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Review

An integrative review of the effects of high-intensity interval training on the autonomic nervous system

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ABSTRACT

High-Intensity Interval Training (HIIT) has gained prominence as a time-efficient and effective exercise modality to improve cardiovascular (CV) fitness, metabolic health, and physical performance. Therefore, our aim was to synthesize current clinical research on the effects of HIIT on the Autonomic Nervous System. We conducted the search for studies in the Directory of Open Access Journals, Embase, Virtual Health Library, Pubmed, and Scielo databases, in January of 2024. We included a total of 20 studies in our review. This literature review highlights the potential of HIIT to modulate the Autonomic Nervous System, enhancing CV function and overall health. Despite the promising findings, the interpretation of the results is tempered by the variability in study designs, populations, and methodologies. Future research should address these limitations, aiming for a more nuanced understanding of the relationship between HIIT and Autonomic Nervous System function. The review indicates that standardized protocols need to consider individual characteristics and baseline autonomic states for clinical application. As the body of evidence grows, HIIT may emerge as a cornerstone of exercise prescriptions aimed at optimizing autonomic function and promoting CV health.

1. Introduction

In recent years, High-Intensity Interval Training (HIIT) has gained prominence as a time-efficient and effective exercise modality to improve cardiovascular (CV) fitness, metabolic health, and physical performance. HIIT is a modality that involves repeated bouts of relatively higher-intensity exercise combined with periods of lower-intensity recovery or rest.[1] It has emerged as an alternative to moderate-intensity continuous training and has been increasingly studied for its broad spectrum of health benefits. It has been shown that HIIT can impact different systems, such as improve the pulmonary ability to take in oxygen for distribution to working skeletal muscle during exercise; improve vascular function; and improve skeletal muscle total fiber amount and type proportions, capillary density, as well as mitochondrial content and function.[2]

HIIT is frequently incorporated into the training regimens of elite athletes; however, its utilization among individuals with lower levels of training has notably increased.[1] One study indicated that incorporating HIIT into the school day is associated with cognitive and mental health benefits in adolescents, despite these improvements not being statistically significant.[3] A recent systematic review concluded that HIIT appears to be safe and effective in increasing fitness in people with Multiple Sclerosis and low levels of disability.[4] Coates and colleagues[1] also highlighted that given the strong, inverse relationship between cardiorespiratory fitness and morbidity and mortality, research is warranted to identify the most effective HIIT strategies in various populations using robust study designs.[1]

Among the various physiological systems influenced by HIIT, the Autonomic Nervous System (ANS) plays a pivotal role in regulating CV function and maintaining homeostasis. The ANS, composed of the sympathetic, parasympathetic, and enteric nervous systems, orchestrates the body's response to exercise, modulating heart rate, vascular resistance, and myocardial contractility.[5]

Understanding the interplay between HIIT and the ANS is crucial for comprehending the holistic impact of exercise on human health and for designing targeted interventions to optimize CV outcomes. This literature review aims to synthesize current clinical research on the effects of HIIT on the ANS. Focusing on clinical studies that implemented an intervention group solely subjected to HIIT, this review scrutinizes the nuanced effects of this training modality on the autonomic modulation of CV

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List of abbreviations

ANS	Autonomic Nervous System
bpm	beats per minute
BVS	Virtual Health Library
CV	cardiovascular
DOAJ	Directory of Open Access Journals
F	female
HbA1c	hemoglobin A1C
HIIT	High-Intensity Interval Training
HR	heart rate
HRV	Heart Rate Variability
M	male
MAS	maximum aerobic speed
MHR	maximum heart rate
min	minutes
n	number
RCT	Randomized Controlled Trial
RPE	rating of perceived exertion
rpm	rotation per minute
s	seconds
VO_{2max}	maximal oxygen consumption

functions.

2. Material and methods

2.1. Search characterization and strategy

The present work is characterized as an integrative review and followed the methodology described by Whittemore and Knafl.[6] This literature review navigates through the multifaceted effects of HIIT on the ANS, drawing from diverse clinical contexts and participant profiles. By analyzing the outcomes of HIIT on autonomic function, as reported in the selected studies, this review looks at the complex interactions between high-intensity exercise and autonomic regulation. The methodology for this review was systematically structured to ensure comprehensive coverage and critical analysis of relevant literature.

After identifying the research problem and stablishing the aim of the review, we conducted the search for studies in the Directory of Open Access Journals (DOAJ), Embase, Virtual Health Library (BVS), Pubmed, and Scielo databases. Search was conducted and concluded in January of 2024. The selection of publications for review had no restrictions on the date of publication, ensuring the inclusion of the broadest possible array of studies.

The descriptors used were: (“High-Intensity Interval Training” OR “Exercise, High-Intensity Intermittent” OR HIIT) AND (“Autonomic Nervous System” OR “Vegetative Nervous System” OR “Visceral Nervous System”).

2.2. Eligibility criteria

Inclusion and exclusion criteria were defined to refine the scope of this review. Inclusion criteria were restricted to clinical studies that focused on an intervention group undergoing HIIT, providing direct insights into the effects of this exercise modality on the ANS. The review excluded in *vitro*, pre-clinical, and ex *vivo* studies, as well as reviews, systematic reviews, meta-analyses, letters to the editor, conference abstracts, editorials, and protocols. Furthermore, only studies published in English, Portuguese, Spanish, or Italian were considered, ensuring the clarity and precision of the synthesized evidence.

2.3. Data extraction and management

The search results were downloaded in files and exported to Rayyan® (Qatar Computing Research Institute, Doha, Qatar). After the exclusion of duplicates, titles and abstracts of the pre-selected articles were read by two independent evaluators with the “Blind on” feature (available in the app). Afterwards, the blinding feature was deactivated and possible conflicts in the evaluators’ decisions were resolved through analysis by both simultaneously. We only included studies that both reviewers agreed upon.

The studies identified through Rayyan® were thoroughly reviewed in their entirety. Those that met all inclusion criteria had their data extracted and cataloged using the Microsoft Excel® software. The data was then analyzed and systematically organized into tables to clearly present the findings.

The selected studies were subjected to a thorough examination, focusing on the HIIT protocols employed, participant demographics, study design, outcomes related to the ANS, and the reported limitations. This approach allows for a nuanced understanding of the relationship between HIIT and ANS function, highlighting potential implications for exercise prescription and health promotion.

3. Results

3.1. Study selection

After searching all the databases, we found a total of 305 studies. There was a total of 122 excluded duplicates and 183 studies to be evaluated. After considering inclusion and exclusion criteria, 20 studies qualified for inclusion and are discussed in this review to offer a comprehensive overview of the impact of HIIT on the ANS. More details of the selection process can be observed in the Study Flow Diagram (Fig. 1).

The studies demonstrate a range of outcomes, indicating both the potential benefits and complexities of HIIT in modulating autonomic function. The results are synthesized under the following categories.

(1) Improvements in ANS Function: A considerable number of studies have documented enhancements in autonomic function following HIIT interventions. The most notable among them are the study of Matsuo et al.,[7] which observed significant improvements in CV autonomic functions among sedentary males after an 8-week HIIT protocol. Also, O'Driscoll and colleagues[8] highlighted improvements in cardiac autonomic modulation, suggesting an enhanced balance between sympathetic and parasympathetic activities. Additional studies echoed these findings, presenting a consistent pattern of ANS improvement across diverse demographic groups, including sedentary individuals, athletes, and individuals with various health conditions.[9–14]
(2) Changes in Heart Rate Variability (HRV): HRV emerged as a common metric for assessing the influence of HIIT on ANS function. Key observations were shown in a study, which found that masters cyclists exhibited a greater parasympathetic response post-HIIT, indicating age-related adaptability of the ANS.[15] Kiviniemi and colleagues[16] reported increases in cardiac vagal activity after a short-term HIIT regimen, pointing to enhanced parasympathetic modulation.[16] Other studies also reported variations in HRV, with some noting increased sympathetic activity and others documenting a more pronounced parasympathetic response, suggesting that individual factors and specificities of the HIIT protocol may influence outcomes.[14,17–22]
(3) Other CV Parameters: Beyond HRV and direct measures of ANS function, several studies explored additional CV parameters impacted by HIIT. Such as, Cipryan and colleagues[19] observed acute cardiorespiratory responses to HIIT, indicative of a complex interplay between sympathetic and parasympathetic activities.[19]

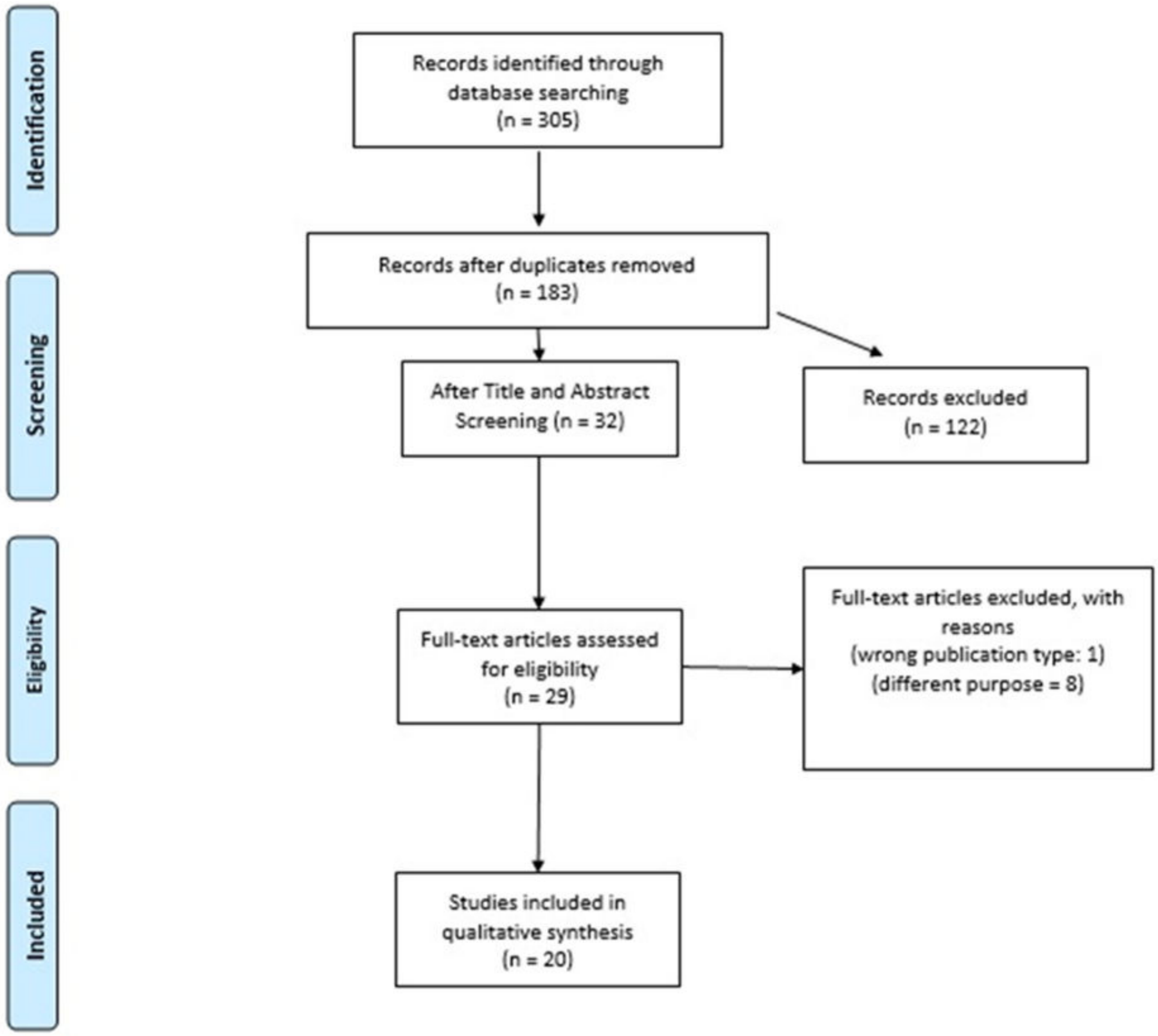

Fig. 1. Study Flow Diagram. All the review steps and study selection are presented in this figure.
n = number.

Also, other studies further elucidated this relationship, examining parameters such as blood pressure, cardiac output, and vascular resistance, contributing to a holistic understanding of the CV adaptations to HIIT.[9,20,23] Table 1 presents more information of all the included studies.

4. Discussion

This literature review has synthesized the findings of 20 studies examining the effects of HIIT on the ANS. The collective evidence suggests that HIIT can positively influence ANS function, potentially contributing to improved CV health and physical performance. However, the discussion of these findings must be contextualized within the broader landscape of exercise physiology and ANS research, taking into consideration the limitations and heterogeneity of the studies reviewed.

The observed improvements in ANS function, as evidenced by increased parasympathetic activity and altered HRV,[12,15] align with the known benefits of aerobic exercise on CV health. These changes are indicative of enhanced cardiac efficiency and reduced stress on the CV system. The variability in responses, with some studies noting increased sympathetic activity, and others that did not observed any changes[24,25] underscores the complexity of the ANS and the need to consider individual factors such as baseline fitness level, age, and health status when interpreting the effects of HIIT.

Cassidy and colleagues[25] observed in their results that twelve weeks of HIIT in type 2 diabetes patients improved hemoglobin A1C (HbA1c), but there was no improvement in CV autonomic function. They suggested that one of the potential reasons for the observed outcomes might be that interventions exceeding three months could be required to elicit more significant changes in this demographic, as previously indicated in the literature.

Overall, the findings of this review are consistent with previous research highlighting the benefits of regular physical activity on ANS function.[2] Although the mechanisms behind changes in HRV are not fully ellucidated, it has been suggested that HIIT is a potent stimulator of nitric oxide bioavailability due to vessel stress and in turn nitric oxide is a modulator of cardiac vagal activity. Furthermore, the resulting increase in blood volume due to training can increase cardiac vagal modulation, via baroreflex activation.[25]

However, the specific impact of HIIT, with its unique stress and recovery cycle, provides valuable insights into the adaptability of the ANS to different forms of exercise stress. The emphasis on HIIT also contributes to the growing body of literature advocating for time-efficient exercise protocols, which may have significant implications for public health recommendations and individual adherence to physical activity guidelines.

The positive impact of HIIT on ANS function supports the incorporation of this training modality in exercise programs for diverse

Table 1
General information of the clinical studies.

Author, year	Title	Study type	HIIT protocol	Sample (size, sex and age)	Effect on ANS function
Matsuo et al., 2014[7]	Low-volume, high-intensity, aerobic interval exercise for sedentary adults: VO_{2max}, cardiac mass, and heart rate recovery	RCT	8-week, 3-day a week supervised cycling exercise intervention: 2-min (30 W, 60 rpm, warm-up); 3-min (85% VO_{2max}, 70–80 rpm); 2-min (50% VO_{2max}, 60 rpm); 3-min (85% VO_{2max}, 70–80 rpm); 2-min (50% VO_{2max}, 60 rpm); 3-min (80% VO_{2max}, 70–80 rpm); 3-min (30 W, 40–60 rpm, cool-down)	$n = 24$; M; 20–30 years	Improvement of function
Borges et al., 2017[15]	Autonomic cardiovascular modulation in masters and young cyclists following high-intensity interval training.	?	6 x 30-s at 175% of peak power output, with 4.5-min rest between efforts.	$n = 17$; masters (age [55.6 ± 5.0] years) and young cyclists (age [25.9 ± 3.0] years)	Greater parasympathetic response
O'Driscoll et al., 2018[8]	Cardiac autonomic and left ventricular mechanics following high intensity interval training: a randomized crossover controlled study	Randomized crossover controlled study	3 × 30-s maximal cycle ergometer sprints against a resistance of 7.5% body weight, interspersed with 2-min of active recovery.	$n = 40$; M; (21 ± 1.7) years	Improvements in cardiac autonomic modulation
Kiviniemi et al., 2014[16]	Cardiac Autonomic Function and High-Intensity Interval Training in Middle-Age Men	RCT	6 supervised exercise sessions within 2 weeks: 4–6 × 30-s of all-out cycling efforts with 4-min of recovery where the participants were allowed to remain still or do unloaded cycling	$n = 26$; M; 40–55 years	Increases in cardiac vagal activity
Cipryan et al., 2016[19]	Cardiac autonomic response following highintensity running work-to-rest interval manipulation	?	3 HIIT bouts and one control session. The HIIT trials consisted of warm-up, followed by 12-min of 15-s, 30-s or 60-s work: relief HIIT sequences at an exercise intensity of 100% of the individual velocity at VO_{2max}, interspersed by relief intervals at 60% VO_{2max} (work/relief ratio = 1).	$n = 12$; M; (22.8 ± 1.7) years	Increase in sympathetic activity
Oliveira J et al., 2022[13]	Effects of High Intensity Interval Training versus Sprint Interval Training on Cardiac Autonomic Modulation in Healthy Women	RCT	Three times a week (Monday, Wednesday, and Friday), totaling 24 training sessions over eight weeks; all sessions were held in the morning. Warm-up: 5-min at 50% HR peak; 4 x 4-min at 90%–95% HR peak/3-min at 50%–60% HR peak.	$n = 43$; F; (31.1 ± 6.5) years and (28.8 ± 6.0) years	Improvement in cardiac autonomic modulation
Navarro-Lomas et al., 2022[12]	Different exercise training modalities similarly improve heart rate variability in sedentary middle-aged adults: the FIT-AGEING randomized controlled trial	RCT	2 sessions/week for 12 weeks following 2 different complementary protocols: (i) HIIT with long intervals (type A session), and (ii) HIIT with short intervals (type B session). The training volume was 40–65-min/week at > 95% of the VO_{2max} in type A sessions, and > 120% of the VO_{2max} in type B sessions. Type A sessions had a maximal duration of 24-min/session, where participants completed 6–10 sets of 4 or 5-min (2- or 3-min work/2-min rest). Type B sessions had a maximal duration of 37-min/session, where participants performed 2 or 3 sets (8–12.5-min of duration) of 16 exercises (15–30-s work/15–30-s rest) with an active rest of 5-min at 60% between sets. The exercise program for type A sessions was based on walking on a treadmill with a personalized slope, and type B sessions included a circuit workout with 8 weight-bearing exercises (i.e., squat, dead lift, high knees up, high heels up, push up, horizontal row, lateral plank, and frontal plank).	$n = 66$; M and F; (53.6 ± 4.4) years	Increase of autonomic and vagal modulation
Bönhof et al., 2022[9]	High-intensity interval training for 12 weeks improves cardiovascular autonomic function but not somatosensory nerve function and structure in overweight men with type 2 diabetes	Clinical trial	HIIT was performed on 3 non-consecutive days per week on a cycle ergometer for 12 weeks. Training sessions lasted 35-min including warm-up and cool-down periods and consisted of four intervals over 4-min at 90% of the individual's MHR,	$n = 43$; M; 30–65 years	Improve CV autonomic function

(continued on next page)

Table 1 (*continued*)

Author, year	Title	Study type	HIIT protocol	Sample (size, sex and age)	Effect on ANS function
			alternating with 3-min intervals of recovery at 70% of the MHR.		
Edwards et al., 2022[11]	Left ventricular mechanical, cardiac autonomic and metabolic responses to a single session of high intensity interval training	?	The HIIT exercise protocol consisted of a single Wingate session, characterised by three 30-s periods of maximal intensity cycling. Using a WATT bike pro, the exercise periods were loaded with 7.5% of the participants body mass and separated with 2-min of unloaded active recovery. Each participant performed a 2-min warm up with no active recovery post-exercise.	$n = 50$; M and F; (22.87 ± 2.58) years	Improvements in autonomic modulation
Oliveira RS et al., 2022[24]	Effects of High-Intensity Interval Training on the Vascular and Autonomic Components of the Baroreflex at Rest in Adolescents	RCT	3 training sessions per week for four weeks providing a total of 12 sessions. Sessions were performed in the morning. For sessions 1–6, participants performed eight bouts, for HIIT sessions 7–9, participants performed 10 bouts, and for HIIT sessions 10–12, participants performed 12 bouts of 1-min running, each interspersed by 75-s of recovery	$n = 19$; M; (13.2 ± 0.5) years	No changes
Rodrigues et al., 2020[23]	β2 adrenergic interaction and cardiac autonomic function: effects of aerobic training in overweight/obese individuals	Randomized	16-week training: 1-HIIT ($n = 25$, 1 × 4-min bout at 85%–95% HR peak, 3 × /week), 4-HIIT ($n = 26$, 4 × 4-min bouts at 85%–95% HR peak, interspersed with 3-min of recovery at 50%–70% HR peak, 3 × /week)	$n = 7$; M and F; 52 and 35.6 years	Promotes adaptation of the cardiac ANS
Cassidy et al., 2019[25]	Unsupervised high-intensity interval training improves glycaemic control but not cardiovascular autonomic function in type 2 diabetes patients: A randomised controlled trial	RCT	36 cycle sessions over 12 weeks (3 sessions/week on non-consecutive days) at a local gym. Each exercise session started with a 5-min warm up where the RPE increased from 9 ('very light') to 13 ('somewhat hard') at a comfortable cadence, followed by five intervals where the pedal cadence was required to exceed 80 revolutions per min, and the RPE reached 16–17 ('very hard'). Each working interval was interspersed with a 3-min recovery period consisting of 90-s of passive recovery, 60-s of band-resisted upper body exercise and 30-sec of preparation for the following working interval. A 3-min recovery cycle followed the final interval. The length of the HIIT in the first week was 2-min, increasing by 10-s each week, so that by week 12 participants were performing intervals lasting 3-min 50-s.	$n = 22$; M and F; (60 ± 2) years	No changes
van Biljon et al., 2018[17]	Short-Term High-Intensity Interval Training Is Superior to Moderate-Intensity Continuous Training in Improving Cardiac Autonomic Function in Children	Quasi-experimental study	Sessions were performed over 5 weeks. A 5-min warm-up and cooldown consisted of jogging at a low intensity, followed by static stretching in all exercise sessions; Participants were required to complete 10 × 60-s interval runs set at an intensity of > 80% of their predicted MHR measured at baseline (the target HR was set at > 167.20 bpm) separated by 75 s of active rest that entailed walking backwards.	$n = 109$; M and F; 10 to 13	Enhanced vagal activity
Clemente-Suárez, Arroyo-Toledo, 2018[10]	The Use of Autonomic Modulation Device to Control Training Performance after High-Intensity Interval Training Program	Pre-post training intervention design	The HIIT session that was evaluated consisted of: 16 × 25-min maximum speed, resting 30-s between sets. Participants combined aerobic training with tethered swimming and HIIT sessions three times per week in a period of 4 weeks.	$n = 14$; M; (16.2 ± 2.6) years	Autonomic modulation and adaptation
Schaun and Del Vecchio, 2018[22]	High-Intensity Interval Exercises' Acute Impact on Heart Rate Variability: Comparison Between	Randomized cross-over design	2 HIIT protocols, 1 on a cycle ergometer (Tabata protocol; eight 20-s bouts at 170% VO_{2max} interspersed by 10-s rest) and another with whole-	$n = 12$; M; (23.3 ± 3.9) years	High parasympathetic inhibition immediately after session

(*continued on next page*)

Table 1 (*continued*)

Author, year	Title	Study type	HIIT protocol	Sample (size, sex and age)	Effect on ANS function
	Whole-Body and Cycle Ergometer Protocols		body calisthenic exercises (McRae protocol; eight 20-s all-out intervals interspersed by 10-s rest).		
Ramos et al., 2017[21]	High-intensity interval training and cardiac autonomic control in individuals with metabolic syndrome: A randomised trial	Randomized, sub study of a multicenter trial	Three/week, with at least a day between sessions. Both HIIT groups were preceded by a 10-min warm-up and terminated with a 3-min cool-down. The 4HIIT group trained for 38-min per session that consisted of 4 bouts of 4-min intervals at 85%–95% HRpeak/RPE of 15–17, separated by 3-min active recovery at 50%-70% HRpeak. The 1HIIT group completed only one 4-min exercise bout at 85%–95% HRpeak/RPE of 15–17 (17-min/session). All HIIT participants were instructed to reach the target intensity (HR or RPE) within the first 2-min of the 4-min interval.	$n = 56$; M and F; (54 ± 11), (56 ± 8), and (58 ± 7) years	Increase in parasympathetic modulation
Castrillón et al., 2017[18]	High-Intensity Intermittent Exercise and Autonomic Modulation: Effects of Different Volume Sessions	Randomized experimental trial	For both exercise trials, the participants performed a warm-up consisting of running at 50% of MAS for 5-min at 1% inclination. The HIIT were performed intermittently with 1-min running at MAS, followed by 1-min of passive recovery (without exercise) until they had completed both 2.5 and 1.25 km.	$n = 13$; M; (22.99 ± 6.84) years	Greater volume created higher stress on the ANS during recovery.
Perkins et al., 2016[14]	Immediate and long term effects of endurance and high intensityinterval exercise on linear and nonlinear heart rate variability	One-way crossover design	The HIIT session involved six sets of 30-s of all-out supramaximal intensity cycling at the participants' self-selected gearing. Between sets participants completed 4- min of recovery during which theyeither rested or cycled below 30 W.	$n = 19$; M and F; ± 21 years	Greater impact on cardiac autonomic activity with decreased complexity and parasympathetic activity
Besnier et al., 2019[26]	Short-term effects of a 3-week interval training program on heart rate variability in chronic heart failure. A randomised controlled trial	Monocentric, prospective, evaluator-blinded, randomised study with a parallel two-group design	The HIIT included two 8-min blocks of interval training separated by 4-min of passive recovery. Each 8-min block consisted of alternating between 30-s at 100% of peak power output and 30-s of passive recovery.	$n = 3$; M and F; ± 59 years	Increase vagal modulation
Cote et al., 2015[20]	Greater autonomic modulation during post-exercise hypotension following high-intensity interval exercise in endurance-trained men and women	?	The second and third testing sessions involved a maximal aerobic power assessment (VO_{2max}) via cycle ergometer and high-intensity interval session (15 bouts of 1:2-min work: recovery cycling: 100% peak power output and 50 W, respectively) as previously described. The exercise sessions were separated by at least 1 week.	$n = 40$; M and F; (30.5 ± 5.7) years	Depression in cardiovagal baroreflex function, and increased sympathetic activity post exercise

Abbreviation: ? – not clear in the study; ANS – Autonomic Nervous System; bpm – beats per minute; CV – cardiovascular; F – female; HIIT – High intensity Interval Training; HR – heart rate; M — male; MAS – maximum aerobic speed; MHR – maximum heart rate; min – minutes; n – number; RCT – Randomized Controlled Trial; RPE – rating of perceived exertion; rpm – rotation per minute; s – seconds; VO2max – maximal oxygen consumption; W – work load; × – times.

populations, including those with limited time for exercise. Healthcare professionals and fitness practitioners should consider the balance between intensity and recovery in HIIT to maximize CV benefits and minimize the risk of overtraining or adverse effects, especially in populations with underlying health conditions.[26]

Interestingly, a study has shown that stress response of HIIT is influenced by both the time of the day and by the chronotype of the subject (morning-type or evening-type). Since it was observed in a sample of soccer players that before evening training session, there was a higher resting heart rate determined by a marked parasympathetic withdrawal with a sympathetic predominance. Evening-type subjects presented during morning training sessions, a significant higher heart rate that corresponded to significant higher vagal indices with a significant lower parasympathetic tone that returned to the rest values 24 hours (h) after HIIT. Whereas, Morning-type subjects did not reveal any significant differences during evening high-intensity interval training session.[27] Even though more studies are recquired to fully understand this differences, this data shows HIIT training might be more effective when individual characteristics are considered.

Considering the results of the review, it can be hypothesized that by conducting multiple periodic measurements of the ANS in subjects undergoing a training program with HIIT, the threshold dose could be monitored more accurately and adjusted based on the subject's adaptations. In pathological subjects, these measurements could even be performed pre- and post-workout to determine both the dosage and intensity for each session. Furthermore, by studying the acute adaptive response of the ANS at different times of administration, it would be possible to estimate the specific time needed to create the intended adaptations.

While the aggregated results from the 20 studies reviewed indicate promising trends in the impact of HIIT on the ANS, several limitations and considerations warrant a cautious interpretation of the findings and highlight areas for future research. The studies utilized a wide array of HIIT protocols, varying in intensity, duration, frequency, and the type of exercises employed. This variability makes it challenging to standardize the effects of HIIT on ANS function and draw generalizable conclusions. The lack of a uniform definition of ‘high intensity’ and the individualized nature of intensity thresholds (e.g., % of VO_{2max} or heart $rate_{max}$) further complicates cross-study comparisons.

Another limitation is the demographic diversity among participants, including age, fitness level, and health status, introduces variables that may influence ANS responses to HIIT. These factors need to be considered when extrapolating the findings to broader populations. However, gender distribution was not uniform across studies, since in the majority of them the sample was composed only of men. This limits the applicability of results across genders, given the known differences in ANS function and exercise responses between males and females.

Some methodological considerations should also be made in assessing ANS function. Most studies relied on HRV as a proxy for ANS function. While HRV is a valuable tool, it provides an indirect measure of autonomic activity and may not fully capture the complex dynamics of the ANS. The timing of HRV measurements (e.g., pre-training, immediately post-training, or during recovery periods) varied across studies, potentially affecting the comparability and interpretation of results.

Regarding sample size, a significant number of studies had relatively small sample sizes, limiting the statistical power and the ability to detect subtle changes in ANS function. As for study designs the predominance of short-term studies with limited follow-up periods restricts understanding of the long-term effects of HIIT on ANS function and CV health.

Furthermore, the possibility of reporting bias, where studies with positive results are more likely to be published, cannot be ignored, even though two studies reported that there were no changes in outcome. This may lead to an overestimation of the beneficial effects of HIIT on ANS function. A comprehensive understanding of the impact of HIIT would benefit from the inclusion and analysis of unpublished data and studies with null or negative results. In light of these limitations, future research should strive for standardized HIIT protocols, larger and more diverse study populations, longer follow-up periods, and a multi-dimensional approach to measuring ANS function. Such research endeavors will enhance the understanding of the nuanced effects of HIIT and guide the development of tailored exercise interventions to optimize autonomic function and CV health.

The heterogeneity of the samples examined and the methods of the studies suggest that the standardized protocols chosen for experimentation cannot be used in the clinic without considering individual characteristics and measuring the baseline autonomic state of the subjects. However, this does not demonstrate that by measuring and personalizing a possible work program for each subject, there will be a superior improvement in autonomic function compared to the studies examined, considering the lack of studies conducted with this modality and subsequent comparisons.

Under this interpretation, HIIT can be considered a destabilizing stimulus with a subjective response, which stimulates an increase in the ability to adapt to short-term acute stress. The response to acute stress is a complex neuroendocrine mechanism that reflects the physiological state of the subject. This is perhaps one of the aspects that determined the results of the review, along with the fact that performing high-intensity work can be limited by the subjects' poor knowledge and awareness of their level of maximum subjective intensity, and the difficulty of measuring and estimating this in a pathological context and in untrained subjects.

5. Conclusion

This literature review highlights the potential of HIIT to modulate the ANS, enhancing CV function and overall health. Despite the promising findings, the interpretation of the results is tempered by the variability in study designs, populations, and methodologies. Future research should address these limitations, aiming for a more nuanced understanding of the relationship between HIIT and ANS function. The review indicates that standardized protocols need to consider individual characteristics and baseline autonomic states for clinical application. Furthermore, regularly measuring the ANS in subjects undergoing HIIT could allow for more accurate dose adjustments based on individual adaptations, particularly in pathological subjects, to optimize training outcomes. As the body of evidence grows, HIIT may emerge as a cornerstone of exercise prescriptions aimed at optimizing autonomic function and promoting CV health.

CRediT authorship contribution statement

Massimo Coretti: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Nathalia Nahas Donatello:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Gianluca Bianco:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Francisco J. Cidral-Filho:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation.

Conflict of interest

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

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