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Heart Rate Variability – Guided Training for Monitoring Training Quality in Recreational Athletes: A Narrative Review

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Abstract

Background: Managing training load in recreational athletes requires accounting for physical, lifestyle, and occupational stressors that influence recovery. Traditional fixed programs often overlook individual readiness. Heart rate variability (HRV), a non-invasive marker of autonomic balance and vagal tone, enables personalized monitoring.

Aim: To review evidence on HRV-guided training and provide practical recommendations for recreational athletes.

Materials and Methods: A narrative review was conducted using PubMed, Scopus, and Web of Science databases, focusing on studies published in the last 15 years. Inclusion criteria were studies on recreational athletes that compared HRV-guided adaptive training with traditional fixed-load programs. The analysis emphasized RMSSD and the coefficient of variation (CV) as primary indicators of autonomic function and recovery. Both short-term (daily/weekly) and long-term (multi-week) HRV-guided interventions were considered, including protocols for load adjustment based on individualized thresholds.

Results: HRV-guided training improves aerobic capacity and endurance more efficiently than standard programs, even with fewer high-intensity sessions. It allows training during optimal

readiness, prioritizes recovery when needed, reduces non-responders, and facilitates precise load regulation.

Conclusions: Regular HRV monitoring with individualized interpretation of RMSSD and CV supports safe, personalized training. HRV-guided approaches optimize adaptation, manage fatigue, and minimize overtraining risk in recreational athletes.

Keywords: heart rate variability, HRV-guided training, exercise recovery, recreational athletes, wearable devices, autonomic nervous system, RMSSD, training adaptation

1. Introduction

Over the past decade, recreational sport has transformed from moderate, health-promoting activity to a structured training process in which amateur athletes increasingly undertake endurance challenges such as marathons, half-marathons, and triathlons. [1] This professionalization requires advanced monitoring systems to balance athletic goals with professional responsibilities, family obligations, and individual recovery capacity. Traditional periodization models, based on rigid multi-week or multi-month plans, often fail in working adult populations, as they do not account for non-training stressors or interindividual differences in adaptive capacity. In this context, heart rate variability (HRV) monitoring has emerged as an objective physiological tool for real-time individualization of training loads, supporting effective training management in recreational sport. [1]

HRV reflects physiological fluctuations in the intervals between consecutive heartbeats (R-R intervals) and indicates the dynamic balance of the autonomic nervous system (ANS), particularly the interaction between the sympathetic branch, responsible for arousal, and the parasympathetic branch (mediated by the vagus nerve), which facilitates recovery and homeostasis. [2] Elevated HRV generally indicates parasympathetic predominance, adequate recovery, high adaptive reserve, and enhanced responsiveness to training stimuli. Reduced HRV reflects relative sympathetic dominance and may signal training overload, accumulated fatigue, infection, or chronic psychophysiological stress. [3]

For recreational athletes with limited recovery opportunities, HRV monitoring enables a shift from "completing the training plan at all costs" to an adaptive model based on physiological readiness. This approach optimizes aerobic and muscular performance, reduces the risk of overuse injuries, endocrine dysregulation, and autonomic disturbances, and integrates physiological, psychological, and

environmental determinants within a holistic framework for athlete assessment. Despite its growing popularity, practical guidance on HRV implementation and interpretation in recreational training remains fragmented.

The aim of this article is to synthesize current evidence on HRV-guided training, including improvements in performance, recovery processes, immunological adaptation, and psychophysiological stress regulation. It also provides practical interpretative frameworks for coaches, sports medicine physicians, and athletes, supporting safe, effective, and individualized HRV monitoring in everyday practice. [4]

2. Physiological Basis of Heart Rate Variability

Understanding the mechanisms underlying HRV requires reference to both cardiac neuroanatomy and physiology. The heart does not beat with metronomic regularity; rather, its rhythm is continuously modulated by brainstem centers that integrate afferent input from baroreceptors, chemoreceptors, and higher cortical structures. [5] The sinoatrial (SA) node, as the primary pacemaker of the heart, receives dense autonomic innervation from both sympathetic and parasympathetic fibers, enabling rapid adjustments in heart rate in response to internal and external stimuli. The sympathetic branch accelerates heart rate and enhances myocardial contractility, while parasympathetic (vagal) input slows the heart and promotes energy conservation.

Beyond simple chronotropic modulation, these autonomic influences are dynamic and nonlinear, reflecting complex feedback loops between cardiovascular, respiratory, and central nervous systems. Respiratory sinus arrhythmia (RSA), for example, exemplifies parasympathetic modulation, where heart rate increases during inspiration and decreases during expiration. Additionally, afferent feedback from arterial baroreceptors provides beat-to-beat regulation of blood pressure, contributing to short-term HRV components, while higher cortical and limbic inputs allow integration of emotional and cognitive states with autonomic output.

At the cellular level, autonomic neurotransmitters, including acetylcholine and norepinephrine, influence pacemaker cell depolarization, modulating both the frequency and variability of SA node firing. These mechanisms ensure that HRV serves as a sensitive marker of the balance between sympathetic and parasympathetic tone, as well as overall physiological adaptability to stress, recovery status, and systemic homeostasis. In this context, HRV provides a non-invasive

window into autonomic nervous system function and the integrative regulation of cardiovascular physiology. [5]

2.1. Autonomic Nervous System and the Sinoatrial Node

The sinoatrial (SA) node, the heart's natural pacemaker, is densely innervated by autonomic fibers. The parasympathetic system, acting through the vagus nerve, releases acetylcholine, which binds to muscarinic receptors in SA node cells, prolonging the action potential duration and slowing heart rate. Due to the short half-life of acetylcholine, vagal effects are extremely rapid and can modulate the duration of each individual heartbeat, directly contributing to high heart rate variability (HRV). [6]

The sympathetic system, in contrast, releases norepinephrine, which acts on β1-adrenergic receptors to increase depolarization frequency of the SA node and enhance myocardial contractility. Sympathetic effects develop more slowly than parasympathetic influences, primarily manifesting in slower oscillations of heart rate, such as minute-to-minute or hourly variations. The balance between these two branches of the autonomic nervous system determines not only resting heart rhythm but also the organism's capacity to adapt rapidly to physical exertion, stress, or hemodynamic changes.

In a healthy athlete at rest, parasympathetic activity should predominate, reflected by a low resting heart rate, relatively high HRV, and an efficient chronotropic response. Disturbances in this balance, such as sympathetic dominance, may serve as early indicators of training overload, chronic stress, infection, or cardiovascular dysfunction. Therefore, HRV monitoring provides a non-invasive marker of autonomic and cardiovascular function integration, allowing assessment of both recovery status and the physiological response to training and environmental stressors. [7] In Table 1, the differences in the direction of action (acceleration vs. deceleration), impact on HRV, and response speed of both branches of the autonomic nervous system are illustrated, which is crucial for understanding the mechanisms regulating heart rate and its variability. [Tab.1]

Branch of ANS	Primary Neurotransmitter	Effect on Heart Rate	Effect on HRV	Response Speed
Parasympathetic (Vagal)	Acetylcholine	Decrease	Increase	Very Fast (beat-to-beat)
Sympathetic	Norepinephrine	Increase	Decrease	Slow (seconds to minutes)

Table 1. Comparison of the effects of autonomic nervous system branches on heart rate and HRV.

2.2. Respiratory Sinus Arrhythmia and Baroreflex

Respiratory sinus arrhythmia (RSA) is a fundamental contributor to heart rate variability, representing the dynamic influence of the parasympathetic nervous system. During inhalation, vagal activity is transiently suppressed, leading to an acceleration of heart rate, whereas during exhalation, vagal tone increases, slowing the heart rate. This beat-to-beat modulation highlights the rapid adaptability of parasympathetic control in response to metabolic and respiratory demands [8].

Complementing RSA, the baroreflex system is crucial for short-term blood pressure regulation. Baroreceptors located in the carotid sinuses and aortic arch detect changes in arterial pressure and relay signals to brainstem centers, which adjust parasympathetic and sympathetic output to stabilize heart rate and maintain adequate organ perfusion during postural changes, physical exertion, or other hemodynamic challenges [9].

In endurance athletes, enhanced RSA and baroreflex sensitivity are associated with improved cardiovascular efficiency and more stable HRV responses to training stress. These mechanisms facilitate better autonomic balance, optimize recovery, and increase resilience to chronic or

acute stressors, making their assessment essential for individualized training monitoring and performance management.

3. Methodology of HRV Analysis in Sports: Indicators and Their Significance

Heart rate variability (HRV) analysis involves the transformation of R–R interval signals obtained from electrocardiographic recordings or validated wearable monitoring systems into quantitative parameters reflecting autonomic nervous system activity and the physiological state of the organism. These signals represent the temporal variation between consecutive heartbeats and constitute a sensitive non-invasive marker of autonomic cardiac regulation. In the scientific literature related to sport and exercise physiology, three principal analytical domains are recognized: time-domain analysis, frequency-domain analysis, and nonlinear analysis. [10]

Time-domain indices are among the most widely used HRV metrics in sports science due to their methodological simplicity and reliability in short-term recordings. The most commonly applied parameters include the root mean square of successive differences between adjacent normal-to-normal intervals (RMSSD) and the standard deviation of normal-to-normal intervals (SDNN). RMSSD is considered a robust marker of parasympathetic (vagal) modulation and is particularly sensitive to short-term changes in autonomic regulation associated with training load and recovery status. SDNN reflects overall heart rate variability during the recording period and represents the combined influence of sympathetic and parasympathetic components of autonomic control.

Frequency-domain analysis provides additional insight into the spectral properties of HRV by decomposing heart rate oscillations into specific frequency bands. The most commonly analyzed components include low-frequency power (LF) and high-frequency power (HF), as well as the LF/HF ratio. The HF component is primarily associated with respiratory-related vagal modulation, whereas LF reflects a combination of sympathetic and parasympathetic influences and baroreflex-mediated cardiovascular regulation. Although the LF/HF ratio has historically been interpreted as an indicator of sympathovagal balance, contemporary research suggests that its physiological interpretation should be approached with caution due to the complex and multifactorial nature of autonomic interactions.

Nonlinear analytical methods capture the dynamic and complex properties of cardiac rhythm regulation that cannot be fully described by linear statistical metrics. Techniques such as entropy-based indices and graphical methods, including the Poincaré plot, allow assessment of the complexity, irregularity, and adaptive capacity of heart rate dynamics. These measures provide additional insight into the integrative regulation of cardiovascular function and may be particularly useful for detecting subtle changes associated with fatigue, training adaptation, and physiological stress.

Within the context of sports training, systematic HRV monitoring enables a more individualized approach to training load management by providing objective information about the athlete's current physiological readiness. Regular assessment of HRV parameters, particularly RMSSD and its day-to-day variability, supports optimization of training programs, facilitates early detection of accumulated fatigue, and may reduce the risk of non-functional overreaching and overtraining.

3.1. RMSSD as the Gold Standard for Sports Monitoring

The root mean square of successive differences between adjacent R-R intervals (RMSSD) is widely recognized as the most practical and reliable indicator of parasympathetic activity in athletes. [11] RMSSD reflects dynamic vagal regulation of heart rate, allowing assessment of the body's readiness for exercise and recovery capacity.

RMSSD has several unique features that make it particularly suitable for recreational athletes. First, it is more stable than frequency-domain measures, such as the high-frequency (HF) component, because it is less influenced by breathing rate or short-term heart rate fluctuations. Second, its short measurement duration—reliable data can be obtained from just a 60-second recording—facilitates morning monitoring and consistent use among individuals with active lifestyles. Third, RMSSD correlates directly with vagal tone, enabling evaluation of autonomic balance at rest and the body's response to training load. [12]

Other metrics, such as SDNN (standard deviation of all R-R intervals), reflect overall heart rate variability but are highly dependent on recording length, which limits their utility for short, daily HRV assessments. For this reason, RMSSD is considered the preferred parameter for monitoring physiological readiness, particularly in the context of recreational training and adaptation to variable exercise stressors.

3.2. Frequency-Domain and Nonlinear HRV Indicators

Spectral analysis of HRV allows the separation of the heart rhythm signal into components of different frequencies, enabling assessment of distinct regulatory mechanisms of the autonomic nervous system. The high-frequency component (HF: 0.15–0.40 Hz) is strongly associated with parasympathetic activity, primarily vagal tone, and reflects the heart's ability to rapidly adapt to short-term physiological changes such as respiration or muscular tension. The low-frequency component (LF: 0.04–0.15 Hz) has a more complex profile and is interpreted as a mixed marker, encompassing both sympathetic influence and baroreflex modulation. Historically, the LF/HF ratio was used as a simple indicator of sympathovagal balance, but contemporary research criticizes this interpretation due to the oversimplification of complex neurocardiological interactions. [13]

In recent years, nonlinear methods such as Detrended Fluctuation Analysis (DFA) have been developed, allowing the analysis of fractal properties of heart rhythm and the identification of metabolic thresholds and changes in autonomic regulation during exercise. This approach enables detection of subtle alterations in autonomic function that may be missed with classical time- or frequency-domain analysis. Nevertheless, for recreational athletes, resting RMSSD remains the most practical and valuable metric, serving as a reliable indicator of recovery, training readiness, and the body’s adaptive capacity during daily training. [14]

4. Reliability of Wearable Technology and Mobile Applications

The availability of modern monitoring technologies has significantly transformed recreational sports, allowing athletes to track training loads daily outside of laboratory settings. Traditional electrocardiograms (ECG), which require specialized equipment and trained personnel, have largely been replaced by wearable devices such as chest straps that record the heart's electrical signal, optical watches using photoplethysmography (PPG), and rings measuring pulse and heart rate variability. [15]

Studies indicate that modern wearable and mobile devices, when properly calibrated and used under optimal conditions, achieve high agreement with reference ECG measurements, particularly at rest or during moderate physical activity. Integration with mobile applications

enables automatic data processing, real-time HRV metrics, and long-term trend tracking, which are essential for individualizing training programs. However, measurement accuracy may decrease during high-intensity exercise or in the presence of signal artifacts caused by body movement, device misfit, or changes in peripheral blood flow. [15]

These technologies provide recreational athletes and their coaches with tools to make informed decisions regarding recovery management, load monitoring, and training adjustments, thereby enhancing both safety and training effectiveness.

4.1. ECG vs. Photoplethysmography (PPG)

The gold standard for heart rate measurement remains the traditional electrocardiogram (ECG) or specialized chest straps (e.g., Polar H10), which allow precise detection of the R wave and accurate analysis of R-R intervals. [16] Photoplethysmography (PPG), used in most smartwatches and rings, relies on measuring blood volume changes in the capillaries, indirectly assessing heart rate and heart rate variability (HRV). Although PPG is more susceptible to artifacts caused by movement, skin tone, ambient temperature, or device positioning, the latest algorithms applied under resting conditions, particularly during sleep, show near-perfect agreement with ECG, making PPG a practical monitoring tool for recreational athletes. [16] Furthermore, PPG-based devices offer continuous, long-term monitoring that would be impractical with traditional ECG, allowing the detection of subtle daily variations in autonomic activity that can inform training and recovery strategies.

4.2. Comparison of Consumer Device Accuracy

In recent years (2022–2025), numerous independent validation studies have evaluated the accuracy of HRV measurements in popular consumer devices. Findings indicate that the lowest errors in nocturnal HRV estimation (MAPE – Mean Absolute Percentage Error) occur in devices measuring signals from the finger (rings) or professional chest straps designed for exercise and recovery monitoring. [17] These devices reliably capture both time-domain (e.g., RMSSD) and frequency-domain parameters, which are essential for interpreting parasympathetic activity and overall autonomic balance.

In contrast, devices such as the Apple Watch or Garmin show high accuracy in measuring resting heart rate (RHR), but their precision in HRV assessment is generally lower compared

to specialized systems (e.g., Whoop, Oura). [17] For recreational athletes, low-cost solutions like smartphone-based applications (e.g., HRV4Training) offer a reliable alternative, enabling daily monitoring of recovery status and allowing training to be adjusted according to current physiological readiness. Importantly, consistent use of validated consumer devices can facilitate long-term trend analysis, helping athletes identify early signs of overreaching, chronic stress, or insufficient recovery, and supporting evidence-based modifications of training load to optimize performance and prevent injury. [17, 18]

Recent studies also emphasize that wearable technologies are increasingly used not only for monitoring physical activity but also for assessing sleep quality, stress levels, and overall recovery status, which are closely related to heart rate variability dynamics. [19] The integration of these multidimensional physiological indicators may further enhance the practical value of HRV monitoring in everyday training and lifestyle management among recreational athletes.

5. Comparison of HRV-Guided Training with Traditional Models

Key evidence for the utility of HRV-guided training in recreational sports comes from comparative studies, including randomized controlled trials (RCTs), in which one group follows a rigid, pre-planned training program, while the other adjusts intensity and volume based on daily morning HRV measurements. [20] These studies allow evaluation of the real impact of individualized training according to the current state of the autonomic nervous system, optimizing physiological adaptations and minimizing the risk of overtraining. Furthermore, recent evidence indicates that specific training modalities may differentially influence autonomic regulation assessed through HRV. For instance, a systematic review and meta-analysis by Xu and Peng demonstrated that isometric training interventions can lead to measurable improvements in heart rate variability parameters, suggesting enhanced parasympathetic modulation and cardiovascular adaptability. [21] Such findings further support the concept that training strategies informed by HRV monitoring may allow more precise adjustment of training loads in accordance with the athlete's physiological readiness.

5.1. Effectiveness in Improving VO_2max and Performance

Meta-analyses and systematic reviews indicate that HRV-guided training leads to greater or at least comparable improvements in maximal oxygen uptake (VO_2max) and endurance performance compared to programs with a fixed training structure, while simultaneously reducing the number of high-intensity training sessions. In the study by Vesterinen et al. (2016),

recreational runners in the HRV-guided group improved their 3000 m run time by 2.1%, whereas the traditionally trained group improved by only 1.1%, despite the HRV group performing approximately 25% fewer high-intensity sessions. [22]

These results are explained by the mechanism of optimizing the timing of training stimuli. High-intensity training (HIT) induces adaptation only when the body is in a state capable of processing the stimulus—that is, during parasympathetic predominance and high HRV. Performing HIT when vagal tone is suppressed (low HRV) can lead to excessive fatigue accumulation, inadequate physiological adaptation, increased risk of muscular strain, sleep disturbances, and, over time, decreased motivation and performance. Therefore, HRV monitoring allows dynamic adjustment of training intensity, promoting optimal adaptation, reducing the risk of overtraining, and enabling more effective planning of both high- and moderate-intensity sessions within the training cycle. [20, 22]

Moreover, HRV-based individualization accounts for extratraining factors such as occupational stress, sleep quality, and illness, which can influence autonomic function. This approach makes training more flexible and safer, allowing recreational athletes to achieve better results with lower cardiovascular and nervous system strain.

5.2. Reduction of Non-Responders

Standardized training programs often exhibit substantial heterogeneity in adaptive responses – while some athletes achieve significant gains in fitness and performance, others, comprising up to 20% of the population, show little to no improvement or may even experience performance decline. HRV monitoring significantly reduces the prevalence of such non-responders by allowing training loads to be adjusted according to the athlete's current physiological status. This approach ensures that each individual trains within their optimal adaptation window, increasing the likelihood of achieving desired training effects while minimizing the risk of cardiovascular, musculoskeletal, and autonomic system overload. HRV-guided training enables dynamic modification of intensity and volume based on daily fluctuations in autonomic nervous system activity, making the training process more individualized and safer for recreational athletes. [23]

6. Interpretation of Long-Term Trends and Daily Variability

For recreational athletes, a single HRV measurement has limited diagnostic and prognostic value. Systematic monitoring of long-term trends relative to the individual baseline is crucial for identifying both positive adaptations and early signs of overtraining or physiological overload. [24]

6.1. Weekly Average RMSSD

The weekly average RMSSD serves as an indicator of chronic adaptation to training stimuli. A consistent increase in RMSSD throughout a training cycle reflects improvements in aerobic capacity, cardiac efficiency, and overall cardiovascular fitness. In a population of female soccer players, changes in RMSSD during the first three weeks of the preparatory period strongly correlated with the final increase in VO_2max ($r = 0.90$). Conversely, a decline in RMSSD accompanied by an increase in external training load (e.g., distance covered or power output in watts) may serve as an early warning signal of non-functional overtraining, indicating the need for program adjustment to optimize adaptations and minimize the risk of injury or psychophysiological strain. [25]

This approach allows coaches and recreational athletes to make informed decisions regarding training volume and intensity, taking into account individual physiological responses and daily variations in recovery status, aligning with modern strategies for performance monitoring and overtraining prevention.

6.2. Coefficient of Variation

The coefficient of variation (CV), calculated as (SD/Mean)×100(SD/Mean)×100, provides insight into the stability of autonomic nervous system function in response to daily training loads and external stressors [25]. A low CV reflects homeostatic stability and efficient adaptation to training stress. Athletes with low CV typically exhibit better tolerance to endurance training, faster recovery after intense sessions, and a lower risk of accumulated fatigue, all of which support more effective long-term adaptation.

Conversely, a high CV indicates autonomic instability, which may result from inadequate recovery, irregular sleep, chronic psychological stress, or the accumulation of high-intensity training sessions. In practical terms, this means the autonomic nervous system becomes less

predictable and less responsive to training stimuli, increasing the risk of overtraining and performance decline.

Analyzing CV allows for more nuanced interpretations than mean RMSSD values alone. Research on elite triathletes has shown that a decrease in CV, when accompanied by a reduction in mean RMSSD, can serve as an early indicator of overtraining. This suggests that, despite lower HRV, the autonomic nervous system had become "rigid," failing to respond appropriately to daily training and recovery stimuli. Under such conditions, training adjustments—such as reducing intensity or incorporating additional recovery days—are necessary to restore autonomic flexibility and prevent further negative effects on performance and health [26, 27].

7. Confounding Factors in Recreational Athletes

Recreational athletes operate in an environment rich in diverse stressors that are less prevalent or better controlled in professional populations. Factors such as occupational demands, time pressure, irregular sleep, and alcohol consumption can significantly influence HRV measurements, potentially leading to misinterpretation of recovery status and training adaptation. [28] Ignoring these influences may result in inappropriate training decisions, excessive load, or inaccurate assessment of the organism's adaptive state.

7.1. Effects of Alcohol and Sleep Quality

Alcohol is one of the strongest lifestyle-related stressors affecting the autonomic nervous system. [28] Even moderate consumption (1–2 standard drinks) leads to a marked increase in resting heart rate and a significant decrease in RMSSD, which may persist for up to 17 hours post-consumption. This effect arises both from a direct influence of ethanol on vagal tone and from disruption of sympathetic regulation. Additionally, alcohol alters sleep architecture by reducing REM sleep, increasing awakenings, and impairing nocturnal recovery, thereby preventing full restoration of autonomic homeostasis. [30,31]

Recent large-scale studies involving over 21,000 Whoop device users demonstrated a strong correlation between elevated HRV coefficient of variation (CV) and frequent alcohol intake, low physical activity, and irregular sleep patterns. For recreational athletes, a low HRV reading in the morning after alcohol consumption should not be interpreted as a typical signal for post-training recovery but rather as an indicator of the toxic impact of ethanol on the autonomic

nervous system. Recognizing this distinction allows for more accurate differentiation between physiological fatigue and lifestyle-induced perturbations, which is crucial for precise load adjustment and effective recovery planning. [32]

7.2. Psychosocial Stress and Age

Occupational and other psychosocial stressors affect HRV in a manner similar to training load, leading to temporary sympathetic dominance and suppression of parasympathetic tone. Recreational athletes experiencing high levels of work-related or personal stress exhibit slower vagal recovery following training sessions, particularly after evening sessions of moderate or high intensity. This phenomenon can mask the true state of physiological adaptation, requiring HRV data to be interpreted in the context of individual non-sport stressors.

Additionally, HRV naturally declines with age, and the dynamics of this decline differ between sexes. In women, a characteristic U-shaped pattern is often observed around the age of 50, associated with menopause and hormonal changes, whereas in men, HRV tends to decrease linearly, gradually reducing parasympathetic responsiveness. Understanding these differences is crucial for individualizing decision thresholds and interpreting measurements in recreational athletes across different age groups. [33,34]

Table 2 illustrates key factors affecting HRV in recreational athletes, showing their impact on RMSSD, RMSSD CV, and performance. It highlights how lifestyle (e.g., alcohol, poor sleep) and physiological factors (age, BMI, functional overreach) can reduce RMSSD, alter CV, and impair recovery or adaptation. [Tab.2]

Tab. 2.

Factor	Effect on RMSSD	Effect on RMSSD CV	Performance Implication
Alcohol (High Dose)	Drastic Decrease	Increase	Impaired recovery; increased cardiovascular load
Poor Sleep	Decrease	Increase	Reduced adaptive capacity; neural

			fatigue
Aging (Male >40)	Decrease	Increase	Slower recovery; need for increased rest
High BMI	Decrease	Increase	Systemic inflammation; lower autonomic resilience
Functional Overreaching	Slight Decrease	Decrease	Potential stagnation; "autonomic stiffness"

8. Designing Decision Algorithms and Measurement Protocols

For HRV monitoring to effectively support the training process, it must be integrated with a clear and practical decision-making system that enables coaches or athletes to adjust training loads in real time. The most widely recognized approach is the concept of the "Smallest Worthwhile Change" (SWC), which determines when a change in HRV is sufficiently substantial to justify modification of the training plan. [35] Measurement protocols should include regular morning recordings under resting conditions to minimize the influence of environmental and lifestyle factors. Data should be analyzed from both short-term (daily fluctuations) and long-term (weekly and monthly trends) perspectives to identify chronic adaptive changes or early signs of overtraining. It is also critical to account for potential confounding factors, such as sleep quality, alcohol intake, and psychosocial stress, as these may significantly affect HRV interpretation and potentially lead to inappropriate training decisions.

8.1. Establishing the Baseline Window and Decision Thresholds

The first step in effective HRV monitoring is the establishment of an individual baseline window for each athlete. This period typically spans three weeks of observation under stable training and daily life conditions, without significant changes in training load. [36] Based on the collected data, the mean RMSSD and the coefficient of variation (CV) are calculated to serve as reference values for interpreting subsequent measurements. Inclusion of the standard deviation enables determination of the natural range of autonomic fluctuations, thereby

facilitating identification of meaningful deviations from the norm. Athletes can subsequently use a zone-based algorithm to dynamically adjust training intensity:

Green Zone (HRV within baseline): Indicates full physiological recovery, allowing completion of the planned training program, including high-intensity sessions (HIT).

Yellow Zone (Slight HRV decrease): Suggests partial fatigue or accumulating physiological stress. Training should be limited to low-intensity exercise or shortened in duration to prevent further fatigue accumulation.

Red Zone (Significant HRV decrease or downward trend for 2–3 days): Signals the need for recovery. These days should involve complete rest or very light activity aimed at circulation and mobility. [37]

This approach enables real-time management of training loads while minimizing the risk of overtraining and autonomic imbalance. Furthermore, decision thresholds can be individualized based on factors such as training status, age, and lifestyle characteristics, thereby enhancing the effectiveness of adaptive responses and ensuring safe participation in recreational training.

8.2. Practical Guidelines for Measurement

To obtain reliable and reproducible HRV data, recreational athletes should follow standardized measurement protocols. Measurements should be performed at a consistent time of day- ideally immediately after waking, before getting out of bed and after using the toilet- to minimize the influence of daily lifestyle factors. Body position is also an important consideration: an orthostatic test performed in a seated or standing position is more sensitive to signs of fatigue and autonomic instability, whereas measurements in the supine position may artificially increase vagal tone, resulting in falsely elevated HRV values (the so-called vagal saturation). Device selection should be based on scientific validation; reliable mobile applications such as HRV4Training or Elite HRV, as well as wearable devices (e.g., watches or rings) that monitor HRV during sleep, provide measurements most comparable to ECG standards. [37]

Consistency is essential- daily measurements enable detection of long-term trends and facilitate differentiation between genuine physiological changes and random variability. Measurements should be avoided after alcohol consumption, intense evening exercise, or disrupted sleep, as these factors may substantially distort HRV interpretation. Implementation of these procedures allows not only assessment of training readiness but also identification of potential risk factors for overtraining or psychophysiological stress.

9. Managerial and Social Aspects in Recreational Sport

Implementation of HRV monitoring provides health, social, and economic benefits. It reduces the risk of injury and chronic fatigue, which may lead to lower absenteeism and improved productivity. Event organizers and companies offering wellness programs can utilize HRV data to design safer and more sustainable physical activity plans. HRV monitoring also has preventive potential, enabling early detection of disturbances in autonomic nervous system function and signaling an increased risk of lifestyle-related diseases such as hypertension or metabolic disorders, thereby supporting the promotion of healthy living. [39, 40]

10. Conclusions and Perspectives

Heart rate variability (HRV) has emerged as a fundamental diagnostic tool for the physiological monitoring of recreational athletes. Shifting from traditional time-based models to physiology-guided periodization enables the optimization of adaptive potential while mitigating the risks of cumulative overload and chronic stress. Systematic HRV assessment provides a precise evaluation of the homeostasis between training stimulus and recovery- a factor of critical importance for individuals managing concurrent lifestyle stressors.

The analysis of RMSSD and CV indices facilitates the objective differentiation between exercise-induced fatigue and confounding variables, such as sleep deprivation, psychosocial stress, or hormonal fluctuations. This allows for evidence-based adjustments in training intensity and volume according to the athlete's current physiological readiness, thereby reducing the risk of non-functional overreaching (NFO).

Furthermore, the proliferation of wearable technologies and mobile applications has enhanced the accessibility and reliability of HRV data, provided that standardized measurement protocols are maintained. Long-term data aggregation enables the early detection of subtle trends indicative of autonomic nervous system dysfunction, metabolic disturbances, or incipient infection. While future integration with artificial intelligence holds promise for filtering confounding variables, HRV should be utilized as a decision-support tool rather than a solitary determinant, complementing the athlete’s subjective perception of well-being. Ultimately, the synergy between objective physiological metrics and self-awareness constitutes a key paradigm for enhancing training efficiency, long-term health, and sustained motivation in recreational sports.

Disclosure

Author's Contribution:

Conceptualization: JS, TL, MF

Methodology: JS, TL, MF

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