



QUALITY IN SPORT

eISSN 2450-3118 · Open Access · Peer-reviewed

apcz.umk.pl/QS Nicolaus Copernicus University in Toruń



Cite as: STRUMIŃSKA, Julia, NOWOSIELSKA-OGÓREK, Agnieszka, ŚMIGIELSKA, Maja, JANCZAK, Sylwia and WĘGRZYN, Tymoteusz. Cardiovascular Autonomic Regulation and Performance Anxiety in Athletes: A Narrative Review. *Quality in Sport*. 2026;58:72696. <https://doi.org/10.12775/QS.2026.58.72696>

ARTICLE TIMELINE

Received: 27.05.2026. Accepted: 07.06.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines: Medical Sciences; Health Sciences.

Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Nauki medyczne; Nauki o zdrowiu. © The Authors 2026.

OPEN ACCESS · CC BY-NC-SA 4.0 This article is published with open access under the License Open Journal Systems of Nicolaus Copernicus University in Toruń, Poland, and is distributed under the terms of the Creative Commons Attribution Non-commercial Share Alike License (<http://creativecommons.org/licenses/by-nc-sa/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the work is properly cited. The authors declare no conflict of interest regarding the publication of this paper.

Cardiovascular Autonomic Regulation and Performance Anxiety in Athletes: A Narrative Review

Julia Strumińska¹, ORCID <https://orcid.org/0009-0007-7338-3670>

julia.struminska333@gmail.com

¹Independent Public Voivodeship Combined Hospital in Szczecin, Szczecin, Poland

Agnieszka Nowosielska-Ogórek², ORCID <https://orcid.org/0009-0001-8062-0837>

anowosielska14@gmail.com

²Maria Skłodowska-Curie Voivodeship Specialist Hospital in Zgierz, Poland

Maja Śmigielska³, ORCID <https://orcid.org/0009-0005-4771-8508>

majka.smigielska@gmail.com

³Bielanski Hospital, Warsaw, Poland

Sylwia Janczak⁴, ORCID <https://orcid.org/0009-0005-0637-7305>

sylwia.janczak00@gmail.com

⁴Józef Struś Multidisciplinary Municipal Hospital with Long-Term Care Unit, Poznań, Poland

Tymoteusz Węgrzyn⁵, ORCID <https://orcid.org/0009-0004-0872-1715>

tymoteusz.wegrzyn@gmail.com

⁵Independent Public Voivodeship Combined Hospital in Szczecin, Szczecin, Poland

Corresponding Author

Sylwia Janczak, sylwia.janczak00@gmail.com

Abstract

Background

Performance anxiety is a well-documented phenomenon in competitive sport with established behavioural and psychological consequences; however, its physiological correlates - particularly with respect to cardiovascular autonomic regulation - remain insufficiently integrated within sport medicine and cardiology literature.

Objectives

This narrative review aims to synthesize current evidence on the relationship between performance anxiety and cardiovascular autonomic function in athletes, with particular emphasis on heart rate variability (HRV) as a non-invasive biomarker of autonomic balance.

Methods

A structured literature search was conducted using PubMed, Scopus, Web of Science, and Google Scholar, including studies published from 1996 to 2026, with selected seminal works

published prior to this period. Eligible sources comprised original research articles, systematic reviews, meta-analyses, and clinical guidelines addressing heart rate variability, performance anxiety, and autonomic nervous system regulation in athletes.

Results

Converging evidence indicates that elevated anxiety is associated with reduced HRV, reflecting sympathetic dominance and reduced parasympathetic activity. This imbalance may negatively affect athletic performance, recovery, and cardiovascular health. Activation of the hypothalamic-pituitary-adrenal (HPA) axis and autonomic nervous system (ANS) appears to link psychological stress with physiological dysregulation.

Conclusions

Performance anxiety may contribute to autonomic imbalance characterized by sympathetic dominance and reduced HRV, leading to impaired performance and recovery. These findings support the use of psychophysiological monitoring and targeted psychological interventions in athlete health management.

Keywords: performance anxiety; heart rate variability; autonomic nervous system; athletes; sport cardiology; psychophysiology; stress

1. Introduction

Athletic performance is shaped by the relationship between physiological capacity and psychological state. Although cardiovascular responses to training have been well characterised - including increased stroke volume, improved cardiac efficiency, and resting bradycardia - the extent to which psychological stressors disrupt autonomic cardiovascular function in athletes is far less understood [1,2].

Performance anxiety is among the most commonly reported psychological challenges in competitive sport. Prevalence estimates vary widely, but studies suggest that clinically relevant anxiety symptoms affect between 14% and 45% of elite athletes depending on the population and measurement tool used [3,4]. It manifests across cognitive, somatic, and behavioural dimensions: athletes may experience intrusive worry and attentional narrowing alongside overtly physical symptoms such as tachycardia, diaphoresis, and increased muscle tension [5]. This overlap between psychological and somatic expression points directly to autonomic nervous system involvement.

Heart rate variability (HRV) - the beat-to-beat fluctuation in R-R intervals - has gained substantial traction as a non-invasive index of autonomic balance [6]. In well-trained athletes, parasympathetic predominance is reflected in characteristically elevated HRV, which correlates with recovery quality and adaptive capacity [7,8]. Reductions in HRV, by contrast, signal a shift toward sympathetic dominance and have been associated with overtraining, poor recovery, and psychological stress [9,10]. This makes HRV a particularly useful lens through which to examine anxiety-related autonomic changes.

The neurobiological pathway linking psychological stress to cardiovascular dysregulation involves coordinated activation of both the autonomic nervous system and the hypothalamic–pituitary–adrenal (HPA) axis [11]. Catecholamine release and cortisol secretion during acute stress produce rapid, measurable effects on heart rate and autonomic tone. Under conditions of chronic competitive pressure, repeated activation of this system may accumulate into sustained physiological strain - a concern with direct implications for both performance and cardiovascular health [12,13].

What remains lacking is a coherent framework that connects these domains. Sport psychology and exercise cardiology have tended to develop their own literatures with limited cross-referencing, and psychophysiological models that account for both anxiety and autonomic function in athletes are scarce. This review draws on interdisciplinary evidence to propose such a framework, with particular focus on HRV as a clinically accessible biomarker bridging psychological and physiological assessment in sport.

2. Research materials and Methods

This article was designed as a narrative review focused on the relationship between cardiovascular autonomic regulation and performance anxiety in athletes. A targeted literature search was conducted in PubMed, Scopus, Web of Science, and Google Scholar, covering publications from 1996 to 2026, with selected seminal works published prior to this period. The search strategy combined terms related to athletes, autonomic cardiovascular control and anxiety, including: “athletes”, “sport”, “performance anxiety”, “competitive anxiety”, “heart rate variability”, “HRV”, “autonomic nervous system”, “cardiac autonomic regulation”, “baroreflex sensitivity”, “heart rate recovery”, “sympathetic activity” and “parasympathetic activity”.

Eligible publications included peer-reviewed original studies published in English, systematic reviews, meta-analyses, consensus statements and narrative reviews addressing cardiovascular autonomic regulation, heart rate variability, baroreflex function, recovery responses, training load monitoring or anxiety-related autonomic changes in athletic populations. Studies were considered relevant when they included trained, competitive, recreational or adolescent athletes, or when they provided essential physiological background for interpreting autonomic responses in sport. Articles not directly related to autonomic cardiovascular regulation, performance anxiety, sports participation or exercise physiology were excluded. Non-peer-reviewed sources, conference abstracts without full text and publications with insufficient methodological information were not included.

The literature was synthesized narratively rather than quantitatively because of heterogeneity in study populations, sport disciplines, training status, psychological measures, HRV recording protocols and outcome definitions. Particular attention was given to commonly used autonomic markers, including heart rate variability, baroreflex sensitivity, resting heart rate and heart rate recovery. The extracted evidence was organized into thematic sections covering: physiological mechanisms of cardiovascular autonomic regulation, autonomic adaptations to athletic training, autonomic responses to competition and performance anxiety, and potential practical implications for athlete monitoring.

3. Cardiovascular Autonomic Regulation in Athletes

Cardiovascular autonomic regulation refers to the neural control of heart rate, cardiac function, vascular tone and blood pressure, primarily through the coordinated activity of the sympathetic and parasympathetic branches of the autonomic nervous system. In athletes, autonomic regulation is essential for maintaining cardiovascular efficiency during exercise, recovery and adaptation to training loads. Physical activity requires continuous adjustment of cardiovascular responses to changing metabolic and physiological demands, which involves coordinated autonomic modulation of the cardiovascular system [6,14,15].

During exercise, parasympathetic activity decreases while sympathetic activity progressively increases, resulting in elevated heart rate, cardiac output and redistribution of blood flow toward active skeletal muscles. These responses are additionally influenced by respiratory activity, central neural command and feedback from peripheral receptors located in muscles and blood vessels [15]. Following exercise, recovery is characterized by gradual sympathetic withdrawal and parasympathetic reactivation, which are considered important markers of autonomic recovery and cardiovascular adaptation [15,16].

Heart rate variability (HRV) is one of the most commonly used non-invasive methods for assessing autonomic cardiac regulation. HRV reflects fluctuations between consecutive heartbeats and provides information about autonomic modulation of the sinoatrial node [6]. HRV is primarily considered a marker of parasympathetic cardiac modulation, while its usefulness as a direct measure of sympathetic activity remains debated. Some authors suggest that cardiac sympathetic activity may be assessed using systolic time intervals (STI), including the pre-ejection period [15]. In sports physiology, higher resting HRV is generally associated with better recovery status, enhanced autonomic flexibility and positive adaptation to training, whereas reduced HRV may indicate fatigue, excessive training load, insufficient recovery or physiological stress [14,16].

Regular endurance and mixed training are commonly associated with lower resting heart rate and enhanced parasympathetic modulation [14,16]. These adaptations contribute to the phenomenon known as athletic bradycardia, frequently observed in trained individuals. Although athletic bradycardia has traditionally been linked to increased vagal activity, some evidence suggests that structural and functional remodelling of the sinoatrial node may also play an important role [17]. Therefore, cardiovascular adaptations in athletes should be interpreted in relation to training history, sport discipline and overall cardiovascular assessment.

Autonomic cardiovascular regulation is also closely related to arterial baroreflex function, which contributes to short-term blood pressure stability. Baroreflex sensitivity reflects the ability of the cardiovascular system to buffer rapid changes in arterial pressure through adjustments in heart rate and vascular tone [18]. In athletic populations, baroreflex function may provide complementary information to heart rate variability when evaluating autonomic cardiovascular responses to training load and recovery. Research in athletes suggests that excessive training load and overreaching may impair baroreflex control, indicating that baroreflex sensitivity can be relevant in the assessment of autonomic adaptation and fatigue [19].

From a practical perspective, monitoring autonomic markers may provide useful information regarding training adaptation, recovery and physiological readiness. Systematic reviews indicate that autonomic indices, including HRV and heart rate recovery, are widely investigated as tools for evaluating training status and fatigue in athletes [16]. Persistent suppression of autonomic recovery markers may indicate accumulated fatigue, excessive physiological strain or inadequate recovery processes.

Overall, cardiovascular autonomic regulation represents an important mechanism supporting exercise performance, recovery and adaptation in athletes. Optimal autonomic function may be characterized by efficient transitions between sympathetic activation during exercise and parasympathetic dominance during recovery. Understanding these physiological mechanisms may improve athlete monitoring strategies and contribute to more individualized approaches to training and recovery management [16].

4. Performance Anxiety in Sport

Competitive anxiety is a complex phenomenon encompassing a general predisposition to fear competition, as well as the body's immediate response to a sporting event, which manifests through cognitive and physiological symptoms [20]. Athletic anxiety can present either as a temporary situational response or as an enduring personality trait, triggering a combination of cognitive concerns, physical tension, and behavioural challenges. Extremely high levels of this stress usually disrupt an athlete's focus and cause severe execution errors, while chronic exposure significantly increases the risk of clinical depression or burnout [21].

Despite these severe risks, its actual impact on athletic success remains highly debated within the scientific community, as it can both impair execution and act as a powerful motivator under pressure [22]. Due to these differing effects and varying research methodologies, a single, universally accepted framework has yet to be established [22]. However, models such as the Individual Zones of Optimal Functioning (IZOF) attempt to explain this paradox by suggesting that while negative thoughts consistently impair an athlete's performance, somatic tension can actually improve results, but only until an optimal threshold is reached, indicating that every competitor possesses a highly personalized zone for peak performance [20].

This perspective builds upon historical approaches, such as the Inverted-U hypothesis, which originally proposed a simple curve where performance improves with arousal up to a certain point before declining. As research progressed, more nuanced theories emerged. Hardy's Catastrophe Model, for instance, illustrates a dynamic interplay between physical arousal and cognitive worry. It posits that when an athlete is free from cognitive anxiety, arousal can be beneficial. However, if cognitive anxiety is high, even a minor surge in physiological activation can trigger a sudden and severe breakdown in performance, explaining why some athletes unexpectedly choke under pressure [23,24]. Additionally, Reversal Theory highlights the importance of subjective interpretation, suggesting that identical physical symptoms can be experienced either as energizing excitement or as crippling fear, depending entirely on the athlete's cognitive appraisal of the situation.

Beyond psychological evaluation, these emotional states are deeply rooted in physiological stress reactions. Competitive anxiety directly stimulates the autonomic nervous system and the hypothalamic-pituitary-adrenal (HPA) axis, resulting in elevated cortisol levels, increased heart rate, and muscle tension. While a moderate physiological boost can sharpen alertness and reaction times, extreme arousal severely impairs decision-making, motor coordination, and attentional focus [23]. The ultimate effect on performance - whether facilitative or debilitating - depends heavily on how this physiological activation interacts with cognitive worry. To effectively study and manage these multifaceted symptoms, researchers rely on validated psychometric instruments. State anxiety, which occurs immediately prior to an event, is frequently measured using the Competitive State Anxiety Inventory-2 (CSAI-2). This tool assesses self-confidence alongside cognitive and somatic anxiety, and remains a foundational instrument in sport psychology [25]. Conversely, the Sport Anxiety Scale-2 (SAS-2) is utilized to measure stable trait anxiety, specifically evaluating concentration disruption, worry, and somatic symptoms. The SAS-2 has demonstrated robust psychometric validity across diverse

cultural contexts, including extensive studies on Polish, Brazilian, and Chinese athletic populations [26–28]. The ability to differentiate between fleeting stress reactions and enduring anxiety traits is crucial for understanding the multidimensional nature of sports performance. Utilizing these scales, researchers have identified distinct anxiety profiles based on demographics and the nature of the sport. Competitors in individual disciplines (such as swimming, tennis, or gymnastics) generally experience higher anxiety than team sport athletes, likely due to the absence of shared responsibility and more intense personal scrutiny. Furthermore, female athletes tend to report greater somatic and cognitive anxiety compared to males. Age and competition level are also significant factors; elite competitors and adolescents show particularly high vulnerability to stress [26,29]. For example, young athletes preparing for critical national sports exams exhibit substantial concentration disruption and pre-competition worry [28]. Ultimately, the differences observed between professional and recreational athletes suggest that prolonged exposure to high-stakes environments, combined with training experience, fundamentally shapes an individual's psychological adaptation to stress.

5. Psychophysiological Integration: Anxiety and Cardiovascular Function

Heart rate variability (HRV) refers to the variability in the time intervals between successive heartbeats and is widely used as a non-invasive marker of autonomic nervous system (ANS) regulation. HRV is assessed through the analysis of consecutive normal-to-normal (NN) or R-R intervals recorded by electrocardiography [30]. Both short-term recordings and 24-hour Holter monitoring may be used for HRV assessment. Physiological factors such as physical activity, respiration, emotional stress, and environmental stimuli may influence HRV through changes in autonomic regulation. Among the most commonly used HRV parameters are SDNN, reflecting overall HRV, and RMSSD, commonly regarded as a marker of vagally mediated HRV [31]. In athletic populations, resting RMSSD values are often substantially higher than those observed in non-athletic individuals, with resting values in well-trained athletes frequently exceeding 40-50 milliseconds, reflecting enhanced vagal modulation and greater autonomic adaptability [32].

HRV is considered an indirect marker of autonomic flexibility and the organism's adaptive capacity in response to internal and external stressors [33]. The ANS regulates HRV through

the dynamic interaction between the sympathetic and parasympathetic nervous systems. Central autonomic regulation involves the hypothalamus and interconnected brain regions, including the amygdala, limbic cortex, and prefrontal cortex, which together participate in emotional processing and stress responsiveness. Under stressful conditions, sympathetic activation is associated with increased norepinephrine release from the locus coeruleus, resulting in elevated heart rate and reduced vagally mediated HRV indices [9,31]. Meta-analytic evidence suggests that anxiety disorders are associated with reductions in vagally mediated HRV indices, particularly RMSSD and HF power, indicating impaired autonomic flexibility and reduced stress adaptability [34,35].

Stress exposure additionally activates the hypothalamic-pituitary-adrenal (HPA) axis, initiating the release of corticotropin-releasing hormone (CRH) from the hypothalamus and ultimately leading to cortisol secretion. While acute activation of both the ANS and HPA axis may represent an adaptive response to competitive demands, chronic sympathetic dominance and prolonged reductions in HRV may contribute to maladaptive psychophysiological responses and impaired recovery processes. The parasympathetic nervous system appears to play a key role in stress mitigation by attenuating sympathetic activation and modulating HPA axis activity [9].

According to the Polyvagal Theory proposed by Stephen W. Porges, vagally mediated autonomic regulation plays a central role in emotional regulation, stress responsiveness, and adaptive behavioural functioning. The theory suggests that reduced vagal activity may impair the ability to effectively regulate emotional and physiological reactions to stress, potentially contributing to increased performance anxiety and decreased adaptability under competitive conditions. In this context, reduced HRV may reflect not only altered cardiovascular regulation but also impaired psychophysiological resilience [31].

Similarly, the Neurovisceral Integration Model proposed by Julian F. Thayer and colleagues suggests that HRV reflects the functional integrity of neural networks involved in emotional regulation and cognitive control, particularly the prefrontal cortex, amygdala, and central autonomic network. According to this model, higher vagally mediated HRV is associated with more efficient top-down regulation of emotional and stress responses, whereas reduced HRV may indicate impaired self-regulation and maladaptive responses to psychological stressors. Studies conducted in athletic populations support these assumptions, demonstrating negative associations between pre-competition anxiety and vagally mediated HRV indices. Lower

RMSSD values have been associated with increased cognitive anxiety, elevated perceived stress, and impaired autonomic recovery following competition [9].

These theoretical frameworks are supported by findings from studies conducted in athletes exposed to competitive stress. One study analysing HRV in esports athletes demonstrated that players on the winning team exhibited significantly higher RMSSD values during gameplay compared to losing players, suggesting greater vagal modulation and more adaptive autonomic regulation under stressful competitive conditions [36]. Similarly, athletes competing at a higher level in shooting sports demonstrated HRV profiles suggestive of greater parasympathetic modulation, including higher HF power and RMSSD values compared to lower-level competitors [32]. These findings may indicate that greater autonomic flexibility and more efficient vagal regulation are associated with improved emotional control and competitive performance.

Importantly, HRV should not be interpreted as a direct measure of sympathetic or parasympathetic nervous system activity, as HRV indices are influenced by multiple physiological, behavioural, and environmental factors [31]. Nevertheless, HRV remains a valuable psychophysiological marker for assessing stress adaptation, emotional regulation, and recovery capacity in athletes [9].

Taken together, the reviewed findings suggest that performance anxiety may influence athletic performance through interconnected psychological, autonomic, and endocrine mechanisms. Cognitive appraisal of competitive stressors may activate both the ANS and HPA axis, promoting sympathetic dominance and reductions in vagally mediated HRV indices. Reduced HRV may, in turn, reflect impaired emotional regulation, diminished adaptive capacity, delayed autonomic recovery, and poorer psychophysiological resilience. These bidirectional interactions form the basis of the proposed integrative psychophysiological model of performance anxiety and cardiovascular autonomic regulation in athletes.

6. Practical Implications

An analysis by Li et al. (2025) indicates that psychological interventions effectively reduce competitive anxiety, with individual athletes and adolescents showing a stronger, albeit more variable, response to therapy compared to adults and team sport participants. Expanding on this,

meta-analytic evidence confirms a large overall effect on anxiety reduction (SMD = -0.99), successfully decreasing both cognitive and somatic symptoms [21].

Among the available methods, traditional psychological skills training (PST) yields by far the highest efficacy when implemented in either very short or very long cycles, as medium-duration programs often lead to discouragement and cognitive overload [21,37]. While cognitive-behavioural therapy (CBT) remains widely implemented through cognitive restructuring and exposure-based coping, its standalone efficacy for anxiety reduction appears to be somewhat lower than these traditional PST protocols [21].

On the other hand, contemporary models such as the Mindfulness-Acceptance-Commitment (MAC) approach have gained substantial empirical support. MAC interventions produce some of the largest overall reductions in competitive anxiety, particularly regarding somatic symptoms, by improving attentional regulation, enhancing present-moment awareness, and reducing maladaptive rumination under pressure [38].

Furthermore, the authors noted that multidimensional tools specific to the sports context, such as the CSAI-2 questionnaire, are optimal for accurately monitoring therapeutic outcomes [39]. Nevertheless, future research in this area should rigorously standardize protocols and supplement subjective self-reports with objective biological markers, such as heart rate variability (HRV) and cortisol levels [21]. In fact, increasing attention is already being directed toward psychophysiological interventions like HRV biofeedback. By allowing athletes to consciously control their breathing patterns and autonomic nervous system activity, biofeedback effectively mitigates somatic manifestations such as elevated muscle tension, tachycardia, and respiratory dysregulation, showing especially favourable outcomes among junior competitors [38].

7. Limitations

Several limitations of this review warrant acknowledgement. The narrative design does not incorporate a formal systematic search protocol or structured quality appraisal, making the synthesis inherently susceptible to selection bias and reducing reproducibility. Substantial heterogeneity across the reviewed literature - in HRV recording conditions, analytical approaches, sport disciplines, competition levels, and anxiety measurement instruments -

precludes quantitative synthesis and complicates cross-study comparisons. Most available studies rely on small convenience samples drawn from single disciplines, limiting generalisability across the wider athletic population. The predominance of cross-sectional designs across the field restricts causal interpretation: whether autonomic dysregulation precedes anxiety, follows from it, or reflects shared physiological mechanisms remains unresolved. Furthermore, key confounders including sleep quality, nutritional status, menstrual cycle phase, and baseline autonomic tone were inconsistently reported or uncontrolled across studies. Finally, the integrative model proposed here, while evidence-informed, remains conceptual and awaits prospective validation in longitudinal and interventional research.

8. Conclusions

Performance anxiety appears to exert significant effects on cardiovascular autonomic regulation in athletes through interconnected psychological, autonomic, and neuroendocrine mechanisms. Current evidence consistently suggests that elevated competitive anxiety is associated with reduced vagally mediated heart rate variability, reflecting sympathetic predominance and diminished autonomic adaptability. These psychophysiological alterations may negatively influence athletic performance, recovery processes, and potentially long-term cardiovascular health.

Heart rate variability, particularly RMSSD and other vagally mediated indices, emerges as a promising non-invasive marker for monitoring stress adaptation, emotional regulation, and recovery capacity in athletes. Integrating psychophysiological assessment with psychological evaluation may therefore improve individualized athlete management and support earlier identification of maladaptive stress responses.

At the same time, the available evidence remains methodologically heterogeneous and largely cross-sectional. Future research should prioritize longitudinal and interventional studies using standardized HRV protocols and validated psychological measures to clarify causal relationships between anxiety, autonomic regulation, and performance outcomes across different athletic populations.

Overall, the integration of sport psychology, autonomic physiology, and cardiovascular monitoring may provide a more comprehensive framework for optimizing both athletic performance and athlete well-being.

Disclosure

The authors declare that there are no financial or personal relationships that could have inappropriately influenced the work reported in this paper.

Author Contributions

Conceptualization, S.J., J.S. and T.W.; methodology, J.S.; formal analysis, J.S. and M.Ś.; investigation, T.W., A.N.O., and M.Ś.; resources, T.W., A.N.O., and M.Ś.; data curation, T.W., A.N.O., and M.Ś.; writing-original draft preparation, T.W., A.N.O., M.Ś. and S.J.; writing-review and editing, S.J. and J.S.; supervision, S.J., J.S., and M.Ś.; project administration, S.J. All authors have read and agreed to the published version of the manuscript

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Acknowledgements

The authors thank colleagues for their valuable input.

Conflicts of Interest

The authors declare no conflicts of interest.

Declaration of generative AI and AI-assisted technologies

In preparing this work, the authors used ChatGPT for the purpose of improving academic English language, clarity, readability, consistency, and text formatting. After using this tool, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

References

1. Baggish AL, Wood MJ. Athlete's Heart and Cardiovascular Care of the Athlete. *Circulation*. 2011;123(23). <https://doi.org/10.1161/circulationaha.110.981571>
2. Sharma S, Merghani A, Mont L. Exercise and the heart: The good, the bad, and the ugly. *European Heart Journal*. 2015. <https://doi.org/10.1093/eurheartj/ehv090>
3. Rice SM, Purcell R, De Silva S, Mawren D, McGorry PD, Parker AG. The Mental Health of Elite Athletes: A Narrative Systematic Review. *Sports Medicine*. 2016. <https://doi.org/10.1007/s40279-016-0492-2>
4. Gouttebargue V, Castaldelli-Maia JM, Gorczynski P, Hainline B, Hitchcock ME, Kerkhoffs GM, Rice SM, Reardon CL. Occurrence of mental health symptoms and disorders in current and former elite athletes: A systematic review and meta-analysis. *British Journal of Sports Medicine*. 2019. <https://doi.org/10.1136/bjsports-2019-100671>
5. Woodman T, Hardy L. The relative impact of cognitive anxiety and self-confidence upon sport performance: A meta-analysis. *J Sports Sci*. 2003;21(6). <https://doi.org/10.1080/0264041031000101809>
6. John Camm et. al. Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology. *Eur Heart J*. 1996;17. <https://doi.org/10.1161/01.CIR.93.5.1043>
7. Shaffer F, Ginsberg JP. An Overview of Heart Rate Variability Metrics and Norms. *Frontiers in Public Health*. 2017. <https://doi.org/10.3389/fpubh.2017.00258>
8. 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. <https://doi.org/10.1007/s40279-013-0071-8>
9. Kim HG, Cheon EJ, Bai DS, Lee YH, Koo BH. Stress and heart rate variability: A meta-analysis and review of the literature. *Psychiatry Investigation*. 2018. <https://doi.org/10.30773/pi.2017.08.17>

10. Meeusen R, Duclos M, Foster C, Fry A, Gleeson M, Nieman D, Raglin J, Rietjens G, Steinacker J, Urhausen A. Prevention, diagnosis and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science (ECSS) and the American College of Sports Medicine (ACSM). *European Journal of Sport Science*. 2013. <https://doi.org/10.1249/mss.0b013e318279a10a>
11. Chrousos GP. Stress and disorders of the stress system. *Nature Reviews Endocrinology*. 2009. <https://doi.org/10.1038/nrendo.2009.106>
12. Porges SW. The polyvagal perspective. *Biol Psychol*. 2007;74(2). <https://doi.org/10.1016/j.biopsycho.2006.06.009>
13. Halson SL. Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine*. 2014. <https://doi.org/10.1007/s40279-014-0253-z>
14. Dong JG. The role of heart rate variability in sports physiology (Review). *Experimental and Therapeutic Medicine*. 2016. <https://doi.org/10.3892/etm.2016.3104>
15. Michael S, Graham KS, Oam GMD. Cardiac autonomic responses during exercise and post-exercise recovery using heart rate variability and systolic time intervals-a review. *Frontiers in Physiology*. 2017. <https://doi.org/10.3389/fphys.2017.00301>
16. Bellenger CR, Fuller JT, Thomson RL, Davison K, Robertson EY, Buckley JD. Monitoring Athletic Training Status Through Autonomic Heart Rate Regulation: A Systematic Review and Meta-Analysis. *Sports Medicine*. 2016. <https://doi.org/10.1007/s40279-016-0484-2>
17. Boyett MR, D'souza A, Zhang H, Morris GM, Dobrzynski H, Monfredi O. Viewpoint: Is the resting bradycardia in athletes the result of remodeling of the sinoatrial node rather than high vagal tone? *Journal of Applied Physiology*. 2013. <https://doi.org/10.1152/japplphysiol.01126.2012>
18. La Rovere MT, Pinna GD, Raczak G. Baroreflex sensitivity: Measurement and clinical implications. *Annals of Noninvasive Electrocardiology*. 2008. <https://doi.org/10.1111/j.1542-474x.2008.00219.x>
19. Bourdillon N, Yazdani S, Nilchian M, Mariano A, Vesin JM, Millet GP. Overload blunts baroreflex only in overreached athletes. *J Sci Med Sport*. 2018;21(9). <https://doi.org/10.1016/j.jsams.2018.01.008>
20. Gabrys K, Wontorczyk A. Sport Anxiety, Fear of Negative Evaluation, Stress and Coping as Predictors of Athlete's Sensitivity to the Behavior of Supporters. *Int J Environ Res Public Health*. 2023;20(12). <https://doi.org/10.3390/ijerph20126084>
21. Li H, Yang Q, Wang B. Effects of psychological interventions on anxiety in athletes: a meta-analysis based on controlled trials. *Front Psychol*. 2025;16. <https://doi.org/10.3389/fpsyg.2025.1621635>

22. Palazzolo J. Anxiety and performance. *Encephale*. 2020;46(2). <https://doi.org/10.1016/j.encep.2019.07.008>
23. Hardy L. Stress, anxiety and performance. *J Sci Med Sport*. 1999;2(3):227–33. [https://doi.org/10.1016/s1440-2440\(99\)80175-3](https://doi.org/10.1016/s1440-2440(99)80175-3)
24. Hardy L, Beattie S, Woodman T. Anxiety-induced performance catastrophes: Investigating effort required as an asymmetry factor. *British Journal of Psychology*. 2007;98(1). <https://doi.org/10.1348/000712606x103428>
25. Lundqvist C, Hassén P. Competitive State Anxiety Inventory-2 (CSAI-2): Evaluating the Swedish version by confirmatory factor analyses. *J Sports Sci*. 2005;23(7). <https://doi.org/10.1080/02640410400021484>
26. Tomeczak M, Kleka P, Walczak A, Bojkowski Ł, Gracz J, Walczak M. Validation of Sport Anxiety Scale-2 (SAS-2) among Polish athletes and the relationship between anxiety and goal orientation in sport. *Sci Rep*. 2022;12(1). <https://doi.org/10.1038/s41598-022-16418-6>
27. Silva-Rocha VV, de Sousa DA, Osório FL. Psychometric properties of the Brazilian version of the Sport Anxiety Scale-2. *Front Psychol*. 2019;10(MAR). <https://doi.org/10.3389/fpsyg.2019.00806>
28. Li S, Tang C, Guo C, Bu T. Psychometric properties of the Sport Anxiety Scale-2 for Chinese adolescent athletes taking the National Sports College Entrance Examination. *Front Pediatr*. 2023;11. <https://doi.org/10.3389/fped.2023.1161842>
29. Rawat K, Błachnio A, Suppan K. Psychometric Properties of the Polish Version of the Sports Anxiety Scale-2 (SAS-2). *Int J Environ Res Public Health*. 2023;20(14). <https://doi.org/10.3390/ijerph20146429>
30. Tiwari R, Kumar R, Malik S, Raj T, Kumar P. Analysis of Heart Rate Variability and Implication of Different Factors on Heart Rate Variability. *Curr Cardiol Rev*. 2021;17(5). <https://doi.org/10.2174/1573403x16999201231203854>
31. Ernst G. Heart-Rate Variability—More than Heart Beats? *Frontiers in Public Health*. 2017. <https://doi.org/10.3389/fpubh.2017.00240>
32. Lucini D, Marchetti I, Spataro A, Malacarne M, Benzi M, Tamorri S, Sala R, Pagani M. Heart rate variability to monitor performance in elite athletes: Criticalities and avoidable pitfalls. *Int J Cardiol*. 2017;240. <https://doi.org/10.1016/j.ijcard.2017.05.001>
33. ChuDuc H, NguyenPhan K, NguyenViet D. A Review of Heart Rate Variability and its Applications. *APCBEE Procedia*. 2013;7. <https://doi.org/10.1016/j.apcbee.2013.08.016>
34. Chalmers JA, Quintana DS, Abbott MJA, Kemp AH. Anxiety disorders are associated with reduced heart rate variability: A meta-analysis. *Front Psychiatry*. 2014;5(JUL). <https://doi.org/10.3389/fpsyg.2014.00080>

35. Koch C, Wilhelm M, Salzmann S, Rief W, Euteneuer F. A meta-Analysis of heart rate variability in major depression. *Psychological Medicine*. 2019. <https://doi.org/10.1017/s0033291719001351>
36. Machado S, Sant'Ana L de O, Cid L, Teixeira DS, Travassos B, Monteiro D, Nardi AE. Effects of a Playoff Match on Competitive Anxiety and Autonomic Regulation in Professional Esports Players. *Clinical Practice & Epidemiology in Mental Health*. 2025;21(1). <https://doi.org/10.2174/0117450179293069250507074009>
37. Ong NCH, Chua JHE. Effects of psychological interventions on competitive anxiety in sport: A meta-analysis. *Psychology of Sport and Exercise*. 2021. <https://doi.org/10.1016/j.psychsport.2020.101836>
38. Li L, Wang J, Li Q, Fu Q. The Effect of Different Psychological Interventions on Athletes' Competitive Anxiety: A Systematic Review and Bayesian Network Meta-Analysis. *Sports Med Open*. 2026 Dec 1;12(1). <https://doi.org/10.1186/s40798-026-01007-y>
39. Huang CJ, Webb HE, Zourdos MC, Acevedo EO. Cardiovascular reactivity, stress, and physical activity. *Front Physiol*. 2013 Nov 7;4:314. <https://doi.org/10.3389/fphys.2013.00314>