Journal of Exercise Science & Fitness 20 (2022) 256–262

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

Full Length Article

Effects of aquatic high-intensity interval training and moderate-intensity continuous training on central hemodynamic parameters, endothelial function and aerobic fitness in inactive adults

Songxin Tang [a, 1, 2], Weiwei Huang [b, 1], Shen Wang [a, 1], Yanying Wu [a], Lianmeng Guo [a], Junhao Huang [a, *], Min Hu [a, **]

[a] Guangdong Provincial Key Laboratory of Physical Activity and Health Promotion, Scientific Research Center, Guangzhou Sport University, Guangzhou, Guangdong, China

[b] Department of Swimming, Guangzhou Sport University, Guangzhou, China

ARTICLE INFO

Article history:
Received 5 January 2022
Received in revised form
20 April 2022
Accepted 23 April 2022
Available online 2 May 2022

Keywords:
High-intensity interval training
Moderate-intensity continuous training
Aquatic exercise
Vascular function
Inactive adults

ABSTRACT

Objective: The effects of land-based high-intensity interval training (HIIT) on the cardiovascular system have already been demonstrated. However, the water environment is different from that on land. Therefore, we investigated the effects of 6-week aquatic HIIT and moderate-intensity continuous training (MICT) on central hemodynamic parameters, endothelial function, and aerobic fitness in inactive adults.
Methods: Thirty-one inactive adults were randomly assigned to HIIT or MICT group. HIIT group performed twelve 30-s swimming exercise bouts with the intensity of 95% HR_{max} and 15–18/20 RPE with a 60-s rest period between each bout. MICT group performed a 30-min uninterrupted swimming exercise with the intensity of 70%–75% HR_{max} and 12–14/20 RPE. Training frequency for both groups was three times a week. The pulse wave analysis and flow-mediated dilation (FMD) were measured by non-invasive equipments.
Results: The aerobic fitness significantly increased after HIIT, but no change was seen after MICT. Augmentation pressure (AP) and augmentation index normalized at 75 bpm (AIx@HR75) significantly decreased after HIIT but not MICT, whereas MICT rather than HIIT improved subendocardial viability ratio (SEVR), central and peripheral blood pressure, and resting HR. Only HIIT significantly increased brachial endothelial function.
Conclusion: A six-week aquatic HIIT and MICT had no differences in hemodynamic parameters, endothelial function, and aerobic fitness, however 6 weeks of aquatic HIIT reduced arterial stiffness, increased endothelial function and aerobic fitness, while 6 weeks of aquatic MICT reduced arterial blood pressure and resting HR and increased the coronary blood flow reserve.

1. Introduction

Cardiovascular diseases (CVD) are still the number one cause of death and disability globally. As one of the major causes of CVD, physical inactivity has become the world's fourth leading risk factor for death.[1] According to the World Health Organization (WHO) report in 2016, more than a quarter of adults around the world (about 1.4 billion) lacked exercise.[2] Increased sedentary behavior may lead to rapid deterioration of cardiovascular health and premature death in people with increased cardiovascular risk. Even 1–4 weeks of inactivity is associated with adverse effects on cardiovascular function and increased cardiovascular risk factors.[3]

* Corresponding author. Scientific Research Center, Guangzhou Sport University, 1268 Middle Guangzhou Avenue, Guangzhou, 510500, China.
** Corresponding author. Scientific Research Center, Guangzhou Sport University, 1268 Middle Guangzhou Avenue, Guangzhou, 510500, China.
E-mail addresses: junhaohuang2006@hotmail.com (J. Huang), whoomin@aliyun.com (M. Hu).
[1] These authors contributed equally to this work.
[2] Present address: ImFINE Research Group, Department of Health and Human Performance, Polytechnic University of Madrid, Madrid, ES, Spain.

https://doi.org/10.1016/j.jesf.2022.04.004

Cardiovascular dysfunction can increase CVD risk, and impaired central hemodynamics is an independent risk factor for CVD.[4] Using applanation tonometry to measure the central hemodynamic parameters, including resting heart rate (HR), central blood pressure, augmentation pressure (AP), augmentation index (AIx), and subendocardial viability ratio (SEVR), these parameters could be used to evaluate central arterial pressure, aortic vascular function, cardiac supply capacity, and endocardial perfusion.[5] Among these parameters, AIx quantifies the augmentation of central aortic pressure. Consequently, AIx represents a measure of peripheral arterial wave reflection. To exclude the effect of heart rate on AIx, AIx is normalized by a standard heart rate of 75 beats per minute (AIx@HR75). SEVR is an independent predictor of coronary blood flow reserve, which has been considered as an alternative to microvascular myocardial perfusion.[6]

In 1985, researchers found that the increase in shear stress of blood flow can act on the vascular endothelium, causing the blood vessel to produce a diastolic response.[7] This phenomenon is named flow-mediated dilation (FMD), which depends on intact endothelium. In practical applications, a non-invasive ultrasound system is used to measure the FMD of the brachial artery to reflect the vascular endothelial function.[8,9]

Land-based high-intensity interval training (HIIT) has exhibited superior or similar improvements in arterial vascular and endothelial function and aerobic fitness, among other cardiovascular risk factors, compared to a moderate-intensity continuous training (MICT) in healthy participants and those with moderate-to-high risk of CVD.[10,11] In this regard, a meta-analysis from Ramos et al. on land-based training also revealed that HIIT promoted better FMD improvements in patients with vascular impairment (such as type 2 diabetes, hypertension, coronary disease, obesity, and metabolic syndrome) than MICT.[12] Nevertheless, based on the current scientific literature, it is unclear whether aquatic HIIT is beneficial to the cardiovascular function of inactive adults. On the other hand, since aquatic training involves minimal weight-bearing stress, which could reduce the risk of injury, it may be considered as a good training modality, especially for individuals who are middle-aged, elderly or obese. Furthermore, immersion in water results in hydrostatic pressure gradient, which could increase venous reflux and the blood volume of heart and intrathoracic vessels by increasing the pressure on immersed body surface.[13] In addition, there is also a lack of study comparing the health effects of aquatic HIIT with MICT. Therefore, we investigated the effects of 6-week aquatic HIIT and MICT on central hemodynamic parameters, endothelial function, and aerobic fitness in inactive adults.

2. Methods

2.1. Subjects

Thirty-one volunteers (8 males and 23 females) were recruited from the local community. The inclusion criteria were adults with low physical activity level according to the International Physical Activity Questionnaires (IPAQ)[14] Those with severe respiratory diseases, kidney dysfunction, and CVD, confirmed by medical history records, were excluded. This study was approved by the Guangzhou Sport University Human Experimental Ethics Board and registered in Chinese Clinical Trial Registry (ChiCTR2000029491). All volunteers gave their written informed consent in accordance with the Declaration of Helsinki.

2.2. Exercise protocols

Both HIIT and MICT groups trained 3 days per week for 6 weeks, with a total of 18 training sessions. Body composition, metabolic parameters, aerobic fitness, and arterial function were assessed pre- and post-training program. Post-test was performed 48 h after the last training session. During experimental intervention, participants were asked to maintain their usual dietary habits and physical activities. Alcohol and caffeine were not allowed to consume 24 h before measurements. Participants were requested to maintain a fasting time for at least 8 h before the blood and vascular function tests.

Both HIIT and MICT groups were subjected to a 15-min warm-up on land before each training session, followed by a specialized aquatic warm-up exercise for 10 min. Both warm-ups were performed at low-intensity (50%–55% HR_{max}). Each training session was ended with a 10-min cool-down. Participants could use floats to assist swimming. Heart rate was continuously monitored by Polar heart rate monitors and recorded by researchers. Fig. 1 showed the exercise protocols of HIIT and MICT .

HIIT sessions lasted for 18–20 min (effective high-intensity swimming of 6 min), consisting of twelve 30-s swimming exercise bouts (breaststroke) separated by a 60-s resting time between each bout. In the first week, participants completed the training with 75%–90% of HR_{max} and 13–16/20 self-reported RPE using the Borg Scale. The intensity of 95% HR_{max} (15–18/20 RPE) was performed from the second week until the end of the training program.

The MICT group performed a 30-min uninterrupted swimming exercise (breaststroke) according to training principles previously described.[15] Participants maintained the intensity of 70%–75%

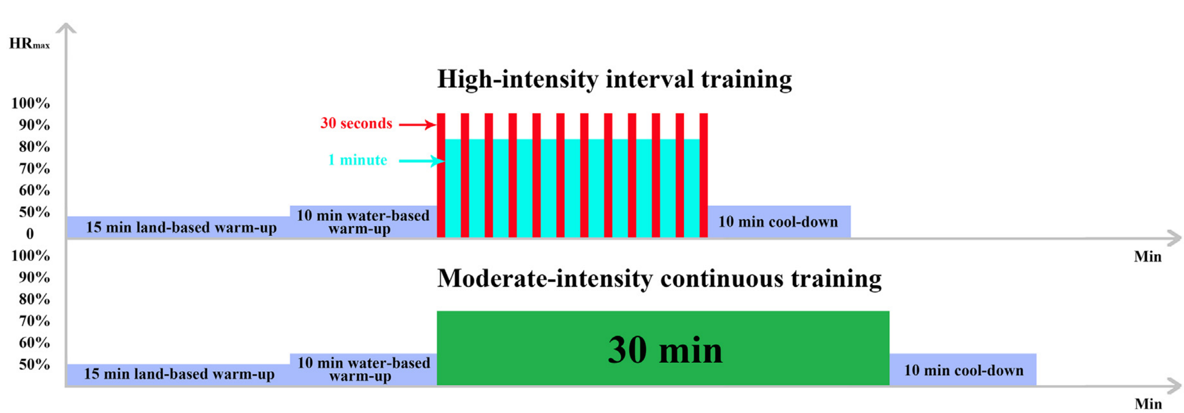

Fig. 1. Exercise protocols.
The HIIT (25-min warm-up, 6 min of HIIT training [95% of HR_{max}], 11 min of recovery, and 10-min cool-down) and the MICT training protocol (25-min warm-up, 30 min of MICT training [70%–75% of HR_{max}], and 10-min cool-down).

HR_{max} and 12–14/20 RPE. The targeted intensity was checked every 5 min during the exercise.

2.3. Vascular function

Resting heart rate (HR) and peripheral blood pressure were measured three times by a digital sphygmomanometer (Omron 705 IT, Omron Health Care, Japan). SphygmoCor system (AtCor Medical, Sydney, Australia) was used to analyze pulse waves, which were commonly applied to detect parameters that reflect cardiovascular function, according to previously described protocols.[6,16,17] The following parameters have been generated: aortic blood pressure, augmentation pressure (AP), augmentation index (AIx), and subendocardial viability ratio (SEVR). SEVR is a measure of myocardial perfusion, and AIx is an index that reflects artery stiffness. Since AIx is influenced by heart rate, AIx is also standardized to AIx at 75 beats/min (AIx@HR75).

An ultrasound device, with a high-definition linear array transducer and edge-tracking system combined with computer-assisted analysis software-generated two-dimensional images (transverse and longitudinal section) using a UNEXEF38G system (UNEX, Nagoya, Japan), was adopted to assess FMD. FMD values were based on the percentage increase in the brachial artery diameter compared to the resting state after the cuff is deflated. Mean blood flow (vessel cross-sectional area × MBV [mean blood velocity]) was calculated to quantify the hyperemic response. Besides, the mean shear rate (MSR) was calculated as follows:

$$MSR\left(s^{-1}\right) = \frac{4 \times MBV}{mean\ diameter\ at\ rest}$$

FMD tests were performed twice on each participant and the same operator conducted all measurements. The results of repeated measurements showed that the correlation coefficient was 0.88 and the coefficient of variation was 11.4%, as previously described.[8,9]

2.4. Body composition

Body composition was measured in an air-conditioned room (25°C) by the direct segmental multifrequency bioelectrical impedance method (InBody 370, Biospace, Seoul, Korea). Hand-foot skin of participants and electrodes were cleaned and dried before the measurements. Then, they were instructed to grasp handles of the analyser with upright position in minimal clothing while barefoot.

2.5. Aerobic fitness

A MasterScreen CPX (CareFusion, Hochberg, Germany) and a procedure of breath-by-breath connected to the treadmill was used for cardiopulmonary exercise testing. We applied a modified Bruce protocol in which stages were designed as follows: warming up at the speed of 2.7 km/h and 0% inclination and then increasing inclination and speed in 2% and 1.28–1.44 km/h every 3 min, respectively. When the estimated maximal heart rate was reached during the test, the operator encouraged the volunteer to continue the test until exhaustion (18–20/20 self-reported RPE). Relevant parameters, such as oxygen uptake and carbon dioxide output, were continuously recorded by the gas analyzer, and HR was assessed by continuous electrocardiography.

2.6. Blood analysis

Fasting blood glucose (BG), triglycerides (TG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-c), and low-density lipoprotein cholesterol (LDL-c) were measured at Kangfulai Hospital, China.

2.7. Statistical analysis

Mixed effect models were applied to analyze the effects of group (HIIT *vs.* MICT), time (0 *vs.* 6 weeks), and the interaction between group and time on anthropometric, metabolic, vascular, and aerobic fitness variables. Repeated covariance type of the models was set to unstructured, and the covariate was age. Tukey post hoc analysis was used to analyze within-group and between-group comparisons.

Effect sizes (ES) were calculated by Cohen's d. The sample size was calculated using software (G*Power 3.1, Software Inc., Kiel, Germany) and was based on a meta-analysis.[18] The calculated sample size (between-group effect of 0.30, with an alpha [α] of 0.05 and power [β] of 0.80) was 23 participants. We increased the sample size to 31 in case of dropouts. All statistical analyses were performed with SPSS 22.0 (SPSS, Inc., Chicago, IL, USA). Data were shown as means ± SD and significance was set at $p < 0.05$.

3. Results

3.1. Effects of HIIT and MICT on anthropometric and metabolic parameters

Five participants (16%) were excluded from statistical analysis due to failure to reach 90% attendance (Fig. 2). The anthropometric and metabolic parameters were shown in Table 1. Body weight, BMI, and fat mass significantly decreased after both HIIT and MICT ($p < 0.05$, $p < 0.01$, or $p < 0.001$). Furthermore, 6 weeks of HIIT significantly increased skeletal muscle mass ($p < 0.01$), with a decrease in body fat percentage ($p < 0.001$). However, there were no changes in skeletal muscle mass ($p > 0.05$) and body fat percentage ($p > 0.05$) after 6 weeks of MICT.

None of the anthropometric and metabolic parameters was detected a significant difference in the group-by-time interactions or between groups. But simple effects test revealed HIIT significantly decreased total cholesterol ($p < 0.01$). However, 6 weeks of MICT could not change total cholesterol ($p > 0.05$). In addition, no difference in HDL-c, LDL-c, and triglycerides was found after neither HIIT nor MICT. However, both of HIIT and MICT markedly reduced fasting blood glucose (both $p < 0.001$).

3.2. Effects of HIIT and MICT on aerobic fitness

Maximal exercise performances of both training groups in the cardiopulmonary exercise test pre- and post-intervention were presented in Table 1. Significant improvements in absolute VO_{2max} ($p < 0.05$), relative VO_{2max} ($p < 0.01$), HR_{max} ($p < 0.05$), peak O_2 pulse ($p < 0.05$), and MET ($p < 0.001$) were detected after HIIT rather than MICT. Group-by-time interactions revealed a significant difference in absolute VO_{2max} [estimate = −132.92, $F(1,24) = 4.300$, $p < 0.05$, partial $\eta^2 = 0.152$], relative VO_{2max} [estimate = −2.31, $F(1,24) = 4.944$, $p < 0.05$, partial $\eta^2 = 0.171$], and MET [estimate = −132.92, $F(1,24) = 5.103$, $p < 0.05$, partial $\eta^2 = 0.175$] between HIIT and MICT, however no significant main effects in VO_{2max} [estimate = −5.81, $F(1,24) = 0.680$, $p = 0.418$, partial $\eta^2 = 0.028$], relative VO_{2max} [estimate = 0.69, $F(1,24) = 0.513$, $p = 0.481$, partial $\eta^2 = 0.021$], and MET [estimate = 0.21, $F(1,24) = 0.494$, $p = 0.489$, partial $\eta^2 = 0.020$] were seen by group. Moreover, no difference in ventilation and RER were detected after neither HIIT nor MICT.

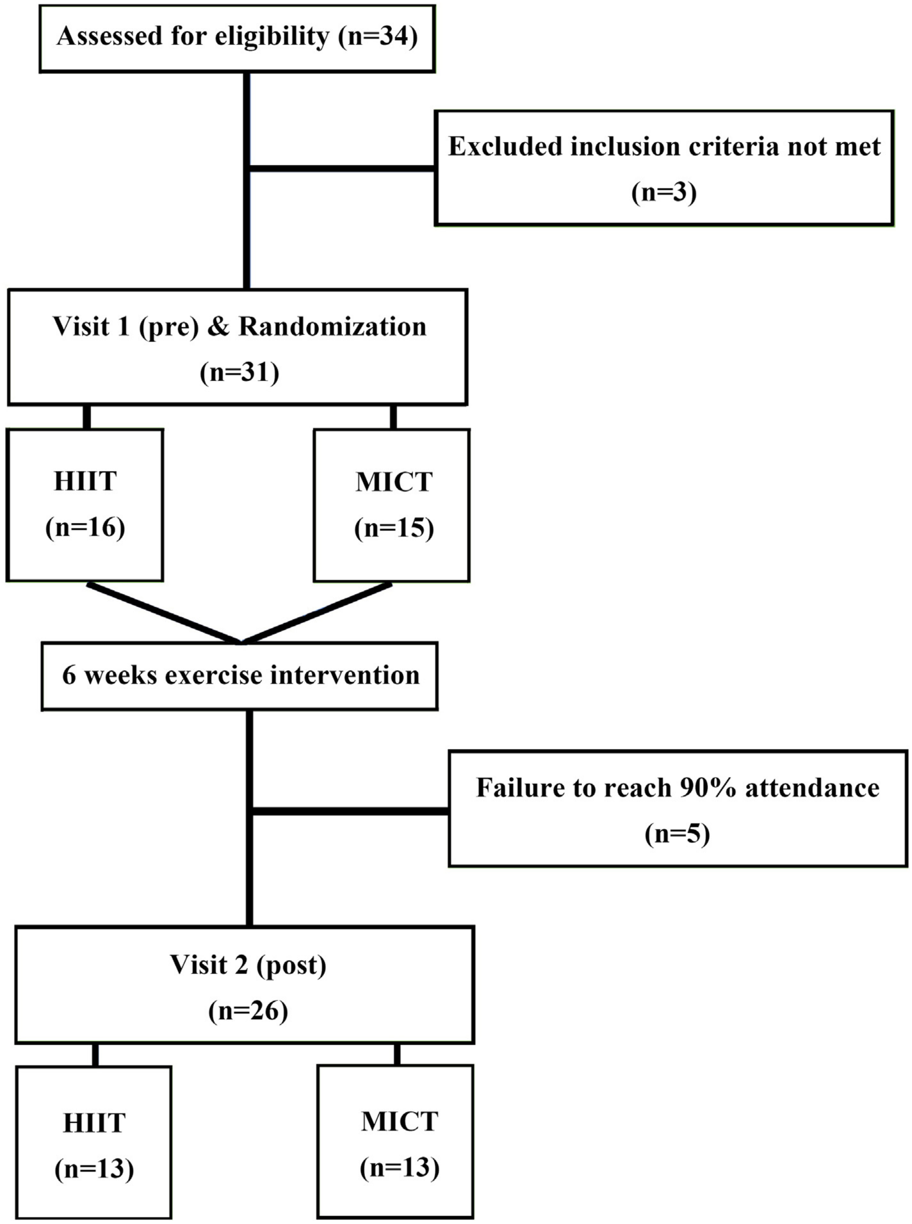

Fig. 2. Flow-chart of the randomized controlled trial.

3.3. Effects of HIIT and MICT on vascular function

PWA demonstrated significant decreases in AIx@HR75 ($p < 0.05$) and AP ($p < 0.05$) after HIIT rather than MICT (Table 2). On the contrary, SEVR was significantly elevated after MICT ($p < 0.01$) but not HIIT ($p > 0.05$). Moreover, there were significant decreases in bSBP ($p < 0.01$), bDBP ($p < 0.001$), aMP ($p < 0.001$), aSBP ($p < 0.01$), aDBP ($p < 0.001$), and HR ($p < 0.001$) after MICT but not HIIT except aMP ($p < 0.05$) (Table 2). Group-by-time interactions revealed significant differences in both aDBP [estimate = −8.08, $F(1,24) = 6.812$, $p < 0.05$, partial $\eta^2 = 0.221$] and HR [estimate = −5.38, $F(1,24) = 7.100$, $p < 0.05$, partial $\eta^2 = 0.228$] between HIIT and MICT, whereas no significant main effects in both aDBP [estimate = 6.79, $F(1,24) = 0.594$, $p = 0.448$, partial $\eta^2 = 0.024$] and HR [estimate = 3.13, $F(1,24) = 0.003$, $p = 0.960$, partial $\eta^2 = 0.000$] were seen by group.

Both of group-by-time interactions and between-group comparisons revealed there was no significant difference in FMD. But simple effects test detected that brachial artery FMD improved in both HIIT and MICT groups after 6 weeks of aquatic exercise (Table 2). However, MICT only showed marginal significance ($p = 0.072$) compared to HIIT ($p < 0.05$). There was no significant change in the brachial artery diameter at rest after neither HIIT ($p = 0.087$) nor MICT ($p = 0.384$). However, peak diameter at the time of the reactive hyperemia significantly increased only in HIIT group ($p < 0.05$). MBV, MD, and MSR were not changed after neither HIIT nor MICT.

4. Discussion

The purpose of the present study was to examine the effects of 6-week aquatic HIIT and MICT on central hemodynamic parameters, endothelial function, and aerobic fitness in inactive adults. To the best of our knowledge, there were no studies investigating the

Table 1
Baseline characteristics of participants and effects of the exercise programs on anthropometric, metabolic, and aerobic fitness parameters (mean ± SD).

Parameters	HIIT (n = 13)			MICT (n = 13)		
	pre-training	post-training	ES	pre-training	post-training	ES
Gender (m/f)	3/10	–	–	4/9	–	–
Age (yr)	42.2 ± 5.7	–	–	39.2 ± 6.0	–	–
Height (m)	163.3 ± 5.6	–	–	161 ± 6.4	–	–
Weight (kg)	63.2 ± 12.6	62.2 ± 12.5*	−0.080	63.0 ± 13.3	61.7 ± 12.6**	−0.100
BMI (kg/m^2)	23.6 ± 4.0	23.2 ± 3.9*	−0.101	24.2 ± 4.8	23.7 ± 4.6**	−0.106
Skeletal muscle (kg)	23.2 ± 4.3	24 ± 5.3**	−0.167	23.8 ± 4.3	23.8 ± 4.4	0
Fat (kg)	20.7 ± 6.6	18.2 ± 5.7***	−0.407	19.5 ± 8.8	18.3 ± 8.1*	−0.142
Fat (%)	32.3 ± 4.6	29.0 ± 5.2***	−0.673	30.1 ± 7.8	28.9 ± 7.6	−0.156
WHR	0.87 ± 0.05	0.85 ± 0.06**	−0.364	0.86 ± 0.04	0.85 ± 0.04	−0.250
TC (mmol/L)	5.36 ± 0.84	4.96 ± 1.00**	−0.435	5.06 ± 0.81	5.03 ± 0.40	−0.050
TG (mmol/L)	1.24 ± 0.73	0.99 ± 0.63	−0.368	1.24 ± 0.65	0.95 ± 0.37	−0.569
HDL-c (mmol/L)	1.51 ± 0.37	1.49 ± 0.37	−0.054	1.44 ± 0.43	1.51 ± 0.35	0.179
LDL-c (mmol/L)	3.40 ± 0.81	3.21 ± 0.99	−0.211	3.16 ± 0.61	3.28 ± 0.47	0.222
BG (mmol/L)	4.69 ± 0.40	4.15 ± 0.50***	−1.200	4.79 ± 0.80	4.18 ± 0.77***	−0.778
Peak						
VO_2 (mL/min)	1918 ± 592	2025 ± 522*#	0.192	2138 ± 430	2113 ± 351	−0.064
VO_2/kg (mL/kg/min)	30.9 ± 6.2	33.5 ± 6.4**#	0.413	33.7 ± 6.1	34.0 ± 5.2	0.053
Ventilation (L/min)	79.7 ± 20.7	80.1 ± 15.4	0.022	84.5 ± 22.9	86.6 ± 17.9	0.103
HR (bpm)	178 ± 12	174 ± 12*	−0.333	175 ± 11	172 ± 13	−0.250
O_2 pulse (mL/beat)	10.9 ± 3.3	12.2 ± 3.6*	0.377	12.4 ± 2.6	13.1 ± 4	0.212
MET	8.83 ± 1.79	9.59 ± 1.82***#	0.421	9.63 ± 1.75	9.72 ± 1.49	0.056
RER	1.30 ± 0.10	1.28 ± 0.08	−0.222	1.25 ± 0.09	1.25 ± 0.11	0

Note: BMI, body mass index; WHR, waist hip rate; BG, blood glucose; TC, total cholesterol; TG, triglycerides; HDL-c, high-density lipoprotein cholesterol; LDL-c, low-density lipoprotein cholesterol; VO_2, oxygen uptake; HR, heart rate; MET, metabolic equivalent; RER, respiratory exchange ratio; SD, standard deviation; ES, effect size.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ *vs.* pre-training. # Significant interaction of group × time $p < 0.05$.

Table 2
The vascular function parameters of participants pre- *vs.* post-training programs (mean ± SD).

parameters	HIIT (n = 13)			MICT (n = 13)		
	pre-training	post-training	ES	pre-training	post-training	ES
bSBP (mmHg)	118.8 ± 17.5	116.5 ± 13.6	−0.148	115.7 ± 13.0	106.9 ± 9.7**	−0.775
bDBP (mmHg)	75.1 ± 10.2	75.0 ± 7.7	−0.011	76.6 ± 11.1	68.3 ± 9.1***	−0.822
Pulse wave analysis						
bPP (mmHg)	43.9 ± 11.4	41.6 ± 8.7	−0.229	39.7 ± 6.9	38.6 ± 4.3	−0.196
aMP (mmHg)	94.6 ± 9.3	90.2 ± 8.6*	−0.492	92.7 ± 8.7	82.5 ± 9.4***	−1.127
aSBP (mmHg)	111.9 ± 16	108.5 ± 12.9	−0.235	107.3 ± 11.9	99.2 ± 10.4**	−0.726
aDBP (mmHg)	75.9 ± 10.3	75.7 ± 7.6#	−0.022	77.2 ± 11.7	68.9 ± 9.4***	−0.787
aPP (mmHg)	36.0 ± 9.9	32.8 ± 8.6	−0.346	30.2 ± 3.7	30.3 ± 4.8	0.024
HR (bpm)	62.0 ± 5.0	61.0 ± 7.6#	−0.159	64.5 ± 10.7	58.2 ± 8.5***	−0.656
AP (mmHg)	11.1 ± 4.3	9.0 ± 4.3*	−0.488	7.7 ± 4.6	7.9 ± 4.3	0.045
AIx@HR75 (%)	22.9 ± 8.8	18.9 ± 7*	−0.508	19 ± 12.8	16.2 ± 12.6	−0.220
SEVR (%)	161.9 ± 6.1	165.1 ± 20.2	0.176	162 ± 39	177.6 ± 36.9**	0.398
Brachial endothelium						
MBV (cm/s)	2.5 ± 1.2	2.2 ± 1.1	−0.261	2.3 ± 1.5	2.5 ± 1.6	0.129
MD (mm)	3.43 ± 0.72	3.64 ± 0.66	0.304	3.61 ± 0.71	3.58 ± 0.47	−0.508
MSR (s^{-1})	2.99 ± 1.45	2.5 ± 1.33	−0.353	2.72 ± 2.01	2.7 ± 1.47	−0.011
Base diameter (mm)	3.58 ± 0.69	3.72 ± 0.68	0.204	3.68 ± 0.62	3.76 ± 0.43	0.152
Peak diameter (mm)	3.70 ± 0.70	3.91 ± 0.68	0.304*	3.84 ± 0.63	3.94 ± 0.45	0.185
FMD	3.56 ± 1.67	4.94 ± 2.10	0.732*	4.02 ± 1.77	5.08 ± 2.80	0.464

Note: bSBP, brachial systolic blood pressure; bDBP, brachial diastolic blood pressure; bPP, brachial pulse pressure; aMP, aortic mean pressure; aSBP, aortic systolic blood pressure; aDBP, aortic diastolic blood pressure; aPP, aortic pulse pressure; HR, heart rate; AP, augmentation pressure; AIx, augmentation index; AIx@HR75, standardized to AIx at 75 beats/min heart rates; SEVR, subendocardial viability ratio; MBV, mean blood velocity; MD, mean diameter; MSR, mean shear rate; FMD, flow-mediated dilation; SD, standard deviation; ES, effect size.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ *vs.* pre-training. #Significant interaction of group × time $p < 0.05$.

effects of aquatic HIIT on vascular function in the inactive population, and there were also few studies to compare the effects of various exercise forms on vascular and endothelial function in inactive adults. The main findings of the study were as follows: (1) After the 6-week swimming program, HIIT and MICT had no significant differences in the hemodynamic parameters, endothelial function, and aerobic fitness; (2) Body composition improved after both interventions, but a significant increase in skeletal muscle mass was found only after HIIT; (3) Both programs significantly reduced fasting blood glucose, but a significant decrease in total cholesterol was detected only after HIIT; (4) The aerobic fitness significantly increased only after HIIT; (5) AIx@HR75 and AP significantly decreased after HIIT but not MICT, whereas MICT rather than HIIT improved SEVR, central and peripheral blood pressure, and resting HR; (6) Only HIIT significantly increased brachial endothelial function.

A previous study found that anaerobic and aerobic systems could be simultaneously mobilized during HIIT with fast-twitch fibers participating in a higher proportion while MICT mobilized mainly slow-twitch fibers.[19] In our results, simple effect analyses showed that aerobic fitness in HIIT group was significantly elevated. This may reveal a possibility that the aerobic fitness of inactive adults could be effectively improved by HIIT, regardless of no significant main effect was seen by group. As reported by most previous studies, HIIT may be beneficial in improving aerobic fitness, either on land or in water.[20,21] However, although both interventions could reduce BMI, only HIIT increased skeletal muscle mass and decreased body fat percentage. This result was consistent with a previous study which demonstrated that, compared to MICT, HIIT is more effective to increase skeletal muscle mass.[22]

An earlier study reported that land-based HIIT had a better effect on TC reduction.[23] Whereas, another study conducted by Nybo et al. showed that while the interval training was completed at more than 95% HR_{max} on land, the TC level only decreased by 0.1 mmol/L, but MICT decreased the TC level by 0.3 mmol/L.[24] In the present study, aquatic HIIT was more effective in lowering TC (−7.5%) than MICT (−0.6%). In this case, it seems that the combination of swimming and HIIT has a better effect on TC reduction than land-based HIIT.

Although previous literature on aquatic HIIT was lacking, Nualnim et al. investigated the effects of 12 weeks of swimming training on fasting blood glucose level in adults over 50 years old. They found no significant change in fasting blood glucose after swimming training.[25] On the contrary, the present study revealed an 11.5% decline in fasting glucose after aquatic HIIT. Our result was similar to a recent study which suggested that aquatic HIIT could significantly reduce fasting blood glucose level.[26] Interestingly, we also found a significant reduction (−12.7%) in fasting glucose in MICT, regardless of no change in fasting blood glucose was seen in the above-mentioned study which performed a similar exercise program.[26] One possible reason could be the greater trainability of inactive individuals in a short-term aquatic MICT. The organ's response to blood glucose may evolve physiological adaptability with the extension of duration of intervention. However, in HIIT program, the physiological adaptability of the organ is constantly discontinued. The excessive recovery makes the exercise performance continuing to improve, even after long-term training (for example, Connolly et al. used a 15-week protocol),[26] therefore keep playing a positive role in blood glucose change.

The present findings showed that 6 weeks of aquatic exercise improved central hemodynamics and endothelial function in inactive adults. In general, the adaptation of arterial stiffness in response to exercise is mainly attributed to the increased rate of nitric oxide (NO) utilization and improved endothelial function. During exercise, increase in shear stress leads to elevated NO production in endothelial cells which promotes vascular smooth muscle relaxation. Since HIIT results in higher intensity of laminar shear stress compared to MICT, HIIT could induce a greater response in NO production.[27] Consistently, our study demonstrated that brachial artery FMD significantly improved only after HIIT. These results indirectly suggested that improvement in NO production depends on different exercise modalities, which may mean that higher intensity of aquatic exercise is able to induce effectively greater changes in vascular function, especially endothelial function. In addition, although there was no change in brachial diameter at rest after neither HIIT nor MICT, the maximal brachial diameter during reactive hyperemia was significantly enhanced in the HIIT group, suggesting a responsive enhancement of FMD.[28] Therefore, our results raised the possibility that endothelial function adaptation could be induced by HIIT, such as the increase in FMD response. Moreover, AIx, an indirect marker of arterial stiffness,[29] is also an independent risk factor for predicting CVD. AIx@75HR is a heart rate-corrected indicator with a more objective nature of central arterial pressure and arterial elasticity. Regarding vessel stiffness, our results were similar to a previous study which revealed that HIIT decreased AIx@HR75 more significantly than MICT in healthy men and episodic migraine patients.[11] AP is the amplitude of the reflected wave, which is closely related to the occurrence and mortality of cardiovascular diseases.[30] Our findings demonstrated that HIIT rather than MICT decreased AIx@75HR and AP. Thus, our results suggested that higher intensity of aquatic exercise may cause effectively greater vascular adaptive changes in inactive adults.

The improvement of the central arterial pressure dynamics also corresponds to the increase in SEVR, an indirect marker for subendocardial perfusion, potentially indicating an improvement in cardiac function. A previous study showed a positive correlation between coronary blood flow reserve and SEVR ($R = 0.65$) in hypertensive patients with normal coronary artery angiography but with myocardial ischemia.[31] In the present study, our results showed that MICT but not HIIT effectively enhanced SEVR, suggesting that 6 weeks of MICT rather than HIIT could improve coronary blood flow reserve in inactive adults.

As mentioned above, the present study found significant improvements in the parameters that reflected the vascular function after both exercise protocols. However, the central and peripheral systolic and diastolic pressures only showed significant decrease after MICT but not after HIIT. Actually, although HIIT did not significantly reduce both central and peripheral systolic and diastolic pressure, it was observed a significant decrease in mean arterial pressure after HIIT. It may be reasonable to mention that 6 weeks of exercise intervention can be considered as a short duration of intervention, especially the total time of the HIIT group immersed in water was nearly half less than in MICT group. Thus, there are less hydrodynamic (buoyancy, hydrostatic pressure, viscosity, etc.) and thermodynamic effects[32] on the wall pressure in HIIT program compared to MICT. This might be one of the reasons why MICT but not HIIT could cause a significant change in blood pressure. Indeed, a previous study showed that the duration of aquatic HIIT intervention was typically 15 weeks and reported that it was effective in improving blood pressure.[33]

Although we obtained some promising results in the present study, there were some limitations. The duration of the intervention was short, and the sample size of the present study was small. It may explain why some cardiovascular indicators (such as blood pressure, AIx@HR75, SEVR, and FMD) were not statistically different between HIIT and MICT programs, even if we had adjusted the baseline characteristics of the subjects. Therefore, future studies on a larger scale should be conducted. Moreover, we couldn't confirm that HR_{max} value on land was proper to utilize in the water, and the participants who couldn't swim may elevate their heart rates mostly due to tensions rather than exercise.

5. Conclusion

In summary, a six-week aquatic HIIT and MICT had no differences in hemodynamic parameters, endothelial function, and aerobic fitness, but HIIT reduced arterial stiffness, elevated endothelial function and aerobic fitness, whereas MICT reduced arterial blood pressure and resting heart rate and increased the reserve of coronary blood flow. It's worth noting that it takes only 18 min of effective exercise per week in the HIIT protocol applied in this trial, while it takes 1.5 h of effective exercise per week in the MICT protocol, suggesting that HIIT could be used as an alternative time-efficient option to improve the body health of inactive adults. Previous studies reported that swimming in different forms had beneficial effects on physiological outcomes in healthy populations and those with non-communicable disease.[15,34] In future studies, researchers could conduct longitudinal studies to optimize the aquatic exercise prescriptions in individuals with different health levels or diseases.

Author statement

JH, WH, SW, and ST contributed to conceive and design the experiments.

ST, WH, YW, and LG organized the database.

ST and JH collected the references, analyzed the data and wrote the first draft of the manuscript.

JH and MH, contributed reagents, materials, and manuscript revision.

Declaration of competing interest

The authors declare there are no competing interests.

Acknowledgements

We would like to thank the subjects in this experiment. The current work was supported by grants from the National Natural Science Foundation of China (31971105, 31771315, 31600969) and the Natural Science Foundation of Guangdong Province (2019A1515012167).

References

1. Bull FC, Bauman AE. Physical inactivity: the "cinderella" risk factor for noncommunicable disease prevention. *J Health Commun*. 2011;16(sup2):13–16.
2. Guthold R, Stevens GA, Riley LM, Bull FC. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. *Lancet Global Health*. 2018;6(10): e1077–e1086.
3. Peçanha T, Goessler KF, Roschel H, Gualano B. Social isolation during the COVID-19 pandemic can increase physical inactivity and the global burden of cardiovascular disease. *Am J Physiol Heart Circ Physiol*. 2020;318(6): H1441–H1446.
4. Doonan RJ, Scheffler P, Yu A, et al. Altered arterial stiffness and subendocardial viability ratio in young healthy light smokers after acute exercise. *PLoS One*. 2011;6(10):e26151–e26161.
5. Huang J, Liao J, Fang Y, et al. Six-week exercise training with dietary restriction improves central hemodynamics associated with altered gut microbiota in adolescents with obesity. *Front Endocrinol*. 2020;11:569085.
6. Huang J, Lai Q, Wang D, et al. Effects of exercise TrainingWith dietary restriction on arterial stiffness, central hemodynamic parameters and cardiac autonomic function in obese adolescents. *Diabet Metab Synd Ob*. 2019;2019(12): 2157–2163.
7. Smieško V, Kožík J, Doležel S. Role of endothelium in the control of arterial diameter by blood flow. *J Vasc Res*. 1985;22(5):247–251.
8. Huang J, Lai Q, Wang S, et al. Exercise training with dietary restriction enhances circulating irisin level associated with increasing endothelial progenitor cell number in obese adults: an intervention study. *PeerJ*. 2017;5:e3669.
9. Wang S, Liao J, Huang J, Yin H, Yang W, Hu M. miR-214 and miR-126 were associated with restoration of endothelial function in obesity after exercise and dietary intervention. *J Appl Biomed*. 2018;16:34–39.
10. Rakobowchuk M, Tanguay S, Burgomaster KA, Howarth KR, Gibala MJ, MacDonald MJ. Sprint interval and traditional endurance training induce similar improvements in peripheral arterial stiffness and flow-mediated dilation in healthy humans. *Am J Physiol-Reg I*. 2008;295(1):R236–R242.
11. Wisløff U, Ø Ellingsen, Kemi OJ. High-intensity interval training to maximize cardiac benefits of exercise training? *Exerc Sport Sci Rev*. 2009;37(3):139–146.
12. Ramos JS, Dalleck LC, Tjonna AE, Beetham KS, Coombes JS. The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a systematic review and meta-analysis. *Sports Med*. 2015;45(5):679–692.
13. Epstein M. Cardiovascular and renal effects of head-out water immersion in man. Application of the model in the assessment of volume homeostasis. *Circ Res*. 1976;39(5):619–628.
14. Craig CL, Marshall AL, Sjö Strö MM, et al. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc*. 2003;35(8): 1381–1395.
15. Lahart IM, Metsios GS. Chronic physiological effects of swim training interventions in non-elite swimmers: a systematic review and meta-analysis. *Sports Med*. 2018;48(2):337–359.
16. Cai L, Huang J, Gao D, et al. Effects of mind-body practice on arterial stiffness, central hemodynamic parameters and cardiac autonomic function of college students. *Compl Ther Clin Pract*. 2021;45:101492.
17. Hu M, Wang S, Wang D, et al. Combined moderate and high intensity exercise with dietary restriction improves cardiac autonomic function associated with a reduction in central and systemic arterial stiffness in obese adults: a clinical trial. *PeerJ*. 2017;5, e3900.
18. Joris PJ, Zeegers MP, Mensink RP. Weight loss improves fasting flow-mediated vasodilation in adults: a meta-analysis of intervention studies. *Atherosclerosis*. 2014;239(1):21–30.
19. Gibala MJ, Little JP, Macdonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. *J Physiol*. 2012;590(5):1077–1084.
20. Tanaka H. Swimming exercise: impact of aquatic exercise on cardiovascular health. *Sports Med*. 2009;39(5), 3770-387.
21. Ramos JS, Dalleck LC, Tjonna AE, Beetham KS, Coombes JS. The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a systematic review and meta-analysis. *Sports Med*. 2015;45(5):679–692.
22. Ravnholt T, Tybirk J, Jørgensen NR, Bangsbo J. High-intensity intermittent "5–10–15" running reduces body fat, and increases lean body mass, bone mineral density, and performance in untrained subjects. *Eur J Appl Physiol*. 2018;118:1221–1230.
23. Racil G, Ben Ounis O, Hammouda O, et al. Effects of high vs. moderate exercise intensity during interval training on lipids and adiponectin levels in obese young females. *Eur J Appl Physiol. Oct*. 2013;113(10):2531–2540.
24. Nybo L, Sundstrup E, Jakobsen MD, et al. High-intensity training versus traditional exercise interventions for promoting health. *Med Sci Sports Exerc*. 2010;42(10):1951–1958.
25. Nualnim N, Parkhurst K, Dhindsa M, Tarumi T, Vavrek J, Tanaka H. Effects of swimming training on blood pressure and vascular function in adults >50 years of age. *Am J Cardiol*. 2012;109(7):1005–1010.
26. Connolly LJ, Nordsborg NB, Nyberg M, Weihe P, Krustrup P, Mohr M. Low-volume high-intensity swim training is superior to high-volume low-intensity training in relation to insulin sensitivity and glucose control in inactive middle-aged women. *Eur J Appl Physiol*. 2016;116(10):1889–1897.
27. Adams V, Reich B, Uhlemann M, Niebauer J. Molecular effects of exercise training in patients with cardiovascular disease: focus on skeletal muscle, endothelium, and myocardium. *Am J Physiol Heart Circ Physiol*. 2017;313(1): H72–H88.
28. Tinken TM, Thijssen DHJ, Black MA, Cable NT, Green DJ. Time course of change in vasodilator function and capacity in response to exercise training in humans. *J Physiol*. 2008;586(20):5003–5012.
29. Laurent S, Cockcroft J, Van Bortel L, et al. Expert consensus document on arterial stiffness: methodological issues and clinical applications. *Eur Heart J*. 2006;27(21):2588–2605.
30. Chirinos JA, Zambrano JP, Chakko S, et al. Aortic pressure augmentation predicts adverse cardiovascular events in patients with established coronary artery disease. *Hypertension*. 2005;45:980–985.
31. Tsiachris D, Tsioufis C, Syrseloudis D, et al. Subendocardial viability ratio as an index of impaired coronary flow reserve in hypertensives without significant coronary artery stenoses. *J Hum Hypertens*. 2012;26(1):64–70.
32. Nagle EF, Sanders ME, Franklin BA. Aquatic high intensity interval training for cardiometabolic health: benefits and training design. *Am J Lifestyle Med*. 2017;11(1):64–76.
33. Mohr M, Helge EW, Petersen LF, et al. Effects of soccer vs swim training on bone formation in sedentary middle-aged women. *Eur J Appl Physiol*. 2015;115(12):2671–2679.
34. Mohr M, Nordsborg NB, Lindenskov A, et al. High-intensity intermittent swimming improves cardiovascular health status for women with mild hypertension. *BioMed Res Int*. 2014;2014:728289.