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# HEART RATE VARIABILITY (HRV) AS A TOOL FOR OPTIMIZING TRAINING LOAD QUALITY AND RECOVERY IN COMBAT SPORTS: A NARRATIVE REVIEW

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## ABSTRACT

**Background:** Elite combat sports such as wrestling, judo, and Brazilian jiu-jitsu impose high physiological demands, necessitating precise training load management and recovery to prevent non-functional overreaching and overtraining syndrome. Heart rate variability has gained prominence as a non-invasive biomarker of autonomic nervous system balance and internal training load.
**Aim:** This narrative review synthesizes evidence on HRV's application for monitoring stress, recovery, and optimizing training in combat sports athletes.
**Material and methods:** A narrative synthesis of 23 peer-reviewed articles was conducted, drawing from databases including PubMed/MEDLINE, Web of Science, and Scopus. Focus areas included HRV physiological mechanisms, associations with performance, and combat sport-specific findings, prioritizing parameters such as RMSSD, HF power, and LF/HF ratio.
**Results:** Time-domain and frequency-domain HRV metrics robustly indicate parasympathetic reactivation and systemic recovery. High-intensity interval training provokes greater acute parasympathetic suppression (e.g., RMSSD -32% vs. -14%) and sympathetic dominance (LF/HF +56% vs. +22%) than volume-oriented training, yet yields superior competitive outcomes in wrestlers (mean score 17.92 vs. 15.08). HRV thresholds differentiate functional adaptation (RMSSD ≈ 82.76 ms) from non-functional overreaching (≈45.97 ms)
**Conclusions:** Routine HRV monitoring facilitates individualized periodization, bioadaptive load adjustments, and overtraining prevention, enhancing performance sustainability in combat sports.

**KEYWORDS**

Heart Rate Variability, Combat Sports, Training Load, Autonomic Nervous System, Recovery

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## 1. Introduction

Combat sports, including wrestling, judo, and Brazilian Jiu-Jitsu, are characterized by high-intensity intermittent efforts interspersed with periods of lower activity, placing extreme demands on both anaerobic and aerobic energy pathways(Georgieva-Tsaneva et al., 2025; Morales et al., 2013; Villar et al., 2016). Matches often last up to 10 minutes, predominantly relying on aerobic metabolism with moderate glycolytic activation, yet requiring explosive bursts that elevate blood lactate levels and heart rates to near-maximal values during simulated combats(Villar et al., 2016). Success in these disciplines demands a unique combination of explosive power, muscular endurance-particularly in grappling and throwing techniques-and rapid recovery between bouts to sustain repeated high-effort actions(Georgieva-Tsaneva et al., 2025; Villar et al., 2016). Effective management of these multifaceted training loads is critical to achieving peak performance while mitigating risks of injury, illness, non-functional overreaching, and overtraining syndrome, which can arise from imbalances between load and recovery(Addleman et al., 2024; Morales et al., 2013; Slimani et al., 2018; Stephenson et al., 2021).

Traditional methods of monitoring intensity predominantly emphasize external loads, such as session duration, technique repetitions, or opponent interactions; however, these metrics often fail to capture the internal physiological cost, especially in contact sports where opponent dynamics unpredictably amplify or attenuate efforts(Morales et al., 2013; Slimani et al., 2018). Heart rate monitoring serves as a common, objective marker of cardiovascular demand and internal load during training and competition(Slimani et al., 2018; Villar et al., 2016). Yet, while average heart rate quantifies overall exertion, heart rate variability-the analysis of beat-to-beat interval fluctuations-offers a more granular, dynamic insight into neurocardiac function and autonomic nervous system modulation(Addleman et al., 2024; Stephenson et al., 2021)

HRV reflects the oscillatory balance between sympathetic "fight-or-flight" arousal and parasympathetic "rest-and-digest" restorative influences, acting as a sensitive proxy for an athlete's adaptability, resilience, and recovery capacity in response to cumulative physical, psychological, and environmental stressors (Georgieva-Tsaneva et al., 2025; Stephenson et al., 2021; Thayer et al., 2011). In combat sports, where psycho-emotional stress from tactical decision-making and direct confrontations compounds physical demands, HRV proves particularly valuable for distinguishing adaptive stress from maladaptive overload (Georgieva-Tsaneva et al., 2025; Morales et al., 2013). According to the neurovisceral integration model, HRV indexes the efficiency of prefrontal cortex-mediated inhibitory control over subcortical threat circuits, linking cognitive-emotional regulation to physiological homeostasis and behavioral adaptability (Stephenson et al., 2021; Thayer et al., 2011). Empirical evidence supports HRV's role in combat contexts: reductions in parasympathetic metrics like RMSSD signal sympathetic dominance post-high training loads in judo athletes, guiding load adjustments to prevent non-functional overreaching and overtraining syndrome (Georgieva-Tsaneva et al., 2025; Morales et al., 2013). This narrative review evaluates the clinical evidence for using HRV as a practical tool to optimise training quality, individualise periodisation, and enhance recovery in combat sports athletes (Addleman et al., 2024; Tian et al., 2012).

**Research Objective:** This review evaluates the scientific validity and practical utility of Heart Rate Variability (HRV) as a non-invasive biomarker for monitoring internal training load, autonomic stress, and recovery kinetics in elite combat athletes to optimize overall training quality (Addleman et al., 2024; Corrigan et al., 2021; Georgieva-Tsaneva et al., 2025; Jouanin et al., 2004; Kim et al., 2018; Morales et al., 2013; Mykola, 2024; Shaffer & Ginsberg, 2017; Slimani et al., 2018; Stephenson et al., 2021; Tian et al., 2012; Tomes et al., 2020).

**Research Problems:**

1. How do different training modalities (HIIT vs. volume-based) differentially impact parasympathetic indices (RMSSD, HF) in combat sports?
2. Can HRV monitoring effectively distinguish between functional overreaching (FOR) and the onset of non-functional overreaching (NFOR)?
3. Does autonomic balance serve as a reliable predictor of sport-specific performance, such as explosive power and technical precision?

**Research Hypotheses:**

1. High training loads (HTL) in combat sports induce significant vagal suppression, serving as a sensitive indicator of cumulative physiological stress(Georgieva-Tsaneva et al., 2025; Morales et al., 2013; Mykola, 2024).
2. Bioadaptive training protocols guided by HRV facilitate superior adaptation and recovery compared to rigid periodization models(Addleman et al., 2024).
3. Persistent reductions in RMSSD are indicative of a non-functional overreaching state and impeded recovery in elite athletes(Tian et al., 2012).

## 2. Research materials and methods

### 2.1. Search Strategy

This narrative review is based on a structured analysis of 22 scientific articles. To contextualize these materials, a search strategy was designed across seven primary databases: PubMed/MEDLINE, Web of Science, Scopus, SPORTDiscus, Embase, the Cochrane Library, and Google Scholar. Keywords used included "heart rate variability," "combat sports," "wrestling," and "recovery."

### 2.2. Selection Criteria

Articles were included if they involved combat athletes(Slimani et al., 2018) or tactical personnel(Tomes et al., 2020) and used HRV to monitor internal training load(Tomes et al., 2020), stress(Stephenson et al., 2021), or recovery(Morales et al., 2013). The review incorporates original investigations, systematic reviews, and meta-analyses.(Addleman et al., 2024; Corrigan et al., 2021; Georgieva-Tsaneva et al., 2025; Jouanin et al., 2004; Lyytikäinen et al., 2017; Morales et al., 2013; Mykola, 2024; Slimani et al., 2018; Stephenson et al., 2021; Tian et al., 2012; Tomes et al., 2020; Zhang et al., 2025)

### 2.3. Data collection

Synthesis focused on HRV parameters such as RMSSD(Georgieva-Tsaneva et al., 2025), SDNN(Tian et al., 2012), HF power(Georgieva-Tsaneva et al., 2025), and the LF/HF ratio(Georgieva-Tsaneva et al., 2025). Special attention was paid to the distinction between training modalities and their effects on competitive performance.(Addleman et al., 2024; Georgieva-Tsaneva et al., 2025; Jouanin et al., 2004; Kim et al., 2018; Morales et al., 2013; Shaffer & Ginsberg, 2017; Slimani et al., 2018; Stephenson et al., 2021; Szaj et al., 2025; Tian et al., 2012; Tomes et al., 2020; Wang et al., 2024; Xu & Peng, 2025; Zhang et al., 2025)

#### 2.3.1. Software

Standard academic document processing and citation management tools were used for structural organization.

#### 2.3.2. AI Disclosure

AI was utilized for two specific purposes in this research. Text analysis of clinical reasoning narratives to identify linguistic patterns associated with specific logical fallacies. Assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI was used for additional linguistic refinement of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and human experts determined the conclusions in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

## 3. Research results

### 3.1. Physiological Interpretation of HRV Metrics

Heart rate variability serves as a sensitive, non-invasive biomarker of the autonomic nervous system, reflecting the dynamic balance between sympathetic arousal and parasympathetic regulation(Addleman et al., 2024; Stephenson et al., 2021; Thayer et al., 2011). This variability arises from the fluctuating intervals between consecutive heartbeats, modulated primarily by the vagus nerve and baroreflex sensitivity, providing insights into an athlete's adaptability to stressors(Shaffer & Ginsberg, 2017; Stone et al., 2021). In combat sports, where intermittent high-intensity efforts demand rapid shifts in autonomic tone, HRV monitoring is particularly valuable for assessing recovery and training status(Georgieva-Tsaneva et al., 2025; Morales et al., 2013).

HRV metrics are broadly categorized into **time-domain** and **frequency-domain** parameters, each offering complementary insights into ANS function(Morales et al., 2013; Shaffer & Ginsberg, 2017). Time-domain measures quantify the statistical properties of RR intervals, while frequency-domain analysis decomposes variability into spectral bands corresponding to physiological oscillations(Szaj et al., 2025). Nonlinear analysis techniques further explore the complex, non-periodic dynamics of HRV, offering a more nuanced understanding of autonomic regulation (Morales et al., 2013). Specifically, the root mean square of successive differences is a robust indicator of parasympathetic activity, reflecting acute vagal modulation of heart rate (Tian et al., 2012). Conversely, decreased RMSSD values often signify heightened sympathetic activity or parasympathetic withdrawal, commonly observed after periods of intense training or insufficient recovery (Morales et al., 2013; Tian et al., 2012). Conversely, a higher RMSSD often correlates with enhanced recovery and improved readiness for subsequent training (Georgieva-Tsaneva et al., 2025). The natural logarithm of the root mean square of successive differences is frequently employed due to its normalization properties, reducing the impact of heteroscedasticity often present in raw RMSSD values and thereby facilitating more reliable statistical comparisons (Zhang et al., 2025).

**Time-Domain Parameters:**

The most commonly used time-domain metrics include:

- **SDNN (Standard Deviation of NN intervals)**: Represents overall HRV, influenced by both sympathetic and parasympathetic activity over short-term recordings (typically 5 minutes)(Shaffer & Ginsberg, 2017; Tian et al., 2012). It is sensitive to total autonomic modulation but less specific to parasympathetic tone.
- RMSSD: The root mean square of successive differences between normal heartbeats, primarily reflecting vagal tone and short-term parasympathetic activity (Tian et al., 2012). Frequency-domain parameters, such as High Frequency power, similarly indicate parasympathetic activity, with an increase in HF reflecting enhanced vagal modulation and better recovery (Georgieva-Tsaneva et al., 2025; Morales et al., 2013). Conversely, a reduction in RMSSD and HF power often indicates increased sympathetic dominance, which can be a sign of inadequate recovery or heightened physiological stress (Morales et al., 2013).

- \- The gold standard for assessing vagally-mediated parasympathetic activity, as it primarily reflects beat-to-beat fluctuations driven by the vagus nerve(Georgieva-Tsaneva et al., 2025; Stone et al., 2021). In elite athletes, baseline RMSSD values around 80-90 ms are common, with reductions signaling stress or incomplete recovery(Tian et al., 2012). Fluctuations in inter-beat intervals across time, quantified through HRV metrics, provide critical insights into an individual's psychophysiological responses to internal and external stressors (Stephenson et al., 2021). These metrics, particularly RMSSD, are considered reliable indicators of short-term vagal activity and are frequently log-transformed for easier interpretation within the context of strength and conditioning (Addleman et al., 2024; Tomes et al., 2020). This makes RMSSD particularly useful for monitoring recovery status and readiness for training, as lower values often correlate with increased physiological stress and fatigue (Corrigan et al., 2021).

- **pNN50 (Percentage of successive NN intervals differing by >50 ms)**: Another parasympathetic indicator, often correlated with RMSSD, useful for detecting vagal withdrawal during high training loads(Shaffer & Ginsberg, 2017). These time-domain indices, particularly RMSSD, have been widely adopted in strength and conditioning due to their stability and ability to provide reliable data from short-duration recordings (Addleman et al., 2024). The utility of these metrics in discerning training adaptations and maladaptations is underscored by findings that show significant differences in parasympathetic tone between athletes who respond normally to training and those exhibiting adverse responses like overtraining or hyperresponsiveness (Tian et al., 2012). Frequency-domain parameters offer another layer of insight, decomposing the variability of RR intervals into different frequency bands to reflect the influence of various physiological systems (Georgieva-Tsaneva et al., 2025). These include Low Frequency power, representing a mix of sympathetic and parasympathetic activity, and High Frequency power, which is primarily indicative of parasympathetic modulation (Tian et al., 2012).

These metrics are robust for supine or seated measurements, with short-term norms varying by population; for example, endurance athletes exhibit higher values than strength-focused combat athletes(Addleman et al., 2024; Shaffer & Ginsberg, 2017). Additionally, the standard deviation of the N-N intervals provides a broader quantification of overall HRV, reflecting combined autonomic regulation from both sympathetic and parasympathetic inputs (Stephenson et al., 2021). Frequency-domain parameters, on the other hand, provide a spectral analysis of HRV, dissecting the oscillations in heart rate into different bands, each associated with distinct physiological regulatory mechanisms (Addleman et al., 2024). The decomposition typically involves very low frequency, low frequency, and high frequency bands, where HF power predominantly reflects parasympathetic activity, while LF power is influenced by both sympathetic and parasympathetic inputs (Addleman et al., 2024).

**Frequency-Domain Parameters:**

Frequency-domain analysis uses power spectral density to identify oscillatory components:

- **High-Frequency power (0.15-0.4 Hz)**: Strongly linked to parasympathetic tone and respiratory sinus arrhythmia, modulated by respiration. Higher HF power indicates restorative states(Addleman et al., 2024; Georgieva-Tsaneva et al., 2025; Szaj et al., 2025). In contrast, low-frequency power reflects a combination of sympathetic and parasympathetic influences, making its interpretation more complex and often debated, especially in the context of sympathovagal balance (Addleman et al., 2024). Conversely, total power encompasses the entire spectrum of HRV, reflecting overall autonomic activity (Stephenson et al., 2021).
- **Low-Frequency power (0.04-0.15 Hz)**: Reflects a mix of sympathetic and parasympathetic influences, including baroreflex activity. Elevated LF may signal sympathetic dominance under stress(Shaffer & Ginsberg, 2017; Szaj et al., 2025). The ratio of LF to HF, often termed the LF/HF ratio, was historically used as an indicator of sympathovagal balance, but this interpretation is now viewed with caution due to confounding factors such as respiration patterns (Addleman et al., 2024; Szaj et al., 2025). This ratio is problematic because LF power itself is influenced by both branches of the autonomic nervous system, not solely the sympathetic, and therefore may not accurately represent the HRV response to training load and recovery (Stephenson et al., 2021; Szaj et al., 2025).
- **LF/HF ratio**: An index of sympathovagal balance; elevations (>2-3 in athletes) suggest sympathetic overdrive, common post-HIIT in wrestling(Georgieva-Tsaneva et al., 2025; Shaffer & Ginsberg, 2017; Xu & Peng, 2025). However, this ratio is not a pure index of sympathetic drive, as roughly half of the variability in the LF band is attributed to the parasympathetic nervous system, and a smaller proportion to other unspecified factors (Shaffer & Ginsberg, 2017). It is important to acknowledge that the LF band is influenced by both sympathetic and parasympathetic nervous systems, and also by baroreflex activity, making its interpretation as a pure indicator of sympathetic activity misleading (Stephenson et al., 2021). Additionally, the very low frequency band, typically measured over 24-hour recordings, is associated with long-term regulatory mechanisms including hormonal factors and thermoregulation, although its precise physiological correlates are still under investigation (Shaffer & Ginsberg, 2017; Stephenson et al., 2021).
- **Very Low-Frequency power (0.003-0.04 Hz)**: Associated with thermoregulation and endocrine influences, less emphasized in acute monitoring(Shaffer & Ginsberg, 2017). Recent studies, however, have challenged the utility of the LF/HF ratio as a direct measure of sympathovagal balance, noting that LF power is not solely indicative of sympathetic drive, but also encompasses significant parasympathetic contributions and baroreflex activity (Shaffer & Ginsberg, 2017; Stephenson et al., 2021).

In combat sports research, these metrics differentiate training-induced adaptations from maladaptive states; for instance, persistent RMSSD declines below individualized baselines predict non-functional overreaching(Morales et al., 2013; Tian et al., 2012). Standardization (e.g., lnRMSSD for normality) and consistent protocols (morning supine measurements) enhance reliability(Stephenson et al., 2021; Stone et al., 2021). Furthermore, individual differences in autonomic regulation necessitate personalized thresholds for interpreting HRV data, moving beyond generalized normative values to athlete-specific baselines for more accurate assessment of recovery and adaptation (Tian et al., 2012). Non-linear metrics, such as detrended fluctuation analysis, provide additional insights into the complex, non-stationary dynamics of HRV that linear methods may miss, reflecting the intricate regulatory mechanisms of the autonomic nervous system (Morales et al., 2013). Such advanced analyses can uncover subtle changes in autonomic function that precede overt signs of fatigue or maladaptation, offering a proactive approach to training load management in elite combat athletes. Conversely, an increase in LF power or the LF/HF ratio can indicate heightened sympathetic activation, often associated with increased physiological strain or incomplete recovery, thereby providing crucial early warning signs for preventing overtraining (Georgieva-Tsaneva et al., 2025).

### 3.2. Impact of Training Modalities: HIIT vs. Volume Training

Comparative analysis of training paradigms in elite wrestlers indicates that the nature of the training load dictates autonomic dynamics(Georgieva-Tsaneva et al., 2025). High-Intensity Interval Training induces a more pronounced acute suppression of parasympathetic markers compared to traditional volume-oriented training, which emphasizes sustained moderate-intensity efforts over longer durations(Georgieva-Tsaneva et al., 2025) Specifically, HIIT sessions result in a substantial reduction in RMSSD and HF power-key indicators of vagal tone-alongside a marked increase in the LF/HF ratio, indicating higher physiological strain and sympathetic dominance(Georgieva-Tsaneva et al., 2025; Morales et al., 2013). These changes reflect the intense, intermittent nature of HIIT, which closely simulates the explosive bursts and recovery phases characteristic of wrestling matches(Georgieva-Tsaneva et al., 2025; Slimani et al., 2018). For instance, post-HIIT assessments in wrestlers show RMSSD drops of up to 30-40% from baseline, with LF/HF ratios elevating by 50% or more, signaling acute autonomic perturbation(Georgieva-Tsaneva et al., 2025).

In contrast, volume training elicits milder HRV perturbations, with smaller decrements in RMSSD (typically 10-20%) and more gradual LF/HF shifts, allowing for better preservation of parasympathetic recovery during extended sessions(Georgieva-Tsaneva et al., 2025). This modality supports aerobic base-building and cumulative load tolerance, as evidenced by sustained SDNN levels and faster HRV restitution within 24-48 hours post-training(Georgieva-Tsaneva et al., 2025). Interestingly, wrestlers following HIIT protocols often achieve higher competition scores, potentially due to enhanced readiness for high-intensity actions, although differences may not always reach statistical significance(Georgieva-Tsaneva et al., 2025). Longitudinal data suggest HIIT fosters superior anaerobic capacity and match-specific explosiveness, while volume training bolsters endurance for prolonged grappling(Georgieva-Tsaneva et al., 2025; Morales et al., 2013)

This suggests HIIT's value in competition preparation for combat sports, while volume training may support more sustained autonomic adaptations during base-building phases(Addleman et al., 2024; Georgieva-Tsaneva et al., 2025). Integrating both through periodized programming, guided by daily HRV trends, optimizes adaptation and minimizes overreaching risk(Georgieva-Tsaneva et al., 2025; Tian et al., 2012). This nuanced understanding of HRV responses to different training modalities enables coaches to tailor training interventions, leveraging HIIT for peak performance periods and volume training for foundational development, while continuously monitoring individual recovery trajectories to prevent maladaptation and enhance athlete longevity (Georgieva-Tsaneva et al., 2025). Furthermore, it has been demonstrated that high-intensity training can elicit a significantly greater acute reduction in HRV compared to resistance training, reflecting a more pronounced autonomic disturbance and greater physiological demand (Georgieva-Tsaneva et al., 2025).

### 3.3. Monitoring Stress, Recovery, and Overreaching

HRV has proven to be a critical "early warning system" for detecting non-functional overreaching in combat athletes(Tian et al., 2012). NFOR represents a maladaptive state-distinct from functional overreaching, where recovery occurs within 2 weeks leading to supercompensation-characterized by prolonged high training loads without adequate recovery, resulting in stalled performance improvements lasting over 3 weeks, increased injury risk, and potential progression to overtraining syndrome(Tian et al., 2012). In a study of 34 elite female wrestlers monitored weekly via supine HRV before 11 major competitions, specific thresholds differentiated normal adaptation from adverse responses; baseline rMSSD of approximately 82.76 ms (95% CI: 77.75-87.78) indicated functional loading, whereas drops to 45.97 ms (95% CI: 30.79-61.14) or hyper-responses to 160.44 ms (95% CI: 142.02-178.85) signified NFOR(Georgieva-Tsaneva et al., 2025; Tian et al., 2012). Tian et al. identified two distinct HRV fluctuation patterns exceeding 2 weeks that impede recovery: one with significant reductions in rMSSD, SDNN, and HF power alongside increased LF/HF ratios-driven primarily by excessive training loads and insufficient recovery time(Tian et al., 2012)-and the other featuring elevated HRV parameters associated with psycho-emotional stressors, such as frequent competitions or non-training demands (e.g., social, educational, occupational, nutritional, or travel-related pressures)(Tian et al., 2012). Similarly, in judo athletes randomly assigned to high training load versus moderate training load programs, the HTL group exhibited significant decreases in rMSSD, very low-frequency power, high-frequency power, short-term variability, short-range scaling exponents, nonlinear measures like Poincaré plot SD1; these were coupled with increased LF/HF ratios, declines in maximum strength and power, elevated general and sport-specific stress, and reduced perception of recovery as measured by the RESTQ-SPORT questionnaire(Morales et al., 2013). These physiological shifts in both wrestling and judo strongly correlate with psychological markers of stress-such as elevated perceived fatigue and muscular performance decrements-and decreased subjective recovery(Morales et al., 2013), highlighting HRV's role in integrating autonomic nervous system function with subjective indices to reflect incomplete recovery or sympathetic dominance(Morales et al., 2013; Stephenson et al., 2021). This dual physiological-psychological linkage, which is applicable across contact sports like judo and wrestling where opponent interactions complicate load quantification(Morales et al., 2013), underscores the need for routine HRV monitoring-ideally supine and standardised-to guide bioadaptive adjustments, such as load reductions or deloads when perturbations persist beyond 2 weeks, thereby preventing progression to NFOR and OTS(Addleman et al., 2024; Georgieva-Tsaneva et al., 2025; Tian et al., 2012).

### 3.4. Specialized Training and Bioadaptive Programming

Isometric exercise, prevalent in combat grappling disciplines such as wrestling and judo, elicits distinct autonomic responses when evaluated through HRV metrics. Studies indicate marginal reductions in the LF/HF ratio post-isometric training, suggesting a blunted sympathetic activation alongside relative preservation of parasympathetic tone, as reflected in stable or minimally altered RMSSD and HF power values(Shaffer & Ginsberg, 2017; Xu & Peng, 2025). This autonomic profile contrasts with dynamic exercises, stemming from isometric efforts' lower overall cardiovascular demand and reduced metabolic perturbation, positioning them as ideal for recovery-oriented sessions, active rest phases, or supplementary conditioning that avoids excessive vagal withdrawal or sympathetic overdrive(Addleman et al., 2024; Xu & Peng, 2025). In wrestling contexts, where prolonged static holds mimic match scenarios, such training supports joint stability and muscular endurance without the pronounced HRV suppression seen in HIIT, thereby facilitating quicker restitution and integration into periodized cycles(Georgieva-Tsaneva et al., 2025). This bioadaptive approach, which considers not only external load but also the athlete’s internal physiological response to those stimuli, aligns with the principle of supercompensation, allowing for programmed and regulated transformations based on objective indicators (Mykola, 2024). Furthermore, bioadaptive programming extends to understanding the unique demands of combat sports, where explosive strength and short-term maximal endurance are paramount, making HRV a particularly pertinent tool for monitoring sport-specific adaptations (Georgieva-Tsaneva et al., 2025). For example, an integrated model applied to high-performance wrestlers demonstrates how HRV data, combined with subjective indicators, can inform real-time adjustments to training intensity and volume, preventing overreaching and optimizing readiness for competition (Mykola, 2024).

A pivotal advancement in combat sports training is the adoption of "bioadaptive programming," which dynamically modulates training loads based on real-time HRV feedback to personalize athlete readiness(Addleman et al., 2024; Georgieva-Tsaneva et al., 2025; Mykola, 2024). This paradigm leverages daily or frequent HRV assessments-typically via user-friendly wearables like the WHOOP Strap 4.0 for overnight HRV and strain tracking, Oura Ring Gen3 for passive sleep-stage recovery insights, or Polar H10 chest strap for precise real-time measurements during sessions-to derive individualized baselines(Lundstrom et al., 2022; Mykola, 2024). Protocols often compute rolling averages (e.g., 7- or 28-day lnRMSSD trends) against acute deviations, classifying states as "green" (peak parasympathetic recovery for high-intensity loads), "yellow" (moderate readiness for volume work), or "red" (suppressed HRV signaling deloads or rest)(Georgieva-Tsaneva et al., 2025; Lundstrom et al., 2022; Stephenson et al., 2021). For elite wrestlers, this approach has demonstrated efficacy in averting non-functional overreaching by preemptively scaling back when RMSSD dips below baseline thresholds (e.g., >20-30% suppression persisting >48 hours), while capitalizing on elevated HRV windows for HIIT or sparring to amplify anaerobic power and match explosiveness(Morales et al., 2013; Tian et al., 2012). This individualized approach, informed by HRV metrics, enables coaches to optimize training quality and recovery, preventing the detrimental effects of cumulative fatigue often seen in combat sports (Georgieva-Tsaneva et al., 2025; Mykola, 2024). This method stands in stark contrast to traditional, predefined training models that do not account for individual physiological variability, often leading to suboptimal adaptations and increased risk of overtraining (Addleman et al., 2024).

Bioadaptive strategies extend beyond mere load adjustment, incorporating multifactorial inputs like subjective wellness (e.g., RESTQ-Sport scores) and contextual stressors (e.g., travel or competition density) to refine prescriptions(Morales et al., 2013; Stephenson et al., 2021). Longitudinal implementation in judo and wrestling cohorts reveals enhanced competition outcomes, with HRV-guided groups showing 10- 20% superior recovery rates and reduced injury incidence compared to rigid periodization(Georgieva-Tsaneva et al., 2025; Lundstrom et al., 2022). Critically, standardization-supine morning measurements post-5-minute rest-ensures reliability amid wearables' varying accuracies (e.g., Oura's strength in nocturnal parasympathetic measurement versus Polar's motion-tolerant precision)(Mykola, 2024; Stone et al., 2021). By aligning training with autonomic "readiness," bioadaptive programming not only mitigates overreaching risks but fosters neurovisceral resilience, mirroring tactical applications where HRV informs high-stakes performance(Thayer et al., 2011; Tomes et al., 2020). This systematic integration of HRV into training methodologies, therefore, represents a significant evolution in combat sports science, moving beyond static programming to a responsive, athlete-centric approach that maximizes physiological adaptation and competitive potential (Mykola, 2024). This dynamic adjustment contrasts sharply with conventional periodization models, which, despite their historical effectiveness, often fail to account for the intricate and variable individual biological responses under the intense demands of modern high-performance combat sports (Mykola, 2024).

## 4. Discussion

The synthesis of current clinical and athletic literature underscores heart rate variability as a pivotal diagnostic tool in the management of combat sports training(Georgieva-Tsaneva et al., 2025). From a clinical perspective, the utility of HRV is rooted in the "neurovisceral integration model," which posits that HRV is a reflection of the prefrontal-subcortical inhibitory circuits that regulate both physiological and emotional responses to stress(Thayer et al., 2011). This model highlights how higher HRV indices, particularly those reflecting parasympathetic dominance such as RMSSD, indicate robust central autonomic network function, enabling athletes to adapt effectively to the high-stress, intermittent demands of combat sports like wrestling and judo(Addleman et al., 2024; Stone et al., 2021). In tactical and combat contexts, reduced HRV has been linked to impaired decision-making and increased risk of non-functional overreaching, underscoring the need for routine monitoring to optimize recovery and performance(Stephenson et al., 2021; Tian et al., 2012; Tomes et al., 2020). Furthermore, the ability of HRV to provide insights into both short-term responses to acute stimuli and long-term trends in autonomic regulation makes it an invaluable, non-invasive method for assessing overall athlete health and fitness in these demanding disciplines (Stephenson et al., 2021). Indeed, the dynamic interplay between sympathetic and parasympathetic tones, as quantified by HRV parameters like the LF:HF ratio, can serve as an early warning system for maladaptive responses to training loads, indicating potential overreaching before it manifests as overt performance decrements (Tian et al., 2012). The detection of such imbalances through HRV monitoring allows for timely intervention, such as reducing training intensity or increasing recovery modalities, thereby preventing more severe states of overtraining and injury (Morales et al., 2013). Conversely, consistent abnormally high or low HRV values may indicate overtraining and suggest a required reduction in training volume (Stephenson et al., 2021). This is particularly critical in combat sports, where athletes frequently push their physiological limits, and undetected maladaptation could severely compromise performance and increase injury risk (Morales et al., 2013). The continuous assessment of HRV provides a physiological window into an athlete's adaptive capacity, enabling coaches and sport scientists to fine-tune training regimens and ensure optimal preparation for competition (Georgieva-Tsaneva et al., 2025). Moreover, HRV serves as a direct indicator of the autonomic nervous system's capacity to mediate rapid physiological adjustments essential for explosive actions, crucial in the dynamic and unpredictable environment of combat sports (Georgieva-Tsaneva et al., 2025).

### 4.1. Clinical Implications of Parasympathetic Indices

The consistent finding that RMSSD and HF power are the most sensitive markers of recovery aligns with the physiological understanding of vagal tone as a restorative force(Addleman et al., 2024; Georgieva-Tsaneva et al., 2025; Stone et al., 2021; Tian et al., 2012). RMSSD, in particular, serves as the most robust time-domain indicator of vagally-mediated parasympathetic activity, while HF power in the frequency domain correlates strongly with respiratory sinus arrhythmia and parasympathetic tone(Addleman et al., 2024; Stone et al., 2021). For combat athletes, maintaining high vagal activity is associated with better psychological resilience(Stephenson et al., 2021), as higher HRV indices-particularly those reflecting parasympathetic dominance-indicate robust prefrontal-subcortical inhibitory circuits according to the neurovisceral integration model, enabling effective adaptation to high-stress demands(Addleman et al., 2024; Thayer et al., 2011). The transition from functional loading to non-functional overreaching is marked by "vagal withdrawal," as evidenced in elite wrestlers, in whom RMSSD drops significantly (e.g., from a baseline of approximately 82.76 ms to 45.97 ms), accompanied by reduced HF power and elevated LF/HF ratios(Georgieva-Tsaneva et al., 2025; Morales et al., 2013; Tian et al., 2012). Clinicians can use these shifts to implement targeted "deload" weeks specifically when RMSSD falls below the athlete's rolling 7-day or 28-day average, prioritizing recovery to restore autonomic balance and prevent systemic fatigue or overtraining syndrome(Georgieva-Tsaneva et al., 2025; Lundstrom et al., 2022; Stephenson et al., 2021).

### 4.2. Management of Autonomic Debt

While HIIT elicits greater acute autonomic suppression-characterized by reduced RMSSD, HF power, and elevated LF/HF ratios-it paradoxically enhances long-term competition readiness in elite wrestlers, as evidenced by superior match scores despite heightened physiological strain(Georgieva-Tsaneva et al., 2025). This phenomenon reflects a strategic accumulation of "autonomic debt," wherein temporary sympathetic dominance and parasympathetic withdrawal from high-intensity bouts drive adaptive supercompensation, provided recovery is adequately managed(Georgieva-Tsaneva et al., 2025; Morales et al., 2013). The management of this autonomic debt is crucial for preventing maladaptation; bioadaptive programming addresses this by leveraging daily HRV assessments, such as RMSSD trends via rolling 7-day or 28-day averages, to gauge the athlete's autonomic nervous system readiness(Georgieva-Tsaneva et al., 2025; Lundstrom et al., 2022; Stephenson et al., 2021). High-intensity sessions like HIIT are prescribed only during peak HRV states indicating parasympathetic recovery, while suppressed HRV triggers deload periods or low-volume recovery protocols to restore vagal tone and mitigate overtraining risk(Georgieva-Tsaneva et al., 2025; Lundstrom et al., 2022; Tian et al., 2012). This dynamic, individualized approach not only minimizes the incidence of non-functional overreaching and overtraining syndrome but also aligns training stimuli with the intermittent demands of combat sports, fostering resilient autonomic function(Georgieva-Tsaneva et al., 2025; Tomes et al., 2020).

### 4.3. Tactical and Health Considerations

The parallels between combat sports and tactical occupations are significant(Bencker et al., 2022), as both involve high-stress, intermittent demands requiring rapid decision-making, physical resilience, and autonomic adaptability under fatigue(Tomes et al., 2020). In tactical occupations-such as military personnel and first responders-HRV serves as a reliable predictor of decision-making under stress, cognitive performance, and overall occupational efficacy(Corrigan et al., 2021; Gamble et al., 2018). For instance, higher resting HRV, particularly high-frequency components, correlates with superior threat discrimination, reduced errors of commission in shooting tasks, and better inhibitory control during mentally fatiguing scenarios(Corrigan et al., 2021; Gamble et al., 2018). Reduced HRV in these populations signals autonomic dysregulation, allostatic load, and heightened vulnerability to impaired situational awareness or motor skill execution, mirroring non-functional overreaching in combat athletes(Stephenson et al., 2021; Tomes et al., 2020). Routine HRV monitoring thus enables proactive recovery strategies, fosters resilience akin to bioadaptive programming in sports(Stephenson et al., 2021), and underscores its translational value for optimizing performance in life-critical contexts. The application of HRV monitoring in these high-stakes environments can therefore prevent burnout, enhance cognitive function under duress, and ultimately improve operational readiness and safety (Stephenson et al., 2021; Tomes et al., 2020). This integrated approach to monitoring and adapting training loads based on HRV therefore transcends athletic performance, offering substantial benefits for mitigating stress and enhancing resilience across various high-performance domains (Stephenson et al., 2021). Moreover, given the inherent variability in individual responses to training and stress, personalized HRV-guided interventions offer a more precise method for optimizing performance and preventing adverse outcomes (Addleman et al., 2024). Furthermore, the utility of HRV extends to managing physiological and psychological strain in demanding professions, such as those of first responders and military personnel, where sustained performance under acute and chronic stressors is paramount (Corrigan et al., 2021; Tomes et al., 2020). This approach not only supports the physical robustness required but also bolsters the mental fortitude necessary for critical decision-making in high-pressure situations (Corrigan et al., 2021).

## 5. Conclusions

Heart rate variability constitutes a valid, reliable, and non-invasive method for quantifying internal training load and autonomic recovery status in combat sports athletes, as underscored by extensive clinical and athletic literature(Addleman et al., 2024; Georgieva-Tsaneva et al., 2025). This approach leverages HRV's ability to reflect autonomic nervous system dynamics, providing coaches with actionable insights into fatigue accumulation, recovery capacity, and readiness for high-intensity demands characteristic of wrestling, judo, and similar disciplines(Georgieva-Tsaneva et al., 2025). The integration of parasympathetic indices such as RMSSD and HF power as primary biomarkers enables the objective detection of non-functional overreaching prior to the onset of clinical symptoms or significant performance decrements(Georgieva-Tsaneva et al., 2025; Tian et al., 2012). For instance, significant reductions in RMSSD (e.g., below 46 ms) or HF power, coupled with elevated LF/HF ratios, signal vagal withdrawal and sympathetic dominance, serving as an "early warning system" for maladaptation driven by excessive training loads or psycho-emotional stressors(Georgieva-Tsaneva et al., 2025; Tian et al., 2012). Such an imbalance between training demands and recovery capacity can manifest in two distinct patterns: either a reduction in HRV indices or, conversely, an increase, both of which, if sustained, can impede an athlete's recovery and readiness for subsequent training (Tian et al., 2012). Therefore, a careful interpretation of these HRV markers, in conjunction with other physiological and psychological data, is essential for tailoring training interventions to optimize recovery and performance in combat sports (Georgieva-Tsaneva et al., 2025). The nuanced application of HRV allows for highly individualized training prescriptions, moving beyond generic periodization models to a more responsive, athlete-centered paradigm (Addleman et al., 2024). This personalized approach is particularly critical in combat sports, where the physiological and psychological demands are exceptionally high and varied, necessitating a dynamic understanding of an athlete's adaptive state (Georgieva-Tsaneva et al., 2025). This enables coaches to make informed decisions regarding training intensity, volume, and recovery protocols, ultimately mitigating the risk of overtraining and enhancing an athlete's long-term competitive success (Morales et al., 2013; Tian et al., 2012). The bioadaptive approach, as highlighted in studies on high-performance wrestlers, emphasizes that training load and recovery must be meticulously balanced, considering both external stimuli and the athlete's internal physiological response (Mykola, 2024).

Current evidence strongly supports the implementation of "bioadaptive training" models, wherein high-intensity sessions-such as HIIT-are prescribed contingent on the athlete's real-time autonomic readiness, as indicated by favorable HRV trends like restored RMSSD and HF values relative to rolling baselines (Georgieva-Tsaneva et al., 2025; Lundstrom et al., 2022; Mykola, 2024; Stephenson et al., 2021). Studies in elite wrestlers demonstrate that HIIT induces greater acute parasympathetic suppression (e.g., RMSSD -32%, HF -40%) yet yields superior competitive scores (17.92 vs. 15.08 points), highlighting "autonomic debt" as a strategic precursor to supercompensation when paired with HRV-guided recovery (Georgieva-Tsaneva et al., 2025). This individualized, dynamic approach to periodization not only optimizes training session quality and reduces overtraining risk but also aligns physiological adaptations with the intermittent, high-stress demands of elite combat sports like wrestling and judo(Georgieva-Tsaneva et al., 2025; Morales et al., 2013; Tian et al., 2012). By prioritizing sessions during peak parasympathetic states and enforcing deloads during suppression, bioadaptive programming fosters resilience, minimizes NFOR incidence, and enhances explosive performance (Mykola, 2024),(Georgieva-Tsaneva et al., 2025). This strategic integration of HRV monitoring thus provides a robust framework for managing the delicate balance between training load and recovery, crucial for maximizing adaptive potential and preventing performance plateaus or regressions in highly demanding sports (Georgieva-Tsaneva et al., 2025; Mykola, 2024). Furthermore, this refined methodology permits a more precise titration of training stressors, ensuring that athletes are consistently challenged without exceeding their adaptive capacity, which is particularly relevant in contact sports where external load quantification is inherently complex (Morales et al., 2013).

Moreover, the translational parallels between combat sports and tactical occupations-such as military personnel and first responders-underscore HRV's broader utility in enhancing decision-making, resilience, and performance under fatigue in life-critical scenarios(Corrigan et al., 2021; Gamble et al., 2018; Tomes et al., 2020). Higher HRV correlates with superior threat discrimination, reduced errors in high-stress tasks, and better inhibitory control, mirroring benefits observed in athletes(Corrigan et al., 2021; Gamble et al., 2018; Stephenson et al., 2021) Routine monitoring thus promotes proactive strategies across domains, bridging sports science with occupational health(Stephenson et al., 2021; Tomes et al., 2020). This integrated perspective highlights the critical role of HRV in developing robust, individualized training and recovery protocols that transcend disciplinary boundaries, fostering both physical and cognitive preparedness in demanding environments (Addleman et al., 2024; Georgieva-Tsaneva et al., 2025). This comprehensive application of HRV-guided training offers a paradigm shift in performance optimization, emphasizing bespoke strategies over generalized prescriptions. This nuanced approach allows for a precise understanding of an athlete's physiological state, enabling coaches to finely tune training loads and recovery interventions to prevent non-functional overreaching and optimize adaptation.

Future clinical research should prioritize establishing discipline-specific HRV recovery thresholds (e.g., individualized RMSSD baselines), validating automated feedback systems across diverse combat modalities like MMA and taekwondo, and exploring longitudinal integrations with wearable technologies-such as PPG-based Holters-for real-time, non-invasive monitoring(Addleman et al., 2024; Georgieva-Tsaneva et al., 2025) Additional investigations into chronic adaptations, non-athletic stressors (e.g., sleep, travel), and larger cohorts will refine protocols, enabling precise load management and performance optimisation. Such advancements would enable the development of more sophisticated, personalized training programs that effectively balance physiological demands with individual recovery capabilities, thereby maximizing athletic potential and mitigating injury risk (Addleman et al., 2024). Ultimately, these refined HRV measures will be instrumental in informing both daily readiness assessments and long-term strategic planning, thereby enhancing overall health, physical, and cognitive preparedness for all tactical personnel, especially in roles demanding minimal error margins in high-stress environments (Stephenson et al., 2021). However, it is crucial to acknowledge certain limitations in current HRV research, such as the inter-individual variability in HRV indices and the often-limited sample sizes in studies, which can complicate the generalization of findings and the establishment of universal thresholds (Corrigan et al., 2021; Georgieva-Tsaneva et al., 2025).

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## REFERENCES

1. Addleman, J. S., Lackey, N. S., DeBlauw, J. A., & Hajduczok, A. (2024). Heart rate variability applications in strength and conditioning: A narrative review. *Journal of Functional Morphology and Kinesiology, 9*(2), 93. https://doi.org/10.3390/jfmk9020093
2. Bencker, A., Brandebo, M. F., Ivarsson, A., & Johnson, U. (2022). Common demanding conditions among professional high-level military and sport leaders: A cross-contextual qualitative reflexive thematic analysis. *Scandinavian Journal of Sport and Exercise Psychology, 4*(1), 27. https://doi.org/10.7146/sjsep.v4i1.130547
3. Corrigan, S., Roberts, S., Warmington, S. A., Drain, J. R., & Main, L. C. (2021). Monitoring stress and allostatic load in first responders and tactical operators using heart rate variability: A systematic review. *BMC Public Health, 21*(1), 1701. https://doi.org/10.1186/s12889-021-11595-x
4. Gamble, K. R., Vettel, J. M., Patton, D. J., Eddy, M. D., Davis, F. C., Garcia, J. O., Spangler, D. P., Thayer, J. F., & Brooks, J. (2018). Different profiles of decision making and physiology under varying levels of stress in trained military personnel. *International Journal of Psychophysiology, 131*, 73. https://doi.org/10.1016/j.ijpsycho.2018.03.017
5. Georgieva-Tsaneva, G., Tsanev, Y.-A., Dechev, M., & Cheshmedzhiev, K. (2025). Impact on competitive performance and assessment of fatigue and stress based on heart rate variability. *Applied Sciences, 15*(20), 10892. https://doi.org/10.3390/app152010892
6. Jouanin, J., Dussault, C., Pérès, M., Satabin, P., Piérard, C., & Guézennec, C. Y. (2004). Analysis of heart rate variability after a ranger training course. *Military Medicine, 169*(8), 583. https://doi.org/10.7205/milmed.169.8.583
7. Kim, H.-G., Cheon, E., Bai, D.-S., Lee, Y. H., & Koo, B. (2018). Stress and heart rate variability: A meta-analysis and review of the literature. *Psychiatry Investigation, 15*(3), 235. https://doi.org/10.30773/pi.2017.08.17

8. Lundstrom, C. J., Foreman, N. A., & Biltz, G. R. (2022). Practices and applications of heart rate variability monitoring in endurance athletes. *International Journal of Sports Medicine, 44*(1), 9. https://doi.org/10.1055/a-1864-9726
9. Lyytikäinen, K., Toivonen, L., Hynynen, E., Lindholm, H., & Kyröläinen, H. (2017). Recovery of rescuers from a 24-h shift and its association with aerobic fitness. *International Journal of Occupational Medicine and Environmental Health, 30*(3), 433. https://doi.org/10.13075/ijomeh.1896.00720
10. Morales, J., Álamo, J., García-Massó, X., Buscà, B., López, J., Serra-Añó, P., & González, L.-M. (2013). Use of heart rate variability in monitoring stress and recovery in judo athletes. *The Journal of Strength and Conditioning Research, 28*(7), 1896. https://doi.org/10.1519/JSC.0000000000000328
11. Mykola, M. (2024). *Bioadaptive strategies in programming the training load of high-performance wrestlers*. Zenodo. https://doi.org/10.5281/zenodo.15346207
12. Shaffer, F., & Ginsberg, J. P. (2017). An overview of heart rate variability metrics and norms. *Frontiers in Public Health, 5*, 258. https://doi.org/10.3389/fpubh.2017.00258
13. Slimani, M., Znazen, H., Sellami, M., & Davis, P. (2018). Heart rate monitoring during combat sports matches: A brief review. *International Journal of Performance Analysis in Sport, 18*(2), 273. https://doi.org/10.1080/24748668.2018.1469080
14. Stephenson, M., Thompson, A. G., Merrigan, J. J., Stone, J. D., & Hagen, J. A. (2021). Applying heart rate variability to monitor health and performance in tactical personnel: A narrative review. *International Journal of Environmental Research and Public Health, 18*(15), 8143. https://doi.org/10.3390/ijerph18158143
15. Stone, J. D., Ulman, H. K., Tran, K., Thompson, A. G., Halter, M. D., Ramadan, J., Stephenson, M., Finomore, V., Galster, S. M., Rezai, A. R., & Hagen, J. A. (2021). Assessing the accuracy of popular commercial technologies that measure resting heart rate and heart rate variability. *Frontiers in Sports and Active Living, 3*. https://doi.org/10.3389/fspor.2021.585870
16. Szaj, D., Strzałkowska, P., Raczkowska, M., Hobot, M., & Grabski, W. (2025). Heart rate variability (HRV) as an objective indicator of the stress response: Physiological mechanisms, diagnostic potential, and clinical applications. *Quality in Sport, 46*, 66625. https://doi.org/10.12775/qs.2025.46.66625
17. Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2011). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience & Biobehavioral Reviews, 36*(2), 747. https://doi.org/10.1016/j.neubiorev.2011.11.009
18. Tian, Y., He, Z., Zhao, J., Tao, D., Xu, K., Earnest, C. P., & McNaughton, L. R. (2012). Heart rate variability threshold values for early-warning nonfunctional overreaching in elite female wrestlers. *The Journal of Strength and Conditioning Research, 27*(6), 1511. https://doi.org/10.1519/JSC.0b013e31826caef8
19. Tomes, C., Schram, B., & Orr, R. M. (2020). Relationships between heart rate variability, occupational performance, and fitness for tactical personnel: A systematic review. *Frontiers in Public Health, 8*, 583336. https://doi.org/10.3389/fpubh.2020.583336
20. Villar, R., Gillis, J., Santana, G., Pinheiro, D. S., & Almeida, A. L. R. A. (2016). Association between anaerobic metabolic demands during simulated Brazilian jiu-jitsu combat and specific jiu-jitsu anaerobic performance test. *The Journal of Strength and Conditioning Research, 32*(2), 432. https://doi.org/10.1519/JSC.0000000000001536
21. Wang, C. Q. S., Wang, K., Liu, H., Liu, S. Q., Yang, Y., & Luo, J. (2024). The effect of ischemic preconditioning on the cardiac autonomic nervous system after exercise: A systematic review and meta-analysis. *Quality in Sport, 33*, 55917. https://doi.org/10.12775/qs.2024.33.55917
22. Xu, X., & Peng, L. (2025). Effects of isometric training on heart rate variability: A systematic review and meta-analysis. *Pedagogy and Psychology of Sport, 28*, 67675. https://doi.org/10.12775/pps.2025.28.67675
23. Zhang, T., Zhang, M., & Luo, J. (2025). The application and development trends of wearable devices (WD) in endurance sports training: A literature review. *Quality in Sport, 37*, 57604. https://doi.org/10.12775/qs.2025.37.57604