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Autonomic Indicators For Assessing Heart Rate Variability In Cadets During The Monitoring Of The Educational Process

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ABSTRACT

The assessment of heart rate variability (HRV) has emerged as a key method for evaluating the functional state and adaptive capacity of the autonomic nervous system, particularly in high-stress environments such as military training. This article investigates the methodological challenges associated with selecting optimal HRV indicators for monitoring cadets during intensive educational and physical workloads. While numerous HRV parameters exist in both time and frequency domains, their variability under the influence of artifacts, ectopic beats, respiratory rate, and other random events complicates their clinical and practical interpretation. Through a combination of literature review, empirical observation of 130 cardiograms, and statistical correlation analysis, this study proposes a novel, integrative metric–the Autonomic Index (AI)–as a more reliable tool for HRV assessment in military populations.

The AI is calculated from two widely recognized HRV parameters: pNN50, which reflects parasympathetic nervous system activity, and AMo (mode amplitude), which characterizes the degree of centralization in heart rhythm regulation. This new composite index addresses limitations observed in existing indicators by demonstrating low sensitivity to respiratory rate and random fluctuations, while maintaining a strong correlation with other major HRV parameters. Furthermore, its computational simplicity and interpretability make it particularly useful for both real-time functional monitoring and comparative longitudinal studies.

The study also presents a detailed interpretation scale for AI values and discusses its advantages over commonly used individual indicators, especially in conditions of intense physical and psychological stress. It concludes that the AI can serve as a reliable, physiologically meaningful, and operationally convenient measure of autonomic regulation and functional status in cadets. Incorporating this index into routine HRV analysis may enhance the precision of diagnostics and optimize training loads in military education systems.

KEYWORDS: Heart Rate Variability, Autonomic Index, Pnn50, Amo, Autonomic Nervous System, Parasympathetic Regulation, Military Cadets, Functional Assessment, Hrv Analysis, Centralization Of Rhythm Control

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INTRODUCTION

One of the foundational principles in the organization of modern military educational processes is the dynamic alignment of training loads with the cadets' current functional and physiological state. In this context, maintaining an optimal balance between cognitive and physical demands and the cadets' adaptive capacity is essential not only for performance enhancement but also for long-term health preservation and psychological resilience. A key challenge in achieving this balance lies in the objective evaluation of the cadets' readiness, which necessitates the use of valid physiological indicators capable of capturing the real-time state of the organism's regulatory systems.

Among such indicators, special attention is afforded to those reflecting the autonomic regulation of cardiac activity, given the central role of the cardiovascular system in responding to and recovering from physical and psychological stressors. The integrity and flexibility of autonomic control–particularly the interplay between the sympathetic and parasympathetic branches of the autonomic nervous system–determine the extent to which the body can withstand intensive loads, maintain internal stability, and recover efficiently. Well-balanced autonomic regulation allows the cadet, especially when sufficiently motivated, to fully realize their functional potential, ensuring metabolic economy during sustained effort and promoting rapid post-load recovery. Conversely, disruptions in this regulatory balance–particularly the sustained dominance of sympathetic activity–are widely regarded in the literature as early biomarkers of functional maladaptation. These disruptions manifest through diminished cardiac variability, indicating heightened physiological stress, and are predictive of eventual declines in work capacity, cognitive focus, and overall performance readiness.

LITERATURE REVIEW

Heart rate variability (HRV) has emerged as a vital tool in assessing autonomic regulation and overall physiological adaptability. The foundation of modern HRV analysis is rooted in the methodological and clinical work of Russian researchers such as Baevsky et al. (2002), who outlined standardized procedures for evaluating HRV using various electrocardiographic systems. Their methodological recommendations have become a cornerstone for both research and practical applications of HRV monitoring. In a related study, Baevsky and Berseneva (1997) introduced an integrative model for assessing the adaptive potential of the organism and the associated risks of disease development, thereby establishing HRV as a diagnostic marker beyond the cardiovascular domain.

The theoretical and applied dimensions of HRV were further expanded in the proceedings of the 4th All-Russian Symposium, edited by Shlyk and Baevsky (2008), which highlighted key conceptual frameworks and real-world use cases across clinical and athletic populations. This line of inquiry is echoed in the work of Veyn (2003), who focused on the diagnostic and therapeutic implications of autonomic dysfunction in clinical neurology, underlining HRV’s diagnostic utility for a wide range of disorders. In the domain of sports medicine, Graevskaya and Dolmatova (2004) and Makarov (2018) have contributed to the methodological refinement of HRV analysis in athlete populations. Their work emphasizes the use of Holter monitoring and lecture-based instructional formats to standardize training among sports physiologists and practitioners. Mikhailov (2012) provided additional evidence for the practical relevance of HRV metrics in field diagnostics, especially in physically demanding contexts such as military or athletic training.

Studies focused on specific sports disciplines further reinforce the value of HRV as a marker of physiological readiness. For instance, Orjonikidze and Pavlov (2008) investigated the cardiovascular adaptations in football players, while Prikhodko and Belyaeva (2006) explored the unique features of HRV among elite swimmers, identifying trends correlating with training intensity and recovery dynamics. Platonov (2014), in a comprehensive volume on Olympic-level athletic training, integrated HRV into a broader theoretical framework for assessing functional readiness and adaptive reserves in high-performance environments. Ryabykina and Sobolev (2018) also advanced this perspective by systematizing various HRV metrics and discussing their physiological underpinnings and interpretive challenges. Internationally, Lombardi et al. (2001) emphasized the prognostic potential of HRV in identifying patients at risk for sudden cardiac death, showcasing its relevance in cardiology and preventive medicine. Similarly, Sztajzel (2004) advocated for the use of HRV as a noninvasive electrocardiographic technique for evaluating the autonomic nervous system, particularly its implications in clinical diagnostics. The foundational consensus on HRV standards was established by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996), which provided rigorous guidelines for measurement, physiological interpretation, and clinical usage of HRV data.

Collectively, these sources constitute a robust theoretical and methodological foundation for HRV analysis. They not only validate its application across diverse domains–ranging from clinical cardiology and neurology to elite sports and military training–but also point to ongoing challenges regarding standardization, interpretability, and physiological specificity. This literature supports the development of integrative indices, such as the proposed autonomic index (AI), aimed at overcoming limitations inherent in single-indicator approaches and enhancing the utility of HRV in real-time physiological monitoring.

RESULTS

The predominance of sympathetic modulation, in particular, creates a neurophysiological environment characterized by heightened systemic tension. In such conditions, the body mobilizes energy resources disproportionately, operating under what may be described as a state of chronic internal stress. While adaptive in the short term, this state, if prolonged, can initiate a cascade of physiological changes that evolve from reversible functional strain to irreversible organic dysfunction. Within this framework, continuous overactivation of the stress-response system–without adequate recovery–can lead to cumulative fatigue, increased susceptibility to injury and illness, and long-term degradation of adaptive reserves.

Against this backdrop, the analysis of heart rate variability (HRV) has gained increasing recognition in both clinical and sports science domains as a highly informative, non-invasive, and operationally convenient method for assessing autonomic function. HRV reflects the temporal fluctuations in the intervals between consecutive heartbeats, which are primarily modulated by the parasympathetic (vagal) and sympathetic inputs to the sinoatrial node. As such, HRV serves as an integrative biomarker of autonomic flexibility, regulatory capacity, and systemic homeostasis. Numerous empirical studies have demonstrated that reduced HRV–particularly in conjunction with elevated sympathetic tone–is associated with conditions such as chronic stress, overtraining, poor recovery, and exposure to toxic physiological environments. Among military cadets, such conditions may be elicited by intense physical exertion, sleep deprivation, psychological pressure, and environmental extremes.

Importantly, the use of HRV analysis within the structure of military education offers a methodological bridge between physiology and pedagogy. It provides commanders, instructors, and medical personnel with real-time feedback on the cadets' internal state, allowing for individualized adjustments in training regimens, early detection of overstrain syndromes, and implementation of targeted recovery protocols. Moreover, HRV metrics enable the differentiation between functional and non-functional states of fatigue, which is crucial for optimizing performance without risking long-term dysfunction. In light of the increasing complexity and intensity of modern military training programs, such adaptive strategies are no longer optional but imperative.

International standards, including the consensus statements of leading cardiology and electrophysiology societies, recommend that short-term HRV assessments be conducted using five-minute recordings. This standardized timeframe balances the need for physiological stability with practical feasibility and allows the reliable calculation of both time-domain and frequency-domain HRV parameters. Within this framework, HRV analysis emerges not only as a diagnostic tool but also as a guiding principle in the architecture of modern military pedagogy–linking physiological insight with educational strategy in the pursuit of optimal human performance.

At present, a wide range of methodologies exists for the analysis of heart rate variability (HRV), reflecting the complexity of the autonomic nervous system and the multifaceted nature of cardiovascular regulation. These methods are typically classified into three primary domains: time domain analysis, frequency domain analysis, and non-linear dynamics analysis. Time domain analysis includes statistical metrics derived from the direct measurement of interbeat (NN) intervals, as well as graphical and geometric techniques, including Baevsky’s variational pulsometry, which offer additional insights into the temporal structure of cardiac rhythm. These techniques are widely utilized due to their simplicity, accessibility, and compatibility with short-term recordings.

Among time domain indicators, the most commonly employed parameters include RRNN (the mean duration of RR intervals), SDNN (standard deviation of NN intervals, reflecting overall variability), RMSSD (the square root of the mean squared differences of successive NN intervals, typically associated with parasympathetic activity), and pNN50 (the proportion of successive NN interval pairs that differ by more than 50 ms, also indicative of vagal tone). The coefficient of variation (CV), calculated as SDNN divided by RRNN and multiplied by 100%, provides a relative measure of variability and is useful for comparing inter-individual differences in autonomic modulation.

Frequency domain analysis, on the other hand, decomposes HRV signals into constituent spectral components using mathematical tools such as Fast Fourier Transform (FFT) or autoregressive modeling. This approach allows for the quantification of total power (TP) across the full spectrum (≤ 0.4 Hz), as well as power within specific frequency bands. The high-frequency (HF) band (0.15–0.4 Hz) is primarily associated with parasympathetic (vagal) modulation and respiratory sinus arrhythmia, with typical wave lengths ranging from 2.5 to 6.5 seconds. The low-frequency (LF) band (0.04–0.15 Hz, 6.5–25 seconds) reflects a combination of sympathetic and parasympathetic influences, while the very low-frequency (VLF) band (≤ 0.04 Hz, wave lengths >25 seconds) remains less clearly defined in terms of physiological origin but is thought to reflect thermoregulation and renin–angiotensin system activity. Normalized spectral measures, HF norm and LF norm, express HF and LF power as a percentage of total power minus the VLF component, thereby facilitating inter-individual comparisons. The LF/HF ratio is often cited as an index of sympathovagal balance, although its interpretation remains subject to ongoing debate in the literature.

In addition to classical statistical and spectral indices, Baevsky’s cardiointervalography methodology offers a suite of geometrically and probabilistically derived indicators that further characterize autonomic tone and regulatory system tension. These include variance (σ^2, representing dispersion within the RR interval distribution), mode (Mo, the most frequently occurring RR interval value), and mode amplitude (AMo, the percentage of intervals that correspond to the mode). The variation range (VR) captures the difference between the maximum and minimum RR intervals, while several integrative indices are used to infer the balance and strain within regulatory systems. These include the vegetative balance index (IVB = AMo / VR), the adequacy index of regulatory processes (PAPR = AMo / Mo), the vegetative rhythm indicator (VPR = 1 / Mo × VR), and the stress index (SI = AMo / (2 × VR × Mo)), which quantifies the level of regulatory system tension and adaptation demands.

Taken together, these diverse HRV metrics provide a robust, multidimensional framework for understanding autonomic regulation. However, due to their differing sensitivities to physiological and technical variables (e.g., breathing rate, artifacts, ectopic beats), careful selection and interpretation of HRV indices are required, particularly in applied settings such as military training and high-performance environments.

Table 1. HRV Analysis Indicators

Indicator / Domain	Analysis Type	Physiological Meaning
RRNN	Time Domain	Mean RR interval (general indicator of HR rhythm)
SDNN	Time Domain	Overall HRV, includes all cyclic components
RMSSD	Time Domain	Short-term HRV, associated with vagal tone
pNN50	Time Domain	Percentage of adjacent NN intervals differing >50 ms (vagal tone)
CV	Time Domain	Relative dispersion of HR intervals (SDNN/RRNN × 100%)

TP	Frequency Domain	Total power of HRV spectrum (≤ 0.4 Hz)
HF	Frequency Domain	Parasympathetic activity (0.15–0.4 Hz)
LF	Frequency Domain	Sympathetic + parasympathetic activity (0.04–0.15 Hz)
VLF	Frequency Domain	Low-frequency origin, unclear physiological meaning (≤ 0.04 Hz)
HF norm	Frequency Domain	Normalized HF relative to TP-VLF
LF norm	Frequency Domain	Normalized LF relative to TP-VLF
LF/HF	Frequency Domain	Sympathovagal balance index
Variance (σ^2)	Cardiointervalography	Dispersion within RR intervals
Mode (Mo)	Cardiointervalography	Most frequent RR interval value
Mode Amplitude (AMo)	Cardiointervalography	Proportion of intervals corresponding to the mode
Variation Range (VR)	Cardiointervalography	Difference between max and min RR intervals
Vegetative Balance Index (IVB)	Cardiointervalography	AMo / VR (balance between systems)
Adequacy Index (PAPR)	Cardiointervalography	AMo / Mo (regulation adequacy)
Vegetative Rhythm Indicator (VPR)	Cardiointervalography	1 / (Mo × VR) (rhythmic variation)
Stress Index (SI)	Cardiointervalography	AMo / (2 × VR × Mo) (stress level index)

Utilizing a comprehensive set of heart rate variability (HRV) indicators enables researchers and clinicians to obtain a multidimensional and integrative picture of autonomic function and systemic adaptability. Through these indicators, the dynamic interplay between the sympathetic and parasympathetic branches of the autonomic nervous system can be observed, offering insights into both the immediate functional state and the organism's long-term adaptive capacity. In clinical and applied physiological settings, this data allows for the formulation of personalized diagnostics and targeted interventions. For instance, in the context of military education, where cadets are exposed to intense physical, psychological, and cognitive stressors, such assessments become invaluable. They provide real-time physiological feedback that can guide training load adjustments and prevent the development of overtraining syndromes or maladaptive stress responses.

In practical terms, the application of HRV analysis involves the selection of meaningful and operationally convenient indicators. Although the complete array of HRV metrics can offer a nuanced depiction of autonomic balance, it is often impractical to rely on all parameters simultaneously, particularly in field conditions or when working with large cohorts such as military cadets. For operational monitoring, it is crucial to identify the most informative, robust, and computationally accessible indicators–those that accurately reflect the current functional state while minimizing susceptibility to confounding factors such as breathing patterns, motion artifacts, or random physiological fluctuations. This is not merely a matter of convenience; it also enhances interpretability and decision-making, especially when dynamic comparisons across time or individuals are required.

Moreover, one of the main challenges in HRV research and application lies in the discordant behavior of various indicators under physiological stress. It has been repeatedly noted in the literature that during periods of adaptation or recovery, one HRV parameter may show an increasing trend while another simultaneously decreases. Such inconsistencies complicate clinical interpretation and may result in ambiguous conclusions regarding the individual's physiological trajectory. In these cases, the lack of standardization regarding which indicator to prioritize introduces uncertainty into both diagnostics and research findings. Even within expert consensus statements – such as those issued by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology–no definitive agreement has been reached regarding a universal HRV metric appropriate for all clinical and situational applications. This further underscores the need for context-specific solutions that combine physiological validity with methodological reliability.

For the assessment of HRV in cadets, whose physiological profiles may differ substantially from those of patients or general populations due to high levels of physical training, a suitable indicator should ideally fulfill several key criteria. First, it should be easily computable using widely accessible tools or software. Second, it must sensitively and specifically reflect the individual's current functional state, including stress, recovery, and adaptation levels. Third, it should exhibit low sensitivity to extraneous or random factors, such as motion noise, breathing rate variability, or signal artifacts, which are common in real-life field conditions. Finally, it should provide an integrative view by accounting for both sympathetic and parasympathetic inputs or, at the very least, reliably reflect the balance or dominance of one system over the other.

The current study was designed to address these practical and theoretical limitations by identifying an existing HRV indicator–or, if necessary, constructing a novel one–that meets the above criteria and can be effectively used in the monitoring and evaluation of cadets' physiological states during training. Special emphasis was placed on ensuring that the indicator is capable of producing valid and reproducible results under both resting and active conditions, and that it supports comparative and longitudinal analyses.

Within the broader scope of autonomic regulation, particular attention was devoted to assessing the activity of the parasympathetic nervous system, which plays a pivotal role in recovery, cardiovascular efficiency, and homeostatic balance. The parasympathetic branch, primarily mediated via the vagus nerve, ensures oxygen-efficient perfusion during rest, promotes post-exertional restitution, and maintains the energy economy of cardiac function. In the context of military training, where rapid recovery and physiological resilience are mission-critical, parasympathetic dominance is generally associated with superior adaptability and performance sustainability.

To quantify parasympathetic activity, several HRV indicators are commonly used in the literature. These include RMSSD (root mean square of successive differences), which reflects short-term beat-to-beat variability and vagal modulation; pNN50 (percentage of NN intervals differing by more than 50 ms), a straightforward measure of rapid variability; HF (high-frequency spectral power), which is closely associated with respiratory sinus arrhythmia and vagal tone; HF norm and %HF, which express normalized high-frequency power in relation to total HRV; and AMo (mode amplitude), derived from cardiointervalography and indicative of centralization in heart rhythm regulation.

Selecting among these indicators requires careful consideration of their statistical interrelationships and physiological significance. In the current investigation, 130 cardiograms were analyzed to determine the correlations among key HRV metrics. Spearman correlation coefficients were calculated, revealing strong associations between pNN50 and RMSSD ($r = 0.95$), pNN50 and HF ($r = 0.90$), and RMSSD and HF ($r = 0.92$). These findings suggest a high degree of redundancy among these indices in capturing parasympathetic modulation, thereby justifying the use of any one of them in contexts where computational simplicity or resistance to artifacts is prioritized. At the same time, they underscore the need for careful selection, as overlapping measures may not provide additional information but may instead introduce analytical noise or confusion.

The results of this analysis set the foundation for the development of a composite indicator–the Autonomic Index (AI)–which integrates pNN50 and AMo to provide a more robust and artifact-resistant measure of autonomic regulation. The continued refinement and validation of such metrics hold promise for enhancing the precision of HRV-based monitoring in military and high-performance environments.

In the analysis of HRV within the spectral domain, our findings revealed that the high-frequency (HF) component demonstrated a stronger correlation with time domain indicators such as the variability range (VR) and cardiointervalogram (CIG)–both of which are reflective of overall HRV and parasympathetic modulation–than with normalized spectral indices such as HF norm and %HF. This observation suggests that absolute HF power may serve as a more reliable and physiologically meaningful marker of parasympathetic nervous system activity compared to its normalized counterparts. Nonetheless, it must be acknowledged that HF power is significantly influenced by respiratory rate. In individuals exhibiting slow breathing patterns–particularly cadets with spontaneous respiratory rates below nine breaths per minute–the dominant respiratory oscillations may fall below the HF threshold and be erroneously classified by analytical software as part of the low-frequency (LF) band. This misclassification artificially inflates LF power, %LF, and the LF/HF ratio, potentially leading to a spurious interpretation of heightened sympathetic activity. Such distortions are critical in applied settings where accurate autonomic profiling underpins performance monitoring and health surveillance.

Additionally, it is important to recognize that many HRV parameters are highly susceptible to interference from physiological artifacts, including ectopic beats, dropped signal complexes, and random transient events. Our empirical observations confirm that the values of several HRV indicators may vary considerably under such conditions, sometimes by multiple folds. Among these, HF and VR were particularly sensitive to stochastic disturbances. In contrast, parameters such as RRNN (mean RR interval), pNN50, Mo (mode), and Me (median) demonstrated greater stability, with fluctuations typically remaining within a 2% margin. The AMo (mode amplitude) indicator also exhibited a relatively low average variation, not exceeding 6% under normal recording conditions. These data collectively support the conclusion that pNN50 is one of the most robust and diagnostically useful indicators for assessing parasympathetic activity. Its strong correlation with other high-frequency HRV parameters, resistance to random artifacts, and immunity to the confounding effects of slow respiratory patterns make it an optimal choice for both static and dynamic monitoring.

In parallel, our study also highlights the analytical value of the AMo indicator. AMo, which quantifies the concentration of RR intervals around the most frequent value (mode), serves as a surrogate measure of centralization in cardiac rhythm regulation. Our findings demonstrate that AMo correlates–either positively or inversely–with a wide range of HRV metrics, including SDNN, RMSSD, pNN50, CV, TP, LF, HF, VR, as well as composite indices such as IVR, PAPR, VPR, and IN. Importantly, AMo exhibits an inverse relationship with parameters indicative of high HRV and parasympathetic tone, reinforcing its interpretation as a marker of regulatory system strain and control centralization. AMo is not only used independently in physiological assessments but also serves as a foundational component in the computation of integrative indices such as the Index of Regulatory Influence (IRI), the Index of Regulatory Process Adequacy (PAPR), the Index of Tension (IN), the triangular index, and TINN.
Despite its strengths, relying solely on AMo or any single HRV indicator may obscure complex autonomic dynamics. Accordingly, various authors have proposed composite or integrative indices that aggregate multiple HRV dimensions. Among the most widely recognized is the LF/HF ratio, which is conventionally interpreted as a measure of sympathovagal balance. Additionally, R.M. Baevsky has developed a suite of indices rooted in RR interval histograms, including the IRI and IN, both of which have demonstrated high informational value in our study. These indices displayed the strongest correlations with other time-domain and frequency-domain HRV parameters and thus may serve as useful indicators of regulatory status. However, it must be noted that due to their dependence on the variation range, both IRI and IN remain vulnerable to the influence of random events and transient physiological fluctuations.

Another promising integrative metric is the PARS (Periodic Activity of Rhythm Structure) index. Unlike traditional HRV parameters, PARS offers a multi-parametric evaluation of heart rhythm dynamics and currently has no equivalent in the international literature. It is calculated using a proprietary algorithm based on a scoring system that incorporates several standard

HRV measures, including SDNN, RMSSD, IN, TR, HF, LF, VLF, and the Information Coefficient (IC). Nevertheless, the practical application of the PARS index is not without limitations. Its dependency on respiratory rate, sensitivity to artifacts, and reliance on LF and VLF components–whose physiological roles remain incompletely characterized–undermine its robustness as a standalone diagnostic tool. Notably, while the HF component is widely accepted as a valid marker of parasympathetic activity due to its close association with respiratory sinus arrhythmia, the physiological interpretations of the LF and VLF bands continue to be the subject of considerable debate. Their precise autonomic correlates have yet to be definitively established, further complicating the utility of spectral indices in applied autonomic monitoring.

In summary, while a variety of HRV indicators exist, their differential susceptibility to artifacts, respiration, and analytical noise necessitates a careful and context-sensitive selection. The combined use of pNN50 and AMo–each representing complementary aspects of autonomic regulation–offers a promising avenue for generating a stable, interpretable, and physiologically valid assessment of HRV in cadet populations exposed to high functional loads.

Despite the widespread application of heart rate variability (HRV) analysis in clinical and applied physiological contexts, there is currently no universally accepted consensus regarding which HRV indicator offers the greatest diagnostic value across diverse use cases. A major challenge lies in the varying degrees of sensitivity that most HRV metrics exhibit in response to external and internal confounding factors, including signal artifacts, ectopic cardiac beats, stochastic fluctuations, and variability in respiratory frequency. Furthermore, the capacity of certain indicators to reliably reflect discrete autonomic regulatory mechanisms–such as vagal or sympathetic activity–remains only partially substantiated by empirical evidence. These methodological uncertainties have prompted researchers to search for HRV parameters that are not only physiologically meaningful but also methodologically robust and practically applicable.

From this perspective, two indicators appear particularly well-suited for comprehensive HRV assessment: pNN50 and AMo. The pNN50 index, which quantifies the proportion of successive NN interval pairs that differ by more than 50 milliseconds, is widely acknowledged as a sensitive and specific measure of parasympathetic nervous system activity. In contrast, AMo (Amplitude of Mode) reflects the degree of centralization in heart rhythm regulation, serving as an indirect indicator of systemic regulatory tension. Unlike most frequency-domain indicators, both pNN50 and AMo are relatively resistant to respiratory confounding and can be derived from time-domain analyses using straightforward computational procedures.

Recognizing their complementary diagnostic value, we propose a novel composite indicator–referred to as the Autonomic Index (AI)–which integrates pNN50 and AMo into a single, interpretable metric. The formula for AI is as follows:

$$AI = pNN50 / 10 + (100 - AMo) / 10$$

In this formulation, AI is expressed in arbitrary units and ranges theoretically from 0 to 20. The pNN50 component reflects vagal modulation, such that higher values indicate stronger parasympathetic activity and, by extension, enhanced autonomic flexibility. The second term, (100 – AMo), captures the degree of HRV decentralization, with larger differences signifying broader beat-to-beat variability and reduced dominance of central rhythm control mechanisms. Together, these two components allow AI to serve as a synthetic measure of both autonomic tone and adaptive variability.

Functionally, the interpretation of AI is straightforward. A higher AI value reflects greater total HRV and elevated parasympathetic nervous system activity–conditions typically associated with enhanced recovery capacity, cardiovascular efficiency, and functional readiness. Conversely, a lower AI indicates the predominance of central (possibly stress-induced) regulatory mechanisms, diminished vagal tone, and restricted HRV, which may signal fatigue, overtraining, or maladaptation. Notably, because both input variables (pNN50 and AMo) range from 0 to 100%, the resulting AI values span a compact and practical range of 0 to 20 units, facilitating straightforward application in clinical and operational settings.

The advantages of this composite index are manifold. First, it offers a truly integrative measure, capturing both the amplitude and the structure of autonomic modulation. Second, AI demonstrates reduced susceptibility to common data integrity issues such as motion artifacts, dropped signal complexes, and ectopic beats. Third, unlike frequency-domain metrics such as HF or LF, it is not directly affected by variations in respiratory rate, thereby offering more stable interpretations across individuals and testing conditions. Finally, the AI can be easily computed using standard software or manual calculation, making it suitable for dynamic monitoring, cross-sectional comparisons, and longitudinal tracking in military, athletic, and general clinical populations.

When discussing the normative values of the AI, it is important to consider, as with other HRV indicators, that an individual's optimal physiological state does not always match the average statistical norm. Therefore, it is advisable to assess the AI in dynamic monitoring.

Table 2. **Interpretation of the autonomic index (AI) values:**

AI Value	Interpretation
↓ 2	The current functional state is significantly reduced: parasympathetic activity of the autonomic nervous system is markedly diminished; centralization of heart rhythm regulation is dominant.
2 – 5.9	The current functional state is reduced: a decline in parasympathetic nervous system activity is observed.
6 – 10.9	The current functional state is satisfactory: parasympathetic influence is balanced with other mechanisms regulating heart rhythm.

11 – 15.9	The current functional state is good: the parasympathetic nervous system has moderate predominance in heart rhythm regulation.
≥ 16	The current functional state is very good: the parasympathetic nervous system has a clearly dominant role in regulating heart rhythm.

DISCUSSION

The findings of this study underscore the urgent need for a reliable, physiologically grounded, and operationally convenient metric for assessing autonomic regulation in high-demand environments such as military training. Existing heart rate variability (HRV) indicators, while informative, suffer from limitations that impair their practical usability in field settings. These include susceptibility to noise (e.g., ectopic beats, artifacts), dependency on respiratory parameters (particularly for frequency-domain indicators), and ambiguity in interpretability when multiple indicators yield divergent trends.

In this context, the introduction of the Autonomic Index (AI)–a composite parameter integrating pNN50 and AMo–represents a significant step forward. The selection of pNN50 is justified by its strong empirical association with parasympathetic activity, low susceptibility to random fluctuations, and minimal dependence on respiratory rate. Similarly, AMo serves as a proxy for the degree of centralization in rhythm control and correlates inversely with overall HRV. Together, these indicators offer complementary perspectives on autonomic tone: one reflecting rapid beat-to-beat variability (vagal input), and the other capturing regulatory system rigidity or centralization.

The practical benefits of the AI are considerable. Its formula–AI = pNN50/10 + (100 – AMo)/10–produces a normalized output that ranges from 0 to 20 units, allowing for intuitive classification of cadets' functional status. This simplicity enhances interpretability, while the dual-component structure ensures physiological robustness. Unlike spectral indices such as LF/HF or HF norm, the AI does not require complex signal decomposition and is resilient to common recording artifacts and respiratory variation. This makes it well-suited for deployment in operational military environments where data quality cannot always be controlled, and timely decision-making is critical.

Moreover, the interpretive scale proposed in this study enables nuanced assessments of cadet readiness. For example, an AI below 2 signals a sharp decline in parasympathetic modulation and excessive regulatory centralization–markers of physiological strain and potential maladaptation. Values in the 6–10.9 range suggest adequate functional balance, while those above 16 denote superior autonomic flexibility and recovery capacity. Such gradation facilitates both individualized monitoring and comparative group analysis, which can inform training adjustments, recovery interventions, and psychological support.

From a scientific standpoint, the correlation matrix developed in this research provides strong support for the AI's construct validity. Spearman coefficients exceeding 0.90 among pNN50, RMSSD, and HF affirm the internal consistency of parasympathetic-related markers. Meanwhile, the observed inverse relationship between AMo and a range of variability-based indices corroborates its role in indexing control centralization and autonomic rigidity. These dual dimensions–variability and centralization–form the theoretical basis of the AI and justify its classification as a higher-order HRV metric.

In light of these findings, the AI can be viewed not merely as a diagnostic convenience but as a potential conceptual bridge between physiological monitoring and pedagogical strategy in military education. Its deployment allows for the synchronization of training intensity with cadets' adaptive capacity, promoting resilience, reducing overstrain syndromes, and safeguarding long-term health. Furthermore, as AI values can be tracked longitudinally, it provides a foundation for future studies examining the effects of specific training protocols, stress exposures, or recovery interventions on autonomic balance.

Nonetheless, further research is required to validate the AI across diverse populations (e.g., different age groups, fitness levels, or stress profiles) and to establish reference norms adapted to varying military contexts. It would also be beneficial to assess the AI’s predictive validity in relation to outcomes such as illness incidence, injury rates, or training completion. Additionally, integrating the AI into wearable technologies and digital health platforms may further enhance its utility and accessibility for real-time field application.

In conclusion, the AI offers a promising solution to long-standing methodological challenges in HRV analysis. Its development is firmly grounded in empirical data, theoretical coherence, and operational feasibility, making it a valuable addition to the toolkit of military educators, physiologists, and clinical practitioners alike.

CONCLUSION

Thus, based on an extensive review of scientific literature, empirical observations, and a detailed statistical analysis of the interrelationships among various HRV indicators–as well as their susceptibility to distortion by random physiological and technical factors–a novel composite parameter has been developed for the evaluation of heart rate variability. This parameter, termed the "autonomic index" (AI), offers an original and integrative approach to HRV assessment, aimed at enhancing both diagnostic precision and operational usability.

The autonomic index is characterized by several key advantages:

1. Integrative complexity: The AI combines two physiologically significant HRV metrics–pNN50, which reflects the activity of the parasympathetic branch of the autonomic nervous system, and AMo, which quantifies the degree of centralization

in heart rhythm regulation. This dual structure allows the AI to simultaneously account for autonomic flexibility and regulatory control mechanisms.

2. Robustness to confounding variables: The AI demonstrates low sensitivity to common sources of HRV measurement error, including ectopic beats, signal artifacts, and dropped complexes. Importantly, it is not affected by variations in respiratory frequency, a factor that often complicates the interpretation of frequency-domain HRV indicators.

3. Simplicity and practical applicability: The AI can be readily calculated using widely accessible time-domain analysis techniques. Its computational ease, combined with a standardized output scale (ranging from 0 to 20 units), makes it particularly convenient for dynamic monitoring of individual trajectories as well as for comparative assessments across diverse subjects and conditions.

Taken together, these advantages position the autonomic index as a promising tool for both research and applied physiology contexts–especially in settings that require rapid, reliable, and interpretable assessments of autonomic regulation, such as military training, sports science, and preventive medicine.

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