdly, all participants in our study were new to *Baduanjin*, enabling a similar skill level among participants of varying skill levels. However, whether intensity and cardiopulmonary responses vary among those who are more skilful is unknown. Therefore, future research is needed, with greater heterogeneity of skill levels to investigate the cardiopulmonary responses of *Baduanjin* in CHF patients and to explore how *Baduanjin* characteristics, such as the postures, practice sessions, or practice skills, influence intensity and cardiopulmonary responses. Lastly, it is difficult to render the studies replicable because *Baduanjin* coaches are not available in all parts of the world. However, with the proliferation of social media, tutorial videos produced by our research team are easy to find online,<sup>30,31</sup> and the certified version from China's General Administration of Sport is also available in English.<sup>32</sup> Hence, our study can serve as a skeleton for future studies, which explore the cardiopulmonary responses of *Baduanjin* or other similar exercises among different races and ethnicities.

## Conclusions

Our findings show that *Baduanjin* is a moderate-intensity aerobic exercise without excessive cardiopulmonary burden. Considering its advantages of being learner-friendly and flexible in terms of time commitment and space requirements, *Baduanjin* could be an effective and safe exercise modality for inclusion in cardiac rehabilitation programmes for CHF patients, especially in home-based settings.



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## Conflict of interest

None declared.

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## Author contributions

X.C., W.L., and W.J. contributed to the conception and design of the research. W.L. contributed to obtaining funding and supervising the work. X.C. contributed to drafting the manuscript. All authors contributed important intellectual content to the critical revision of the manuscript. All authors read and approved the final manuscript.

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