Sport Sciences and Health Research

University of Tehran
Faculty of
Physical Education and Sport Science

The Role of Heart Rate Variability (HRV) in Health, Exercise Performance, and Athlete Training Monitoring: A Systematic Review

Mohammad Amin Farhani[1], Hamid Rajabi[1*], Sadegh Amani Shalamzari[1], Seyed Shervin Shahshahani[1], Jamil Jafari Pouresmaeili[1], Azam Ahmadi[1]

1. Department of Exercise Physiology, Faculty of Physical Education and Sport Sciences, Kharazmi University, Tehran, Iran.

Corresponding Author's Email: hrajabi@khu.ac.ir

Article Info

Article type:

Review Article

Article history:

Received: 09 May 2025

Revised: 20 Jun 2025

Accepted: 22 Jun 2025

Published online: 01 July 2025

Abstract

Background: Heart Rate Variability (HRV) serves as a crucial physiological marker for assessing autonomic nervous system function.

Aim: This review systematically examines recent studies on the potential role of Heart Rate Variability (HRV) in physical activity, encompassing health, performance, cognitive, and physiological perspectives. Specifically, it investigates the impact of HRV monitoring methods on physical performance, fatigue, and recovery across various aspects of sports performance.

Materials and Methods: A comprehensive search for primary articles and relevant scientific literature was conducted across academic databases, including PubMed, Cochrane Library, Web of Science, and Scopus, using keywords such as Heart Rate Variability, physical activity, health, sports physiology, and cognitive factors.

Results: HRV is widely recognized as a non-invasive, practical, and valuable tool for assessing autonomic nervous system function. Due to its methodological advantages, HRV provides critical insights into fitness levels and training adaptation, optimal training intensity and volume, overtraining detection, injury risk assessment, and cognitive factors such as stress and anxiety. The reviewed literature indicates that individuals with lower baseline HRV tend to experience increased HRV levels following regular physical activity.

Conclusion: exercise training is directly associated with improved HRV, which enhances athletic performance, mitigates overtraining risks, and reduces injury incidence.

Keywords: Autonomic Nervous System, Physical Activity, Fatigue Monitoring, Overtraining Detection, Physiological Monitoring, Non-invasive Assessment.

Cite this article: Farhani, M. A., Rajabi, H., Amani Shalamzari, S., Shahshahani, S. S., Jafari Pouresmaeili, J., & Ahmadi, A. (2025). The role of heart rate variability (HRV) in health, exercise performance, and athlete training monitoring: A systematic review. *Sport Sciences and Health Research*, 17(2), 1-13.

1. Introduction

Physical activity is widely recognized as an effective strategy for enhancing autonomic nervous system (ANS) function. Given that heart rate variability (HRV) serves as a dynamic reflection of physiological and cognitive states, a systematic review of its role in exercise spanning health, performance, and physiological adaptation is critical to address inconsistencies in current methodologies and applications [1]. HRV, defined as the variation in time intervals between consecutive heartbeats [2], is measured using linear (time-domain and frequency-domain) and non-linear methods (e.g., sample entropy, Poincaré plot, and detrended fluctuation analysis) [3, 4]. While time-domain metrics like SDNN (standard deviation of R-R intervals) offer simplicity, non-linear methods capture complex ANS dynamics, highlighting the need for standardized protocols in HRV assessment.

HRV's non-invasive nature and utility in monitoring training readiness [5] and ANS balance [6] have made it a cornerstone in sports science and clinical research. However, despite its potential, the interpretation of HRV data remains fragmented across disciplines, with limited consensus on its predictive value for injury prevention and performance optimization [7, 8]. For instance, while reduced HRV is linked to cardiovascular risk [9, 10], its application in real-world athletic settings—such as tailoring training loads or mitigating overtraining lacks robust evidence. This gap underscores the necessity of synthesizing existing literature to establish evidence-based guidelines for HRV utilization in sports and clinical practice.

Moreover, HRV's role extends beyond physiological monitoring; it reflects cognitive and emotional states, such as stress and anxiety [11]. Sedentary individuals and those with chronic diseases exhibit diminished HRV, correlating with elevated morbidity risks [12, 13]. Conversely, exercise training improves HRV, suggesting its dual utility as a diagnostic and interventional tool [14, 15]. However, the mechanisms linking HRV, cognitive performance, and long-term athletic outcomes remain underexplored, particularly in high-stakes environments like competitive sports. HRV is a well-established indicator of autonomic nervous system responsiveness to internal and external stressors, making it a valuable tool for identifying anxiety and stress in athletes during both training and competition [16]. By modulating HRV, physical activity can enhance stress resilience and optimize performance [17]. However, while HRV is widely used to monitor training load, recovery, and overtraining [18, 19], its practical implementation remains inconsistent due to methodological variability and a lack of consensus on optimal thresholds. Therefore, this systematic review thus aims to consolidate existing evidence on HRV's role in athlete monitoring, focusing on bridging the gap between theoretical insights and practical strategies for coaches and clinicians. In addition, this review focuses on the potential role of HRV in monitoring physical activity and cognitive and physiological performance in professional athletes.

2. Materials and Methods

This systematic review examined the role of HRV across four domains: health, athletic performance, cognitive function, and physiological adaptation. A comprehensive search was conducted across electronic databases, including PubMed, Cochrane Library, Web of Science, and Scopus, using a combination of MeSH terms and keywords (e.g., "Heart Rate Variability," "physical activity," "exercise physiology," "cognitive factors,"). To minimize publication bias, gray literature and reference lists of included articles were manually screened for additional relevant studies.

Three researchers independently performed the search, screening, and data extraction processes, with discrepancies resolved through consensus or consultation with a fourth reviewer. The inclusion criteria were original research articles involving human participants and studies published in peer-reviewed journals without restrictions on publication date, subject demographics, exercise intensity, or HRV measurement techniques. Exclusion criteria were strictly applied to maintain focus and validity: animal studies, non-original research (e.g., editorials, narrative reviews without novel data), and studies involving pharmacological interventions or artificial manipulation of HRV (e.g., drugs, pacemakers). Extracted data were categorized thematically (health, performance, cognition, physiology) and critically evaluated for trends, contradictions, and gaps. Given the heterogeneity of HRV measurement protocols across studies, findings were synthesized qualitatively to highlight consensus and disparities in methodology (Table 1).

2.1. Eligibility criteria

Inclusion criteria for all studies were based on the population, intervention, comparison, outcome, and study design.

The studies were included for the review if they met the following criteria:

• The full text of the articles must have been available.

• Articles must be written in English or Persian.

• Articles must be published in scientific journals and be randomized controlled trials (RCTs).

2.2. Exclusion criteria

• Articles in which full text have not been available or found.

• Animal or in vitro studies (non-human studies).

• Duplicates or overlapping datasets from the same study population.

• Studies not related to the defined population, intervention, comparator, or outcome (PICO) criteria.

3. Results

The systematic search across relevant databases initially identified 429 articles. After preliminary screening of titles and abstracts, 213 articles were deemed relevant to the study's scope. The second and third researchers independently performed secondary and tertiary reviews of the database records to ensure comprehensive coverage. Subsequent evaluation narrowed the selection to 89 articles addressing HRV, physical activity, and performance metrics. After obtaining full-text versions and applying rigorous inclusion/exclusion criteria to studies published between 2008 and 2025, 21 high-quality articles were selected for final analysis (Figure 1). The multi-stage screening process, involving independent assessments by multiple researchers, was designed to minimize selection bias and ensure the inclusion of methodologically robust studies. The systematic review findings demonstrate that comparisons of physical recovery techniques following resistance and aerobic training have shown inconsistent effects on cardiovascular parameters across studies. However, these techniques facilitate autonomic nervous system reactivation, with exercise modality influencing HRV's efficacy as a monitoring tool for cardiovascular and neurological status [20].

HRV and heart rate are established biomarkers for evaluating cardiovascular recovery and autonomic balance in athletes. Yoga practice - incorporating postures, breathing techniques, and meditation - enhances parasympathetic activation and autonomic balance, promoting post-exercise recovery. Empirical evidence confirms yoga's positive influence on HRV modulation [21], establishing HRV as a valid indicator of physical and cognitive fitness improvements.

A 5-week aerobic exercise intervention study with twelve active males demonstrated that combined low- and high-intensity training significantly improved VO_2max independent of training load [22]. Similarly, González-Fernández et al. (2024) examined female soccer players undergoing an 8-week pre-season aerobic-based program. Their results showed improved physical performance (VO_2max, Sargent jump) and a notable increase in HRV indices such as RMSSD and pNN50, indicating enhanced autonomic recovery and cardiovascular regulation. Post-intervention assessments revealed enhanced lean body mass, Sargent jump performance, and VO_2max, with HRV showing significant correlations with body composition and fitness metrics [23]. These findings position HRV and strength measures as valuable tools for monitoring training status, adaptation, and progression. Notably, reduced HRV may indicate overtraining syndrome, particularly in aerobic athletes, highlighting its broad applicability across athletic, clinical, and general populations [24].

In adolescent athletes (n=18), HRV reduction occurred more rapidly during elevated heart rate conditions in higher-fit individuals, detectable exclusively through cardiac measurements [25].

A large-scale study (n=28,175) established smartphone-monitored BMI, resting heart rate, and HRV as effective indicators of cardiovascular health in free-living conditions [26].

Physiological exercise responses appear mediated by sympathetic-parasympathetic balance, making HRV a valuable metric for individualized training prescription and performance enhancement [17]. A systematic review of HRV biofeedback interventions (n=187) confirmed its effectiveness for athletic performance improvement [27], while maintaining optimal HRV ranges may prevent chronic diseases and preserve cardiac homeostasis during increased exercise loads [28]. High-intensity interval training (5km HIIT) studies emphasized the need for further research on HRV-power performance relationships [29]. In futsal players, 1-minute HRV intervals effectively identified training adaptations, with lnRMSSD proving particularly sensitive to training-induced changes [30].

Cognitive performance studies revealed that HRV improvements correlated with enhanced sustained attention capabilities, underscoring fitness maintenance as a critical factor for cognitive-physiological health [31]. Resting HRV assessments demonstrated exercise's positive effects on autonomic regulation and post-exercise cardiac control [32], with regular activity improving overall autonomic function and cardiovascular health.

While increased exercise intensity elevated nighttime heart rates, it did not significantly affect HRV. Ninety-minute training sessions reduced nighttime HRV without compromising sleep quality, suggesting extended durations are necessary for meaningful HRV modifications [33]. Endurance training intensity produced comparable effects on resting systolic blood pressure in older adults, though higher intensities elicited more pronounced post-exercise heart rate responses [34]. Regular exercise was shown to mitigate obesity's adverse HRV effects and improve cardiac autonomic function [35].

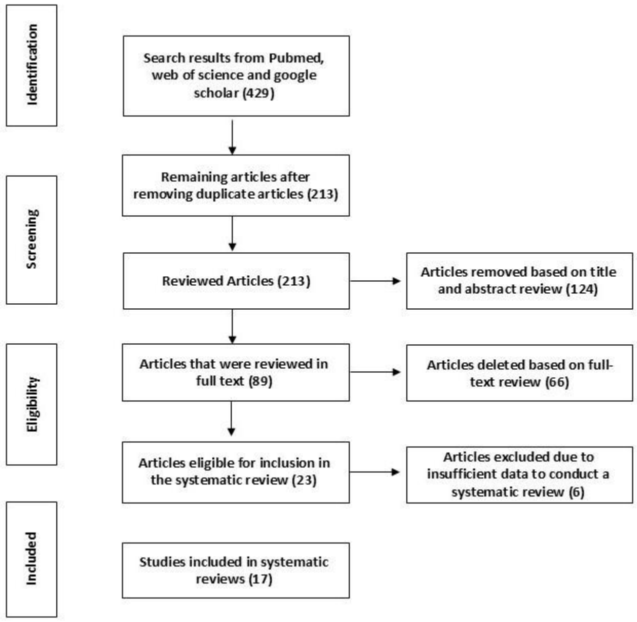

Figure 1. Flowchart of studies' search and selection process using relevant keywords in reputable databases.

Table 1. Characteristics of the studies reviewed.

Number	Researchers	Year	Sample description	Method	Results
1	[21]	2025	20 male athletes	Recovery methods, 15 minutes, and 15-minute yoga after HIIT.	Based on heart rate variability, relaxation in yoga facilitates the recovery phase more effectively than doing stretching exercises.
2	[22]	2025	12 active men	Combined exercises, assessing heart rate variability	Combined low-intensity and high-intensity exercises enhance aerobic capacity regardless of the training load.
3	[36]	2025	24 participants: 12 resistance training, 12 moderate exercise controls.	HRV was measured using a Polar RS800CX heart rate monitor and analyzed with Kubios HRV software.	Long-term resistance training was associated with improved parasympathetic modulation, indicatingpotential cardiovascular benefits and enhanced autonomic function.
4	[37]	2025	twenty-ninemale athletes aged 18 to 20 years	HRV was measured using a Polar V800 heart rate monitor (sampling rate: 1,000 Hz) and analyzed with Kubios HRV software.	This study shows that HRV reflects autonomic activity in soccer players and suggests that machine learning can help track related molecular changes.
5	[23]	2024	Women's Soccer	The jump was Sergeant and VO2max. Heart rate variability (HRV)	There was no relationship between cognitive performance and physical fitness, but (HRV) impacted body composition and physical fitness during the pre-season in female football players.
6	[25]	2022	18 young athletes	Cardiovascular and respiratory readiness, aerobic capacity, and heart rate variability	Heart rate variability (HRV) decreases faster among athletes in better shape when the heart rate goes up.
7	[26]	2021	28175 men and women	The relationship between body mass index, resting heart rate, and heart rate variability.	A smartphone app can effectively measure heart rate at rest and heart rate variability (HRV) upon waking.
8	[17]	2020	Athlete women	Measuring VO2 max and heart rate variability	(HRV) depends on the type of daily training of athletes.
9	[38]	2020	34 professional soccer players	HRV was measured using heart rate monitors	In conclusion, daily HRV analyses help detect individual changes in professional soccer players.
10	[28]	2018	25 soccer players	Heart rate variability and exercise load	High training load capacity may affect cardiac homeostasis disturbances.
11	[29]	2016	Athletic men	Heart rate variability assessment	Both RR and lnRMSSD intervals are associated with detrimental effects on power performance.
12	[30]	2015	24 elite futsal players	Heart rate variability assessment	lnRMSSD measured over a short 1-minute period is sensitive to training-induced changes in futsal

					players.
13	[31]	2013	28 young men	VO_2max, lactate, strength, heart rate variability (HRV)	The physiological and morphological results suggest that the athlete's fitness level appears to be the primary benefit gained.
14	[32]	2013	21 healthy men	Low-intensity and high-intensity training and heart rate variability assessment	Exercise has a beneficial effect on cardiac autonomic control following physical activity.
15	[33]	2012	14 healthy men	Five different running protocols and heart rate variability assessment	An increase in the intensity or duration of exercise delays the improvement of the cardiac autonomic nervous system at night. However, it does not appear that increased exercise intensity or duration disrupts sleep quality.
16	[39]	2010	44 patients	Beck Depression Inventory, Spiroergometer for estimating VO2peak, and heart rate variability assessment	The results showed that exercise reduced emotional distress while improving heart rate variability (HRV).
17	[35]	2008	1712 male and female participants	Regular weekly physical activity and heart rate variability assessment	Regular physical exercise substantially benefits cardiac autonomic function and seems to counteract the adverse effects of obesity on heart rate variability (HRV).

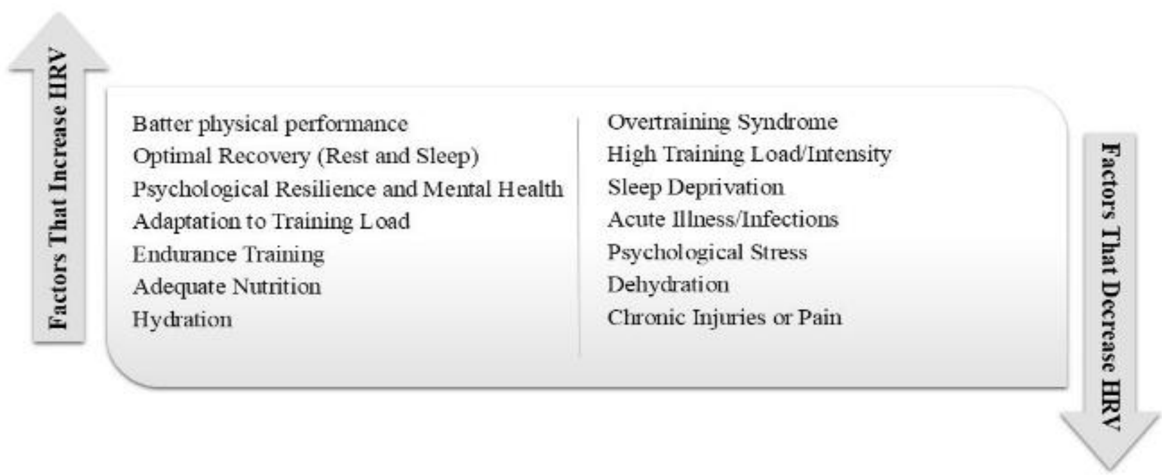

Figure 2. List factors affecting heart rate variability (HRV) monitoring in professional

4. Discussion

4.1. HRV as a Monitoring Tool for Physiological Adaptation

This systematic review demonstrates that HRV is a sensitive, non-invasive indicator of physiological responses to physical activity across health, performance, cognitive, and physiological domains. As illustrated in Figure 2, HRV fluctuations reflect the interplay of factors such as exercise intensity, recovery status, and autonomic nervous system (ANS) balance [40]. Elevated HRV correlates with improved cardiovascular flexibility and stress resilience, whereas reduced HRV signals ANS dysfunction, often preceding clinical symptoms of overtraining or chronic stress [41, 42]. The body's adaptation to endurance training enhances parasympathetic tone, increasing HRV and recovery capacity over time [43]. However, individual variability in HRV responses influenced by fitness level, age, and health status necessitates personalized interpretation [44, 45]. This review highlights HRV as a reliable, non-invasive marker reflecting physiological adaptation to physical activity. Higher HRV indicates better cardiovascular resilience and recovery. Due to individual differences, HRV assessment should be interpreted based on personal fitness, age, and health status.

4.2. Health and Clinical Implications

HRV's stratification into low, standard, and high ranges provides actionable cardiovascular and mental health insights. High HRV signifies optimal ANS function and is associated with reduced risks of cardiovascular diseases and psychological disorders (e.g., depression and anxiety) [46, 47]. Notably, even in clinical populations, physical activity can restore ANS balance: Zhou et al. [48] reported HRV improvements in chronic disease patients. At the same time, the Whitehall study linked moderate-to-vigorous exercise to higher HRV in healthy adults [49]. Conversely, low HRV may reflect pathological states, with hormonal markers (e.g., cortisol, adrenaline) and inflammatory pathways contributing to ANS suppression [42, 50]. The autonomic effects of resistance training in athletic populations depend on chronic exposure and acute load characteristics. Barbosa et al. (2025) compared resistance-trained individuals (≥6 months experience) with non-lifters and found significantly higher resting RMSSD and SDNN in the trained group, indicating long-term autonomic adaptation from regular resistance training [51]. These findings underscore HRV's dual role as a diagnostic and interventional biomarker. For example, HRV monitoring has been examined in research settings, and improvements in HRV parameters have also been observed in clinical populations following regular physical activity programs. Meta-analyses investigating the effects of exercise training on patients with type 2 diabetes [52], coronary artery disease [53], and heart failure [54] have demonstrated a significant increase in RMSSD in intervention groups. The standardized mean difference (SMD) was 0.62 (95% CI: 0.28–0.95) in the meta-analysis of type 2 diabetes, 0.30 (95% CI: 0.12–0.49) for coronary artery disease, and approximately 10.44 (95% CI: 0.60–20.28) for heart failure [52, 55]. The heart failure meta-analysis used the mean difference (MD) instead of the SMD. These findings suggest that exercise training may enhance parasympathetic nervous system activity across various patient populations. HRV assessment can be valuable for identifying pathological conditions and monitoring physiological adaptations over time. In a related study, Deng et al. assessed autonomic nervous system (ANS) function indirectly through the heart rate response (HRr) during a treadmill-based cardiopulmonary exercise test in individuals with varying levels of obesity. HRr was calculated as the difference between maximal and resting heart rate divided by the difference in oxygen consumption. The obese group required greater sympathetic activation to complete the test, as reflected by lower HRr values than healthy controls. These results are consistent with Yadav et al.[56, 57] , who found a strong inverse relationship between body mass index (BMI) and heart rate variability (HRV), indicating that individuals with higher BMI tend to have lower HRV. Collectively, these findings highlight HRr and HRV as applicable, non-invasive markers for detecting autonomic dysfunction and increased cardiovascular risk in obese individuals. Moreover, regular monitoring of HRV in clinical and athletic populations offers valuable insights into stress, recovery, and overall health status.

4.3. Performance Optimization and Overtraining Prevention

In athletic contexts, HRV is critical for managing training loads and mitigating overtraining risks. Endurance athletes exhibit HRV instability under high-volume training, with prolonged suppression indicating inadequate recovery [58, 59]. Sport-specific differences are evident: Footballers, wrestlers, and rowers show distinct HRV patterns under stress, influenced by training age and competition level [60, 61]. Resistance training's high-intensity loads acutely reduce HRV, reflecting transient physiological stress [62], while prolonged overtraining alters biochemical markers (e.g., cortisol, IGF-1) for up to 48 hours post-exercise [63, 64]. Real-time HRV monitoring enables coaches to tailor recovery phases, preventing overtraining syndromes and associated injuries [65]. The effects of heart rate variability monitoring demonstrate that recent evidence shows aerobic training can significantly enhance vagal-mediated HRV in trained individuals. In a 5-week intervention, Morinaga and Takai (2025) reported that HRV-guided aerobic training significantly increased VO_2max and improved parasympathetic activity, as reflected by increased RMSSD and reduced resting heart rate in active male athletes, despite a lower training load than the control group [22]. Edmonds et al. (2020), investigating elite female rowers across a competitive season, observed transient reductions in RMSSD and SDNN during peak training loads, with recovery in HRV measures following the taper phase. This pattern reflects the acute autonomic stress of intensified aerobic training, followed by adaptive restoration with appropriate periodization [66]. Together, these studies suggest that aerobic training improves parasympathetic HRV indices (e.g., RMSSD, pNN50), especially when appropriately managing the training load. However, excessive or poorly managed training loads may lead to overtraining and fatigue, which are often associated with reductions in parasympathetic activity and impaired HRV responses.

4.4. Cognitive and Recovery Applications

HRV's utility extends to cognitive performance and recovery strategies. Enhanced parasympathetic activity through yoga or controlled breathing improves HRV and accelerates post-exercise recovery [20, 21]. Cognitive tasks requiring sustained attention correlate with higher HRV, suggesting fitness-mediated neurogenic benefits [31]. Sleep-quality studies reveal that while intense exercise transiently reduces nighttime HRV, it does not impair sleep, highlighting ANS resilience [33]. Medellín-Ruiz et al. (2024) examined the effect of three different squat training intensities (10%, 20%, and 40% velocity loss) on HRV in trained male athletes. HRV measures (RR intervals, RMSSD, pNN50) were significantly lower 24 hours after the 40% velocity loss protocol, suggesting that training to failure imposes greater autonomic fatigue and delayed recovery than submaximal effort [67]. For athletes, integrating HRV biofeedback into training regimens can optimize mental focus and physiological recovery, bridging the gap between acute stress responses and long-term adaptation [27, 43]. HRV plays a vital role in cognitive performance and recovery, with practices like yoga and controlled breathing enhancing parasympathetic activity. Monitoring and optimizing HRV, primarily through biofeedback, supports mental focus, faster recovery, and long-term physiological adaptation in athletes.

5. Conclusions

HRV is established as a clinically validated, non-invasive tool for evaluating ANS function. This review demonstrates that HRV provides critical insights into multiple physiological and cognitive domains, including fitness level and training adaptation, optimal exercise intensity and volume thresholds, early detection of overtraining and injury risks, and stress and anxiety modulation. The synthesis of evidence confirms two key findings:

1) Structured physical activity consistently elevates HRV in individuals with low baseline values, demonstrating a dose-response relationship between exercise and ANS resilience.
2) HRV-guided interventions can enhance recovery trajectories in clinical populations, particularly for cardiovascular rehabilitation and stress related disorders.

This review highlights HRV's dual utility as a diagnostic and interventional tool. Its applications extend beyond athletic performance monitoring to therapeutic settings, where it can personalize treatment plans and objectively track progress. Future research should prioritize standardized HRV assessment protocols to improve cross-study comparability and clinical translation.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the study design. Material preparation, data collection, and manuscript writing.

Acknowledgment

Hereby the authors of the current paper acknowledge the help of all those who have cooperated in conducting the present research.

Ethical considerations

The author has completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. Farajivafa V, Khosravi N, Molanouri Shamsi M, Agha-Alinejad H. Exercise and Heart Rate Variability in Cancer Patients: A Systematic Review. Iranian Journal of Breast Diseases. 2020;12(4):64-75.
2. Hon E. Electronic evaluations of the fetal heart rate patterns preceding fetal death: further observations. Am J Obstet Gynecol. 1965;87:814-26.
3. Niskanen J-P, Tarvainen MP, Ranta-Aho PO, Karjalainen PA. Software for advanced HRV analysis. Computer methods and programs in biomedicine. 2004;76(1):73-81.
4. Quiceno-Manrique A, Alonso-Hernandez J, Travieso-Gonzalez C, Ferrer-Ballester M, Castellanos-Dominguez G, editors. Detection of obstructive sleep apnea in ECG recordings using time-frequency distributions and dynamic features. 2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society; 2009: IEEE.
5. Plews DJ, Laursen PB, Le Meur Y, Hausswirth C, Kilding AE, Buchheit M. Monitoring training with heart-rate variability: How much compliance is needed for valid assessment? International journal of sports physiology and performance. 2014;9(5):783-90.
6. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. Sports medicine. 2013;43(5):313-38.
7. Wulsin LR, Horn PS, Perry JL, Massaro JM, D'Agostino RB. Autonomic imbalance as a predictor of metabolic risks, cardiovascular disease, diabetes, and mortality. The Journal of Clinical Endocrinology & Metabolism. 2015;100(6):2443-8.
8. RE K. the Multicenter Post-infarction Research Group. Decreased heart rate variability and its association with increased mortality after acute myocardial infarction. Am J Cardiol. 1987;59:256-62.
9. Dong J-G. The role of heart rate variability in sports physiology. Experimental and therapeutic medicine. 2016;11(5):1531-6.
10. Park G, Thayer JF. From the heart to the mind: cardiac vagal tone modulates top-down and bottom-up visual perception and attention to emotional stimuli. Frontiers in psychology. 2014;5:278.
11. Ewing DJ, Martyn CN, Young RJ, Clarke BF. The value of cardiovascular autonomic function tests: 10 years experience in diabetes. Diabetes care. 1985;8(5):491-8.
12. Electrophysiology TFotESoCtNASoP. Heart rate variability: standards of measurement, physiological interpretation, and clinical use. Circulation. 1996;93(5):1043-65.
13. Routledge FS, Campbell TS, McFetridge-Durdle JA, Bacon SL. Improvements in heart rate variability with exercise therapy. Canadian Journal of Cardiology. 2010;26(6):303-12.
14. Aubert AE, Seps B, Beckers F. Heart rate variability in athletes. Sports medicine. 2003;33:889-919.
15. Luft CDB, Takase E, Darby D. Heart rate variability and cognitive function: Effects of physical effort. Biological psychology. 2009;82(2):186-91.
16. Cumming J, Hall C. Athletes' use of imagery in the off-season. The Sport Psychologist. 2002;16(2):160-72.
17. Carrasco-Poyatos M, González-Quílez A, Martínez-González-Moro I, Granero-Gallegos A. HRV-guided training for professional endurance athletes: A protocol for a cluster-randomized controlled trial. International journal of environmental research and public health. 2020;17(15):5465.
18. Moreno Sánchez J, Parrado Romero E, Capdevila Ortís L. Variabilidad de la frecuencia cardíaca y perfiles psicofisiológicos en deportes de

equipo de alto rendimiento. Revista de psicología del deporte. 2013;22(2):0345-352.
19. Lagos L, Vaschillo E, Vaschillo B, Lehrer P, Bates M, Pandina R. Heart rate variability biofeedback as a strategy for dealing with competitive anxiety: A case study. Biofeedback. 2008;36(3):109.
20. Laborde S, Wanders J, Mosley E, Javelle F. Influence of physical post-exercise recovery techniques on vagally-mediated heart rate variability: A systematic review and meta-analysis. Clinical physiology and functional imaging. 2024;44(1):14-35.
21. Rusmeeroj S, Rukdang B. Yoga vs. Static Stretching: Recovery Impact on Male Athletes' Post-HIIT Heart Rate, Respiratory Rate, Blood Pressure, and Heart Rate Variability Analysis. International Journal of Exercise Science.18(6):79-91.
22. Morinaga H, Takai Y. Heart rate variability-guided aerobic training without moderate-intensity enhances submaximal and maximal aerobic power with less training load. Journal of Human Sport and Exercise. 2025;20(1):366-80.
23. González-Fernández FT, Silva AF, Rodriguez AC, Onetti-Onetti W, Clemente FM. Effects of 8 weeks pre-season training on physical fitness, heart rate variability and cognition in women soccer players. Heliyon. 2024;10(2).
24. Addleman JS, Lackey NS, DeBlauw JA, Hajduczok AG. Heart Rate Variability Applications in Strength and Conditioning: A Narrative Review. Journal of Functional Morphology and Kinesiology. 2024;9(2):93.
25. Mongin D, Chabert C, Extremera MG, Hue O, Courvoisier DS, Carpena P, et al. Decrease of heart rate variability during exercise: An index of cardiorespiratory fitness. Plos one. 2022;17(9):e0273981.
26. Altini M, Plews D. What is behind changes in resting heart rate and heart rate variability? A large-scale analysis of longitudinal measurements acquired in free-living. Sensors. 2021;21(23):7932.
27. Pagaduan JC, Chen Y-S, Fell JW, Wu SSX. Can heart rate variability biofeedback improve athletic performance? A systematic review. Journal of Human Kinetics. 2020;73:103.
28. Flatt AA, Esco MR, Allen JR, Robinson JB, Earley RL, Fedewa MV, et al. Heart rate variability and training load among national collegiate athletic association division 1 college football players throughout spring camp. The Journal of Strength & Conditioning Research. 2018;32(11):3127-34.
29. Panissa VL, Cal Abad CC, Julio UF, Andreato LV, Franchini E. High-intensity intermittent exercise and its effects on heart rate variability and subsequent strength performance. Frontiers in physiology. 2016;7:81.
30. Nakamura FY, Flatt AA, Pereira LA, Ramirez-Campillo R, Loturco I, Esco MR. Ultra-short-term heart rate variability is sensitive to training effects in team sports players. Journal of sports science & medicine. 2015;14(3):602.
31. Luque-Casado A, Zabala M, Morales E, Mateo-March M, Sanabria D. Cognitive performance and heart rate variability: the influence of fitness level. PloS one. 2013;8(2):e56935.
32. Pecanha T, Paula-Ribeiro Md, Nasario-Junior O, Lima JRPd. Post-exercise heart rate variability recovery: a time-frequency analysis. Acta Cardiologica. 2013;68(6):607-13.
33. Myllymäki T, Rusko H, Syväoja H, Juuti T, Kinnunen M-L, Kyröläinen H. Effects of exercise intensity and duration on nocturnal heart rate variability and sleep quality. European journal of applied physiology. 2012;112:801-9.
34. Cornelissen V, Verheyden B, Aubert A, Fagard R. Effects of endurance training intensity on resting, exercise and post exercise blood pressure, heart rate and heart rate variability. Journal of Hypertension. 2009;27(3):175-82.
35. Felber Dietrich D, Ackermann-Liebrich U, Schindler C, Barthélémy J-C, Brändli O, Gold DR, et al. Effect of physical activity on heart rate variability in normal weight, overweight and obese subjects: results from the SAPALDIA study. European journal of applied physiology. 2008;104(3):557-65.
36. Barbosa GM, Gobbo HR, Oliveira LCd, Morales AP, Oliveira GVd. The impact of resistance training on heart rate variability parameters in physically active young adults. Jornal Vascular Brasileiro. 2025;24:e20240150.
37. Materko W, Miranda SAM, Bezerra THL, de Oliveira Figueira CAM. Heart rate variability in soccer players and the application of unsupervised machine learning. Exploration of Cardiology. 2025;3:101241.
38. Muñoz-López A, Naranjo-Orellana J. Individual versus team heart rate variability responsiveness analyses in a national soccer team during training camps. Scientific Reports. 2020;10(1):11726.
39. Kouidi E, Karagiannis V, Grekas D, Iakovides A, Kaprinis G, Tourkantonis A, et al. Depression, heart rate variability, and exercise training in dialysis patients. European Journal of Preventive Cardiology. 2010;17(2):160-7.
40. Amano M, KANDA T, UE H, MORITANI T. Exercise training and autonomic nervous system activity in obese individuals. Medicine & Science in Sports & Exercise. 2001;33(8):1287-91.

41. Thayer JF, Lane RD. The role of vagal function in the risk for cardiovascular disease and mortality. Biological psychology. 2007;74(2):224-42.
42. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training adaptation and heart rate variability in elite endurance athletes: opening the door to effective monitoring. Sports medicine. 2013;43:773-81.
43. Kiviniemi AM, Hautala AJ, Kinnunen H, Tulppo MP. Endurance training guided individually by daily heart rate variability measurements. European journal of applied physiology. 2007;101(6):743-51.
44. Kemp AH, Quintana DS, Gray MA, Felmingham KL, Brown K, Gatt JM. Impact of depression and antidepressant treatment on heart rate variability: a review and meta-analysis. Biological psychiatry. 2010;67(11):1067-74.
45. Posadzki P, Kuzdzal A, Lee MS, Ernst E. Yoga for heart rate variability: a systematic review and meta-analysis of randomized clinical trials. Applied psychophysiology and biofeedback. 2015;40:239-49.
46. Fatisson J, Oswald V, Lalonde F. Influence diagram of physiological and environmental factors affecting heart rate variability: an extended literature overview. Heart international. 2016;11(1):heartint. 5000232.
47. Kemp AH, Quintana DS. The relationship between mental and physical health: insights from the study of heart rate variability. International journal of Psychophysiology. 2013;89(3):288-96.
48. Zhou W, Wan Y-H, Chen Q, Qiu Y-R, Luo X-M. Effects of Tai Chi exercise on cancer-related fatigue in patients with nasopharyngeal carcinoma undergoing chemoradiotherapy: a randomized controlled trial. Journal of pain and symptom management. 2018;55(3):737-44.
49. Rennie KL, Hemingway H, Kumari M, Brunner E, Malik M, Marmot M. Effects of moderate and vigorous physical activity on heart rate variability in a British study of civil servants. American journal of epidemiology. 2003;158(2):135-43.
50. Lanfranchi PA, Somers VK. Arterial baroreflex function and cardiovascular variability: interactions and implications. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology. 2002;283(4):R815-R26.
51. Barbosa GM, Gobbo HR, de Oliveira LC, Morales AP, de Oliveira GV. The impact of resistance training on heart rate variability parameters in physically active young adults. J Vasc Bras. 2025;24:e20240150.
52. Picard M, Tauveron I, Magdasy S, Benichou T, Bagheri R, Ugbolue UC, et al. Effect of exercise training on heart rate variability in type 2 diabetes mellitus patients: A systematic review and meta-analysis. PloS one. 2021;16(5):e0251863.
53. Manresa-Rocamora A, Ribeiro F, Sarabia JM, Ibias J, Oliveira NL, Vera-Garcia FJ, et al. Exercise-based cardiac rehabilitation and parasympathetic function in patients with coronary artery disease: a systematic review and meta-analysis. Clinical autonomic research. 2021;31:187-203.
54. Pearson M, Smart N. Exercise therapy and autonomic function in heart failure patients: a systematic review and meta-analysis. Heart failure reviews. 2018;23:91-108.
55. Amekran Y. Effects of exercise training on heart rate variability in healthy adults: a systematic review and meta-analysis of randomized controlled trials. Cureus. 2024;16(6).
56. Yadav RL, Yadav PK, Yadav LK, Agrawal K, Sah SK, Islam MN. Association between obesity and heart rate variability indices: an intuition toward cardiac autonomic alteration–a risk of CVD. Diabetes, metabolic syndrome and obesity: targets and therapy. 2017:57-64.
57. Storniolo JL, Correale L, Buzzachera CF, Peyré-Tartaruga LA. New perspectives and insights on heart rate variability in exercise and sports. Frontiers Media SA; 2025. p. 1574087.
58. Flatt AA, Hornikel B, Nakamura FY, Esco MR. Effect of competitive status and experience on heart rate variability profiles in collegiate sprint-swimmers. The Journal of Strength & Conditioning Research. 2022;36(10):2898-904.
59. Seiler S, Haugen O, Kuffel E. Autonomic recovery after exercise in trained athletes: intensity and duration effects. Medicine and science in sports and exercise. 2007;39(8):1366.
60. Buchheit M, Racinais S, Bilsborough J, Bourdon P, Voss S, Hocking J, et al. Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. Journal of science and medicine in sport. 2013;16(6):550-5.
61. Plews DJ, Laursen PB, Buchheit M. Day-to-day heart-rate variability recordings in world-champion rowers: appreciating unique athlete characteristics. International journal of sports physiology and performance. 2017;12(5):697-703.
62. Schneider C, Wiewelhove T, Raeder C, Flatt AA, Hoos O, Hottenrott L, et al. Heart rate variability monitoring during strength and high-intensity interval training overload microcycles. Frontiers in physiology. 2019;10:582.
63. González-Badillo JJ, Rodríguez-Rosell D, Sánchez-Medina L, Ribas J, López-López C, Mora-Custodio R, et al. Short-term recovery following resistance exercise leading or not to failure.

International journal of sports medicine. 2016;37(04):295-304.
64. Pareja-Blanco F, Rodríguez-Rosell D, Sánchez-Medina L, Ribas-Serna J, López-López C, Mora-Custodio R, et al. Acute and delayed response to resistance exercise leading or not leading to muscle failure. Clinical physiology and functional imaging. 2017;37(6):630-9.
65. Williams S, Booton T, Watson M, Rowland D, Altini M. Heart rate variability is a moderating factor in the workload-injury relationship of competitive crossfit™ athletes. Journal of sports science & medicine. 2017;16(4):443.
66. Edmonds R, Egan-Shuttler J, Ives SJ. Heart rate variability responses to a training cycle in female youth rowers. International Journal of Environmental Research and Public Health. 2020;17(22):8391.
67. Medellín Ruiz JP, Abellán-Aynés O, García DP, Martínez-Aranda LM. Delayed Effects of Different Velocity Loss-Based Resistance Training on Autonomic Regulation, Sleep Quality and Muscle Soreness. J Hum Kinet. 2025;95:83-94.