

Acute Effects of Time-Matched Low-Volume High-Intensity Functional Training versus Concurrent Training in Male Myocardial Infarction Patients

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Abstract

Purpose

This study compared acute physiological and psychological responses to two time-matched, low-volume High-Intensity Functional Training (HIFT) and High-Intensity Concurrent Training (HICT) novel protocols in AMI patients.

Methods

Seventeen men (age: 63.3 ± 6.9 year; $\dot{V}O_{2\max}$: 29.7 ± 6.7 ml·kg⁻¹·min⁻¹) completed two randomized sessions (20 × 15-s all-out efforts: 15-s passive recovery; 5 min total work); HIFT (4 × 5 exercises) and HICT (8 × 2 resistance exercises + 4 × 1 endurance exercise). Mean Heart Rate (Absolute [HR_{mean}] and Relative to Maximal Heart Rate [% HR_{max}]), time in % HR_{max} zones, Blood Pressure (BP), end-session HR (HR_{end}), HR Variability (HRV), HR Recovery (HRR), and psychological responses (Rating of Perceived Exertion [RPE], Affective Valence, Self-Efficacy, Intention, Well-Being, Mood, Enjoyment, and Preference) were assessed.

Results

No significant differences appeared in HR_{mean} (113.1 ± 17.1 beats·min⁻¹), % HR_{max} (80–89% HR_{max}), time in % HR_{max} zones, BP, or HRV. During HICT, higher HR_{end} (124.8 ± 21.8 versus 116.6 ± 17.7 beats·min⁻¹), HRR and post-session RPE (~ 5 versus ~ 4 units) were observed. Affective Valence, Self-Efficacy, and Enjoyment (~ 36 units) were comparable between conditions, although HIFT induced greater Intention at ×3 (~ 5.5 versus ~ 4 units) and ×5 (~ 3.5 versus ~ 2 units) weekly sessions, and was preferred by 88.2% of participants.

Conclusion

Time-matched, low-volume interval sessions elicited vigorous cardiovascular stimuli without compromising acute tolerability in post-AMI males. Overall, HIFT may offer a more favorable perceptual and behavioral profile than HICT, supporting its practical application as a time-efficient exercise strategy in cardiac rehabilitation.

Introduction

Acute Myocardial Infarction (AMI), caused by thrombotic coronary artery occlusion leading to hypoxia (Mayo Clinic 2023), impairs quality of life and increases morbidity and mortality (Pocock et al. 2021). Ischemic heart disease remains the leading global cause of death, accounting for ~ 9.1 million deaths in 2021 (WHO 2024) and imposing a substantial economic burden (€282 billion·yr⁻¹ in the European Union) (Luengo-Fernandez et al. 2023). Current guidelines recommend exercise-based cardiac rehabilitation, which improves physical fitness and quality of life while reducing hospital readmissions, morbidity, and

mortality (Brown et al. 2024). Notably, a $\sim 3.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ increase in Maximal Oxygen Consumption ($\dot{V}\text{O}_{2\text{max}}$) is associated with a 13% and 15% lower all-cause and Cardiovascular Disease (CVD) mortality risk, respectively (Kodama et al. 2009).

Interval training consists of repeated high-intensity exercise bouts (4 s–4 min) interspersed with passive or active recovery (Batacan et al. 2017). Its clinical relevance stems from its effectiveness in improving cardiometabolic health and adaptability across fitness levels (Weston et al. 2014; Poon et al. 2024; Tabata 2025). Interval training can involve submaximal efforts (High-Intensity Interval Training [HIIT] at $\geq 80\%$ of Maximal Heart Rate [HR_{max}]) or supramaximal efforts (Sprint Interval Training [SIT] at $\geq 100\%\dot{V}\text{O}_{2\text{max}}$) (Weston et al. 2014). Its safety is established in CVD patients, with one major adverse event reported per 17,083 sessions, comparable to Moderate-Intensity Continuous Training (Wewege et al. 2018).

In healthy and CVD populations, interval training improves Blood Pressure (BP), cardiac output, $\dot{V}\text{O}_{2\text{max}}$, endothelial function, and left ventricular ejection fraction (Weston et al. 2014; Qin et al. 2022; Astorino et al. 2022), and psychological outcomes such as self-perceived Quality of Life, Enjoyment, Motivation, and Self-Efficacy (Weston et al. 2014). In CVD patients, it is also associated with reduced coronary atheroma volume (Vesterbekkmo et al. 2023) and improved 10-year survival (Hsu et al. 2024). Even low-volume sessions ($\leq 15 \text{ min}$) induce significant cardiometabolic adaptations in healthy and clinical populations (Sabag et al. 2022; Yin et al. 2023). This is clinically relevant since lack of time remains a major barrier to physical activity, resulting in only $\sim 20\%$ of CVD patients meeting moderate-to-vigorous exercise guidelines (Lee et al. 2024). However, many interval training protocols still exceed these recommendations (Vollaard and Metcalfe 2017). Importantly, short-effort protocols (10–15 s) elicit physiological (e.g., Heart Rate [HR], $\dot{V}\text{O}_2$) and psychological (e.g., Rating of Perceived Exertion [RPE], discomfort, time to exhaustion) responses comparable or superior to volume-matched protocols with longer efforts (60 s) (Meyer et al. 1996; Guiraud et al. 2010).

Besides endurance training, resistance training is a core component of cardiac rehabilitation (Brown et al. 2024). Combining both modalities within a session, which is termed concurrent training, produces superior functional, neuromuscular, and cardiorespiratory adaptations compared with either modality alone (Wood et al. 2001; Benítez-Flores et al. 2019). A recent meta-analysis identified concurrent training as the most effective modality for improving cardiometabolic markers in overweight/obese adults, with High-Intensity Functional Training (HIFT) ranking second (Batrakoulis et al. 2022). The latter is an interval-based approach integrating multimodal exercises (e.g., resistance, plyometric, gymnastic, endurance training) through multi-joint, body-mass-based movements requiring minimal equipment and adaptable to real-world settings (Feito et al. 2018). Meta-analyses report improvements in body composition, neuromuscular function, and cardiometabolic health in healthy and clinical populations (Batrakoulis et al. 2022; Scoubeau et al. 2022). Moreover, HIFT elicits more favorable psychological responses than continuous training and unimodal interval training in untrained and trained adults (Wilke et al. 2019; Mayr Ojeda et al. 2022). However, its acute physiological and psychological responses in CVD patients remain unknown.

To our knowledge, no studies have compared HIFT and High-Intensity Concurrent Training (HICT) in CVD patients. Therefore, this study examined acute physiological and psychological responses to time-matched, low-volume HIFT and HICT in men with AMI. Given the matched volume, work-to-recovery ratio, and all-out efforts with passive recovery, we hypothesized that both protocols would elicit similar responses.

Methods

Experimental Design

A randomized, counterbalanced crossover design was implemented. The study, approved by the Ethics Committee of the University Clinic Hospital (Res. 73 – 23; Mar. 19th, 2024), was conducted in accordance with the Declaration of Helsinki (2024). Sessions were performed on the same weekday over three consecutive weeks. Procedures took place in the same gym under standardized environmental (21–23°C; 65–75% relative humidity) and temporal conditions (6:00–9:00 pm).

On day one, participants provided written informed consent, underwent medical screening, completed the short Spanish International Physical Activity Questionnaire (IPAQ) (Roman-Viñas et al. 2010), and were familiarized with the psychological scales and exercise protocols (50% of session volume). On days two and three, protocols were completed in randomized order (HIFT = 7 and HICT = 10; Fig. 1).

Participants were instructed to maintain habitual routines (e.g., work, sleep), avoid moderate-to-vigorous physical activity and alcohol consumption for 48 h before each session, and abstain from stimulants (coffee, energy drinks, etc.) on intervention days. Dietary intake was recorded 24 h before day two and replicated before day three to minimize nutritional variability (Gillen 2024). Psychometric responses were recorded directly on spreadsheets and subsequently logged by researchers.

Participants

Seventeen men enrolled in an exercise-based cardiac rehabilitation program participated (Table 1). No women were recruited, reflecting their lower participation in cardiac rehabilitation programs (Guo et al. 2026). Inclusion criteria were: (a) ≥ 1 prior AMI; (b) left ventricular ejection fraction $\geq 45\%$; (c) no significant electrocardiogram abnormalities or severe arrhythmias; (d) no history, signs, or biomarker evidence of heart failure; (e) no uncontrolled hypertension or resting BP $> 220/110$ mmHg (Systolic BP [SBP] and Diastolic BP [DBP]); (f) no pacemaker; (g) no musculoskeletal injuries or functional limitations; (h) no supplements, recreational drugs, or tobacco use; and (i) no contraindications to interval training (Weston et al. 2014).

Table 1
Characteristics of the men with AMI included in the sample (n = 17).

Variable	Descriptive Statistics
Demographic	
Age (yr)	63.3 ± 6.9
Ethnicity	
	European / White [n (%)] 14 (82.4%)
	African [n (%)] 0 (0.0%)
	Native American / Indigenous [n (%)] 0 (0.0%)
	Other / Mixed [n (%)] 3 (17.6%)
Training background (yr)	6 [4]
Body Composition / Clinical	
Body Mass Index (kg·m ⁻²)	27.0 ± 3.2
Muscle Mass (%)	32.8 ± 2.2
Fat Mass (%)	25.5 ± 4.3
Visceral Fat Mass (%)	11.5 ± 4.9
Waist-to-Hip Ratio	0.94 ± 0.07
Basal SBP / DBP (mmHg)	113.5 ± 10.7 / 67.6 ± 7.3
Estimated $\dot{V}O_{2\max}$ (ml·kg ⁻¹ ·min ⁻¹)	29.7 ± 6.7
Habitual Physical Activity (MET·min ⁻¹ ·wk ⁻¹)	2493 [2169]
Intervention	
Time since AMI (yr)	5.7 ± 4.9
PCI only [n (%)]	11 (64.7%)
CABG only [n (%)]	1 (5.9%)
Data are Mean ± SD, or Median [IQR], unless otherwise specified. SBP = Systolic Blood Pressure; DBP = Diastolic Blood Pressure; $\dot{V}O_{2\max}$ = Maximal Oxygen Consumption; AMI = Acute Myocardial Infarction; PCI = Percutaneous Coronary Intervention; CABG = Coronary Artery Bypass Grafting; ACE-Is = Angiotensin Converting Enzyme Inhibitors; ARBs = Angiotensin Receptor Blockers; CCAs = Calcium-Channel Antagonists.	

Variable	Descriptive Statistics
Demographic	
PCI and CABG [n (%)]	5 (29.4%)
Comorbidities	
Hypertension [n (%)]	7 (41.2%)
Diabetes [n (%)]	2 (11.8%)
Hypercholesterolemia [n (%)]	5 (29.4%)
Previous smoking habit [n (%)]	8 (47.1%)
Pharmacological Treatment	
ACE-Is / ARBs [n (%)]	12 (70.6%)
Beta-blockers [n (%)]	13 (76.5%)
CCAs [n (%)]	2 (11.8%)
Diuretics [n (%)]	2 (11.8%)
Statins [n (%)]	15 (88.2%)
Cholesterol reductors [n (%)]	5 (29.4%)
Antiplatelet agents [n (%)]	13 (76.5%)
Data are Mean $\pm$ SD, or Median [IQR], unless otherwise specified. SBP = Systolic Blood Pressure; DBP = Diastolic Blood Pressure; $\dot{V}O_{2\max}$ = Maximal Oxygen Consumption; AMI = Acute Myocardial Infarction; PCI = Percutaneous Coronary Intervention; CABG = Coronary Artery Bypass Grafting; ACE-Is = Angiotensin Converting Enzyme Inhibitors; ARBs = Angiotensin Receptor Blockers; CCAs = Calcium-Channel Antagonists.	

Procedures

Incremental Stress Test

Maximal HR and estimated $\dot{V}O_{2\max}$ were obtained from each participant's most recent Bruce incremental stress test (Bruce 1971) using a PC-ECG 1200 electrocardiograph (Norav Medical, Florida, USA).

Body Composition

Body mass, fat mass and muscle mass were assessed by bioimpedance (HBF 514C, OMRON, Kyoto, Japan) (Loenneke et al. 2013). Height (stadiometer; 2096 PP, Toledo do Brazil), and waist and hip

circumferences (anthropometric tape; SN-4010, Sanny, São Paulo, Brazil) were measured. The mean of two measurements was used to calculate Body Mass Index and Waist-to-Hip Ratio.

Exercise Protocols

Sessions began with a standardized warm-up: 3-min self-paced cycling (Embreex, Brusque, Santa Catarina, Brazil) at moderate intensity (i.e., Category Ratio-10 RPE Scale [CR-10 RPE] ≈ 3), followed by 1 min of whole-body mobility exercises. Both protocols comprised 20 all-out 15-s bouts interspersed with 15-s passive recovery (1:1 work-to-recovery ratio). Participants performed as many repetitions as possible within each bout (Guiraud et al. 2010). Total exercise volume was 5 min, and total session time was 15:45 min, meeting low-volume criteria (Yin et al. 2023).

The HIFT protocol, adapted from McRae et al. (2012), consisted of four rounds of Thrusters with two 2-kg dumbbells, Lunges, Jumping Jacks, Push-Ups, and Planks. The HICT protocol began with 16 sets alternating Back Squats and Bench Presses (Eddens et al. 2018). Low-to-moderate external loads (20–50% of 1-Repetition Maximum [1RM]) induced similar power gains to higher loads (70–80%1RM) in older adults (Bandeira-Guimarães et al. 2023). However, given the limitations of 1RM-based prescription in real-world settings (Loturco et al. 2026), external load was prescribed relative to body mass. In physically active young adults, 50% body mass loads promoted strength adaptations (Benítez-Flores et al. 2019), whereas resistance-based interval training using 20% body mass external load elicited comparable autonomic responses to cycling Sprint Interval Training (SIT) and reduced arterial stiffness to a greater extent (Wang et al. 2024). Accordingly, our HICT approach prescribed a moderate external load (30% body mass) to balance stimulus, safety, and feasibility in this physically active clinical sample. Following prior suggestions, the endurance component was performed secondly (Eddens et al. 2018). Four all-out cycling SIT bouts were completed (Fig. 1) in order to minimize a potential interference effect within concurrent training (Ferraro-Farro et al. 2026). This total SIT volume (60 s) improved cardiometabolic profiles in overweight/obese patients (Gillen et al. 2014).

Heart Rate Parameters

Chest-strap sensors and validated software (Firstbeat Sports v4.7.3.1; Firstbeat Technologies, Finland) (Parak et al. 2021) recorded real-time HR. Parameters included Mean Heart Rate (HR_{mean}), percentage of Maximal Heart Rate ($\%HR_{\text{max}}$), End-Session HR (HR_{end}), and time within 60–69%, 70–79%, 80–89%, and 90–100% HR_{max} .

Blood Pressure

Systolic and Diastolic BP were measured at baseline, pre-, and post-exercise (digital sphygmomanometer; OMRON HEM-7120, OMRON, Kyoto, Japan) (Zhang et al. 2021) following standardized procedures (Haff and Dumke 2019). Baseline and pre-exercise values represent the mean

of two measurements obtained after 3 min seated rest. Post-exercise BP was measured once to capture immediate responses, minimizing the influence of rapid post-exercise decline.

Autonomic Function

Autonomic function was assessed via HR Variability (HRV) and HR Recovery (HRR) in a quiet, dimly lit room (Buchheit 2014). Participants rested supine 2 min pre- and post-exercise while breathing spontaneously, analyzing only the second minute, with the first considered a stabilization period (Esco and Flatt 2014). The Root Mean Square of Successive R–R Interval Differences (RMSSD) was the primary HRV index (Buchheit 2014). Heart Rate Recovery was defined as the difference between HR_{end} and HR at 30, 60, 90, and 120 s post-exercise ($HRR_{30-120s}$).

Rating of Perceived Exertion and Affective Valence

The validated CR-10 RPE assessed self-perceived intensity (0–2 = “Light”; 3–6 = “Moderate”; and 7–10 = “Hard-to-Maximal”) (Foster et al. 2001), while the validated 11-point bipolar Feeling Scale (FS; –5 = “Very bad” to +5 = “Very good”) (Hardy and Rejeski 1989) measured Affective Valence. Standardized instructions were provided to capture momentary affect during exercise (Hardy and Rejeski 1989), and current recommendations were followed to ensure methodological rigor (Ekkekakis et al. 2023). Scales were administered pre-, immediately post-, and 20 min post-exercise (Jung et al. 2014).

Exercise Task Self-Efficacy and Intention to Participate

Twenty min post-exercise, a validated 5-item scale (Jung et al. 2014) evaluated Self-Efficacy in performing the exercise modality 1–5 times·wk⁻¹ over the next four weeks (0% = “Not confident at all”, to 100% = “Completely confident”, in 10% increments). Intention to Participate ≥ 3 and ≥ 5 times·wk⁻¹ over the next month was assessed using a validated 2-item questionnaire (1 = “Very unlikely”, to 7 = “Very likely”) (Jung et al. 2014).

Overall Well-being and Recovery Status

The validated Hooper Index assessed Fatigue, Muscular Soreness, Sleep, and Stress on a 7-point scale (Hooper and Mackinnon 1995) pre-, immediately post-, and 24 h post-exercise.

Profile of Mood States Scale

Mood was assessed pre- and post-exercise using the validated Spanish version of the Profile of Mood States Scale (POMS) (Andrade et al. 2013), rating Friendliness, Anger, Depression, Fatigue, Tension, and Vigor (0 = “Not at all”, to 4 = “Extremely”).

Exercise Task Enjoyment and Personal Preference

Exercise Enjoyment was assessed 20 min post-exercise using the validated short Spanish version of the Physical Activity Enjoyment Scale (PACES) (Fernández García et al. 2008), rating six bipolar items (e.g., “I like it” versus “I do not like it”) on a 7-point scale. After completing both conditions, participants reported

their Preference (“HIFT” or “HICT”) and rated their liking of each protocol (1 = “Very much dislike”, 4 = “Neutral”, to 7 = “Extremely like”).

Statistical Analysis

A *post hoc* sensitivity analysis (G*Power v3.1.9.7; University of Düsseldorf, Germany) considering HR_{mean} for a two-tailed repeated-measures *t*-test ($\alpha = 0.05$, 80% power, $n = 17$), indicated the minimum detectable effect size was $d = 0.72$.

The Shapiro–Wilk test tested data normality, reported as Mean $\pm$ Standard Deviation (SD; normal distribution) or Median (Interquartile Range [IQR]; non-normal distribution). Between-protocol comparisons at single time points (HR, PACES, Preference) were conducted using paired *t*-tests or Wilcoxon signed-rank test, accordingly. Effect sizes were expressed as Cohen’s *d* (0–0.19 = “Trivial”; 0.20–0.59 = “Small”; 0.60–1.19 = “Moderate”; 1.20–1.99 = “Large”; 2.00–3.99 = “Very large”; and ≥ 4.00 = “Nearly perfect”) or matched rank-biserial correlation (0.11–0.27 = “Small”; 0.28–0.42 = “Medium”; and ≥ 0.43 = “Large”) (Hopkins et al. 2009). Psychological variables (Hooper Index, CR-10 RPE, FS, Intention, Self-Efficacy, POMS), HRR, and HRV were analyzed using two-way Repeated-Measures Analysis of Variance (time $\times$ condition). Sphericity was assessed with Mauchly’s test and corrected using Greenhouse–Geisser when violated. Bonferroni-adjusted *post hoc* analyses were performed when appropriate. Effect sizes were reported as partial eta squared (η^2 ; 0–0.05 = “Small”; 0.06–0.13 = “Medium”; and ≥ 0.14 = “Large”). Analyses were conducted using JASP version 0.19.1 (JASP Team 2025, Netherlands) with $\alpha = 0.05$, and figures were created using RStudio version 2025.05.0 + 496 (Posit Software, USA).

Results

Adverse Events

No participants reported musculoskeletal injuries, episodes of angina, dyspnea, cyanosis, presyncope, ST-segment depression, a > 10 mmHg SBP decline, or arrhythmias.

Physiological Parameters

Heart Rate Parameters

No between-condition differences were observed in HR_{mean} (HIFT = 111.6 ± 16.3 beats·min^{−1}, HICT = 114.5 ± 18.2 beats·min^{−1}; $p = 0.208$), $\%HR_{\text{max}}$ (HIFT = $80.0 \pm 3.8\%$, HICT = $82.1 \pm 6.1\%$; $p = 0.233$), or time across HR zones (60–69% HR_{max} : HIFT = 58.5 ± 55.0 s, HICT = 57.2 ± 71.3 s; 70–79% HR_{max} : HIFT = 185.1 ± 74.5 s, HICT = 156.5 ± 109.5 s; 80–89% HR_{max} : HIFT = 253.1 ± 88.0 s, HICT = 219.8 ± 119.4 s; 90–100% HR_{max} : HIFT = 75.4 ± 77.3 s, HICT = 141.6 ± 127.1 s, all $p \geq 0.114$) (Fig. 2). However, HICT exhibited higher HR_{end} (124.8 ± 21.8 beats·min^{−1}) than HIFT (116.6 ± 17.7 beats·min^{−1}, $p = 0.044$, $d = 0.529$).

Blood Pressure

No condition ($p = 0.976$ and 0.193) or time $\times$ condition interaction ($p = 0.202$ and 0.729) effects were observed for SBP or DBP. A significant time effect was found (both $p < 0.001$, $\eta^2 = 0.969$), with higher post- than pre-session BP within HIFT (SBP: $p < 0.001$, $d = 6.586$; DBP: $p < 0.001$, $d = 4.162$) and HICT (SBP: $p < 0.001$, $d = 7.086$; DBP: $p < 0.001$, $d = 4.097$) (Fig. 2).

Autonomic Function

Regarding RMSSD, no main effect of condition ($p = 0.545$) or time $\times$ condition interaction ($p = 0.280$) was detected, but a significant main effect of time was observed ($p = 0.001$, $\eta^2 = 0.478$). Thus, lower post- than pre-exercise RMSSD presented within HIFT ($p = 0.006$, $d = 1.135$) and HICT ($p < 0.001$, $d = 1.402$) (Fig. 3A). For HRR, significant effects of time ($p < 0.001$, $\eta^2 = 0.847$), condition ($p = 0.005$, $\eta^2 = 0.394$), and their interaction ($p = 0.047$, $\eta^2 = 0.204$) were observed. Recovery increased progressively across time-points within HIFT ($p < 0.05$, $d = 0.209$ – 0.555) and HICT ($p < 0.001$, $d = 0.247$ – 0.823), and was consistently lower in HIFT at all time-points ($p < 0.05$, $d = 0.375$ – 0.798) (Fig. 3B).

Psychological Parameters

Rating of Perceived Exertion and Affective Valence

No time $\times$ condition interaction was observed for CR-10 RPE ($p = 0.091$), but time ($p < 0.001$, $\eta^2 = 0.615$) and condition ($p = 0.017$, $\eta^2 = 0.308$) effects were significant. Rating of Perceived Exertion increased from pre- to post-session within HIFT ($p = 0.006$, $d = 1.533$) and HICT ($p < 0.001$, $d = 2.234$). In HIFT, post-20 min CR-10 RPE was similar to post- ($p = 0.060$), remaining higher than pre-session ($p = 0.043$, $d = 1.095$). During HICT, it declined from post- to post-20 min ($p = 0.005$, $d = 0.526$), but remained higher than pre-session ($p < 0.001$, $d = 1.708$). No between-protocol differences were observed pre-session ($p = 0.632$) or post-20 min ($p = 0.076$), although post-session CR-10 RPE was lower in HIFT than HICT ($p = 0.006$, $d = 0.613$) (Fig. 4A).

For FS, no effects of condition ($p = 0.154$) or time $\times$ condition interaction ($p = 0.321$) were found, but a time effect was noted ($p < 0.001$, $\eta^2 = 0.410$). Post- values were similar to pre-session within HIFT ($p = 0.147$) and HICT ($p = 0.064$). Affective Valence increased from post- to post-20 min in HIFT ($p = 0.003$, $d = 1.248$), but not in HICT ($p = 0.055$). Post-20 min FS did not differ from pre- within either condition (HIFT: $p = 0.137$; HICT: $p = 1.000$) (Fig. 4A).

Exercise Task Self-Efficacy and Intention to Participate

Self-Efficacy showed no condition ($p = 0.287$) or time $\times$ condition interaction ($p = 0.863$) effects, but a significant time effect ($p < 0.001$, $\eta^2 = 0.655$). Scores decreased across all frequencies in HIFT ($p < 0.05$, $d = 0.270$ – 1.397), and across $\times 1$ – 4 times $\cdot$ wk $^{-1}$ in HICT ($p < 0.05$, $d = 0.338$ – 1.464), with no further decline from $\times 4$ to $\times 5$ times $\cdot$ wk $^{-1}$ ($p = 0.060$) (Fig. 4B).

Regarding Intention to Participate, no time $\times$ condition interaction was found ($p = 0.707$), but effects of time ($p < 0.001$, $\eta^2 = 0.608$) and condition ($p = 0.002$, $\eta^2 = 0.451$) were significant. Intention decreased from $\times 3$ to $\times 5$ sessions $\cdot$ wk $^{-1}$ within HIFT ($p < 0.001$, $d = 1.164$) and HICT ($p < 0.001$, $d = 1.232$), rating higher in HIFT at $\times 3$ ($p = 0.003$, $d = 0.684$) and $\times 5$ ($p = 0.006$, $d = 0.753$) (Fig. 4B).

Overall Well-Being and Recovery Status

No condition or time $\times$ condition interaction effects were observed for any Hooper Index domain (all $p > 0.05$), whereas time effect was significant for all ($p < 0.05$) except Stress ($p > 0.05$) (Table 2).

Table 2

Hooper Index and POMS responses during time-matched low-volume HIFT and HICT sessions in men with AMI (n = 17).

Scale	Item	Time-point	Protocol		Time Effect	Condition Effect	Interaction Effect
			HIFT	HICT	p-value (η²)	p-value (η²)	p-value (η²)
Hooper Index							
Fatigue							
		Pret	1.59± 0.80	1.47± 0.62	< 0.001 (0.753)	0.320 (0.062)	0.138 (0.116)
		Post	3.06± 0.97	3.59± 1.28			
		Post 24 ht	1.59± 0.71	1.71± 0.85			
Muscular Soreness							
		Pre‡	2.00± 1.37	1.82± 1.19	< 0.001 (0.367)	0.186 (0.107)	0.121 (0.124)
		Post‡	2.06± 1.30	2.18± 1.13			
		Post 24 h	2.47± 1.07	3.35± 1.41			
Sleep							
		Pre	2.82± 1.33	2.53± 1.18	0.027 (0.203)	0.161 (0.119)	0.327 (0.067)

Data are Mean ± SD. HIFT: High-Intensity Functional Training; HICT: High-Intensity Concurrent Training; POMS: Profile of Mood States Scale; ¶ Greenhouse-Geisser correction applied. * Significant between-condition difference ($p < 0.05$). † Significant difference from post- within the same condition ($p < 0.05$). ‡ Significant difference from post-24 h within HICT ($p < 0.05$). Hooper Index–Fatigue: pre- versus post- (HIFT $p < 0.001$, $d = 1.641$; HICT $p < 0.001$, $d = 2.364$); post- versus post-24 h (HIFT $p < 0.001$, $d = 1.641$; HICT $p < 0.001$, $d = 2.101$). Hooper Index–Muscular Soreness: pre- versus post-24 h (HICT $p = 0.007$, $d = 1.224$); post- versus post-24 h (HICT $p = 0.035$, $d = 0.941$). POMS–Friendliness: post- (HIFT versus HICT $p = 0.049$, $d = 0.266$). POMS–Fatigue: pre- versus post- (HIFT $p < 0.001$, $d = 0.919$; HICT $p < 0.001$, $d = 1.378$). POMS–Vigor: post- (HIFT versus HICT $p = 0.009$, $d = 0.680$).

Scale	Item	Time-point	Protocol		Time Effect	Condition Effect	Interaction Effect
			HIFT	HICT	p-value (η²)	p-value (η²)	p-value (η²)
Hooper Index							
		Post	2.35± 1.58	1.65± 0.70			
		Post 24 h	2.47± 1.18	2.47± 1.23			
Stress							
		Pre	2.12± 1.22	2.12± 1.05	0.113 ¶ (0.137)	0.501 (0.029)	0.535 (0.038)
		Post	1.77± 0.83	1.82± 1.13			
		Post 24 h	1.88± 1.05	1.53± 0.72			
POMS							
Friendliness							
		Pre	14.88± 2.52	15.06± 3.53	0.485 (0.031)	0.356 (0.054)	0.036 (0.246)
		Post*	15.18± 2.68	14.35± 3.53			
Anger							
		Pre	1.06± 2.05	1.47± 3.00	0.048 (0.222)	0.327 (0.060)	0.509 (0.028)
Data are Mean ± SD. HIFT: High-Intensity Functional Training; HICT: High-Intensity Concurrent Training; POMS: Profile of Mood States Scale; ¶ Greenhouse-Geisser correction applied. * Significant between-condition difference (p < 0.05). † Significant difference from post- within the same condition (p < 0.05). ‡ Significant difference from post-24 h within HICT (p < 0.05). Hooper Index–Fatigue: pre-versus post- (HIFT p < 0.001, d = 1.641; HICT p < 0.001, d = 2.364); post- versus post-24 h (HIFT p < 0.001, d = 1.641; HICT p < 0.001, d = 2.101). Hooper Index–Muscular Soreness: pre- versus post-24 h (HICT p = 0.007, d = 1.224); post- versus post-24 h (HICT p = 0.035, d = 0.941). POMS–Friendliness: post- (HIFT versus HICT p = 0.049, d = 0.266). POMS–Fatigue: pre- versus post- (HIFT p < 0.001, d = 0.919; HICT p < 0.001, d = 1.378). POMS–Vigor: post- (HIFT versus HICT p = 0.009, d = 0.680).							

Scale	Item	Time-point	Protocol		Time Effect	Condition Effect	Interaction Effect
			HIFT	HICT	p-value (η²)	p-value (η²)	p-value (η²)
Hooper Index							
		Post	0.59± 1.42	0.77± 2.49			
Depression							
		Pre	1.65± 2.71	1.53± 2.72	0.159 (0.120)	0.750 (0.007)	0.826 (0.003)
		Post	1.18± 2.43	1.18± 2.46			
Fatigue							
		Pre†	3.29± 2.78	2.41± 2.48	< 0.001 (0.708)	0.821 (0.003)	0.073 (0.188)
		Post	6.35± 3.82	7.00± 3.98			
Tension							
		Pre	2.71± 2.49	3.35± 3.28	0.287 (0.071)	0.181 (0.109)	0.652 (0.013)
		Post	2.94± 2.66	3.88± 3.24			
Vigor							
		Pre	12.29± 2.76	12.18± 3.30	0.485 (0.001)	0.356 (0.182)	0.036 (0.351)

Data are Mean ± SD. HIFT: High-Intensity Functional Training; HICT: High-Intensity Concurrent Training; POMS: Profile of Mood States Scale; ¶ Greenhouse-Geisser correction applied. * Significant between-condition difference ($p < 0.05$). † Significant difference from post- within the same condition ($p < 0.05$). ‡ Significant difference from post-24 h within HICT ($p < 0.05$). Hooper Index–Fatigue: pre- versus post- (HIFT $p < 0.001$, $d = 1.641$; HICT $p < 0.001$, $d = 2.364$); post- versus post-24 h (HIFT $p < 0.001$, $d = 1.641$; HICT $p < 0.001$, $d = 2.101$). Hooper Index–Muscular Soreness: pre- versus post-24 h (HICT $p = 0.007$, $d = 1.224$); post- versus post-24 h (HICT $p = 0.035$, $d = 0.941$). POMS–Friendliness: post- (HIFT versus HICT $p = 0.049$, $d = 0.266$). POMS–Fatigue: pre- versus post- (HIFT $p < 0.001$, $d = 0.919$; HICT $p < 0.001$, $d = 1.378$). POMS–Vigor: post- (HIFT versus HICT $p = 0.009$, $d = 0.680$).

Scale	Item	Time-point	Protocol		Time Effect	Condition Effect	Interaction Effect
			HIFT	HICT	p-value (η²)	p-value (η²)	p-value (η²)
Hooper Index		Post*	13.24±	11.12±			
			2.77	3.55			

Data are Mean ± SD. HIFT: High-Intensity Functional Training; HICT: High-Intensity Concurrent Training; POMS: Profile of Mood States Scale; ¶ Greenhouse-Geisser correction applied. * Significant between-condition difference ($p < 0.05$). † Significant difference from post- within the same condition ($p < 0.05$). ‡ Significant difference from post-24 h within HICT ($p < 0.05$). Hooper Index–Fatigue: pre- versus post- (HIFT $p < 0.001$, $d = 1.641$; HICT $p < 0.001$, $d = 2.364$); post- versus post-24 h (HIFT $p < 0.001$, $d = 1.641$; HICT $p < 0.001$, $d = 2.101$). Hooper Index–Muscular Soreness: pre- versus post-24 h (HICT $p = 0.007$, $d = 1.224$); post- versus post-24 h (HICT $p = 0.035$, $d = 0.941$). POMS–Friendliness: post- (HIFT versus HICT $p = 0.049$, $d = 0.266$). POMS–Fatigue: pre- versus post- (HIFT $p < 0.001$, $d = 0.919$; HICT $p < 0.001$, $d = 1.378$). POMS–Vigor: post- (HIFT versus HICT $p = 0.009$, $d = 0.680$).

Profile of Mood States Scale

No POMS domains showed a condition effect (all $p > 0.05$). Time × condition interaction effect was significant for Friendliness and Vigor (both $p = 0.036$), and time effect for Fatigue and Anger ($p \leq 0.048$) (Table 2).

Exercise Task Enjoyment and Personal Preference

Enjoyment was similar between sessions (PACES: HIFT = 36.5 ± 3.6 , HICT = 35.6 ± 5.5 , $p = 0.390$). In contrast, Preference significantly favored HIFT (5.8 ± 1.3) versus HICT (4.6 ± 1.4 , $p = 0.033$, matched rank-biserial correlation = 0.648), with 88.2% of participants (15/17) choosing HIFT over HICT.

Discussion

This study is the first to compare acute physiological and psychological responses to time-matched, low-volume HIFT and HICT in men undergoing post-AMI cardiac rehabilitation. A key strength is the rigorous matching of training variables and session structure, with similar pre-session Hooper Index responses suggesting equivalent baseline conditions. Both protocols elicited comparable cardiovascular responses (HR_{mean} , $\%HR_{max}$, and time in $\%HR_{max}$ zones) and similar variations in BP and HRV, indicating comparable cardiovascular and autonomic stress. However, HICT resulted in higher HRR values, whereas HIFT induced lower RPE, greater Intention to Participate, and was strongly preferred. Collectively, these findings suggest that low-volume interval training is feasible and well tolerated following AMI, while HIFT may offer advantages for promoting long-term participation in cardiac rehabilitation.

Chest-strap HR sensors are ecological, non-invasive tools to monitor real-time exercise intensity in applied settings. Similar HR responses (HR_{mean} , $\%HR_{max}$, time across $\%HR_{max}$ zones) and BP increments

indicate comparable physiological stimuli, supporting classification as vigorous exercise ($77-95\%HR_{max}$) (Ozemek 2025). A well implemented interval regimen in CVD populations is $4 \times (4\text{-min efforts: } 3\text{-min active recovery})$, either at $85-95\%HR_{reserve}$: $70\%HR_{reserve}$ (Yakut et al. 2022), or at $85-95\%HR_{peak}$: $60-70\%HR_{peak}$ (Reed et al. 2022), targeting intensities comparable to that achieved in the present study ($\sim 80-89\%HR_{max}$). However, it exceeds the currently unmet vigorous physical activity guidelines (Lee et al. 2024), potentially limiting real-world applicability. In this sense, Guiraud et al. (2010) compared low-volume protocols equalized for total volume (5 min) and work-to-rest ratio (1:1) consisting of $10 \times 15\text{-s}$ versus 60-s efforts at 100% of Peak aerobic Power Output (PPO), interspersed with passive or active recovery at 50%PPO. Shorter efforts with passive recovery elicited similar time spent at $\geq 80\%\dot{V}O_{2max}$ compared to longer efforts, while improving time to exhaustion and RPE (Guiraud et al. 2010). Moreover, low-volume HIFT (~ 11 min; $6 \times 1\text{-min efforts: } 1.25\text{-min active rest}$) elicited similar cardiovascular strain ($\sim 80\%HR_{max}$) to volume-matched rowing-based HIIT in active adults (Astorino et al. 2025). Within this context, our protocols proved sufficient to elicit high cardiorespiratory demands without provoking adverse events in this clinical population. However, further evidence is warranted to support low-volume HIFT and HICT protocols capable of inducing meaningful neuromuscular and cardiometabolic adaptations in patients with AMI, based on findings currently derived from non-CVD populations (Benítez-Flores et al. 2019; Sabag et al. 2022; Yin et al. 2023).

Heart Rate Variability—particularly RMSSD—and HRR are non-invasive autonomic modulation markers, influenced by factors such as plasma epinephrine, lactate accumulation, blood acidosis, arterial oxygenation, and further modulated by chemoreceptor and baroreflex feedback mechanisms, primarily mediated through group III and IV afferent fibers (Stanley et al. 2013). The 2-min assessment utilized reliably measures autonomic balance during field-based exercise and may aid in identifying elevated cardiovascular risk across large populations (Esco et al. 2018; Orini et al. 2023). Here, RMSSD decreased from pre- to post-exercise in both protocols, without significant between-condition differences, indicating similar parasympathetic withdrawal. This aligns with findings in trained adults showing comparable HRV reductions between low-volume cycling HIIT ($10 \times 1\text{-min efforts at } 90\% \text{ aerobic PPO: } 1\text{-min recovery at } 25\% \text{ aerobic PPO}$) versus resistance-based intervals ($10 \times 1\text{-min all-out Squats with } 20\% \text{ body mass: } 1\text{-min passive recovery}$) matched for internal load (Wang et al. 2024). Using the same measurement approach, Benítez-Flores et al. (2023) reported a greater reduction in RMSSD following SIT compared to an equalized ($10 \times 5\text{-s all-out efforts: } 35\text{-s passive recovery; } 6 \text{ min total work}$) Burpee Interval Training (BIT) protocol, indicating higher cumulative cardiovascular strain. Collectively, these findings suggest that exercise intensity, rather than modality, is the primary determinant of post-exercise HRV (Stanley et al. 2013).

Although HR, BP, and HRV indicated comparable internal load, HRR was lower following HIFT. This parameter is a strong independent predictor of mortality risk in clinical populations (Cole et al. 1999), and higher intensities generally elicit slower recovery (Ye et al. 2022). However, this finding should be cautiously interpreted, as the higher HR_{end} in HICT likely resulted in greater HRR values across time-points, potentially inflating HRR independently of true autonomic recovery. Thus, this difference may

reflect the physiological state at exercise cessation rather than modality-specific parasympathetic reactivation, and may be influenced by session structure. Specifically, selecting Planks as the final HIFT exercise potentially reduced HR_{end} , whereas the all-out cycling bouts concluding HICT likely maintained an elevated HR, as illustrated in Fig. 2. Clinically, these findings highlight the importance of considering session termination characteristics when interpreting post-exercise autonomic responses, particularly in cardiac rehabilitation where excessive sympathetic activation increases arrhythmic and ischemic event risk post-AMI (Jouven et al. 2005). Importantly, no adverse events occurred, supporting the safety of these short-effort, low-volume protocols within cardiac rehabilitation, where misconceptions regarding their safety persist among patients and clinicians, reflected in their absence from current cardiac rehabilitation guidelines (Brown et al. 2024).

Psychological responses are critical predictors of exercise adherence (Bauman et al. 2012). Post-session CR-10 RPE was “Moderate” (HIFT ≈ 4 , HICT ≈ 5 , $p = 0.06$, $d = 0.613$), aligning with a similar HIIT protocol in CVD patients (RPE 6–20 Scale ≈ 15) (Guiraud et al. 2010). These findings support the notion that shorter efforts are perceived as less strenuous throughout several populations (Benítez-Flores et al. 2026). The significantly higher post-session RPE in HICT is likely explained by the additional external load and higher HR_{end} . Consistently, affective responses were similarly positive (Fig. 4A), aligning with previous studies reporting favorable affect during various BIT (Mayr Ojeda et al. 2022), HIFT (Ferraro-Farro et al. 2025), and cycling SIT (Jung et al. 2014; Martinez et al. 2015; Niven et al. 2018; Astorino et al. 2019; Li et al. 2022) protocols applied in healthy active (Jung et al. 2014; Mayr Ojeda et al. 2022; Ferraro-Farro et al. 2025) and sedentary (Niven et al. 2018) adults, as well as clinical populations (Martinez et al. 2015; Astorino et al. 2019; Li et al. 2022). Given that Affective Valence predicted long-term adherence to interval training in overweight/obese inactive adults (Oliveira et al. 2024), and it was associated with HR-derived intensity metrics (Benítez-Flores et al. 2024), these results become clinically relevant, suggesting that low-volume interval training would be both psychologically well tolerated and clinically applicable in AMI patients.

Self-Efficacy, another robust predictor of adherence (Bauman et al. 2012), showed no between-condition differences. However, it declined as frequency increased in both conditions, with high scores (~ 70 – 90%) at ≤ 3 sessions $\cdot$ wk $^{-1}$ and a $\sim 20\%$ reduction at 5 sessions $\cdot$ wk $^{-1}$, indicating limited perceived feasibility at higher frequencies. Intention to Participate also decreased as frequency increased, but remained higher for HIFT than HICT at both $\times 3$ (~ 5 versus ~ 4 units; $p = 0.003$, $d = 0.684$) and $\times 5$ sessions $\cdot$ wk $^{-1}$ (~ 3 versus ~ 2 units, $p = 0.006$, $d = 0.753$) (Fig. 4B). Interval formats generally enhance Self-Efficacy and Intention in active and inactive groups due to their “on-off” structure of brief, manageable efforts compared to continuous training (Jung et al. 2014; 2022). Enjoyment, a key mediator of adherence in heart failure patients (Klompstra et al. 2022), was similarly high across protocols (PACES $\approx 36/42$). Interval training is typically rated as more enjoyable than continuous training (Jung et al. 2014; Mayr Ojeda et al. 2022), potentially explained by opponent process theory, whereby positive affect follows discomfort as a reward mechanism (Solomon 1980). Still, HIFT was preferred by 88.2% ($n = 15$), underscoring the importance of protocol design in shaping motivation. Furthermore, HICT elicited lower

post-session Vigor and Friendliness in the Hooper Index, and greater Muscular Soreness post-24 h in the POMS. Altogether, these findings suggest that HIFT may offer a more favorable balance between effort and tolerability in CVD patients.

Conclusions

Time-matched, low-volume interval exercise can provide a vigorous cardiovascular stimulus during post-AMI cardiac rehabilitation without compromising acute tolerability. Importantly, when cardiovascular demand is matched, exercise selection may influence the perceptual and behavioral response to training, with HIFT offering a more favorable profile than HICT. Overall, these findings support HIFT as a practical strategy for implementing time-efficient vigorous-intensity exercise in cardiac rehabilitation settings and highlight exercise modality as a potentially relevant determinant of the real-world feasibility of interval training.

Limitations

First, the acute design precludes inference on long-term adaptations. Second, $\dot{V}O_{2\max}$ was not directly measured, limiting fitness characterization and session intensity expression as $\% \dot{V}O_{2\max}$. Third, despite matching volume, effort type, and work-to-recovery ratio, external load was not quantified in kJ, the most robust measure of external load. Hence, load equivalence should be assessed critically. Finally, despite females appearing to achieve comparable long-term clinical outcomes to males (Guo et al. 2026), the trained, exclusively male sample limits generalizability. Future studies should include more diverse cohorts (e.g., females, early-stage cardiac rehabilitation, patients with other comorbidities), incorporate laboratory-based physiological assessments, and adopt longitudinal designs to evaluate chronic adaptations.

Abbreviations

%HRmax

Percentage of Maximal Heart Rate

1RM

1-Repetition Maximum

AMI

Acute Myocardial Infarction

BP

Blood Pressure

CR-10 RPE

Category Ratio-10 Rating of Perceived Exertion Scale

CVD

Cardiovascular Disease

DBP

Diastolic Blood Pressure
FS
Feeling Scale
HICT
High-Intensity Concurrent Training
HIFT
High-Intensity Functional Training
HIIT
High-Intensity Interval Training
HR
Heart Rate
HRender
End-Session Heart Rate
HRmax
Maximal Heart Rate
HRmean
Mean Heart Rate
HRR
Heart Rate Recovery
 $HRR_{30-120S}$
Heart Rate Recovery at 30–120 s post-exercise
HRV
Heart Rate Variability
IPAQ
International Physical Activity Questionnaire
IQR
Interquartile Range
PACES
Physical Activity Enjoyment Scale
POMS
Profile of Mood States Scale
PPO
Peak aerobic Power Output
RMSSD
Root Mean Square of Successive R–R Interval Differences
RPE
Rating of Perceived Exertion
SBP
Systolic Blood Pressure
SD

Standard Deviation
SIT
Sprint Interval Training
SIT
Sprint Interval Training
 $\dot{V}O_{2\max}$
Maximal Oxygen Consumption
 η^2
Partial eta squared

Declarations

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Competing Interests

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

Data will not be shared publicly and will be available upon request with the contact of the corresponding author.

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Figures

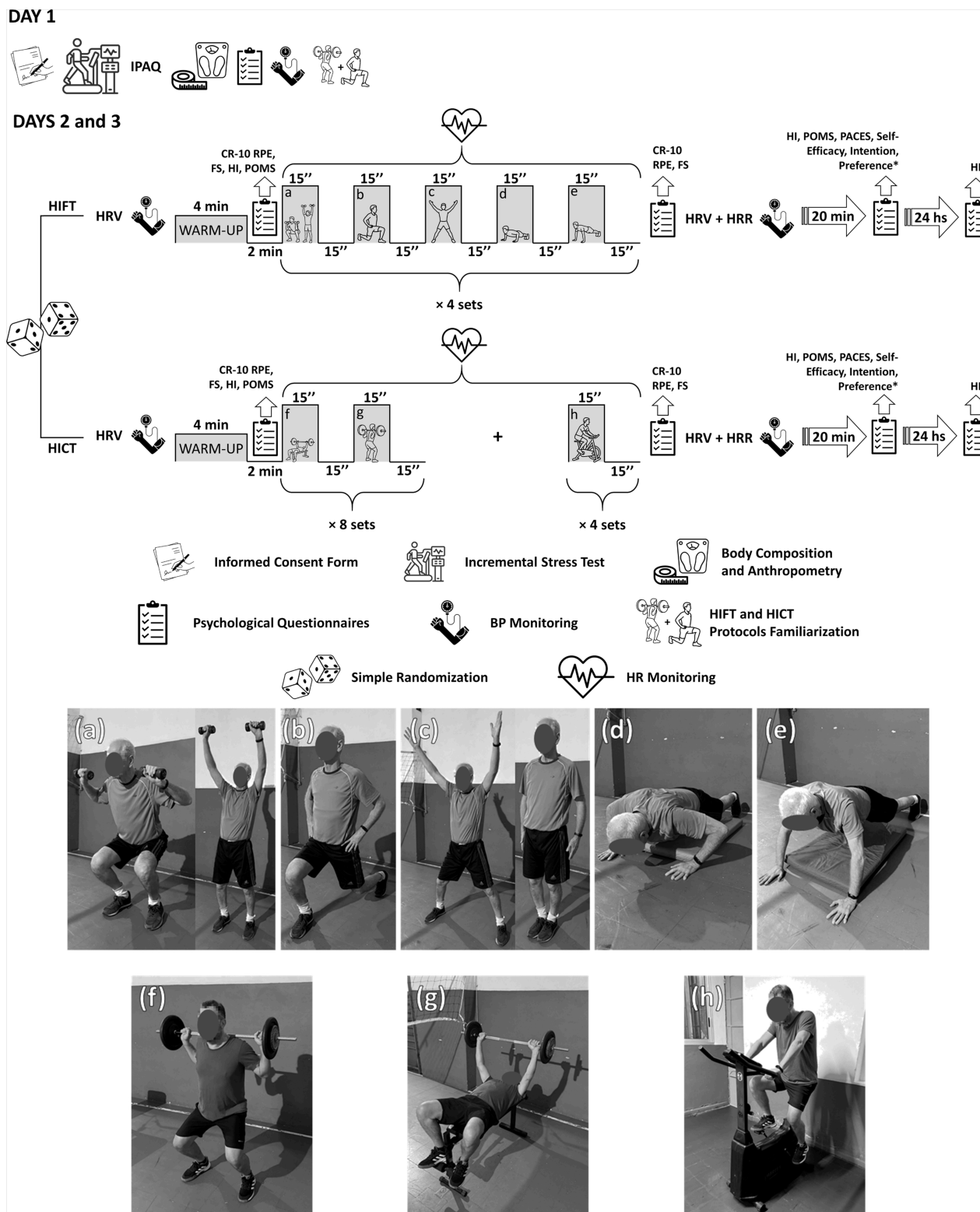


Figure 1

Experimental design flowchart. IPAQ: International Physical Activity Questionnaire; HR: Heart Rate; BP: Blood Pressure; HIFT: High-Intensity Functional Training; HICT: High-Intensity Concurrent Training; HRV: Heart Rate Variability; CR-10 RPE: Category Ratio-10 Rating of Perceived Exertion Scale; FS: Feeling Scale; HI: Hooper Index; POMS: Profile of Mood States Scale; HRR: Heart Rate Recovery; PACES: Physical Activity Enjoyment Scale; * Assessed only after the last session; (a) Thrusters with two 2-kg dumbbells;

(b) Lunges; (c) Jumping Jacks; (d) Push-Ups; (e) Planks; (f) Back Squats; (g) Bench Presses; (h) Cycling-based Sprint Interval Training.

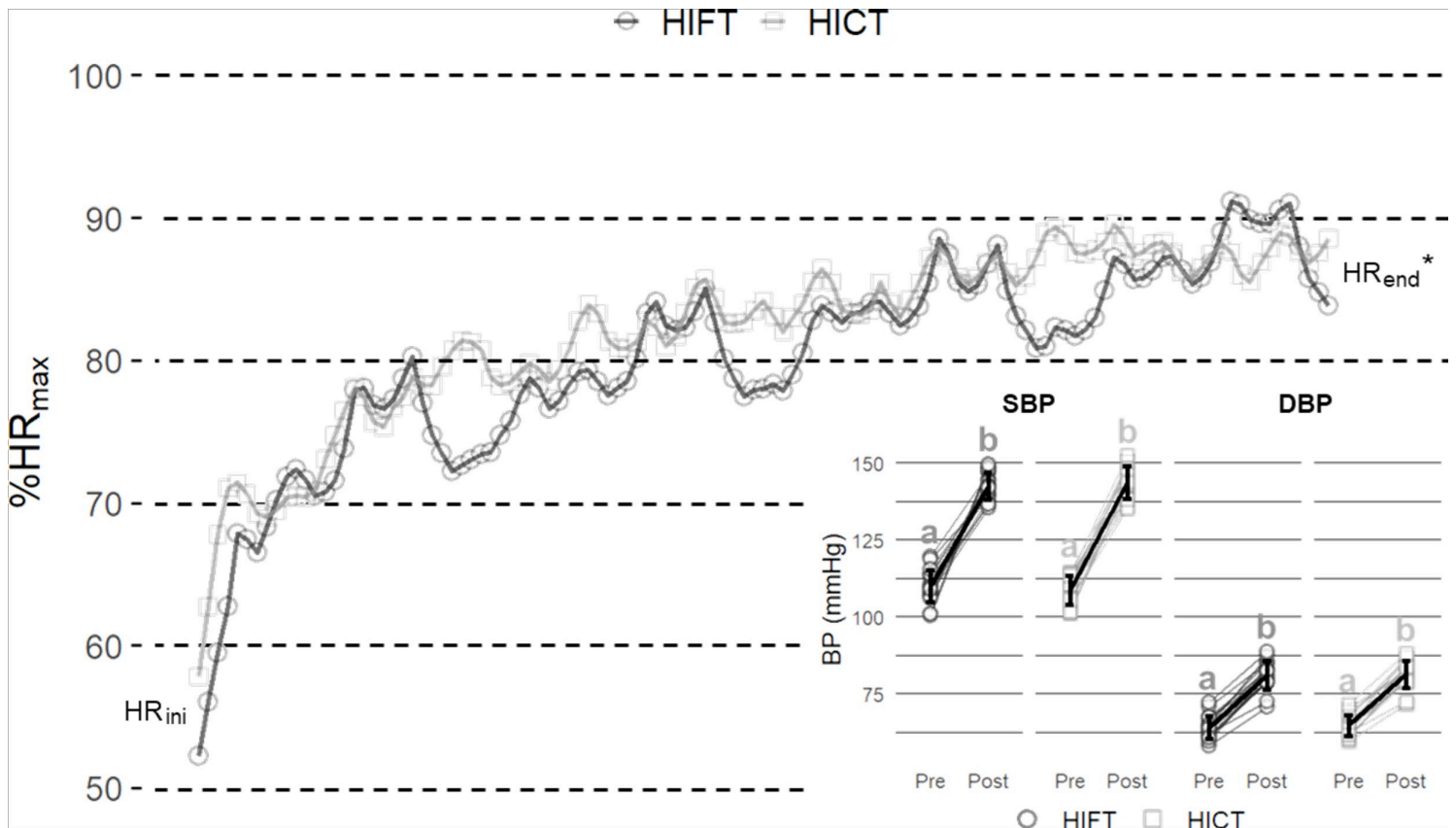


Figure 2

Real-time HR and BP responses to time-matched low-volume HIFT and HICT sessions in men with Acute Myocardial Infarction (n=17). HIFT: High-Intensity Functional Training; HICT: High-Intensity Concurrent Training; HR: Heart Rate; %HR_{max}: Percentage of Maximal Heart Rate; HR_{ini}: Initial-Session Heart Rate; HR_{end}: End-Session Heart Rate; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure. Each individual HR-point represents a 5-s average. * Significantly higher in HICT versus HIFT (p<0.05). Different letters indicate significant pre-to-post within-condition differences (p<0.05). Black error bars are Mean ± SD.

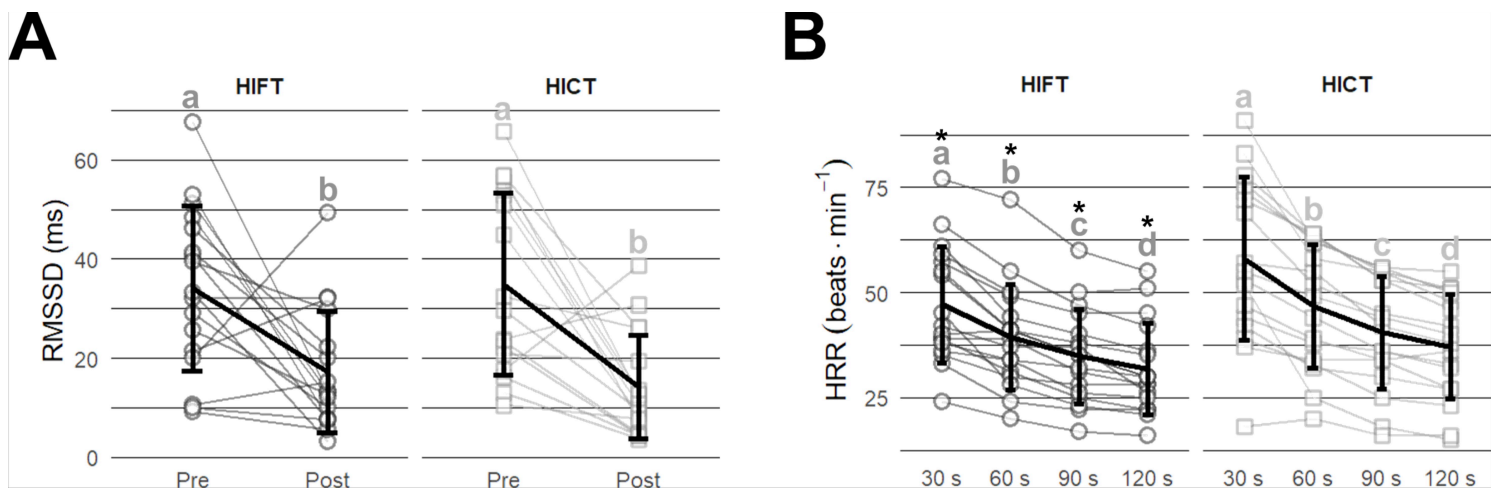


Figure 3

Autonomic responses to time-matched low-volume HIFT and HICT sessions in men with Acute Myocardial Infarction (n=17). **Figure 3A.** Pre- versus post-session RMSSD. **Figure 3B.** HRR at 30, 60, 90 and 120 s post-session. HIFT: High-Intensity Functional Training; HICT: High-Intensity Concurrent Training; RMSSD: Root Mean Square of Successive R-R Interval Differences; HRR: Heart Rate Recovery. * Significant between-condition difference ($p<0.05$). Different letters indicate significant differences between time-points within the same condition ($p<0.05$). Black error bars are Mean $\pm$ SD

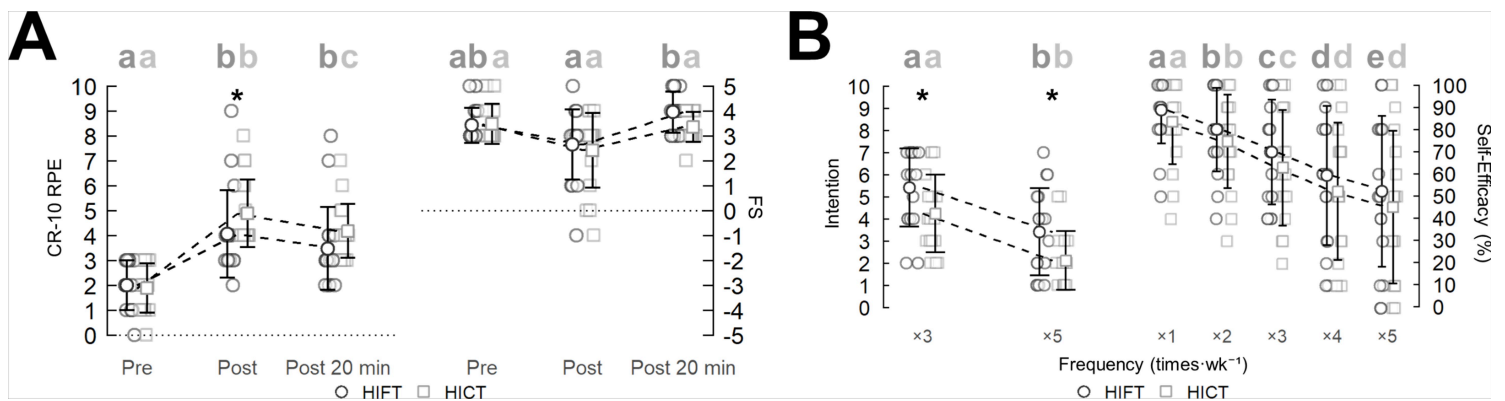


Figure 4

Psychological responses during time-matched low-volume HIFT and HICT sessions in men with Acute Myocardial Infarction (n=17). **Figure 4A.** CR-10 RPE and FS responses. **Figure 4B.** Intention and Self-Efficacy responses. HIFT: High-Intensity Functional Training; HICT: High-Intensity Concurrent Training; CR-10 RPE: Category Ratio-10 Rating of Perceived Exertion scale; FS: Feeling Scale. * Significant between-condition difference ($p<0.05$). Different letters indicate significant differences between time-points within the same condition ($p<0.05$). Black error bars are Mean $\pm$ SD.