


Comparable Improvements in Heart Rate Recovery Following Short-Term High-Intensity and Moderate-Intensity Interval Training in Patients with Cardiovascular Disease

Qianqian Song^{1,2,*}, Jinna Chang^{3,*}, Bingqing Bai¹, Mayila Abudoukelimu¹, Zhongxing Jiang¹, Junshuo Zhu⁴, Zhaoqin Lin¹, Jianjun Guo², Huan Ma¹ , Dayi Hu^{2,5}

¹Department of Cardiac Rehabilitation, Guangdong Provincial People's Hospital (Guangdong Academy of Medical Sciences), Southern Medical University, Guangzhou, People's Republic of China; ²Center for Sports-Medicine Integrative Innovation, Capital University of Physical Education and Sports, Beijing, People's Republic of China; ³Guangdong Cardiovascular Institute, Guangdong Provincial People's Hospital, Guangdong Academy of Medical Sciences, Guangzhou, People's Republic of China; ⁴School of Medicine South China University of Technology, Guangdong, People's Republic of China; ⁵Institute of Cardiovascular Diseases, Peking University People's Hospital, Beijing, People's Republic of China

*These authors contributed equally to this work

Correspondence: Dayi Hu, Center for Sports-Medicine Integrative Innovation, Capital University of Physical Education and Sports, Beijing, China; Institute of Cardiovascular Diseases, Peking University People's Hospital, Beijing, People's Republic of China, Email 23008006028@cupes.edu.cn; Huan Ma, Department of Cardiac rehabilitation, Guangdong Provincial People's Hospital (Guangdong Academy of Medical Sciences), Southern Medical University, Guangzhou, People's Republic of China, Email mahuandocor@163.com

Objective: Heart rate recovery (HRR) is a validated prognostic marker in cardiovascular disease (CVD). This study evaluated and compared the effects of 4-week high-intensity interval training (HIIT) and moderate-intensity interval training (MIIT) on post-exercise HRR in patients with CVD.

Methods: A total of 1,020 CVD patients undergoing cardiac rehabilitation (Jan 2021-May 2024) were screened, and 209 who completed 12 sessions and cardiopulmonary exercise tests were included (HIIT: 82; MIIT: 127). The mean ages were 55.2 (HIIT) and 52.9 years (MIIT), with females comprising 34.1% and 34.6%, respectively. The MIIT protocol included four 8-min cycling bouts (RPE 12–14) with 2-min active recovery, while HIIT involved 20–25 × 30-s high-intensity bouts (RPE 14–15) alternating with 30-s low-intensity recovery.

Results: Both interventions significantly improved HRR (HIIT: 3.1±8.7 bpm, $P = 0.002$; MIIT: 3.0±10.0 bpm, $P = 0.001$), with no between-group difference ($P = 0.816$). Peak VO_2 similarly increased in both groups (HIIT: 3.3±2.8; MIIT: 3.0±3.6 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $P < 0.001$). Other related measures were also notably improved ($P < 0.05$). Multivariable regression analysis revealed that the change in HRR was inversely associated with the change in resting heart rate in both HIIT ($\beta = -0.227$, $P = 0.04$) and MIIT ($\beta = -0.318$, $P < 0.001$) cohorts.

Conclusion: Both short-term HIIT and MIIT comparably enhance HRR in patients with CVD, highlighting the clinical applicability of interval training as an efficient option for patients with limited time availability. However, the retrospective design limits causal inference and requires confirmation in future studies.

Keywords: cardiovascular disease, high-intensity interval training, moderate-intensity interval training, heart rate recovery

Introduction

Cardiovascular disease (CVD) remains the leading cause of mortality worldwide, accounting for approximately 19 million deaths annually, or nearly one-third of all death,¹ placing a substantial burden on healthcare systems. The rising prevalence of metabolic risk factors such as hypertension, diabetes, obesity, dyslipidemia, and physical inactivity

continues to drive CVD incidence while impairing long-term quality of life.^{2,3} Psychological comorbidities, including anxiety and depression, further exacerbate cardiovascular pathology and worsen prognosis.^{4,5}

In addition to conventional risk factor management, an increasing body of evidence highlights autonomic dysfunction as a key pathophysiological mechanism in CVD progression.^{6,7} HRR is a well-established noninvasive marker of autonomic regulation during the post-exercise period, reflecting the coordinated process of rapid parasympathetic reactivation and gradual sympathetic withdrawal.⁸ Impaired or delayed HRR, particularly within the first minute after exercise, indicates autonomic imbalance driven primarily by reduced vagal reactivation.⁹ Importantly, delayed HRR has been identified as an independent predictor of major adverse cardiovascular events, hospital readmission, and all-cause mortality in patients with CVD.^{10,11} These combined burdens highlight the urgent need for effective strategies to improve outcomes and reduce disease progression in patients with CVD.

While pharmacological therapies and invasive interventions,^{12,13} address certain aspects of CVD, structured exercise training represents a cornerstone for modulating autonomic function.¹⁴ Cardiac rehabilitation (CR) demonstrates efficacy in restoring autonomic balance in patients with acute coronary syndrome, characterized by attenuated sympathetic overactivity and enhanced parasympathetic tone.¹⁵ Notably, parasympathetic reactivation is postulated as a primary mechanism underpinning the cardioprotective effects of CR.¹⁶

Current CR guidelines predominantly recommend moderate-intensity continuous training (MICT), which involves sustained aerobic exercise performed at a prescribed moderate workload over a continuous duration.^{17,18} In recent years, however, accumulating evidence has supported high-intensity interval training (HIIT) as a safe and effective alternative.¹⁹ HIIT involves alternating short bouts of high-intensity exercise with active recovery and has been shown in randomized trials and meta-analyses to be superior or at least non-inferior to MICT in improving cardiovascular function and cardiorespiratory fitness.^{20,21} Similar advantages have been observed for autonomic recovery, where HIIT appears to outperform or match MICT in enhancing HRR, a key marker of autonomic reactivation.^{22,23} Collectively, these findings highlight HIIT as a time-saving and efficient training modality capable of eliciting meaningful cardiovascular and autonomic benefits in cardiac rehabilitation, underscoring the importance of exploring alternative interval-based approaches. Moderate-intensity interval training (MIIT) lies between the two modalities, incorporating moderate-intensity intervals with recovery phases. It offers a hybrid training approach, and its moderate intensity may provide a more favorable balance between training efficacy and patient tolerance.²⁴

However, the application of MIIT in patients with cardiovascular disease remains limited, and evidence specifically addressing its effects on HRR is insufficient. Direct comparisons between MIIT and HIIT are also lacking, which results in insufficient clarity in the guidance regarding the autonomous recovery strategies based on intermittent training in cardiac rehabilitation. Moreover, considering that most existing studies have intervention periods ranging from 8 to 12 weeks,²⁵ real-world CR programs an urgent need to explore efficient and feasible short-term rehabilitation strategies.²⁶ Several studies have demonstrated that short-term interventions can already elicit meaningful improvements in patients with CVD.^{20,27} Therefore, this study aims to address these unmet needs by evaluating the effects of a short-term HIIT and MIIT intervention on HRR and cardiopulmonary function in patients with CVD, and by directly comparing the two modalities to clarify their relative efficacy.

We hypothesized that both HIIT and MIIT would improve HRR and cardiopulmonary function in patients with CVD. Furthermore, during short-term intervention, MIIT would demonstrate beneficial effects comparable to those of HIIT, providing an efficient and feasible alternative exercise modality for cardiac rehabilitation.

Materials and Methods

Design and Participants

This retrospective cohort study screened 1,020 CVD patients participating in cardiac rehabilitation at Guangdong Provincial People's Hospital between 2021 and 2024. Based on predefined eligibility criteria, 209 patients who completed all 12 prescribed training sessions and both pre- and post-intervention cardiopulmonary exercise testing (CPET) were included in the analysis. Key inclusion criteria comprised: (1) age 18–76 years; (2) coronary artery disease (eg, stable angina, post-percutaneous coronary intervention, or post-coronary artery bypass grafting),

valvular heart disease after surgical or transcatheter treatment; (3) completion of 12 supervised outpatient rehabilitation sessions (HIIT: $n=82$; MIIT: $n=127$) in one month; and (4) provision of written informed consent for data use. Exclusions were primarily due to missing CPET or psychological assessment data (Figure 1). The study complied with the Declaration of Helsinki and was approved by the hospital's Ethics Committee (Approval No: KY2023-514).

It should be noted that the 209 patients were allocated to the HIIT or MIIT group as part of routine clinical decision-making prior to the initiation of cardiac rehabilitation, rather than by the research team. The assignment was jointly determined by the cardiology director and rehabilitation physicians based on individualized clinical assessments, including baseline cardiopulmonary function, exercise tolerance, and risk stratification, to ensure safety and appropriateness of the prescribed training program. The researchers subsequently performed a retrospective analysis of the clinical records and outcome data to evaluate the effects of the two training modalities. Furthermore, no adverse cardiovascular events (eg, angina or syncope) occurred during training in either group, and session adherence was better. As this study employed a retrospective design and non-randomized group assignment, selection bias may exist. To minimize bias, all patients received a standardized rehabilitation program, and age, sex, BMI, and baseline differences were controlled for in the analysis, with outcome assessments performed by blinded evaluators.

Sample Size and Power Justification

An a priori power analysis was conducted in G*Power (version 3.1) for an ANCOVA design with two groups (F -tests, fixed effects, main effects and interactions), assuming an effect size of $f = 0.25$, $\alpha = 0.05$, power = 0.80, and five covariates (group, age, sex, BMI, baseline), which indicated a required total sample size of $N = 134$. Our final analytic sample of $N = 209$ exceeded this requirement, indicating adequate statistical power to detect clinically meaningful effects.

Cardiopulmonary Exercise Test

Standardized CPET was performed on all patients before and after the intervention using identical equipment and protocols to ensure data comparability. Tests were conducted on electronically braked cycle ergometers with individualized incremental ramp protocols, adjusted for each patient's clinical status and exercise tolerance. The protocol continued until volitional exhaustion or meeting predefined termination criteria (symptoms, electrocardiography abnormalities, or blood pressure limits). HRR was calculated as the reduction in heart rate from peak exercise to 1 minute after exercise cessation ($HRR_{1min} = \text{Peak HR} - \text{HR at 1 min post-exercise}$), which reflects early parasympathetic reactivation. Throughout testing, real-time monitoring included 12-lead electrocardiography, blood pressure, oxygen saturation, and HR. HR data were acquired via a computerized automated system to ensure measurement precision.

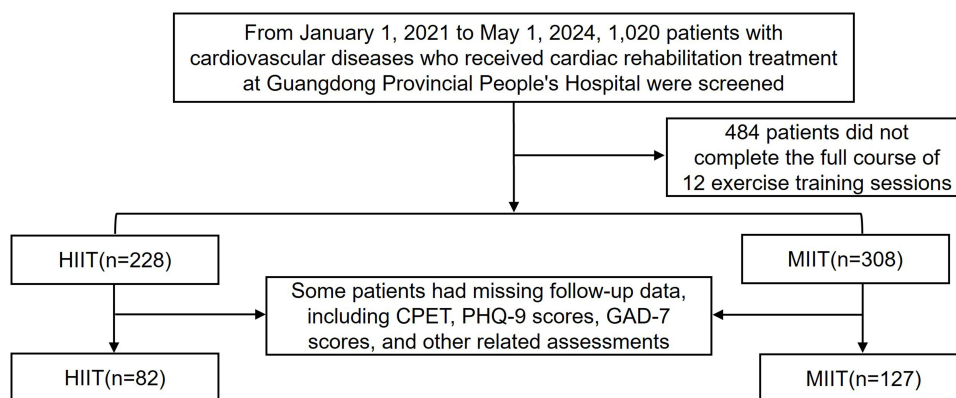


Figure 1 Study enrollment.

HIIT and MIIT Protocols

All exercise interventions were performed at the CR Center of Guangdong Provincial People’s Hospital. Participants underwent a 4-week, supervised cycling program comprising 12 sessions (3 sessions/week) under the guidance of a multidisciplinary team of cardiologists, rehabilitation therapists, and nurses. Exercise intensity was individually prescribed according to baseline CPET-derived peak VO₂ and maximal work rate (WR).

The MIIT protocol consisted of a 5-min warm-up followed by four cycles of 8-min continuous cycling at 40–55% WR (RPE 12–14) interspersed with 2-min active recovery. The target WR was progressively increased from 40% to 55% in 4-session increments while maintaining the same session structure, and the total session duration was approximately 50 min including a cool-down period.

The HIIT protocol consisted of a 5-min warm-up followed by 20–25 repeated bouts of 30-s high-intensity cycling at 80–90% WR (RPE 14–15) alternated with 30-s low-intensity recovery. Training load was progressively increased every four sessions by raising both exercise intensity (80%, 85%, 90% WR) and the number of repetitions (20 to 25 cycles) to ensure a consistent overload stimulus, and the total session duration was approximately 40–45 min including a cool-down period, see [Figure 2](#) for details.

Psychological Symptom Assessment

Psychological symptoms were assessed at baseline and post-intervention using validated self-report scales. Depressive symptoms were measured with the Patient Health Questionnaire-9 (PHQ-9). Anxiety symptoms were evaluated with the Generalized Anxiety Disorder-7 (GAD-7).^{28,29} All assessments were conducted under researcher supervision to ensure data accuracy and confidentiality.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± SD and categorical variables as number (percentage). Normality was assessed using the Shapiro–Wilk test. Within-group changes from baseline to post-intervention were analyzed using paired t-tests or Wilcoxon signed-rank tests with Cohen’s d as the effect size indicator. Between-group comparisons were performed using independent samples t-tests or Mann–Whitney U-tests when appropriate. ANCOVA was applied with post-intervention values as dependent variables, group as a fixed factor, and baseline values, age, sex, and BMI as covariates, with partial η² reported as the effect size. ANCOVA assumptions were verified, including the normality and homogeneity of residuals ([Supplement Tables S4–12](#) and [Figure S1–S4](#)). A sensitivity analysis using a linear mixed-effects model was conducted to confirm the robustness of the primary findings.

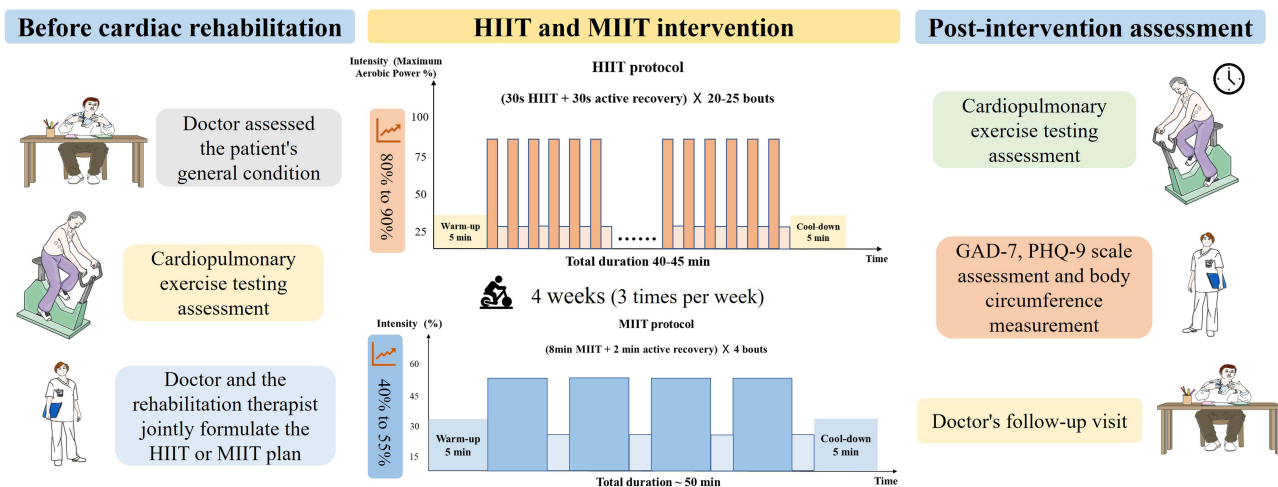


Figure 2 Exercise protocols of HIIT and MIIT in CR.

Multivariable linear regression models were used to identify predictors of HRR change, including a pooled model incorporating group \times predictor interaction terms. Candidate predictors were selected based on physiological relevance and prior evidence. Regression results are reported as standardized coefficients (β) with 95% confidence intervals (CIs) and p -values. Pearson or Spearman correlation analyses, as appropriate, were further used to examine the association. All tests were two-tailed with a significance level of $p < 0.05$.

Results

Study Patients

Baseline demographic, clinical, and medication characteristics were similar between the two groups (Table 1). There were no significant differences in age (55.2 ± 12.1 vs 52.9 ± 13.3 years, $p = 0.18$), sex distribution (34.1% vs 34.6% female, $p = 0.941$), height, body weight, BMI, or resting hemodynamic parameters, including resting HR, SBP, and DBP (all $p > 0.05$). The prevalence of comorbidities, including CAD ($p = 0.653$), valvular heart disease ($p = 0.413$), diabetes ($p = 0.473$), hypertension ($p = 0.340$), hyperlipidemia ($p = 0.301$), and previous cardiac surgery ($p = 0.269$), was also comparable between groups. Likewise, the use of statins ($p = 0.727$), beta-receptor blockers ($p = 0.764$), ACEIs/ARBs ($p = 0.882$), hypoglycemic drugs ($p = 0.158$), and SSRIs ($p = 0.639$) did not differ significantly between groups.

These findings confirm that baseline demographic characteristics, comorbidities, and medication use were well balanced between the HIIT and MIIT groups, minimizing the potential influence of confounding factors on subsequent outcomes.

Heart Rate Parameters

After the 4-week intervention (Table 2), both groups exhibited significant improvements in HRR. The mean change was 3.1 ± 8.7 bpm in the HIIT group ($p = 0.002$) and 3.0 ± 10.0 bpm in the MIIT group ($p = 0.001$), with no significant difference between groups ($p = 0.816$). Resting HR decreased markedly in both groups, with reductions of 7.0 ± 12.9 bpm

Table 1 Baseline Characteristics of Study Patients

	HIIT (n=82)	MIIT (n=127)	<i>p</i>
Age, years	55.2 \pm 12.1	52.9 \pm 13.3	0.180
Female sex, n (%)	28 (34.1%)	44 (34.6%)	0.941
Height, cm	164.7 \pm 7.5	165.4 \pm 7.8	0.519
Body weight, kg	63.8 \pm 11.7	65.7 \pm 12.8	0.538
BMI, kg/m ²	23.4 \pm 3.4	23.9 \pm 3.8	0.693
Resting HR, bpm	82.6 \pm 15.2	80.9 \pm 14.7	0.578
Resting SBP, mmHg	124.4 \pm 21.2	122.4 \pm 18.4	0.845
Resting DBP, mmHg	75.3 \pm 11.5	76.3 \pm 12.4	0.546
Medical history, n (%)			
Coronary artery disease	42 (51.2%)	61 (48.0%)	0.653
Valvular Heart Disease	4 (4.9%)	11 (8.7%)	0.413
Diabetes	6 (7.3%)	14 (11.0%)	0.473
Hypertension	22 (26.8%)	42 (33.1%)	0.340
Hyperlipidemia	11 (13.4%)	24 (18.9%)	0.301
Medications, n (%)			
Statins	38 (46.3%)	62 (48.8%)	0.727
Beta receptor blockers	37 (45.1%)	60 (47.2%)	0.764
ACEIs/ARBs	18 (22.0%)	29 (22.8%)	0.882
Hypoglycemic drugs	10 (12.2%)	25 (19.7%)	0.158
SSRIs	17 (20.7%)	23 (18.1%)	0.639

Abbreviations: ARBs, angiotensin II receptor blockers; ACEIs, angiotensin-converting enzyme inhibitors, Resting; SBP, resting systolic blood pressure, Resting; DBP, resting diastolic blood pressure.

Table 2 Pre- and Post-Intervention Changes in CPET, Psychological Scores, and Body Circumference in HIIT and MIIT Groups

	HIIT (n=82)			MIIT (n=127)			HIIT VS MIIT		
	Baseline	Change	p	Baseline	Change	p	p	η ²	F
Cardio-pulmonary fitness									
HRR (bpm)	17.1±8.9	3.1±8.7	0.002	18.2±9.2	3.0±10.0	0.001	0.816	< 0.001	0.055
Resting HR (bpm)	82.6±15.2	-7.0±12.9	< 0.001	80.9±14.7	-4.6±13.8	< 0.001	0.249	0.007	0.249
Peaking HR (bpm)	136.0±20.4	0.6±16.7	0.752	131.4±20.5	2.5±17.1	0.102	0.850	< 0.001	0.036
Peak VO ₂ (mL/min/kg)	19.4±3.7	3.3±2.8	< 0.001	18.4±4.9	3.0±3.6	< 0.001	0.122	0.012	2.414
AT VO ₂ (mL/min/kg)	12.3±2.4	1.9±2.3	< 0.001	12.1±2.7	1.3±2.5	< 0.001	0.010	0.033	6.841
Exercise time (s)	473.6±115.1	67.8±120.8	< 0.001	458.6±120.4	73.3±106.9	< 0.001	0.898	< 0.001	0.016
Maximum load (w)	94.8±33.8	17.2±13.5	< 0.001	93.1±37.9	17.2±20.6	< 0.001	0.375	0.004	0.791
RER	1.2±0.1	0.02±0.1	0.039	1.2±0.1	0.03±0.1	0.009	0.198	0.008	1.666
Resting SBP (mmHg)	124.4±21.2	-4.7±19.2	0.029	122.4±18.4	-6.1±17.9	< 0.001	0.349	0.004	0.881
Resting DBP (mmHg)	75.3±11.5	-4.2±13.3	0.006	76.3±12.4	-4.5±13.4	< 0.001	0.965	< 0.001	0.002
Peaking SBP (mmHg)	170.7±31.1	2.7±30.6	0.420	166.2±31.6	1.1±29.4	0.669	0.198	0.008	1.670
Peaking DBP (mmHg)	86.2±13.8	-2.5±15.3	0.142	85.9±12.5	-0.02±15	0.991	0.261	0.006	1.273
O ₂ pulse (mL/beat)	9.3±2.7	1.2±1.5	< 0.001	9.2±2.8	1.3±1.8	< 0.001	0.550	0.002	0.359
VO ₂ /WR (mL/min/w)	10.3±1.6	0.3±1.8	0.137	10.3±1.8	0.3±2.1	0.096	0.907	< 0.001	0.014
VE/VCO ₂ @AT	28.5±3.5	-1.2±2.7	< 0.001	29.2±4.2	-0.6±3.0	0.028	0.013	0.030	6.223
VE/VCO ₂ slope	27.4±4.0	-0.5±3.9	0.234	28.9±5.8	-0.5±3.9	0.176	0.223	0.007	1.428
PETCO ₂ (mmHg)	34.1±3.4	-0.3±3.0	0.374	33.1±3.7	-0.4±3.7	0.215	0.125	0.012	2.379
Psychological scale (score)									
GAD-7	4.5±4.6	-2.5±3.7	< 0.001	5.2±5.9	-2.6±4.9	< 0.001	0.679	0.001	0.172
PHQ-9	4.1±3.8	-2.0±3.1	< 0.001	5.1±5.3	-1.9±3.7	< 0.001	0.176	0.009	1.847
Body circumference (cm)									
Waist circumference	83.5±10.8	-1.7±5.4	0.005	84.8±10.3	-1.5±4.2	< 0.001	0.365	0.004	0.823
Hip circumference	94.3±7.1	-0.3±5.4	0.616	95.5±6.8	0.04±3.4	0.908	0.373	0.004	0.796
Left thigh circumference	50.0±5.0	-0.2±4.2	0.575	49.8±5.8	0.7±4.2	0.049	0.561	0.002	0.339
Right thigh circumference	50.4±5.1	-0.5±4.0	0.257	50.0±5.8	0.8±4.3	0.032	0.268	0.006	1.236
Left calf circumference	34.4±4.2	-0.1±3.2	< 0.001	35.4±3.6	-0.5±1.9	< 0.001	0.989	< 0.001	< 0.001
Right calf circumference	34.5±4.2	-0.1±3.2	0.740	35.4±3.5	-0.4±1.9	0.008	0.972	< 0.001	0.001
Left upper arm	28.1±2.9	-0.6±2.0	0.004	28.2±3.2	-0.3±2.4	0.233	0.337	0.005	0.924
Right upper arm	28.5±3.0	-0.8±2.3	0.004	28.5±3.1	-0.3±2.2	0.157	0.277	0.006	1.189

Abbreviations: Peaking HR, peak heart rate; Peak VO₂, peak oxygen uptake; AT VO₂, oxygen uptake at anaerobic threshold; RER, respiratory exchange ratio; Peaking SBP, peak systolic blood pressure; Peaking DBP, peak diastolic blood pressure.

in the HIIT group ($p < 0.001$) and 4.6 ± 13.8 bpm in the MIIT group ($p < 0.001$). The magnitude of reduction did not differ significantly between groups ($p = 0.249$).

Cardiopulmonary Exercise Capacity

After the 4-week intervention (Table 2), both groups demonstrated significant improvements in key Cardio-pulmonary fitness parameters. Peak VO₂ increased by 3.3 ± 2.8 mL·kg⁻¹·min⁻¹ in the HIIT group ($p < 0.001$) and 3.0 ± 3.6 mL·kg⁻¹·min⁻¹ in the MIIT group ($p < 0.001$), with no significant difference between groups ($p = 0.122$). AT VO₂ also improved in both groups, with mean increases of 1.9 ± 2.3 mL·kg⁻¹·min⁻¹ in HIIT and 1.3 ± 2.5 mL·kg⁻¹·min⁻¹ in MIIT (both $p < 0.001$). The increase was significantly greater in the HIIT group than in the MIIT group ($p = 0.01$). Regarding exercise tolerance, exercise time increased significantly in both groups, with changes of 67.8 ± 120.8 s in HIIT and 73.3 ± 106.9 s in MIIT (both $p < 0.001$). Maximum load increased by an average of 17.2 w in both groups ($p < 0.001$). Resting SBP decreased significantly in both groups, with reductions of 4.7 ± 19.2 mmHg in HIIT ($p = 0.029$) and 6.1 ± 17.9 mmHg in MIIT ($p < 0.001$). Resting DBP also declined significantly, with reductions of 4.2 ± 13.3 mmHg in

HIIT ($p=0.006$) and 4.5 ± 13.4 mmHg in MIIT ($p < 0.001$). $VE/VCO_2@AT$ decreased significantly in both groups, with reductions of 1.2 ± 2.7 in HIIT ($p < 0.001$) and 0.6 ± 3.0 in MIIT ($p = 0.028$). The reduction was significantly greater in the HIIT group than in the MIIT group ($p = 0.013$).

Psychological Scale Assessment

Both interventions significantly reduced anxiety and depression scores compared with baseline (Table 2). For anxiety, GAD-7 scores decreased by 2.5 ± 3.7 in the HIIT group ($p < 0.001$) and by 2.6 ± 4.9 in the MIIT group ($p < 0.001$). For depression, PHQ-9 scores decreased by 2.0 ± 3.1 in the HIIT group ($p < 0.001$) and by 1.9 ± 3.7 in the MIIT group ($p < 0.001$). The magnitude of reduction did not differ significantly between groups ($p > 0.05$).

Consistent with the descriptive findings, repeated-measures ANCOVA demonstrated significant time effects across all outcomes (partial $\eta^2 = 0.04$ – 0.32 , all $p < 0.001$), without significant group \times time interactions (all $p > 0.05$; Supplement Table S1). Effect-size analysis further showed moderate-to-large within-group improvements in both interventions (Cohen's $d = 0.30$ – 1.18), particularly for increases in peak VO_2 and decreases in resting HR (Supplement Table S2).

Body Circumferences

Significant reductions in waist circumference were observed in both groups after the intervention (Table 2). In the HIIT group, waist circumference decreased by 1.7 ± 5.4 cm ($p = 0.005$), whereas in the MIIT group, it decreased by 1.5 ± 4.2 cm ($p < 0.001$). The magnitude of reduction did not differ significantly between groups ($p = 0.493$).

Predictors of HRR Change

Multiple linear regression models were developed to identify determinants of ΔHRR , adjusting for covariates that included changes in resting HR, peaking HR, GAD-7, PHQ-9, exercise time, maximum load, peak VO_2 , and AT VO_2 (Table 3). The analysis showed that the change in resting HR was the only consistent independent predictor of HRR improvement across all cohorts. In the HIIT group, the regression coefficient was $\beta = -0.227$ (95% CI -0.302 to -0.007 , $p = 0.04$); in the MIIT group, $\beta = -0.318$ (95% CI -0.352 to -0.109 , $p < 0.001$); and in the overall cohort, $\beta = -0.286$ (95% CI -0.295 to -0.110 , $p < 0.001$). The pooled model including the group \times predictor interaction confirmed that the reduction in resting HR remained the most robust and consistent predictor of HRR improvement across intervention modalities, independent of training intensity (Supplement Table S3).

Correlation Analysis Between HRR and Resting HR

A significant negative correlation was observed between changes in HRR and resting HR in the overall sample ($r = -0.268$, $P < 0.001$; Figure 3). This association persisted in subgroup analyses for both the MIIT group ($r = -0.282$, $P = 0.001$) and the HIIT group ($r = -0.255$, $P = 0.021$).

Discussion

The primary finding of this study was that both short-term HIIT and MIIT significantly improved HRR, with comparable magnitudes of improvement between the two training modalities, thereby offering clinicians two equally effective options for enhancing this important prognostic marker. Notably, the intervention period was only 4 weeks, whereas most previous trials typically lasted 8–12 weeks or longer. Furthermore, this study is the first to demonstrate, within a short-term HIIT and MIIT intervention, the pivotal role of resting heart rate in HRR improvement, highlighting its central importance in mediating post-exercise cardiac autonomic recovery.

Most prior trials employed longer-term training or focused on continuous protocols, whereas the present study uniquely compared two structured interval modalities over a short period. The present study found that MIIT and HIIT produced comparable improvements in HRR after a 4-week intervention. This may be because early improvements in HRR are primarily driven by rapid adaptations in autonomic regulation rather than relying on slower structural or peripheral cardiovascular remodeling. Aerobic training can promote parasympathetic reactivation while suppressing sympathetic excitability within a short period, thereby accelerating post-exercise heart rate recovery.^{27,30} Among these mechanisms, the potential advantage of HIIT has been attributed to its repeated high-intensity stimuli, which may more

Table 3 Predictors of HRR Change in HIIT, MIIT, and Overall Cohort

Change Variable	HIIT (n=82)					MIIT (n=127)					ALL (n=209)				
	β	95% CI	p	R ²	Adjusted R ²	β	95% CI	p	R ²	Adjusted R ²	β	95% CI	p	R ²	Adjusted R ²
Resting HR	-0.227	(-0.302, -0.007)	0.040	0.052	0.040	-0.318	(-0.352, -0.109)	< 0.001	0.101	0.094	-0.286	(-0.295, -0.110)	< 0.001	0.082	0.078
Peaking HR	0.232	(0.008, 0.235)	0.036	0.054	0.042	0.073	(-0.060, 0.147)	0.412	0.005	-0.003	0.129	(-0.004, 0.149)	0.063	0.017	0.012
GAD-7	-0.135	(-0.832, 0.200)	0.226	0.018	0.006	-0.128	(-0.617, 0.097)	0.152	0.016	0.008	-0.130	(-0.563, 0.013)	0.061	0.017	0.012
PHQ-9	-0.105	(-0.917, 0.327)	0.349	0.011	-0.001	-0.031	(-0.569, 0.399)	0.730	0.001	-0.007	-0.055	(-0.529, 0.226)	0.430	0.003	-0.002
Exercise time	0.143	(-0.006, 0.026)	0.199	0.021	0.008	0.150	(-0.002, 0.030)	0.093	0.022	0.015	0.146	(0.001, 0.024)	0.035	0.027	0.017
Maximum load	0.144	(-0.049, 0.236)	0.197	0.021	0.009	0.073	(-0.051, 0.122)	0.416	0.005	-0.003	0.091	(-0.024, 0.120)	0.189	0.008	0.004
Peak VO ₂	0.048	(-0.537, 0.830)	0.672	0.017	0.004	0.156	(-0.053, 0.912)	0.080	0.000	-0.008	0.123	(-0.038, 0.737)	0.077	0.001	-0.004
AT VO ₂	0.077	(-0.552, 1.135)	0.493	0.006	-0.007	-0.004	(-0.727, 0.698)	0.968	0.000	-0.008	0.024	(-0.441, 0.633)	0.726	0.001	-0.004

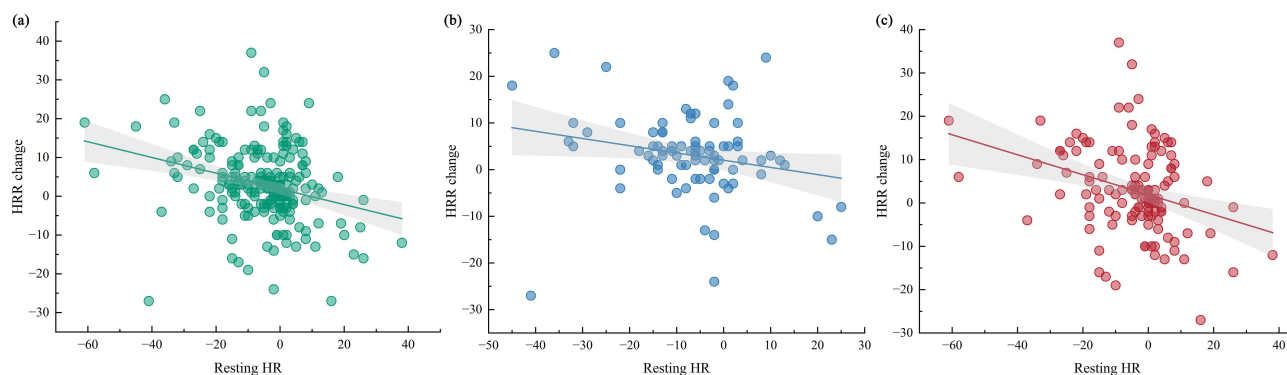


Figure 3 HRR-resting HR relationship analysis. (a) Overall cohort: Resting HR was significantly and inversely associated with HRR change; (b) HIIT group: Resting HR showed a significant inverse relationship with HRR change; (c) MIIT group: Resting HR was significantly and inversely correlated with HRR change.

effectively trigger vagal reactivation and sympathetic withdrawal.³¹ MIIT may induce similar autonomic adaptations by providing an equivalent training load at moderate intensities through structured intervals, thereby reducing acute physiological stress while maintaining sufficient stimulus for adaptation.³²

Resting HR has been recognized as an independent risk factor for both cardiovascular-specific and all-cause mortality.³³ In this study, both the HIIT and MIIT groups exhibited a significant reduction in resting HR after the short-term intervention, reinforcing existing evidence that aerobic exercise effectively decreases resting HR.^{34,35} Lower resting HR is typically associated with better exercise capacity and enhanced cardiac vagal modulation.³⁶ Enhanced vagal tone and reduced sympathetic activity are well-established mechanisms underlying exercise-induced decreases in resting HR,^{27,37,38} which in turn facilitate faster HRR recovery. Furthermore, multivariable regression consistently identified reductions in resting HR as the strongest independent predictor of HRR improvement across HIIT, MIIT, and the overall cohort. This robust association supports the concept that resting HR is a sensitive physiological marker reflecting dynamic autonomic adaptations.

Both HIIT and MIIT effectively enhanced overall exercise capacity in patients with CVD. Significant increases in peak VO_2 and AT VO_2 were observed in both groups. These improvements may be attributed to exercise-induced enhancements in mitochondrial function, microcirculatory remodeling, and increased skeletal muscle oxygen extraction efficiency.^{39,40} Previous studies have shown that short-term high-intensity training (3 weeks) is more effective than moderate-intensity continuous training in improving the AT, with particularly pronounced effects during the early adaptive phase of training.⁴¹ Consistent with these findings, the present study also observed that HIIT was superior to MIIT in enhancing AT VO_2 , but their clinical significance remains uncertain due to the short intervention duration. Longer-term follow-up and extended intervention studies are needed.

Moreover, both HIIT and MIIT significantly improved exercise time, maximal workload, RER, and O_2 pulse, accompanied by reductions in resting systolic and diastolic blood pressure. These findings are consistent with previous cardiac rehabilitation studies demonstrating similar enhancements in exercise capacity and cardiac efficiency,^{42,43} as well as comparable improvements in blood pressure.⁴⁴ Previous studies have shown that reductions in VE/VCO_2 slope or $\text{VE}/\text{VCO}_2@AT$ following exercise-based cardiac rehabilitation are associated with better survival and lower hospitalization risk in patients with cardiovascular disease.⁴⁵ The reductions in $\text{VE}/\text{VCO}_2@AT$ observed in both groups in this study, particularly in the HIIT group, suggest that HIIT may provide additional benefits by further optimizing ventilation-perfusion matching.

Given that waist circumference is a representative indicator of abdominal and visceral fat burden, it has been widely used to predict the risk of cardiovascular events such as hypertension, heart failure, and atherosclerosis.^{46,47} It is worth noting that both groups demonstrated significant reductions in waist circumference following the intervention. In addition, both interval training modalities significantly reduced GAD-7 and PHQ-9 scores, effectively alleviating anxiety and depressive symptoms. Consistent with previous studies, regular aerobic exercise can improve mental health through multiple mechanisms, including increasing neurotransmitter levels such as BDNF and enhancing autonomic nervous

system function.⁴⁸ These findings underscore the added value of interval training in providing metabolic and psychological benefits, which may contribute to improved quality of life and long-term outcomes in CVD patients.

In summary, short-term HIIT and MIIT produced clinically meaningful and comparable improvements in HRR and multiple cardiopulmonary indicators. For patients with limited exercise tolerance, insufficient cardiac functional reserve, or more conservative participation willingness, MIIT can provide adequate training stimulus while reducing acute physiological load, indicating favorable feasibility and suitability.²⁴ In contrast, HIIT is more appropriate for individuals who can tolerate higher exercise intensities and may lead to additional improvements in exercise capacity and prognosis-related outcomes. Therefore, selecting interval training strategies based on functional status and individualized goals can enhance the precision and overall clinical benefit of CR.

Notably, the retrospective design represents the primary limitation of this study, as it may introduce selection bias and restrict causal inference. In addition, the wide age range of participants and variability in disease severity may introduce confounding effects. Furthermore, the relatively small sample size may have limited the statistical power to detect modest associations. Therefore, nonsignificant results should be interpreted with caution, given that a lack of significance may reflect insufficient power rather than the absence of a true effect. The intervention period was also relatively short, and long-term effects on HRR and clinical outcomes were not evaluated. Moreover, autonomic function was assessed solely through HRR without complementary measures such as heart rate variability or baroreflex sensitivity. Finally, all participants were recruited from a single cardiac rehabilitation center, which may limit the generalizability of the findings. Future studies with longer intervention durations, larger and more diverse multicenter cohorts, and mechanistic evaluations involving multimodal autonomic assessments are needed to confirm the sustainability of HRR improvements and clarify the underlying physiological pathways. These research directions will help strengthen the overall quality of evidence.

Conclusion

This study compared the effects of short-term HIIT and MIIT on HRR in patients with CVD and demonstrated that both training modalities significantly enhanced HRR and multiple cardiopulmonary indicators with comparable clinical benefits. These findings support interval training as a time-efficient and practical rehabilitation strategy, with MIIT offering better feasibility for those with limited exercise tolerance and HIIT providing potential additional benefits in individuals capable of higher workloads. This study supports the integration of HRR-targeted interval training into routine cardiac rehabilitation practice. Future multicenter, longer-term, and mechanistic studies incorporating multimodal autonomic assessments are needed to confirm the durability and physiological basis of these improvements, as well as their impact on long-term clinical outcomes.

Data Sharing Statement

The datasets generated and analyzed during the current study are available from the corresponding author, Dr. Huan Ma, upon reasonable request.

Ethics Approval and Informed Consent

This study adhered to established ethical guidelines. The experimental procedures were approved by the Ethics Committee of Guangdong Provincial People's Hospital (Ethics No. KY2023-514) and were in accordance with the ethical standards specified by the Helsinki Declaration of 1975 (revised in 2008). The patients/participants provided their written informed consent to participate in this study.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically

reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare no conflicts of interest and no financial relationships with any commercial entities related to this research.

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