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Impact of heart rate variability-guided, aerobic, and combined exercise training on cardiac autonomic function in cardiovascular patients: a systematic review

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Summary. Aim. This review aimed to evaluate the effects of combined training, HRV-guided training, and aerobic training on cardiac autonomic function and other health-related outcomes in patients with cardiovascular disease (CVD). **Review methods.** A systematic search was conducted across nine electronic databases to identify relevant randomized controlled trials (RCTs). A total of 11 RCTs involving 489 participants were included. The quality of the 11 included studies was assessed using two study quality and reporting assessment scales (TESTEX and $STARD_{HRV}$). **Key points.** Exercise interventions lasted 6–16 weeks, with 2–5 sessions per week and 30–60 min per session. Substantial heterogeneity was observed across studies in both exercise prescriptions and HRV assessment protocols. Evidence comparing different training modalities remains limited and inconsistent. Some studies reported improvements in vmHRV indices (RMSSD, HF (ms^2), and SD1) following combined training or HRV-guided training, although these findings were not consistently replicated across studies. Aerobic training generally showed limited and heterogeneous effects on HRV outcomes. Exercise interventions, however, showed more consistent improvements in cardiorespiratory fitness and body composition. While current evidence does not support a definitive superiority of any single exercise modality, combined training and HRV-guided approaches show possible benefits for improving cardiac autonomic regulation and may inform individualized cardiac rehabilitation strategies. Future research may benefit from larger randomized controlled trials using standardized HRV assessment protocols.

Key words. Heart rate variability, cardiovascular disease, exercise therapy, autonomic nervous system, rehabilitation.

Impatto dell'allenamento guidato dalla variabilità della frequenza cardiaca, dell'allenamento aerobico e dell'allenamento combinato sulla funzione autonomica cardiaca nei pazienti cardiovascolari: una revisione sistematica

Riassunto. **Scopo**. Questa revisione mirava a valutare gli effetti dell'allenamento combinato, dell'allenamento guidato dalla HRV e dell'allenamento aerobico sulla funzione autonomica cardiaca e su altri esiti relativi alla salute in pazienti con malattie cardiovascolari (CVD). **Metodi di revisione**. È stata condotta una ricerca sistematica su nove banche dati elettroniche per identificare studi clinici randomizzati controllati (RCT) pertinenti. Sono stati inclusi in totale 11 RCT che hanno coinvolto 489 partecipanti. La qualità degli 11 studi inclusi è stata valutata utilizzando due scale di valutazione della qualità degli studi e della rendicontazione (TESTEX e STARDHRV). **Punti chiave**. Gli interventi di esercizio sono durati da 6 a 16 settimane, con 2-5 sessioni a settimana e 30-60 minuti per sessione. È stata osservata una sostanziale eterogeneità tra gli studi sia nelle prescrizioni di esercizio che nei protocolli di valutazione della HRV. Le evidenze che mettono a confronto diverse modalità di allenamento rimangono limitate e incoerenti. Alcuni studi hanno riportato miglioramenti negli indici vmHRV (RMSSD, HF (ms^2) e SD1) a seguito di un allenamento combinato o guidato dalla HRV, sebbene questi risultati non siano stati replicati in modo coerente tra gli studi. L'allenamento aerobico ha generalmente mostrato effetti limitati ed eterogenei sugli esiti della HRV. Gli interventi di esercizio fisico, tuttavia, hanno mostrato miglioramenti più consistenti nella capacità cardiorespiratoria e nella composizione corporea. Sebbene le prove attuali non supportino una superiorità definitiva di una singola modalità di esercizio, l'allenamento combinato e gli approcci guidati dalla HRV mostrano possibili benefici per il miglioramento della regolazione autonomica cardiaca e possono fornire indicazioni per strategie di riabilitazione cardiaca personalizzate. La ricerca futura potrebbe trarre beneficio da studi randomizzati controllati su scala più ampia che utilizzino protocolli standardizzati di valutazione della HRV.

Parole chiave. Variabilità della frequenza cardiaca, malattie cardiovascolari, terapia fisica, sistema nervoso autonomo, riabilitazione.

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Introduction

Cardiovascular disease (CVD) remains the leading cause of death worldwide, accounting for approximately 19.8 million deaths in 2022 alone, representing 32% of total global mortality[1]. To reduce the risk of recurrence and improve long-term prognosis, the restoration of cardiac autonomic function has become a central focus in CVD rehabilitation[2]. Although conventional pharmacological therapies play a key role in disease management, their capacity to restore autonomic regulation remains limited[3]. The cardiac autonomic nervous system (ANS) consists of the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS, also referred to as the vagus nerve). Together, these systems maintain cardiovascular homeostasis through top-down regulation mediated by the central autonomic network (CAN)[4]. Heart rate variability (HRV) is a widely used non-invasive marker reflecting the dynamic balance of the ANS and its regulatory flexibility[5]. Among commonly used HRV metrics, RMSSD, HF (ms^2), and SD1 are interpreted as indices of cardiac vagal activity, collectively referred to as vagally mediated HRV (vmHRV)[6-8]. The definitions and physiological significance of the main HRV metrics are summarized in table 1. In patients with cardiovascular disease, autonomic dysfunction is typically characterized by reduced vagal activity and lower vmHRV levels[9]. Lower vmHRV has been associated with adverse cardiovascular outcomes and poorer clinical prognosis[9-11]. Therefore, enhancing cardiac autonomic regulation, as reflected by vmHRV indices, may represent a potential target in cardiovascular rehabilitation. In this context, identifying effective strategies to enhance vmHRV and improve autonomic regulation in patients with CVD remains an important research priority.

Accumulating evidence indicates that exercise interventions are associated with improvements in cardiac autonomic regulation, typically reflected by increases in vmHRV across different populations[12,13]. In patients with CVD, structured exercise training has also been reported to improve vmHRV indices (RMSSD and HF), accompanied by reductions in resting heart rate and improvements in autonomic regulation[14,15]. In the context of cardiac rehabilitation, exercise-based interventions are widely recommended as an important component of treatment. Studies have shown that these interventions are associated with improvements in cardiorespiratory fitness and physical function[16-18]. These exercise interventions are typically implemented through different train-

Table 1. HRV metrics and physiological notes.

Variable	Units	Definition	Physiological significance
SDNN[10]	[ms]	represents the standard deviation of all normal RR intervals	reflects overall heart rate variability, with higher values indicating better cardiac autonomic regulation
RMSSD[10]	[ms]	the square root of the mean of the squared differences between successive RR intervals.	primarily reflects cardiac parasympathetic nervous activity
LF (Low Frequency)[10]	[ms^2]	represents the low-frequency power, typically in the range of 0.04–0.15 Hz	reflects both cardiac sympathetic and parasympathetic nervous activity
LF [n.u.] (Low Frequency)[7]	normalized units[n.u.]	represents powers of LF bands in normalised units	LF [n.u.] = LF [ms^2]/(total power [ms^2] – VLF [ms^2]). Changes in LFnu do not directly index sympathetic or vagal activity, and shifts can arise from alterations in the complementary band or total power. This study report LFnu descriptively.
HF (High Frequency)[7]	[ms^2]	represents the high-frequency power, typically in the range of 0.15–0.4 Hz	primarily reflects cardiac parasympathetic nervous activity
HF [n.u.] (High Frequency)[7]	normalized units[n.u.]	represents powers of HF bands in normalised units	HF [n.u.] = HF [ms^2]/(total power [ms^2] – VLF [ms^2]). Changes in HF [n.u.] do not directly index sympathetic or vagal activity, and shifts can arise from alterations in the complementary band or total power. This study report HF [n.u.] descriptively.
LF/HF ratio[10]		the ratio of low-frequency (LF) to high-frequency (HF) power	The physiological significance of this indicator is currently controversial, so this article interprets it conservatively.
SD1[42]	[ms]	represents short-term variability on the Poincaré plot	reflects short-term fluctuations driven by cardiac parasympathetic activity, with higher values indicating stronger parasympathetic activity

Source: compiled by the authors based on Meier et al.[15]; Gonzalez et al.[27]; Wu et al.[28]; Gallo et al.[29]; Stern et al.[30].

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ing modalities, most commonly aerobic training and combined (aerobic–resistance) training. In recent years, HRV-guided training has been proposed as a novel training strategy. This approach dynamically adjusts training intensity based on daily autonomic status reflected by individual HRV indices, thereby enabling more individualized exercise prescriptions[19-21]. However, the relative effects of different training modalities (aerobic training, combined training, and HRV-guided training) on improving autonomic regulation in patients with CVD remain unclear.

Several systematic reviews have examined the effects of exercise training on HRV. However, a considerable proportion of these reviews included non-randomized studies, crossover designs, or quasi-experimental studies, which are generally associated with a higher risk of bias[12,15,22,23]. In addition, some reviews lacked clear classification of exercise intervention types. Substantial differences in training protocols and study quality across the included studies further limited the interpretability and comparability of their findings[24,25]. To address these methodological issues, the present review included only randomized controlled trials (RCTs) and conducted a structured comparison of different exercise training modalities (aerobic training, combined training, and HRV-guided training) in patients with cardiovascular disease. This study aims to compare the effects of different exercise training modalities on cardiac autonomic regulation in patients with CVD.

Methods

The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[26] and was prospectively registered in PROSPERO (registration number: CRD420251018026).

Search strategy

A systematic search was conducted across nine English-language databases, including PubMed, Web of Science, Ovid Medline, Embase, Scopus, CINAHL, PsycINFO, Cochrane Library, and SPORTDiscus. The Boolean search strategy combined the following terms using AND/OR operators: ("physical training*" OR "aerobic training*" OR "HRV-guided training*" OR "exercise*" OR "resistance training*") AND ("HRV*" OR "heart rate variability*") AND ("cardiovascular disease*" OR "cardiovascular diseases*"). Search strings were adapted as needed to accommodate differences in indexing terms and syntax across databases. The complete search strategies for nine databases are provided in supplementary 1 (table S1).

Study eligibility

The PICOS (Population, Intervention, Comparison, Outcome, Study design) framework[26] was used to define the eligibility criteria for this review. Studies involving patients with cardiovascular disease (coronary artery disease, myocardial infarction, or peripheral arterial disease) were included. Eligible interventions comprised aerobic training, combined training (aerobic plus resistance), and HRV-guided training, with comparisons including usual care, no-exercise control groups, or alternative exercise modalities. Studies were required to report HRV outcomes, including time-domain, frequency-domain, or nonlinear indices. Only randomized controlled trials were considered. Further details are provided in table 2.

Table 2. Study eligibility.

Framework	Methods
Population	The study subjects were patients aged ≥18 years who were diagnosed with cardiovascular diseases (coronary heart disease, myocardial infarction, atherosclerosis, etc.).
Intervention (exposure)	Exercise training/physical training include Aerobic Exercise (Low/Moderate/High), Resistance Training, High-Intensity Interval Training (HIIT), Combined Training (aerobic exercise + resistance training). Studies using yoga, tai chi, meditation, or breathing exercises as the primary intervention were not considered.
Comparison	The eligible comparators were whether to exercise, different types, intervention duration, and exercise supervision.v
Outcome	Primary outcomes were HRV parameters, including Time-domain indices (SDNN, RMSSD, pNN50%, RR-intervals), Frequency-domain indices (LF, HF, LF/HF, TP), and Non-linear indices (SD1, ApEn). Health-related variables: maximal oxygen uptake (VO_2max), blood pressure (BP), and body mass index (BMI), body fat (BF%), waist circumference (WC), and Resting heart rate (HR).
Study design	RCT studies were only considered. Animal experiments, meetings, dissertations, narrative or systematic reviews, and meta-analyses were excluded.

Note: VO_2max, BMI, BF%, BP, WC and resting HR were extracted only when reported by the included trials as exploratory secondary outcomes and were not used as eligibility criteria.

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Study selection and data extraction

Zotero, developed by George Mason University, was used as the reference management tool to identify, and remove duplicate records. Two reviewers Donghai Huang (HD) and Chika Umunnawuike (CU) independently screened the titles and abstracts of all retrieved studies according to the PICOS criteria. Disagreements were resolved by a third reviewer Chigozie Charity Okwuwa (CCO). Data extraction was performed independently by the same two reviewers using a standardized Excel spreadsheet, and all extracted data were cross verified by Xiuling Zhang (XZ). Extracted variables included sample characteristics (sample size, age, sex), HRV measurement protocols (measurement method, breathing control, posture, sam-pling frequency), HRV parameters (LF ms^2, LF nu, HF ms^2, HFnu, LF/HF ratio, SDNN, RMSSD, pNN50%, TP, SD1), health-related outcomes (body weight, body fat percentage (BF%), BMI, BP, waist circumference (WC), VO_2max, recording duration, intervention characteristics (type, duration, frequency), and details of the control group. For further information on the physiological background of HRV metrics, refer to references[7,27]. If relevant data were missing, attempts were made to contact the corresponding study authors for clarification.

Classification of exercise interventions

For the purpose of comparative analysis, exercise interventions were classified into three categories: aerobic training (including HIIT), combined training (aerobic plus resistance), and HRV-guided training. This classification was informed by the recommendations of the American College of Sports Medicine (ACSM)[28] and the 2021 ESC Guidelines on cardiovascular disease prevention[29], and aligned with the FITT-VP framework in terms of exercise type and intensity structure. Where applicable, the classification was also consistent with the original study definitions.

In this review, HRV-guided training refers to an approach in which training load is adjusted on a day-to-day basis according to HRV measurements, typically derived from indices such as RMSSD[20,21]. Predefined decision rules are used to modify exercise intensity, with higher HRV values indicating readiness for higher training loads and lower values suggesting the need for reduced intensity or recovery sessions.

Quality assessment

To evaluate the methodological quality and reporting transparency of the included studies, two validated assessment tools were employed: the Tool for the assEssment of Study qualiTy and reporting in Exercise (TESTEX)[30] and standard for reporting diagnostic accuracy studies guidelines for HRV research (STARDHRV)[31]. The TESTEX scale comprises 12 items with a total score of 15(including 5 points for study quality and 10 points for reporting) and is designed to assess aspects such as randomization, adherence, intervention reporting, and statistical analysis. In specific applications, the quality of the studies was classified according to their total TESTEX score as "high" (≥12 points), "good" (7–11), or "low" (≤6)[32]. The STARDHRV checklist, an adaptation of the original STARD guideline for diagnostic research, was modified to reflect the unique features of HRV studies. It includes 25 items (1 point per item) aimed at enhancing the clarity, transparency, and consistency of HRV study design, data processing, and reporting[8,33]. The evaluation tools were slightly adapted in this review[34] details of the modifications can be found in supplementary 2 and 3.

Results

Selection and classification

A total of 2,102 records were initially identified through database searches, and one additional study were identified through manual reference checking. After applying all inclusion and exclusion criteria, 11 RCTs were included in the final analysis[35-45]. The study selection process is illustrated in figure 1. In the absence of meta-analytic subgroup analyses, this review conducted a narrative, stratified synthesis of the included studies and compared the direction and consistency of effects across two dimensions: (1) HRV measurement protocols; (2) exercise prescription characteristics. Table 3 summarizes the general characteristics of the included studies, while table 4 presents the primary HRV outcomes and health-related physiological variables.

Study characteristics

The 11 RCTs (n=489) included patients with CAD[36-38,41,42], post–myocardial infarction[39,40,44,45], and peripheral arterial disease (PAD)[33,41] (mean age ≈ 57 years; male=362, female=58, unreported=69). Most were sedentary or without systematic training.

There was marked heterogeneity in HRV assessment methods among the included studies. Measurement devices fell into three categories: electrocardiography (ECG)[33,37,38,41,43], electrode chest belts[37,38,41,42,44], and photoplethysmography (PPG)[36]. Recording conditions varied substantially, four studies explicitly reported breathing protocols (spontaneous breathing[37], 12 breaths/min[42,44], or a standardized breathing frequency[40] whereas the remaining studies did not report breathing. Seven studies

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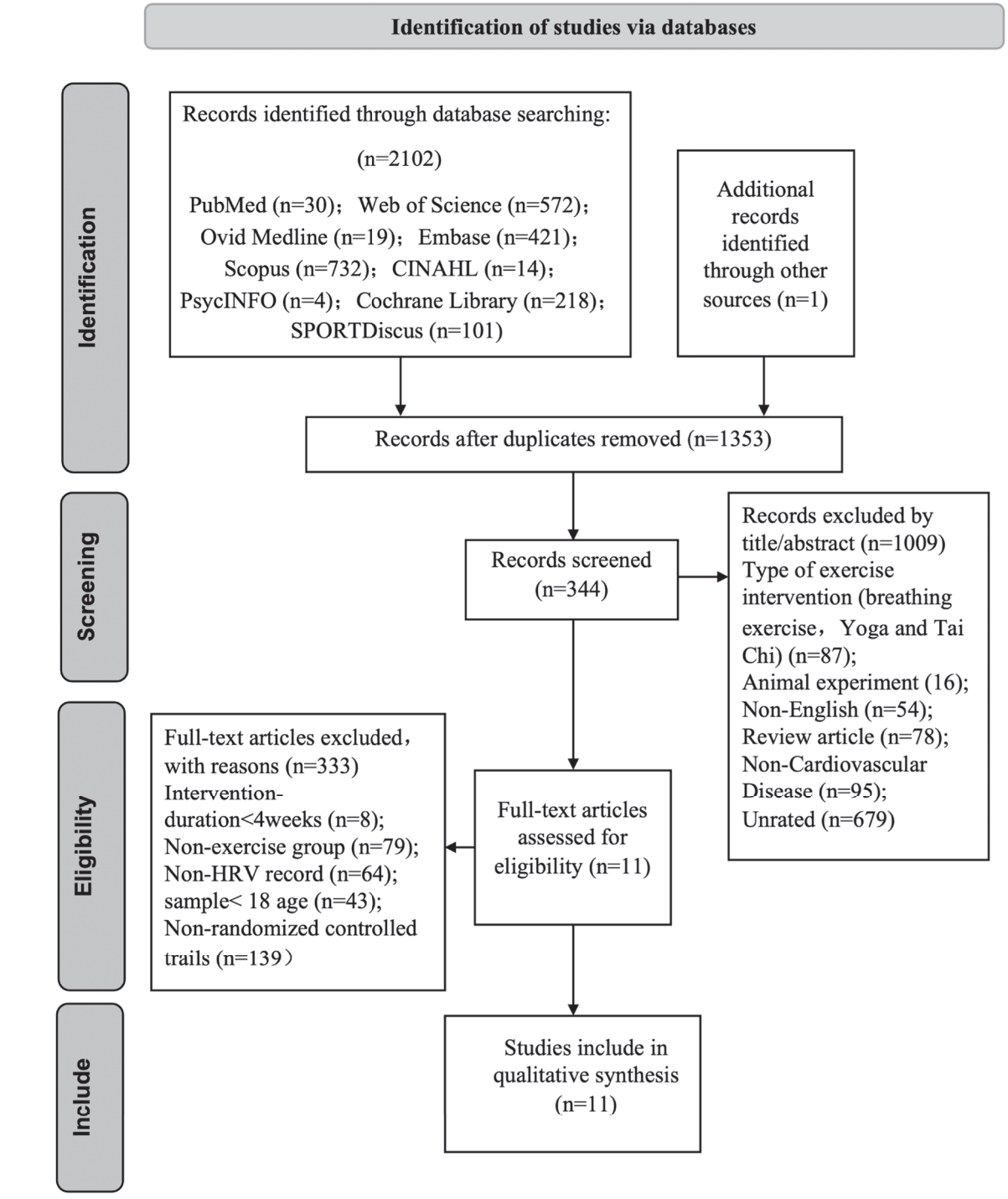

Figure 1. PRISMA flow diagram of study selection for a systematic review of cognitive impairments due to sports-related traumatic brain injuries.
Source: compiled by the authors.

recorded HRV in the supine position[35,37,40-44], one in the seated position[36], and three did not report body position[38,39,45]. Recording duration was most commonly 5-10 min[35,37,39,40,42-44], with other durations also used, including 60 s[36], 3 min[38], 15 min[41], and 24 h[45]. Reporting of technical parameters was inconsistent; only five studies specified sampling frequency, ranging from 4[44] to 1000 Hz[35,40,41].

The intervention groups in the three studies employed combined training[37-39]. Prescriptions were delivered over 8-12 weeks, 2-4 sessions per week, 30-60 minutes per session, comprising moderate-in-

Table 3. Characteristics of Included studies and TESTEX and $STARD_{HRV}$ Score

	Participants (sample size, age [year], gender: female/male)		HRV protocol (measurement method, respiration pattern, sampling frequency)	Tests (measuring body position/ duration)	Intervention (type, duration, sessions/ week, Intensity, Training forms)		TESTEX	STARD HRV
	IG	CG			IG	CG		
Caruso et al., 2017[38] Brazil	10 62 ± 5.5 0/10	10 61.3 ± 4.4 0/10	ECG/Polar S810i NR NR	NR/3min	AE+RET 8weeks 4S /30min/week AE:50% to 70% of VO_2max (TC) RT: proximately 30% of 1-RM;45° LP	AE 8weeks 4S /30min/week AE:50% to 70% of VO_2max TC	12	22
Caruso et al., 2015[37] Brazil	10 61.3±5.2 0/10	10 61±4.4 0/10	Polar S810i breath spontaneously NR	Sup/10min/ NR	AE+RET+usual care 8weeks 4S/60min/week RT: exercise training was 30% of 1-RM (LP) AE: 70% of HRmax TC	AE 8weeks 2S/60min/week AE: 70% of HRmax TC	13	20
Dor-Haim et al., 2022[39] Israel	22 57.07±9.57 0/22	26 61.21±8.03 0/26	Polar Electro/ECG telemetry NR NR	rest/10min	AE+RET 12week 2S/60min/week Alternate 8 sets of RT (30–50% 1-RM) aerobic intervals (75–85% HRR) with progressively shorter rest periods NR	AE 12week 2S/60min/week) 60% to 70% of their HRR TC	11.5	19.5
Manresa-Rocamora et al., 2022[42] Spain	10 56.9 ± 5.6 1/9	11 56.9 ± 5.6; 1/10	Polar H7 12time/min NR	Sup/5min	HRV-Guided Training 6weeks 3S/30-40min/week Dynamic adjustment Decision Value RMSSD CE	AE 6weeks 3S/30min/week 60% ~ 70%VO_2max Low-intensity cycling	12.5	21.5
Carrasco-Poyatos et al., 2024[36] Spain	22 58.4 ± 9.95 0/22	19 51 ± 11.13 3/16	HRV4Training smartphone application NR NR	seat/60s	HRV-Guided Training 8week 3S/week/60min NR NR	HIIT 8week 3S/week/60min 85%-100% of the HRmax CE	13.5	16.5

Continued

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Table 3. Continued.

	Participants (sample size, age [year], gender: female/male)		HRV protocol (measurement method, respiration pattern, sampling frequency)	Tests (measuring body position/ duration)	Intervention (type, duration, sessions/ week, Intensity, Training forms)		TESTEX	STARD HRV
	IG	CG			IG	CG		
Zengin et al., 2020[45] Turkey	68 58.23±9.69 14/54	33 58.48±9.99 6/27	Holter monitorization NR NR	NR/48h	AE 8weeks 4S/30min/week 70%-85%HRR CE	Non-exercise	8.5	18
Fiogbé et al., 2018[41] Brazil	14 59.6 ± 4.23 0/14	12 58.8 ± 3.28 0/12	Polar RS800CX HR monitor NR 1,000 Hz	Sup/300 beats	AE 16weeks 3S/60min/week The HR target between the HRVT1 and 10% below the HRVT2 WAET (aerobic in water)	Non-exercise	11.5	19.5
Oliveira et al., 2014[44] Portugal	47 54.8 ±10.6 7/40	45 58.6 ±10.7 8/37	Polar RS800CX 12times/min 4 Hz	Sup/5min	AE 8weeks 3S/week/50min 70%-85% of HRmax NR	usual medical care	13.5	22
Eser et al., 2022[40] Switzerland	34 53 (49–66) NR	35 59 (52–62) NR	ECG, Task Force Monitor standardized breathing frequency 1000 Hz	Stan or Sup/5min	HIIT 9week 3S/week/38min HIIT: Borg score 15 to 16 CE	AE 9week 3S/week/38min MICE CE	11.5	20.5
Brenner et al., 2020[35] Canada	18 68.56 ± 6.87 6/12	15 63.67 ± 8.47 6/9	ECG Spacelab 514T cardiac monitor NR 1,000 Hz	Sup/10min	AE 12weeks 5S/week/30min intensity <40% of their HRR and an RPE between 11 and 13 or pain NR	Non-exercise	11	19.5
Novaković et al., 2019[43] Slovenia	10 65.1 ± 7.6 4/6	8 62.0 ± 8.3 2/6	Cardiax®, IMED NR 500-Hz	Sup/5min	AE 36S (3month) 2-3S/week/60min 65-70%HRmax NR	usual exercise routine	11.5	19

Note: IG; Intervention Group; CG, Control group; NR, Not Reported; RT, resistance exercise training; MICE, moderate-intensity continuous exercise; AE, aerobic train; ECG, electrocardiogram; HR, heart rate; Stan, standing; Sup, supine; S, session; TC, treadmill or cycle; CE, cycle ergometer; LP, leg press; HRR, heart rate reserve; HRmax, heart rate maximal; HR: heart rate

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tensity aerobic work together with low-to-moderate resistance loads. One study alternated resistance and aerobic intervals (75-85% HRR) and progressed by shortening rest periods. The intervention groups in the two studies used HRV-guided training[36,42], characterized by day-to-day individualized load decisions based on morning RMSSD; both applied short-term prescriptions (6-8 weeks), three sessions per week, 30-60 minutes per session. Aerobic training was the most implemented intervention and appeared in all 11 trials, either as the intervention or comparator condition. Among these trials, aerobic training served as the intervention in five studies[33,39,41-43] and five as control group[37-40,42]. Overall, aerobic prescriptions typically spanned 6-16 weeks, with 2-5 sessions per week and 30-60 minutes per session. Two studies implemented HIIT[36,40], with interventions lasting 8-9 weeks, three sessions per week, and 38-60 minutes per session, anchored at 85-100% HRmax or RPE 15-16.

HRV outcomes

Between-group comparisons across the three studies showed that, compared with aerobic training, combined training demonstrated greater between-group differences in RMSSD and SD[37]. Similarly, during the leg press test, greater between-group differences in SDNN and RMSSD were observed in the combined training group. However, no clear between-group superiority was observed during the cycling test[38]. In addition, greater between-group differences in HF (ms^2) were reported in the combined training group compared with the aerobic control group ($p < 0.016$)[39].

Across the two included studies, the HRV-guided training group showed greater increases in weekly mean RMSSD and greater reductions in resting heart rate compared with the aerobic control group[42]. Compared with the HIIT group, the HRV-guided training group showed lower LnRMSSDcv values, while no clear between-group differences were observed for other HRV indices[36].

Across the studies that included aerobic training, patients with PAD demonstrated more favorable between-group differences in selected HRV indices (RMSSD, SDNN, and pNN50) following walking-based interventions[43]. Similarly, compared with control conditions, low-intensity pain-free walking was associated with slight improvements in PNS indices and reductions in SNS indices[35]. Water-based aerobic training showed significant between-group differences in nonlinear HRV indices, including Shannon entropy and normalized conditional entropy[41]. Differences were also observed across testing conditions: greater between-group differences in LF (ms^2) were reported understanding conditions, whereas smaller or non-significant differences were observed at rest. In studies comparing moderate-intensity aerobic training with HIIT[36,40], no clear between-group differences were observed in SDNN, LnRMSSD, or HF (ms^2).

Health-related variables

Seven studies assessed health-related indices, including VO_2max, BMI, BF%, BP, and WC. Notably, four studies[36,40,42,44] reported significant post-intervention increases in VO_2max. Three studies observed reductions in BMI and BF%[39,41,44]. Regarding blood pressure, most studies reported reductions in systolic blood pressure following the intervention[35,42,44], while some studies also observed a decreasing trend in diastolic blood pressure[36,40].

Quality assessment

This study assessed the methodological and reporting quality of the included studies using TESTEX and STARDHRV. Total scores are shown in table 3, item-level ratings are provided in Supplementary 4 and 5. The average score of the TESTEX was 11.81 ± 1.40 and ranged from 8.5[45] to 13.5 points[36,44]. Five studies were classified as high quality (score ≥12)[34-36-38,42,44]. Another six studies scored between 7 and 11 points, categorized as moderate quality.

The average of the STARDHRV score was 19.81 ± 1.67, with scores ranging from 16.5[36] to 22[40,44]. Five studies[37,38,40,42,44] scored ≥ 20. An additional six studies[35,36,39,41,43,45] had a score ≥ 16.5. All studies fulfilled criteria 1, 2, 5, 19, 20, 22, and 25. Notably, item 21[45] and item 23[42] each received a 0.5-point deduction.

Discussion

The review included 11 RCTs comparing combined training, HRV-guided training, and aerobic training with respect to autonomic function, using HRV indices as the primary outcomes and evaluating health-related indices. All exercise interventions lasted ≥ 6 weeks, with ≥ 2 sessions per week and ≥ 30 minutes per session. Substantial heterogeneity was observed in both exercise training protocols and HRV assessment methods, which limited the comparability of findings across studies. Within this heterogeneous and limited evidence base, derived from a small number of trials, three tentative patterns were identified. First, combined training showed limited and inconsistent between-group effects compared with aerobic training, with substantial variability in its effects on vagally mediated HRV across studies. Second, between-group evidence for HRV-guided training remains limited and inconsistent. Finally, aerobic

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Table 4. Directional summary of HRV and Health-related outcomes across included trials.

	HR (bpm)		LF [ms²]		LF [n.u.]		HF [ms²]		HF [n.u.]		LF/HF ratio		SDNN [ms]	
	IG	CG	IG	CG	IG	CG	IG	CG	IG	CG	IG	CG	IG	CG
Caruso et al., 2017[36]	CE ↓*	CE ↓					LP ↓* CE ↑*	LP ↑ CE ↓					LP ↑ CE ↑*	LP ↓ CE ↓
Caruso et al., 2015[35]	↓*	↔												
Dor-Haim et al., 2022[37]														
Manresa-Rocamora et al., 2022[40]	RHR ↓* HRR ↓	RHR ↓ HRR ↓*					↓ Iso	↑ Iso						
Carrasco-Poyatos et al., 2024[34]	Res ↓ Max ↓ Rec ↑*	Res ↔ Max ↑ Rec ↑*	↓	↑			↓	↑			↓	↑	↑	↓
Zengin et al., 2020[43]	↑		↓		↑		↑		↑		↓		↓	
Fiogbé et al., 2018[39]			↓	↑	↓	↑	↑	↓			↓	↑		
Oliveira et al., 2014[42]	↓	↑												
Eser et al., 2022[38]	Stand ↑ Sup ↑	Stand ↓ Sup ↓	Stand ↓ Sup ↓	Stand ↑* Sup ↑										
Brenner et al., 2020[33]	Rest ↔ Stand ↓ Exe ↓	Rest ↔ Stand ↑ Exe ↓	Rest ↓ Stand ↓ Exe ↑	Rest ↑ Stand ↑ Exe ↓										
Novaković et al., 2019[41]					MPT ↔	↓			MPT ↔	↔			MPT ↑	↑

Note. IG, Intervention Group; CG, Control Group; CE, cycle ergometer; LP, leg press; RHR, resting heart rate; HRR, heart rate recovery; MPT, moderate-pain training; Iso, Isolated; WA, weekly averaged; Res, resting; Max, maximal; Rec, Recovery; LnRMSSD (ms), natural logarithm of the root mean square of successive differences; $LnRMSSD_{CV}$ (%), coefficient of variation of ln RMSSD; Stand, standing; Sup, supine; Exe, exercise; ↑, indicates an increase from baseline within the respective group; ↓, indicates a decrease from baseline within the respective group; ↔, indicates no significant within-group change; *, indicates a statistically significant between-group difference between the intervention and control groups ($P < 0.05$).

training generally demonstrated modest and heterogeneous between-group effects, with responses appearing to depend on population characteristics and exercise prescriptions. Beyond HRV outcomes, exercise interventions improved cardiorespiratory fitness and body composition, whereas effects on blood pressure were inconsistent. In addition, TESTEX and STARDHRV assessments indicated overall moderate methodological and reporting quality among the included studies.

Heterogeneity in HRV measurement and exercise prescriptions

The included trials showed substantial variability in recording duration, body position, breathing strategy. These differences may lead to variability in HRV outcomes, thereby reducing comparability across studies. Current methodological guidelines generally recommend a 5-min short-term resting recording and the explicit reporting of body position and respiratory control[7,10]. Among the included studies, those using short-term (5-min) supine recordings with reported respiratory control showed an increasing trend in some vmHRV indices[40,42,44]. In studies using paced breathing with reported respiratory control, some studies observed increases in RMSSD without corresponding changes in HF[40,42]. Under spontaneous breathing conditions[37], RMSSD also showed an improving trend. Differences in HF outcomes under varying respiratory conditions suggest that breathing strategy may influence the comparability of certain frequency-domain indices, particularly HF[8,10,46].

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RMSSD [ms]		pNN50%		TP [ms²]		SD1[ms]		SBP		DBP		VO_2 max		BMI (kg/m²)	
IG	CG	IG	CG	IG	CG	IG	CG	IG	CG	IG	CG	IG	CG	IG	CG
LP ↑* CE ↑*	LP ↓* CE ↔					LP ↑* CE ↑*	LP ↓ CE ↔					↑	↓		
↑*	↓					↑*	↓								
														↑	↓
↑* WA	↓ WA					↑ Iso	↑ Iso					↑*	↑*		
LnRMSSD (ms) ↓ LnRMSSDCV (%) ↑	LnRMSSD (ms) ↑ LnRMSSDCV (%) ↑							Res ↓* Max ↓* Rec ↓	Res ↑ Max ↑ Rec ↓	Res ↓* Max ↓* Rec ↓	Res ↓ Max ↑ Rec ↓	↑*	↑*		
↑		↓													
↑	↑			↑	↑									↓	↑
								↓	↓	↓	↓	↑*	↓	↓	↓
												↑*	↑		
				Rest ↑ Stand ↓ Exe ↑	Rest ↑ Stand ↓ Exe ↓			Rest ↓ Stand ↓ Exe ↓	Rest ↓ Stand ↓ Exe ↓	Rest ↑ Stand ↓ Exe ↓	Rest ↑ Stand ↓ Exe ↓				
MPT ↑	↓	MPT ↑	↓												

Substantial heterogeneity was also observed in exercise prescription parameters across the included studies, particularly in intervention duration and weekly training volume, with some trials having relatively short intervention periods (≤6–8 weeks). Previous research suggests that longer intervention durations may be more favorable for improving vmHRV indices (RMSSD/HF) in older adults[47]. Regarding session duration, a 60-min exercise prescription was the most common among the included studies (5/11). Two HIIT protocols reported session durations of 38 min and 60 min, respectively[40,48]. Across the included studies, HRV responses under different session durations did not show a consistent pattern.

Overall, heterogeneity in HRV measurement conditions and exercise prescription design represents a key factor influencing the consistency of findings across studies. Therefore, when comparing the effects of different training modalities on HRV, these methodological differences should be considered as potential moderating factors. The present study systematically identified key sources of variability from both measurement and prescription perspectives, providing a useful reference for the standardization of future research designs.

Mechanisms underlying differences in HRV responses to excercise training

This study systematically compared the effects of aerobic training, combined training, and HRV-guided training on HRV in patients with cardiovascular disease. Although differences in HRV outcomes were observed

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across training modalities, no single modality demonstrated a consistent between-group advantage.

These differences are more likely attributable to variations in training structure, load organization, and HRV measurement protocols rather than a definitive advantage of any specific training modality. In combined training, the alternating or sequential integration of aerobic and resistance components varied across studies in terms of load distribution, recovery intervals, and training order[37-39]. These variations may induce fluctuations in autonomic responses and thereby affect the stability of between-group comparisons[12]. For HRV-guided training, the available evidence remains limited and inconsistent, which may be related to differences in HRV metrics and assessment timing. Different HRV indices reflect distinct dimensions of autonomic regulation[49], while short-term pre-session measurements (60 s) are more susceptible to transient physiological fluctuations. In addition, variations in training load adjustment strategies, comparator interventions, and statistical approaches may further contribute to inconsistencies in findings.

Regarding aerobic training, although all included studies involved this modality, its effects on vmHRV were generally limited and inconsistent, with most studies showing no stable advantage over control conditions. These differences may be associated with variations in participant characteristics, exercise prescription design, and measurement conditions. Furthermore, in comparisons between moderate-intensity aerobic training and high-intensity interval training (HIIT), most HRV indices did not show a consistent advantage for either modality[40,48].

Overall, heterogeneity in training structure, prescription dosage, and HRV measurement protocols appears to be a key factor influencing the consistency of findings across studies.

Health-related adaptations and their potential links to HRV

In addition to HRV outcomes, some included studies reported changes in health-related variables following exercise interventions. Overall, compared with no-exercise or usual care conditions, exercise training was generally associated with improvements in cardiorespiratory fitness and body composition. These changes may be relevant to cardiac autonomic regulation. From a mechanistic perspective, improvements in aerobic capacity (VO_2max) are typically associated with enhanced cardiovascular efficiency and greater stability of autonomic control[50,51]. Meanwhile, reductions in body weight, body fat percentage, and waist circumference may reflect improvements in metabolic status and inflammatory profiles, which are also closely related to cardiovascular risk and autonomic function[52,53]. Taken together, these adaptations may represent potential pathways through which exercise influences HRV responses[54]. However, these findings should be interpreted with caution. In the included studies, health-related variables were mostly reported as secondary outcomes, and their relationships with HRV changes were not directly examined. Therefore, the current evidence remains exploratory, and causal inferences cannot be established.

Research limitations and prospects

Several limitations should be considered when interpreting the findings of this review. First, the number of available RCTs remains limited, and most studies involved relatively small sample sizes, which may restrict the statistical power and generalizability of the findings. Second, substantial heterogeneity existed across studies in HRV assessment protocols and exercise prescription designs, reducing comparability between studies and hindering robust estimation and pooling of effect sizes. Third, several studies did not fully report key methodological details, such as control group interventions, HRV artifact correction procedures, and respiratory control protocols, which increase the complexity of interpreting HRV outcomes. Fourth, most included studies did not predefine clinical endpoints such as mortality, rehospitalization, or arrhythmia incidence, making it difficult to directly infer risks related to clinical events. Finally, restricting the search to English-language databases may have introduced language bias.

Future studies should include large-sample, multi-centre RCTs. HRV protocols should be standardized by incorporating nonlinear indices and artifact-correction methods to improve cross-study comparability and generalizability. It is also recommended to explicitly report training adherence and ensure that HRV measurements are taken at least 48 hours after the final training session to eliminate acute exercise effects[55]. Furthermore, future research should incorporate the TESTEX and STARDHRV frameworks to enhance reporting quality. It should also explore integrating pharmacological tracking, long-term adaptation mechanisms of cardiac autonomic function, and remote wearable technologies into home-based rehabilitation.

Conclusions

The review identified 11 RCTs through searches of nine databases and evaluated their methodological and reporting quality using TESTEX and STARDHRV. The available evidence comparing different exercise training modalities remains limited and heteroge-

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neous. Across the included studies, between-group comparisons of vmHRV indices varied considerably among combined training, HRV-guided training, and aerobic training. Although some studies reported improvements in vmHRV indices (RMSSD, HF, and SD1) following combined training or HRV-guided training, these findings were not consistently replicated across studies or testing conditions. Therefore, the current evidence remains insufficient to support a stable advantage of any specific training modality in improving cardiac autonomic regulation in patients with cardiovascular disease. In addition, several studies reported improvements in health-related variables. Future research could benefit from larger, multicenter RCTs with standardized HRV assessment protocols, clearly defined exercise prescriptions, and comprehensive reporting of pharmacological treatments to enhance comparability and strengthen the certainty of the evidence.

Conflicts of interest. The authors declare there is no conflict of interest.

Authors' contributions. Dr. Donghai Huang and Heng Wang conceived the article, completed the writing. Chika Umunnawuike performed the literature search and data editing. Chigozie Charity Okwuwa completed the literature search and language revision. Yuan Hou and Pengyun Zhang made optimizations in the writing of literature review.

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Data availability. The study protocol was preregistered in the International Prospective Register of Systematic Reviews (PROSPERO) prior to data extraction and analysis, under the ID number CRD420251018026.

Supplementary materials. S1: The complete search strategies; S2: Description of each modified TESTEX criterion; S3: Description of each modified STARDHRV criterion; S4: Detailed results of the TESTEX scale; S5: Detailed results of the STARDHRV scale.

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Supplementary 1. Number of articles searched in each database.

database	Search Strategy	Number of articles
PubMed	(((((((physical training[Title/Abstract]) OR (aerobic training [Title/Abstract])) OR (HRV-guided training[Title/Abstract])) OR ("Exercise"[Mesh])) OR ("Resistance Training"[Mesh])) AND (HRV[Title/Abstract])) OR (heart rate variability[Title/Abstract])) AND ("Cardiovascular Diseases"[Mesh]) and select "Randomized controlled trials".	30articles
Web of Science	TS=("physical training*" OR "aerobic training*" OR "HRV-guided training*" OR "Exercise*" OR "Resistance Training*") AND TS=("HRV*" OR "heart rate variability*") AND TS=("Cardiovascular Diseases*") and exclude review in the filter, select "article".	572 articles
Embase	('physical training'/exp OR 'physical education' OR 'aerobic exercise'/exp OR 'aerobic exercise' OR 'hrv-guided training':ab,ti OR 'exercise'/exp OR 'resistance training'/exp) AND ('hrv:ab,ti' OR 'heart rate variability'/exp) AND ('cardiovascular disease'/exp), and select "article", "human".	421articles
Ovid Medline	(physical training.m_titl. OR aerobic training.m_titl. OR HRV-guided training.m_titl. OR "Exercise*".m_titl. OR "Resistance Training*".m_titl.) AND ("HRV*".m_titl. OR "heart rate variability*".m_titl.) AND ("cardiovascular diseases*".m_titl.), and select "article", "human", "English".	19 articles
Scopus	TITLE-ABS-KEY ("exercise" OR "physical training" OR "aerobic training" OR "HRV-guided training" OR "Resistance Training") AND TITLE-ABS-KEY ("cardiovascular disease") AND TITLE-ABS-KEY ("heart rate variability" OR "HRV"), and select "article", "human", "Published Finally".	723articles
SPORTDiscus	TI Exercise training OR TI physical activity OR TI Exercise OR TI HRV-guided training OR TI Resistance Training AND XB cardiovascular disease AND TX heart rate variability OR TX HRV, excluding papers, book reviews, and non-article.	101articles
Cochrane library	(MeSH descriptor: [Physical Conditioning, Human] explode all trees OR MeSH descriptor: [Exercise] explode all trees OR MeSH descriptor: [Resistance Training] explode all trees OR aerobic training OR HRV-guided training) AND (HRV OR heart rate variability) AND MeSH descriptor: [Cardiovascular Diseases] explode all trees, and select "article", "human", "English".	218 articles
CINAHL	XB (Exercise OR training OR physical training OR HRV-guided training OR Resistance Training) AND XB cardiovascular disease AND XB (heart rate variability OR HRV OR heart rate variation), and select "article", "human".	14articles
PsycINFO	TITLE-ABS-KEY ("exercise" OR "physical training" OR "aerobic training" OR "HRV-guided training" OR "Resistance Training") AND TITLE-ABS-KEY ("cardiovascular disease") AND TITLE-ABS-KEY ("heart rate variability" OR "HRV"), and select "article", "human", "Published Finally".	4articles

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Supplementary 2. HRV metrics and physiological notes.

	Evaluation point	Points	Assessment standard
1	Eligibility criteria specified	1	Information on inclusion and exclusion criteria. For HRV recording, no medication with cardiac effects.
		0.5	Specification of inclusion or exclusion.
		0	Not reported.
2	Randomization specified	1	Yes.
		0	No or not reported.
3	Allocation concealment	1	Yes.
		0	No or not reported.
4	Groups similar at baseline	1	All parameters (gender, age, BMI).
		0.5	Partially.
		0	No or not reported.
5	Blinding of assessor (for at least one key outcome)	1	Yes.
		0	No or not reported.
6	Outcome measures assessed in at least 85% of patients	3	Dropout of subjects <15% + report of dropout events + persistent subjects with 85% participation in sessions
		2	2 of the aforementioned
		1	Only persistent subjects with 85% participation in sessions
		0	Nothing or not reported.
7	Intention-to-treat analysis	1	Yes.
		0	No.
8	Between-group statistical comparisons reported	2	Reported for primary (HRV) and secondary endpoint (BMI, BP, VO_2, ..) …
		1	Reported for primary endpoint.
		0	Not reported.
9	Point measures and measures of variability for all reported outcome measures	1	p-values and effect size
		0.5	Only p-values.
		0	Not reported.
10	Activity monitoring in control groups	1	Yes, with protocol.
		0	No or not reported.
11	Relative exercise intensity remained constant	1	Increase in the process with adaptation to performance (intermediate measurement of the performance parameters).
		0.5	Step-by-step concept planned from the beginning.
		0	Constant training during the monitoring period.
12	Exercise volume and energy expenditure stated	1	Specification of intensity, frequency, mode and duration of the training with a minimum of:
			Endurance training VO or other equivalent.
			Resistance training 1RM or other equivalent.
		0.5	Specification of intensity, frequency, mode and duration of the training without VO_2, 1RM or other equivalent.
		0	Not reported.

BMI, body mass index; BP, blood pressure; HRV, heart rate variability; RM, repetition maximum; VO_2, oxygen consumption.

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Supplementary 3. STARDHRV.

		Evaluation point	Points	Assessment standard
1	**Title or Abstract**	Identification as a study of validation	1	Reported
			0	Not reported.
2	**Abstract**	Structured summary of study objective, design, methods, results, and conclusions	1	Yes.
			0.5	Yes, but not structured.
			0	Not reported.
3	**Introduction**	Scientific and practical background, including the intended use of the index device/software	1	Complete, including the application of the HRV method.
			0.5	With limitations available.
			0	Insufficient background.
4		Study objectives and hypotheses described	1	Study objectives and hypothesis.
			0.5	Study objectives without hypothesis.
			0	Not reported.
5	**Methods**	Study uses within-subject design	1	Reported
			0	Not reported.
6		Intended sample size and how it was determined (e.g. G*Power 3)	1	Reported.
			0	Not reported.
7		Eligibility criteria including specific restrictions (medical use, gender, age, activity level or BMI)	1	Reported for health, medical use, gender, age, activity and body composition (BMI).
			0.5	Reported in some criteria less than 1P.
			0	Not reported.
8		Pre-testing guidelines reported (e.g., limitations to caffeine, alcohol, physical activity etc.)	1	Reported for limitations to caffeine, alcohol and physical activity.
			0.5	Reported in some criteria less than 1P.
			0	Not reported.
9		Setup of reference standard and index device described in sufficient detail to allow replication (e.g. hardware/software such as brand, electrode configuration, etc.)	1	Sufficient description. A replication is possible.
			0.5	Limited description. A replication is partially possible.
			0	Insufficient description. Replication is not possible.
10		Description of environmental conditions (e.g. temperature, humidity, lights on or off, time of day) and posture	1	Temperature + time of day or same time of day + body position
			0.5	Reported in some criteria less than 1P.
			0	Not reported.
11		A stabilization period prior to sampling was described	1	Yes, with information about when and how long.
			0.5	Yes, with information about when or how long.
			0	Not reported
12		The raw sampling rate and length of collection are described	1	Sampling rate + length of collection
			0.5	Only length of collection
			0	Not reported
13		Acknowledgment of breathing (e.g. controlled or not controlled)	1	Reported
			0	Not reported.
14		Description of how estimates or comparison measures were calculated (e.g. ES, LOA, Pearson's r or ICC)	1	Reported
			0	Not reported.
15		Reasons for missing data, along with percentage missing (e.g., equipment, persistent ectopy) and how it was handled	1	Reasons for missing data + percentage + handling
			0.5	Reported in some criteria less than 1P.
			0	Not reported.
16		Interbeat artefact identification method (e.g. algorithm, manual inspection)	1	Manual inspection of artefacts.
			0.5	Automatically without manual correction
			0	Not reported.
17		Artefact cleaning methods and percentage of beats corrected	1	Description Method (e.g. smoothing or decimation) and percentage.
			0.5	Reported in some criteria less than 1P
			0	Not reported.
18		Description of metrics used and software/script for HRV calculation (log transformation etc.)	1	Reported
			0	Not reported.

Continued

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Supplementary 3. Continued.

		Evaluation point	Points	Assessment standard
19		Specification of frequency bands used and how they were calculated (e.g. Fast Fourier Transform or Autoregressive modelling)	1	Reported
			0	Not reported.
20	**Results**	Baseline demographics of participants	1	Reported
			0	Not reported.
21		Mean ± SD along with at least one estimates of precision (e.g. LOA, Pearson's r or ICC)	1	p-values and effect size
			0.5	Only p-values.
			0	Not reported.
22	**Discussion**	Study limitations, (e.g., sources of potential bias, confounding variables, statistical uncertainty, and generalizability)	1	In detail (if necessary also as extra section)
			0.5	Discussed, but not in detail.
			0	Not reported.
23		Implications for practice, including the intended use	1	Detailed, giving practical recommendations (e.g. clientele, how often), extra section
			0.5	Discussed, but not in detail.
			0	No statement or simple statement "We have seen differences and suggest that".
24	**Other information**	Where the full study protocol can be accessed if not fully described	1	Reported
			0	Not reported.
25		Sources of funding and other support; role of funders	1	Information about funding and conflict of interest.
			0.5	Funding, conflict of Interest or acknowledgement
			0	Not reported.

BMI, body mass index; ES, effect size; ICC, intra-class correlation; HRV, heart rate variability; LOA, limits of agreement; P, point; SD, standard deviation.

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Supplementary 4. TESTEX-Result.

First author, year	Eligibility criteria specified	Randomization specified	Allocation concealment	Groups similar at baseline	Blinding of assessor (for at least one key outcome)	Outcome measures assessed in at least 85% of patients	Intention-to-treat analysis	Between-group statistical comparisons reported	Point measures and measures of variability for all reported outcome measures	Activity monitoring in control groups	Relative exercise intensity remained constant	Exercise volume and energy expenditure stated	Sum
Zengin et al., 2020 Turkey	0,5	0	0	1	0	2	1	2	0,5	0	0,5	1	**8,5**
Fiogbé et al., 2018 Brazil	1	1	1	1	0	3	0	2	1	0	0,5	1	**11,5**
Caruso et al., 2015 Brazil	1	1	1	1	0	3	0	2	1	1	1	1	**13**
Manresa-Rocamora et al., 2022 Spain	0,5	1	1	1	1	3	0	2	1	0	1	1	**12,5**
Dor-Haim et al., 2022 Israel	0,5	1	1	1	1	0	1	2	1	1	1	1	**11,5**
Caruso et al., 2017 Brazil	0,5	1	1	1	1	2	0	2	1	1	0,5	1	**12**
Oliveira et al., 2014 Portugal,	1	1	1	1	1	3	1	2	1	0	0,5	1	**13,5**
Eser et al., 2022 Switzerland	0	1	1	1	1	2	0	2	0,5	1	1	1	**11,5**
Carrasco-Poyatos et al., 2024 Spain	1	1	1	0,5	1	3	0	2	1	1	1	1	**13,5**
Brenner et al., 2020 Canada	0,5	1	1	1	1	1	0	2	1	1	0,5	1	**11**
Novaković et al., 2019 Slovenia	1	1	1	1	0	2	0	2	1	1	0,5	1	**11,5**

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Supplementary 5. STARDhrv-Result.

First author, year	Title or Abstract	Abstract	Introduction	Methods															Results		Discussion		Other information	
	Identification as a study of validation	Structured summary of study objective, design, methods, results, and conclusions	Scientific and practical background, including the intended use of the index device/software	Study objectives and hypotheses described	Study uses within-subject design	Intended sample size and how it was determined (e.g. G*Power 3)	Eligibility criteria including specific restrictions (medical use, gender, age, activity level or BMI)	Pre-testing guidelines reported (e.g., limitations to caffeine, alcohol, physical activity etc.)	Setup of reference standard and index device described in sufficient detail to allow replication (e.g. hardware/software such as brand, electrode configuration, etc.)	Description of environmental conditions (e.g. temperature, humidity, lights on or off, time of day) and posture	A stabilization period prior to sampling was described	The raw sampling rate and length of collection are described	Acknowledgment of breathing (e.g. controlled or not controlled)	Description of how estimates or comparison measures were calculated (e.g. ES, LOA, Pearson's r or ICC)	Reasons for missing data, along with percentage missing (e.g., equipment, persistent ectopy) and how it was handled	Interbeat artefact identification method (e.g. algorithm, manual inspection)	Artefact cleaning methods and percentage of beats corrected	Description of metrics used and software/script for HRV calculation (log transformation etc.)	Specification of frequency bands used and how they were calculated (e.g. Fast Fourier Transform or Autoregressive modelling)	Baseline demographics of participants	Mean ± SD along with at least one estimates of precision (e.g. LOA, Pearson's r or ICC)	Study limitations, (e.g., sources of potential bias, confounding variables, statistical uncertainty, and generalisability)	Implications for practice, including the intended use	Where the full study protocol can be accessed if not fully described	Sources of funding and other support; role of funders	Sum
Zengin et al., 2020 Turkey	1	1	1	0,5	1	0	1	0	0,5	0,5	1	1	0	1	0,5	0,5	0	1	1	0,5	1	1	1	18
Fiogbé et al., 2018 Brazi	1	1	0,5	1	1	0	1	0	1	0,5	0	1	0	1	1	1	1	1	1	1	1	1	0	19,5
Caruso et al., 2015 Brazil	1	1	0,5	1	1	1	1	1	1	1	0,5	0,5	1	1	0,5	0,5	0	0	1	1	1	1	0	20
Manresa-Rocamora et al., 2022 Spain	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0,5	1	21,5
Dor-Haim et al., 2022 Israel	1	1	1	1	1	1	1	0,5	0,5	0,5	0,5	1	0	1	0,5	0	0	0	1	1	1	1	1	19,5
Caruso et al., 2017 Brazil	1	1	1	1	1	1	0,5	1	1	0,5	1	1	0	1	0,5	1	0,5	1	1	1	1	1	1	22
Oliveira et al., 2014 Portugal	1	1	1	0,5	1	0	1	1	1	1	1	1	1	1	1	0,5	0	1	1	1	1	1	1	22
Eser et al., 2022 Switzerland	1	1	1	0,5	1	0	0,5	0	0,5	1	1	1	1	1	0	1	1	1	1	1	1	1	1	20,5
Carrasco-Poyatos et al., 2024 Spain	1	1	1	1	1	1	1	0	0,5	0,5	1	0,5	0	0	0	0	0	0	1	1	1	1	1	16,5
Brenner et al., 2020 Canada	1	1	1	1	1	0	1	0	1	1	1	1	0	0	1	0,5	0	1	1	1	1	1	1	19,5
Novaković et al., 2019 Slovenia	1	1	1	0,5	1	1	1	0	0,5	0,5	1	1	0	1	0	0,5	0	1	1	1	1	1	1	19

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