# Heart Rate Variability as a Physiological Biomarker of Academic Stress: Current Evidence and Future Directions

*Running Title: HRV and Academic Stress*

**Balaji Mallela**
ORCID ID: 0009-0004-2239-5792
MBBS Intern, Government Medical College, Kozhikode, Kerala, India

Corresponding Author
**Dr Sireesha Prabhala**
Consultant Radiologist, Apollo Hospitals
ORCID ID: 0009-0008-9298-7653

**Abstract**

Academic stress has become an increasingly important concern in contemporary educational environments, affecting students across secondary, higher, and professional education. Prolonged exposure to academic demands, examination pressure, competitive learning environments, and performance-related expectations has been associated with adverse psychological, cognitive, and physiological consequences. In recent years, Heart Rate Variability (HRV), a non-invasive measure of autonomic nervous system activity, has emerged as a promising physiological biomarker for evaluating stress-related responses and autonomic regulation.

This review aims to synthesize and critically evaluate the current evidence regarding the relationship between academic stress and HRV. A structured literature search was conducted across major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar. Literature identification and evidence mapping were further supported using the Elicit artificial intelligence-assisted research platform. Relevant studies investigating HRV in relation to academic stress, examination stress, cognitive workload, student well-being, and autonomic nervous system function were reviewed and synthesized.

The available evidence consistently indicates that increased academic stress is associated with alterations in HRV parameters, particularly reductions in indices reflecting parasympathetic activity and autonomic flexibility. Examination periods, sustained cognitive demands, and competitive academic environments have been shown to influence autonomic balance, often resulting in sympathetic predominance and reduced vagal modulation. Furthermore, HRV has demonstrated potential utility in understanding stress resilience, emotional regulation, cognitive performance, and overall student well-being.

Despite growing research interest, substantial heterogeneity exists in study designs, participant populations, HRV measurement protocols, and stress assessment methodologies. Future research should prioritize standardized assessment frameworks, longitudinal monitoring approaches, and the integration of wearable technologies for real-time physiological assessment. The current evidence suggests that HRV represents a valuable physiological biomarker for understanding academic stress and offers promising opportunities for future applications in educational, clinical, and preventive health settings.

***Keywords:*** *Heart Rate Variability; Academic Stress; Autonomic Nervous System; Stress Physiology; Educational Health*

## 1. Introduction

Academic stress has become an increasingly significant concern in modern educational systems, affecting students across secondary, higher, and professional education. Growing academic expectations, competitive learning environments, frequent examinations, performance-related pressures, and concerns regarding future educational and career opportunities contribute substantially to psychological stress and emotional burden(1,2). While moderate levels of stress may enhance motivation and performance, excessive or prolonged stress can adversely affect cognitive functioning, emotional well-being, academic achievement, and overall health.

The physiological response to stress is primarily mediated through the coordinated activity of the autonomic nervous system (ANS) and the hypothalamic-pituitary-adrenal (HPA) axis(3–6). Exposure to stressful situations activates sympathetic nervous system pathways, resulting in increased heart rate, elevated blood pressure, heightened vigilance, and the release of stress-related hormones. Conversely, parasympathetic activity, which is responsible for recovery, restoration, and physiological homeostasis, may become suppressed during periods of sustained stress. Chronic autonomic imbalance has been associated with a wide range of adverse outcomes, including anxiety, sleep disturbances, impaired concentration, emotional dysregulation, reduced resilience, and increased cardiovascular risk(7,8).

Heart Rate Variability (HRV) has emerged as one of the most widely studied non-invasive indicators of autonomic nervous system function. HRV refers to the natural variation in the time intervals between successive heartbeats and reflects the dynamic interaction between sympathetic and parasympathetic influences on cardiac activity(9–12). Rather than maintaining a perfectly regular rhythm, a healthy heart continuously adjusts its beat-to-beat intervals in response to internal physiological demands and external environmental challenges. Higher HRV is generally associated with greater autonomic flexibility, effective emotional regulation, enhanced stress adaptability, and better overall health, whereas reduced HRV has been linked to stress, fatigue, anxiety, depression, burnout, and several pathological conditions.

Over the past two decades, advances in psychophysiology, neuroscience, cardiology, and behavioural medicine have significantly expanded the application of HRV as a biomarker of physiological and psychological states(13–15). Researchers have investigated HRV in diverse populations, including athletes, healthcare professionals, military personnel, patients with psychiatric disorders, and individuals exposed to occupational or environmental stressors. A growing body of evidence suggests that HRV may serve as an objective physiological marker capable of quantifying stress responses and assessing autonomic adaptability under varying conditions(16–21).

Academic environments provide a particularly relevant context for investigating stress-related physiological changes. Students frequently encounter high-stakes examinations, intensive study schedules, academic competition, and performance expectations that may induce significant psychological and physiological stress responses. These stressors are especially pronounced among students pursuing demanding educational pathways, such as medical, engineering, and other professional training programs. Consequently, understanding the physiological mechanisms underlying academic stress has become an important area of interest for researchers, educators, and healthcare professionals alike(22–28).

Traditionally, academic stress has been assessed using self-reported questionnaires, psychological scales, and subjective evaluations. While such instruments provide valuable insights into perceived stress levels, they remain susceptible to reporting bias, individual differences in stress perception, and variations in emotional awareness. The increasing availability of objective physiological measures has therefore generated interest in identifying reliable biomarkers capable of complementing traditional psychological assessments. Among these biomarkers, HRV has emerged as a promising candidate due to its non-invasive nature, relative ease of measurement, and established association with autonomic nervous system regulation.

Despite increasing research interest, the literature examining the relationship between academic stress and HRV remains dispersed across multiple disciplines, including physiology, psychology, neuroscience, cardiology, educational medicine, and behavioural science. Differences in study populations, stress assessment methods, HRV measurement protocols, and analytical approaches have contributed to considerable variability within the existing evidence base. As a result, a comprehensive synthesis of current findings is necessary to clarify the physiological significance of HRV in academic settings and to identify emerging directions for future investigation.

The present review aims to critically examine the current evidence regarding heart rate variability as a physiological biomarker of academic stress. By exploring the physiological foundations of stress and autonomic regulation, reviewing existing empirical research, identifying key methodological challenges, and discussing future research opportunities, this review seeks to provide a comprehensive understanding of the role of HRV in assessing academic stress and promoting student well-being.

## 2. Methodology

### 2.1 Review Design

This study was conducted as a narrative literature review informed by a structured literature search strategy. The review aimed to synthesize and critically evaluate existing evidence regarding the relationship between heart rate variability (HRV) and academic stress across diverse student populations. The review further sought to identify current knowledge gaps, methodological challenges, and future research directions within this emerging field of investigation.

### 2.2 Information Sources

A comprehensive literature search was conducted using multiple electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar. To enhance literature discovery and evidence mapping, the Elicit artificial intelligence-assisted research platform was also utilized. Reference management, organization, and screening were performed using Zotero.

### 2.3 Search Strategy

Literature searches were conducted using combinations of keywords and search terms related to heart rate variability, academic stress, examination stress, student well-being, autonomic nervous system function, physiological stress responses, medical students, university students, cognitive workload, and psychophysiological stress assessment. Boolean operators such as AND/OR were employed to refine search results and improve retrieval accuracy.

### 2.4 Eligibility Criteria

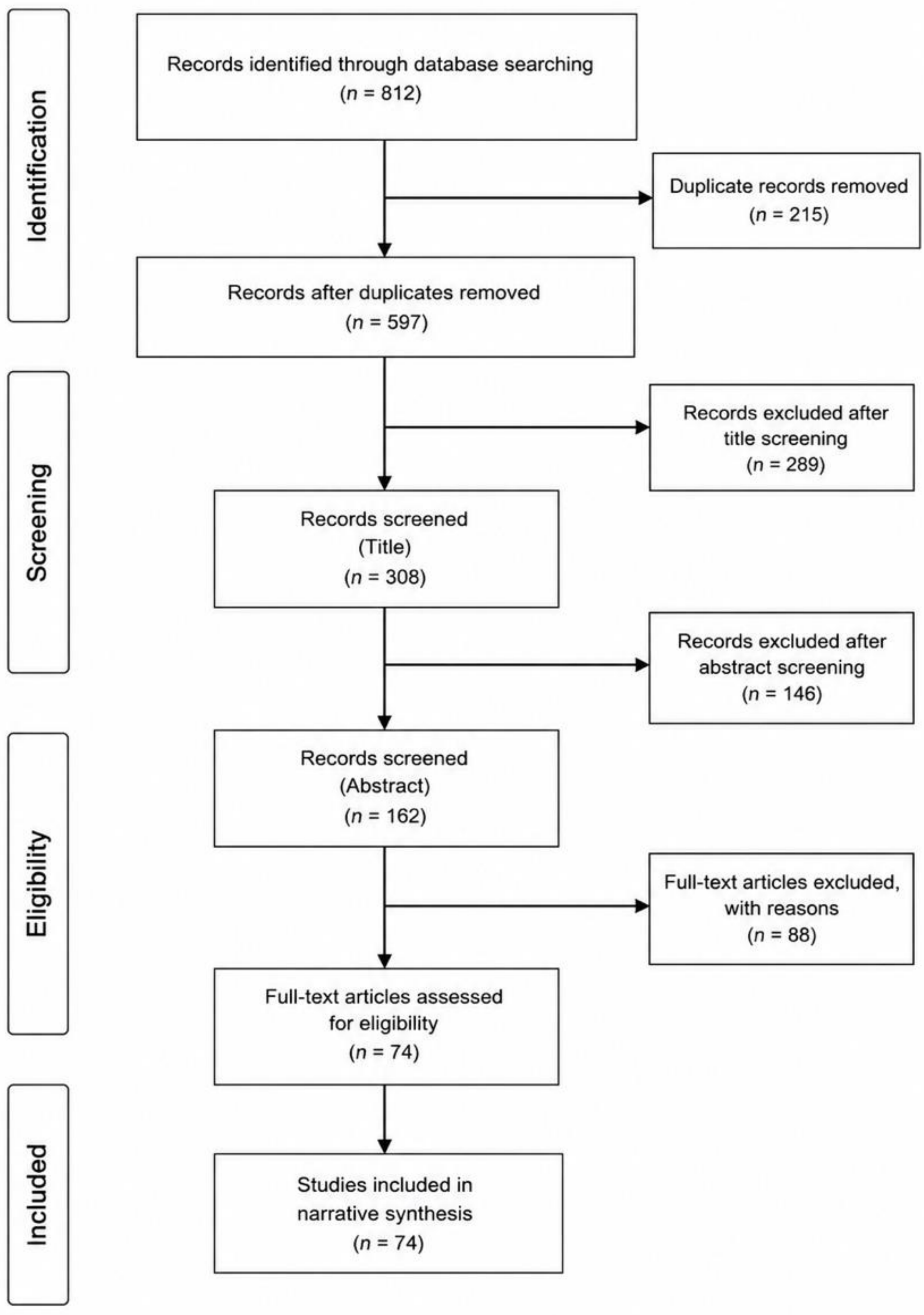
Studies were considered eligible for inclusion if they examined heart rate variability in relation to academic stress, examination stress, cognitive stress, psychological stress, student well-being, autonomic nervous system regulation, or related psychophysiological outcomes. Peer-reviewed journal articles, review papers, observational studies, longitudinal studies, cross-sectional investigations, and relevant theoretical contributions published in English were considered for inclusion.

Studies focusing exclusively on unrelated clinical populations, non-human subjects, or topics not directly contributing to the understanding of HRV and academic stress were excluded from detailed analysis.

### 2.5 Study Selection and Data Management

The initial literature search identified a substantial body of potentially relevant publications. Titles, abstracts, and keywords were screened for relevance to the review objectives. Following screening and preliminary assessment, 166 articles were retained within the Zotero reference database for detailed evaluation and thematic synthesis. Duplicate records were removed during the screening process, and studies were categorized according to their primary focus areas, including stress physiology, autonomic nervous system function, heart rate variability, academic stress, examination stress, student populations, and psychophysiological assessment.

**Figure 1.** Flow diagram illustrating the literature search strategy and study selection process used for the structured narrative review.



## 2.6 Data Synthesis

The included literature was analyzed using a thematic approach. Evidence was synthesized across major themes, including the physiology of stress, autonomic nervous system regulation, heart rate variability measurement and interpretation, academic stress and student well-being, examination-related stress responses, and emerging technological approaches for physiological stress monitoring. Particular emphasis was placed on identifying recurring findings, methodological patterns, areas of agreement, and unresolved questions within the existing literature.

## 2.7 Limitations of the Review Methodology

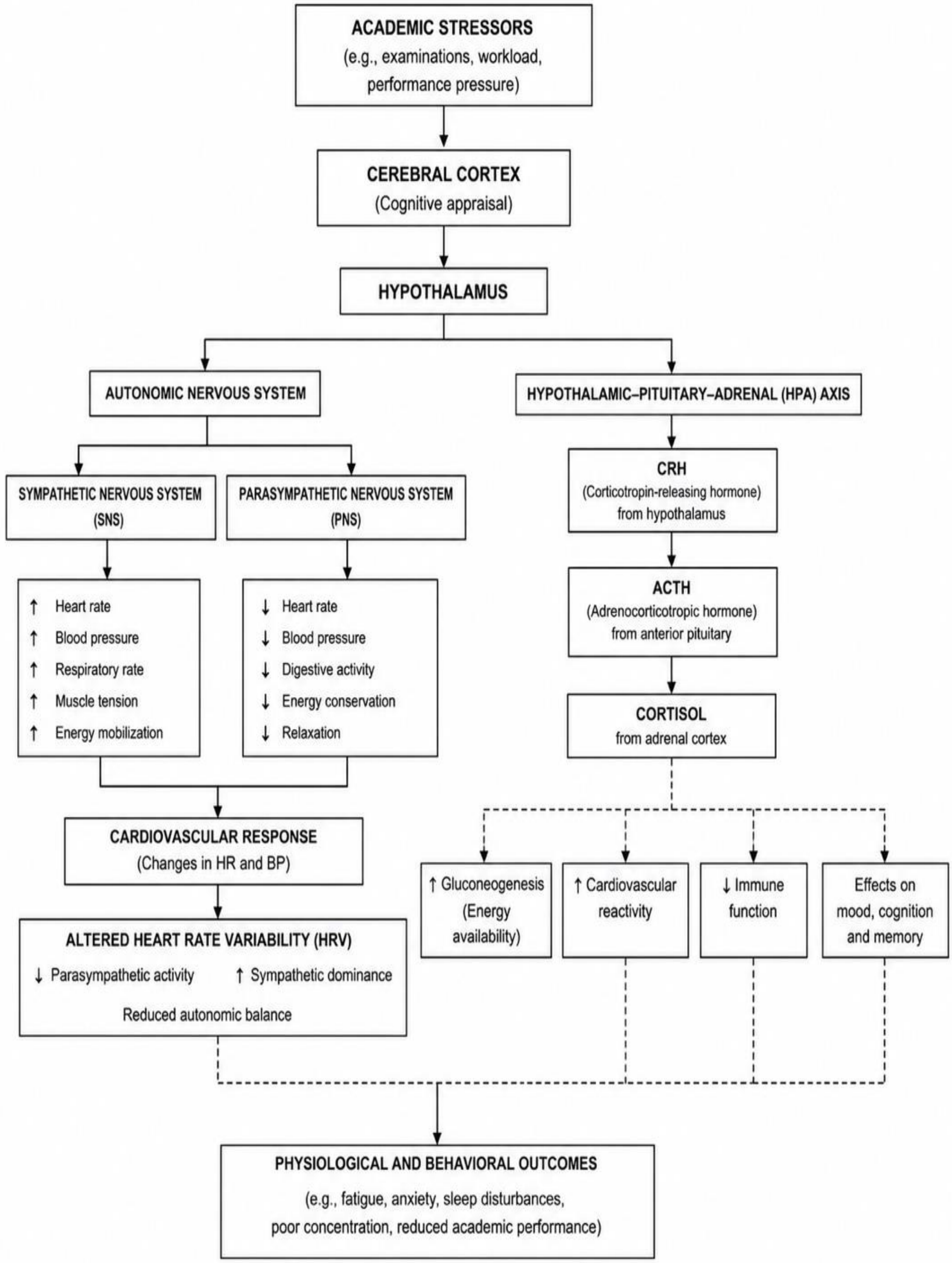
As a narrative review informed by a structured search strategy, this study does not claim the methodological rigor of a formal systematic review or meta-analysis. Although efforts were made to identify and evaluate a broad range of relevant literature, the possibility of publication bias, database selection bias, and variability in study methodologies cannot be completely excluded. Nevertheless, the structured search process enabled the inclusion of a diverse body of evidence and facilitated a comprehensive examination of current knowledge regarding heart rate variability and academic stress.

# 3. Physiology of Stress

Stress is a fundamental biological response that enables organisms to adapt to internal and external challenges. The concept of stress extends beyond psychological experiences and encompasses a complex series of physiological, neuroendocrine, autonomic, and behavioural responses designed to maintain homeostasis in the face of actual or perceived threats. While acute stress responses are generally adaptive and essential for survival, prolonged or chronic activation of stress-response systems may contribute to significant physical and psychological dysfunction.(21,29,30)

The physiological stress response is primarily regulated through two interconnected systems: the autonomic nervous system (ANS) and the hypothalamic-pituitary-adrenal (HPA) axis. Together, these systems coordinate rapid and long-term adaptations that allow individuals to respond effectively to environmental demands(4,31). Upon exposure to a stressor, sensory and cognitive processing centers within the brain evaluate the potential threat and initiate a cascade of physiological responses aimed at maintaining stability and promoting survival.

**Figure 2.** Physiological pathways activated by academic stress, illustrating the roles of the autonomic nervous system (ANS) and hypothalamic–pituitary–adrenal (HPA) axis in mediating cardiovascular, neuroendocrine, and behavioural responses, including alterations in heart rate variability.



The autonomic nervous system plays a central role in the immediate response to stress. It consists of two major divisions: the sympathetic nervous system and the parasympathetic nervous system. During stressful situations, sympathetic nervous system activity increases, leading to elevated heart rate, increased blood pressure, enhanced respiratory activity, pupil dilation, and the mobilization of energy reserves. These changes collectively constitute the classic "fight-or-flight" response, preparing the body for rapid action(32–34). Conversely, parasympathetic activity, which is responsible for rest, recovery, and energy conservation, is often reduced during periods of acute stress.

Alongside autonomic activation, the hypothalamic-pituitary-adrenal axis contributes to the hormonal regulation of stress responses. Stress-induced activation of the hypothalamus stimulates the release of corticotropin-releasing hormone, which subsequently triggers the secretion of adrenocorticotropic hormone from the anterior pituitary gland. This hormonal cascade ultimately results in the release of cortisol from the adrenal cortex. Cortisol plays a crucial role in regulating metabolism, immune function, cardiovascular activity, and energy availability during stressful situations(1,14,35). Although short-term cortisol release is adaptive, sustained elevations may negatively affect cognitive function, emotional regulation, immune competence, and cardiovascular health.

The brain serves as the primary integrator of stress responses. Several interconnected neural structures contribute to the perception, processing, and regulation of stress. The amygdala plays a critical role in threat detection and emotional processing, while the hippocampus contributes to memory formation and contextual interpretation of stressful events. The prefrontal cortex is involved in executive control, decision-making, and the regulation of emotional responses. Interactions among these regions influence both autonomic and endocrine activity, ultimately determining the magnitude and duration of physiological stress responses.

Individual responses to stress vary considerably due to differences in genetics, personality, coping mechanisms, environmental influences, and previous life experiences. Consequently, exposure to similar academic or psychological stressors may produce markedly different physiological responses among individuals. This variability highlights the importance of objective physiological measures capable of quantifying stress-related changes beyond subjective self-reports.

One of the most influential contemporary concepts in stress physiology is allostasis, which refers to the body's ability to achieve stability through physiological adaptation. Repeated activation of stress-response systems may lead to allostatic load, a cumulative burden resulting from chronic physiological stress. Elevated allostatic load has been associated with impaired cardiovascular regulation, autonomic dysfunction, metabolic disturbances, reduced cognitive performance, and increased vulnerability to both physical and mental health disorders.

Academic stress represents a particularly relevant form of chronic psychological stress. Students preparing for examinations, managing extensive academic workloads, and coping with competitive educational environments may experience repeated activation of autonomic and endocrine stress-response pathways. Over time, such physiological activation may influence cardiovascular regulation and autonomic nervous system balance, making physiological indicators of stress increasingly important in educational and health-related research.

**Table 1.** Components of Heart Rate Variability Parameters.

| Parameter | Domain | Clinical Meaning |
|---|---|---|
| SDNN | Time | Overall variability |
| RMSSD | Time | Parasympathetic activity |
| pNN50 | Time | Vagal modulation |
| HF | Frequency | Parasympathetic activity |
| LF | Frequency | Mixed autonomic influence |
| LF/HF | Frequency | Sympathovagal balance |

Given the central role of the autonomic nervous system in stress regulation, measures capable of assessing autonomic function provide valuable insights into physiological adaptation and resilience. Among these measures, Heart Rate Variability has emerged as one of the most widely studied and clinically relevant indicators of autonomic nervous system activity. Understanding the physiological foundations of HRV is therefore essential for evaluating its potential role as a biomarker of academic stress(22,23,35,36).

**HRV Metrics**

Example:

Mean RR Interval $\bar{RR} = \frac{\sum RR_i}{n}$

RMSSD: $RMSSD = \sqrt{\frac{\sum(RR_{i+1} - RR_i)^2}{n-1}}$

SDNN: $SDNN = \sqrt{\frac{\sum(RR_i - \bar{RR})^2}{n-1}}$

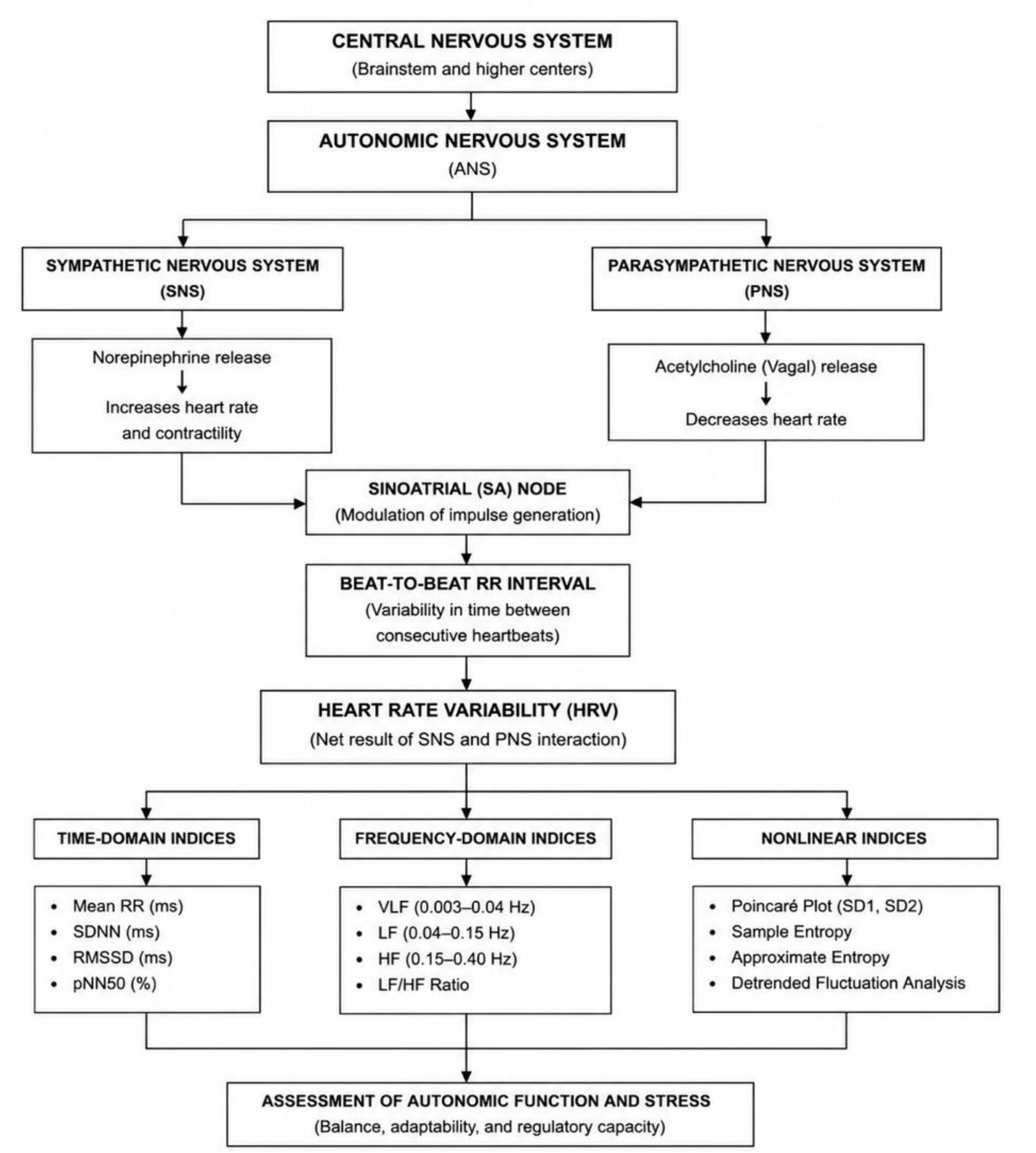
## 4. Heart Rate Variability: Physiological Basis and Measurement

Heart Rate Variability (HRV) is one of the most extensively studied non-invasive physiological indicators of autonomic nervous system function. Rather than representing abnormalities in cardiac rhythm, HRV refers to the natural fluctuation in the time intervals between consecutive heartbeats, commonly termed R-R or NN (normal-to-normal) intervals(37,38). These continuous variations reflect the dynamic interplay between sympathetic and parasympathetic branches of the autonomic nervous system, enabling the cardiovascular system to adapt rapidly to changing physiological and environmental demands.

The healthy human heart does not beat at perfectly regular intervals. Instead, beat-to-beat variability occurs continuously as a result of complex regulatory mechanisms involving the central nervous system, autonomic nervous system, respiratory activity, endocrine responses, and cardiovascular reflexes(25,26,35,39). This physiological variability represents an important indicator of cardiovascular adaptability and biological resilience. Higher HRV generally reflects greater autonomic flexibility and efficient parasympathetic regulation, whereas lower HRV indicates reduced adaptive capacity and autonomic imbalance.

The autonomic nervous system continuously modulates sinoatrial node activity through opposing sympathetic and parasympathetic influences. Sympathetic activation increases heart rate and reduces beat-to-beat variability by promoting cardiovascular arousal and energy mobilization during stressful situations. In contrast, parasympathetic stimulation, primarily mediated through the vagus nerve, slows heart rate and enhances variability by facilitating rapid adjustments in cardiac activity. The balance between these two regulatory systems forms the physiological basis of HRV and explains its widespread use as an indicator of autonomic function.

**Figure 3.** Schematic representation of the physiological regulation of heart rate variability (HRV), illustrating autonomic modulation of the sinoatrial node and the principal time-domain, frequency-domain, and nonlinear HRV indices used to assess autonomic function.



The vagus nerve plays a particularly important role in HRV regulation. Vagal modulation allows rapid beat-to-beat adjustments in heart rate, supporting emotional regulation, cognitive flexibility, cardiovascular efficiency, and recovery following stressful experiences. Consequently, indices reflecting parasympathetic activity have become central to HRV research and are frequently used to evaluate stress resilience, emotional health, and autonomic recovery.

HRV can be measured using electrocardiography (ECG), Holter monitoring systems, chest-strap heart rate monitors, and increasingly through validated wearable devices capable of recording R-R intervals with high temporal resolution. Recent advances in wearable biosensors have enabled continuous monitoring of HRV in real-world settings, facilitating longitudinal assessment of physiological stress during daily activities, educational environments, occupational settings, and clinical practice. These technological developments have substantially expanded the application of HRV in both research and healthcare.

Several analytical approaches have been developed to quantify HRV. Time-domain analysis evaluates statistical variations in successive R-R intervals and includes parameters such as the Standard Deviation of Normal-to-Normal intervals (SDNN), Root Mean Square of Successive Differences (RMSSD), and the percentage of adjacent intervals differing by more than 50 milliseconds (pNN50)(5,40–42). Among these, RMSSD is widely regarded as a reliable indicator of parasympathetic activity and is frequently employed in psychophysiological and stress-related investigations.

**Table 2.** Physiological Changes During Academic Stress

| System | Change |
|---|---|
| Heart Rate | ↑ |
| Blood Pressure | ↑ |
| Cortisol | ↑ |
| HRV | ↓ |
| Sympathetic Activity | ↑ |
| Parasympathetic Activity | ↓ |

Frequency-domain analysis provides additional insight into autonomic regulation by separating HRV into different spectral components. High-frequency (HF) power is generally considered to reflect parasympathetic activity, whereas low-frequency (LF) power represents more complex interactions involving both sympathetic and parasympathetic influences. The LF/HF ratio has historically been used as an index of sympathovagal balance; however, recent evidence suggests that its physiological interpretation should be approached cautiously due to the multifactorial influences affecting both frequency components.

In addition to conventional time- and frequency-domain analyses, non-linear HRV measures have gained increasing importance in contemporary cardiovascular research. Techniques such as Poincaré plot analysis, entropy measures, detrended fluctuation analysis, and fractal dimension analysis provide valuable information regarding the complexity and adaptability of autonomic regulation. These methods recognize that cardiovascular control is governed by complex, non-linear biological systems that cannot always be adequately described using traditional linear statistical measures(26,43).

The clinical and research applications of HRV have expanded considerably over the past three decades. Reduced HRV has been associated with cardiovascular disease, diabetes mellitus, hypertension, depression, anxiety disorders, chronic stress, burnout, sleep disturbances, cognitive impairment, and increased mortality risk. Conversely, higher HRV has been associated with improved emotional regulation, greater psychological resilience, enhanced executive functioning, and better cardiovascular health. These findings support the growing recognition of HRV as a valuable physiological biomarker capable of reflecting both physical and psychological well-being.

Within educational settings, HRV provides a unique opportunity to objectively assess physiological responses to academic demands. Unlike subjective stress questionnaires, HRV offers continuous, quantifiable information regarding autonomic nervous system activity and stress adaptation. Consequently, HRV has become increasingly important in studies investigating examination stress, cognitive workload, learning environments, academic performance, and student well-being. Its non-invasive nature, reproducibility, and compatibility with wearable monitoring technologies further strengthen its potential as a practical tool for physiological stress assessment.

Despite its widespread application, HRV measurement is influenced by numerous physiological and methodological factors, including age, sex, physical fitness, circadian rhythm, respiratory rate, caffeine intake, medication use, body posture, environmental conditions, and measurement duration. Standardization of recording protocols and careful consideration of these confounding variables remain essential for ensuring the validity, reliability, and comparability of HRV findings across studies.

Collectively, the existing evidence establishes HRV as a scientifically robust and clinically relevant indicator of autonomic nervous system function. Its ability to objectively reflect physiological responses to psychological stress provides a strong theoretical foundation for investigating academic stress among students. The following section reviews the current evidence linking academic stress with alterations in HRV and examines how educational demands influence autonomic regulation across diverse student populations.

## 5. Academic Stress and Autonomic Nervous System Function

Academic stress represents one of the most prevalent forms of chronic psychological stress experienced by students in contemporary educational environments. Increasing academic expectations, frequent examinations, competitive learning environments, assignment deadlines, and concerns regarding academic achievement collectively activate physiological stress-response mechanisms(34,44,45). While short-term stress may enhance alertness and motivation, prolonged exposure to academic stress can adversely affect autonomic regulation, cognitive performance, emotional well-being, and physical health.

The autonomic nervous system (ANS) plays a central role in mediating physiological responses to academic stress. Exposure to academic stressors initiates rapid activation of the sympathetic nervous system, resulting in increased heart rate, elevated blood pressure, enhanced respiratory activity, and mobilization of metabolic energy reserves(46–51). Simultaneously, parasympathetic activity declines, reducing vagal tone and limiting the body's capacity for physiological recovery. These coordinated autonomic changes enable individuals to respond rapidly to perceived academic challenges but may become maladaptive when sustained over prolonged periods.

Academic stress also activates the hypothalamic–pituitary–adrenal (HPA) axis, resulting in the secretion of cortisol and other stress-related hormones. Although cortisol is essential for maintaining energy availability during stressful situations, persistent elevations may impair memory consolidation, executive functioning, immune competence, and emotional regulation(24). The combined activation of the ANS and HPA axis therefore contributes to both immediate physiological adaptation and long-term health consequences when stress becomes chronic(26,52–55).

Multiple investigations have demonstrated that examination periods are accompanied by measurable physiological alterations, including increased resting heart rate, elevated blood pressure, reduced heart rate variability (HRV), increased sympathetic activity, decreased parasympathetic modulation, and elevated salivary cortisol concentrations. These objective physiological changes occur alongside subjective experiences of anxiety, fatigue, reduced concentration, emotional exhaustion, and impaired academic performance(35,56–58). Collectively, these findings indicate that academic stress is not merely a psychological phenomenon but a measurable physiological condition involving coordinated autonomic and neuroendocrine responses.

The severity of autonomic responses varies considerably among students due to individual differences in coping strategies, resilience, personality traits, sleep quality, physical activity, and emotional regulation. Students possessing greater resilience and adaptive coping mechanisms generally demonstrate faster autonomic recovery following stressful events and maintain relatively higher HRV. Conversely, chronic stress, poor sleep quality, sedentary lifestyle, and elevated anxiety have consistently been associated with reduced vagal activity and impaired autonomic flexibility(45,59,60).

Sleep represents another critical determinant of autonomic regulation during periods of academic stress. Examination preparation is frequently associated with shortened sleep duration, irregular sleep schedules, and poorer sleep quality. Sleep deprivation further amplifies sympathetic nervous system activation while suppressing parasympathetic recovery, creating a self-perpetuating cycle of stress, impaired recovery, reduced HRV, and declining cognitive performance. This interaction highlights the multifactorial nature of autonomic dysfunction within academic settings.

**Table 3.** Physiological and Psychological Responses to Academic Stress

| Parameter | Acute Academic Stress | Chronic Academic Stress |
|---|---|---|
| Heart Rate | Increased | Persistently elevated |
| Blood Pressure | Increased | Mild sustained elevation |
| Sympathetic Activity | Increased | Sympathetic predominance |
| Parasympathetic Activity | Reduced | Reduced vagal tone |
| Heart Rate Variability | Decreased | Persistently reduced |
| Cortisol | Increased | Dysregulated secretion |
| Respiratory Rate | Increased | Variable |
| Sleep Quality | Mild disturbance | Poor sleep quality |
| Cognitive Function | Increased alertness | Reduced attention and memory |
| Emotional Status | Anxiety | Burnout, emotional exhaustion |

Advances in wearable biosensors and portable electrocardiographic monitoring systems have enabled continuous assessment of autonomic function throughout routine educational activities. Such technologies permit real-time evaluation of physiological responses during classroom learning, examination preparation, clinical training, and daily academic routines. Continuous HRV monitoring therefore offers considerable potential for identifying students experiencing excessive physiological stress and may facilitate early preventive interventions aimed at improving health, resilience, and academic performance.

Overall, current evidence strongly supports the existence of a close relationship between academic stress and autonomic nervous system dysfunction. Persistent sympathetic predominance, reduced vagal activity, and diminished HRV consistently accompany periods of heightened academic demand. These physiological alterations provide the foundation for understanding HRV as an objective biomarker capable of quantifying stress responses within educational environments.

## 6. Current Evidence Linking Heart Rate Variability and Academic Stress

A substantial body of literature has demonstrated a consistent association between academic stress and alterations in heart rate variability (HRV) across diverse student populations(1,2,61,62). Most studies report that examination periods and increased academic workload are associated with reduced parasympathetic activity, reflected by decreases in HRV parameters such as RMSSD, SDNN, and high-frequency (HF) power, accompanied by increased heart rate and sympathetic activation(5,31).

**Table 4**. Summary of Representative Studies Investigating Heart Rate Variability and Academic Stress

| Author | Year | Country | Population | Sample Size | Study Design | HRV Parameter(s) | Principal Findings |
|---|---|---|---|---|---|---|---|
| Shaffer & Ginsberg | 2017 | USA | Narrative review | 132 studies | Review | SDNN, RMSSD, HF, LF | Comprehensive interpretation of HRV metrics and clinical significance. |
| Laborde et al. | 2017 | Germany | General population | - | Expert review | Time & Frequency domains | Standardized recommendations for HRV measurement in psychophysiological research. |
| Thayer et al. | 2012 | USA | Healthy adults | Multiple studies | Review | Resting HRV | Higher HRV associated with better emotional regulation and executive function. |
| Thayer & Lane | 2009 | USA | General population | Multiple studies | Theoretical review | Resting HRV | Introduced the Neurovisceral Integration Model linking HRV and cognition. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Kim et al. | 2018 | South Korea | General population | Multiple studies | Systematic review | Various | Reduced HRV consistently associated with psychological stress. |
| Hammoud et al. | 2019 | Lebanon | University students | 90 | Observational | LF, HF, LF/HF | Examination stress increased sympathetic activity and reduced HRV. |
| Yoo et al. | 2021 | South Korea | Medical students | 97 | Cross-sectional | SDNN, Stress Index | HRV-derived stress associated with academic performance |
| Kumar et al. | 2013 | India | MBBS students | 16 | Prospective observational | RMSSD, SDNN, LF/HF | Examination stress significantly reduced HRV. |
| Thomas et al. | 2021 | India | First-year MBBS students | 100+ | Cross-sectional | Time & Frequency domains | High academic stress associated with altered HRV. |
| Immanuel et al. | 2023 | Australia | Multiple populations | 245 studies | Systematic review | Multiple HRV metrics | Methodological factors strongly influence HRV–stress relationships. |
| Eslami et al. | 2022 | Iran | Healthy adults | - | Review | HRV indices | Summarized interpretation of high and low HRV in stress physiology. |
| Forte et al. | 2019 | Italy | Healthy adults | Multiple studies | Review | Resting HRV | HRV closely associated with cognitive functioning and decision-making. |
| Forte et al. | 2021 | Italy | Adults | Multiple studies | Review | HRV | Strong association between HRV and executive functions. |
| Castaldo et al. | 2015 | Italy | Healthy adults | Meta-analysis | Meta-analysis | HRV indices | Acute mental stress significantly decreases HRV. |
| Kim, Cheon et al. | 2018 | South Korea | Adults | Meta-analysis | Systematic review | Time & Frequency domains | Psychological stress consistently lowers HRV. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lehrer & Gevirtz | 2014 | USA | Adults | Review | Review | HRV Biofeedback | HRV biofeedback improves autonomic regulation and resilience. |
| Porges | 2007 | USA | General population | Theoretical | Review | Vagal indices | Polyvagal Theory explaining vagal regulation and stress adaptation. |
| McEwen | 1998 | USA | General population | Review | Review | Physiological stress | Chronic stress leads to allostatic load and autonomic dysregulation. |
| Sapolsky | 2004 | USA | General population | Book/Review | Review | Stress physiology | Chronic stress adversely affects cognition and physiological health. |
| Chen et al. | 2024 | China | Students | - | Observational | Wearable HRV | Wearable heart-rate sequences successfully predicted stressful academic days. |

Several investigations have shown that reductions in HRV often precede students' subjective perception of stress, suggesting that HRV may serve as an early physiological biomarker of academic stress(5,63–68). Furthermore, higher baseline HRV has been associated with better emotional regulation, cognitive performance, and resilience, whereas reduced HRV has been linked to anxiety, fatigue, impaired concentration, and poorer academic performance.

Recent advances in wearable biosensors have enabled continuous HRV monitoring during routine academic activities, providing valuable insights into real-time physiological responses to educational stressors(69). Integration of wearable technologies with artificial intelligence-based analytical tools offers promising opportunities for early identification of excessive stress and personalized intervention strategies.

Despite these encouraging findings, methodological differences among studies-including variations in participant characteristics, HRV recording protocols, stress assessment instruments, and analytical methods-limit direct comparison across investigations(70–72). Larger multicentre longitudinal studies employing standardized methodologies are therefore required to strengthen the current evidence base.

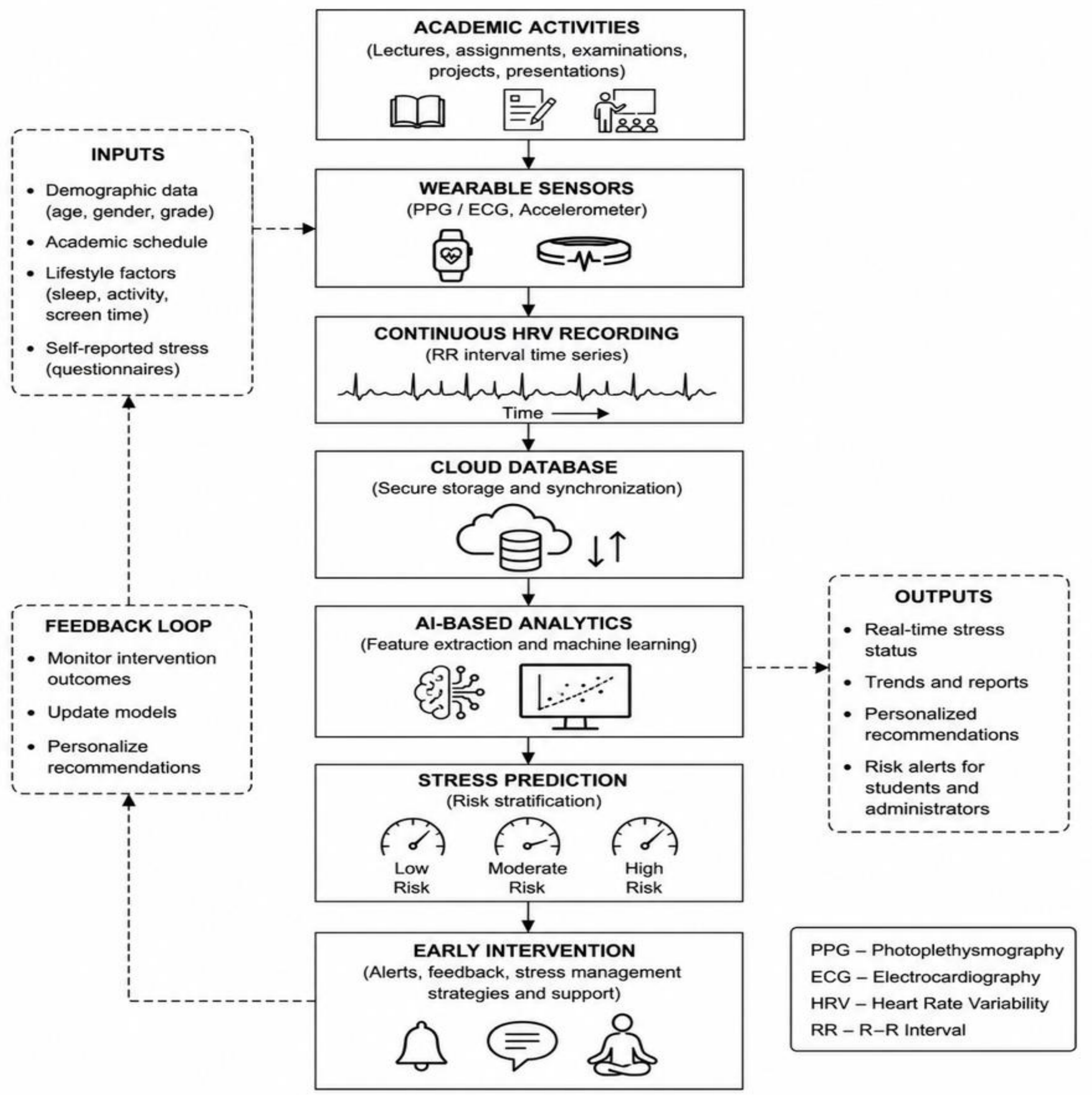
Overall, the existing literature strongly supports HRV as a reliable, non-invasive biomarker of academic stress. Its ability to objectively quantify autonomic responses makes HRV a promising tool for monitoring student well-being, identifying individuals at risk of stress-related dysfunction, and evaluating interventions aimed at improving academic performance and psychological resilience.

## 7. Future Directions

The growing body of evidence supporting heart rate variability (HRV) as an objective indicator of academic stress has created numerous opportunities for future research and practical applications. Although current studies consistently demonstrate an association between reduced HRV and increased academic stress, greater methodological standardization is required to strengthen the clinical and educational utility of HRV assessment(73–75).

Future investigations should prioritize large multicentre longitudinal studies involving diverse student populations across different educational settings(2,62,72,76,77). Standardized HRV recording protocols, uniform stress assessment instruments, and consistent analytical approaches would improve comparability among studies and facilitate the development of evidence-based guidelines for academic stress monitoring.

**Figure 4.** Conceptual framework illustrating the integration of wearable biosensors, continuous heart rate variability (HRV) monitoring, cloud-based data management, and artificial intelligence (AI)-driven analytics for personalized assessment and early intervention of academic stress.



Rapid advances in wearable biosensor technology are expected to transform physiological stress assessment. Modern wearable devices capable of continuously recording electrocardiographic and photoplethysmographic signals enable real-time HRV monitoring with minimal disruption to daily academic activities. Continuous physiological monitoring may facilitate early identification of students experiencing excessive stress before significant psychological or academic deterioration occurs(62).

Artificial intelligence and machine learning techniques offer additional opportunities for personalized stress prediction. Integration of HRV data with sleep patterns, physical activity, academic workload, and psychological assessments may enable predictive models capable of identifying students at increased risk of burnout, anxiety, or reduced academic performance. Such approaches could support individualized interventions aimed at improving both mental health and educational outcomes.

Future research should also explore the effectiveness of interventions designed to improve autonomic regulation. Regular physical activity, mindfulness-based stress reduction, yoga, breathing exercises, adequate sleep hygiene, and resilience training have demonstrated promising effects on HRV in various populations(67,78,79). Evaluating these interventions within educational settings may contribute to the development of comprehensive student well-being programmes supported by objective physiological monitoring.

Overall, continued advances in physiological monitoring technologies, data analytics, and interdisciplinary research are likely to establish HRV as an integral component of student health assessment. Future evidence may support the routine incorporation of HRV monitoring into educational health programmes, enabling early detection of excessive academic stress and promoting preventive strategies that enhance both academic performance and psychological well-being.

**Table 5.** Major research priorities and recommendations for advancing the application of heart rate variability in academic stress research.

| Research Area | Current Limitation | Future Recommendation |
|---|---|---|
| Study Design | Mostly cross-sectional | Longitudinal multicentre studies |
| HRV Measurement | Variable protocols | Standardized recording guidelines |
| Wearable Devices | Limited validation | Clinical validation across populations |
| Artificial Intelligence | Early-stage applications | Predictive stress models |
| Student Populations | Small cohorts | Large, diverse educational settings |
| Intervention Studies | Limited evidence | Randomized controlled trials |
| Educational Health | Minimal implementation | Integration into student wellness programmes |

## 8. Limitations of Current Literature

Despite the increasing number of studies investigating the relationship between heart rate variability (HRV) and academic stress, several important limitations remain within the existing literature. A substantial proportion of published studies involve relatively small sample sizes and single-institution cohorts, limiting the generalizability of their findings across broader student populations.

Considerable methodological heterogeneity also exists among studies. Variations in HRV recording duration, measurement devices, analytical methods, stress assessment instruments, and participant characteristics make direct comparisons difficult. Furthermore, important confounding factors such as physical activity, sleep quality, caffeine intake, medication use, circadian rhythm, and respiratory rate are not consistently controlled, potentially influencing HRV outcomes.

**Table 6.** Major limitations identified in the current literature and recommendations for future research.

| Limitation | Potential Impact | Recommendation |
|---|---|---|
| Small sample sizes | Reduced generalizability | Conduct large multicentre studies |
| Cross-sectional designs | Limited causal inference | Perform prospective longitudinal studies |
| Heterogeneous HRV protocols | Difficult comparison between studies | Adopt standardized HRV guidelines |
| Variable stress assessment tools | Reduced consistency | Use validated psychological instruments |
| Confounding variables | Potential measurement bias | Control lifestyle and physiological factors |
| Limited school-based research | Evidence gap | Expand research to adolescent and school populations |
| Short monitoring periods | Limited understanding of chronic stress | Implement long-term HRV monitoring |

Most available evidence is derived from cross-sectional or short-term observational studies, while longitudinal investigations examining long-term autonomic adaptations to sustained academic stress remain limited. In addition, the majority of published research has focused on university or medical students, with comparatively fewer studies involving secondary school students or other educational populations.

These limitations highlight the need for standardized research protocols, larger multicentre studies, and long-term investigations that integrate physiological, psychological, and behavioural assessments. Addressing these methodological challenges will strengthen the evidence supporting HRV as a reliable biomarker of academic stress and facilitate its translation into educational and clinical practice.

## 9. Conclusion

Heart rate variability (HRV) has emerged as one of the most promising non-invasive physiological biomarkers for assessing autonomic nervous system function and quantifying responses to academic stress(6,7). The evidence synthesized in this review consistently demonstrates that periods of increased academic demand, particularly examinations and prolonged study workloads, are associated with reduced parasympathetic activity, increased sympathetic dominance, and measurable alterations in HRV. These physiological changes frequently parallel declines in emotional well-being, cognitive performance, sleep quality, and overall student health.

Unlike subjective stress assessment tools, HRV provides an objective and quantifiable measure of physiological stress, enabling continuous evaluation of autonomic function in real-world educational settings. Recent advances in wearable biosensor technology and artificial intelligence have further expanded the potential applications of HRV, allowing continuous monitoring, early detection of excessive stress, and the development of personalized intervention strategies to support student well-being.

Despite encouraging findings, the current literature is characterized by methodological variability, heterogeneous study populations, and limited longitudinal evidence. Standardization of HRV measurement protocols, larger multicentre investigations, and integration of physiological, psychological, and behavioural assessments are essential to strengthen the evidence base and facilitate wider implementation in educational and clinical practice.

In conclusion, HRV represents a scientifically robust, practical, and clinically relevant biomarker for evaluating academic stress(67,68,80). Continued interdisciplinary collaboration among physiologists, clinicians, psychologists, educators, and data scientists will be instrumental in advancing HRV research and translating emerging evidence into effective educational health programmes. Future developments in wearable health technologies and predictive analytics have the potential to transform HRV from a research tool into an integral component of preventive student healthcare, ultimately promoting healthier learning environments, improved academic performance, and enhanced psychological resilience.

## References


1. Schaich C, Malaver D, Shaltout H, Hazzouri A, Herrington D, Hughes T. Abstract P301: Heart Rate Variability is Associated with Future Global Cognitive Performance: the Multi-Ethnic Study of Atherosclerosis. Hypertension. 2018 Sep 1. doi:10.1161/hyp.72.suppl_1.p301

2. Latyshevskaya N, Sevriukova G, Levchenko N, Tikhonova E. Adaptation of Medical College Students to the Learning Conditions with Different Educational Standards. J Med Biol Res. 2025 May 17. doi:10.37482/2687-1491-z247

3. Schaich C, Malaver D, Chen H, Shaltout H, Hazzouri ZA, Herrington D, et al. Association of Heart Rate Variability With Cognitive Performance: The Multi-Ethnic Study of Atherosclerosis. J Am Heart Assoc Cardiovasc Cerebrovasc Dis. 2020 Mar 21;9. doi:10.1161/jaha.119.013827

4. Muntaner-Mas A, Vidal-Conti J, Salmon J, Palou-Sampol P. Associations of Heart Rate Measures during Physical Education with Academic Performance and Executive Function in Children: A Cross-Sectional Study. Int J Environ Res Public Health. 2020 Jun 1;17. doi:10.3390/ijerph17124307

5. Gupta C, Kaur N, Dwivedi D, Verma K, Sehan. Assessment of Stress in First Year Medical Students by Measuring Heart Rate Variability and its Correlation with Academic Achievement: A Cross-sectional Study. J Clin Diagn Res. 2026 Jan 1. doi:10.7860/jcdr/2026/76903.22322

6. Mitra K, Rakshit S, Banerjee T, Das M. Assessment of heart rate variability among healthy 1st year medical students in a Government Medical College of Kolkata: A cross-sectional observational study. Natl J Physiol Pharm Pharmacol. 2024 Jan 1. doi:10.5455/njppp.2024.14.01035202430012024

7. Tharion E, Kachroo U, Noel J, Samuel P. Cardiac Autonomic Activity, Personality Traits, and Academic Performance in First-Year Medical Students: A Gender-Specific Relation. Cureus. 2023 Nov 1;15. doi:10.7759/cureus.49087

8. Ginty A, Tyra A, Young D, Brindle R, De Rooij S, Williams S. Cardiovascular reactions to acute psychological stress and academic achievement. Psychophysiology. 2022 Mar 30;59. doi:10.1111/psyp.14064

9. Scrimin S, Moscardino U, Finos L, Mason L. Effects of Psychophysiological Reactivity to a School-Related Stressor and Temperament on Early Adolescents' Academic Performance. J Early Adolesc. 2018 Sep 10;39:904–31. doi:10.1177/0272431618797008

10. Magnon V, Vallet G, Benson A, Mermillod M, Chaussé P, Lacroix A, et al. Does heart rate variability predict better executive functioning? A systematic review and meta-analysis. Cortex J Devoted Study Nerv Syst Behav. 2022 Aug 1;155:218–36. doi:10.1016/j.cortex.2022.07.008

11. Imbimbo C, Spallazzi M, Ferrari-Pellegrini F, Villa A, Zilioli A, Mutti C, et al. Heart rate variability and cognitive performance in adults with cardiovascular risk. Cereb Circ - Cogn Behav. 2022 Mar 1;3. doi:10.1016/j.cccb.2022.100136

12. Derby C, Qin J, Liu G, Koorathota S, Wang C, Sloan R. Heart rate variability is associated with global cognition and cognitive impairment: Results from the einstein aging study. Alzheimers Dement. 2023 Jun 1;19. doi:10.1002/alz.064226

13. Farooqui MEA, Ali I. Effect of Academic Stress and Its Relationship With HRV in Young 1St year MBBS Students. Int J Physiol. 2018 Jan 1;6:154–7. doi:10.5958/2320-608x.2018.00072.0

14. Latyshevskaya N, Sevriukova G, Levchenko N, Tikhonova E. Adaptation of Medical College Students to the Learning Conditions with Different Educational Standards. J Med Biol Res. 2025 May 17. doi:10.37482/2687-1491-z247

15. Santos ADD, Da Silva Bezerra M, De Farias NB, Nascimento RCD, Júnior JEGL, Vanderlei ESO, et al. Analysis of Stress Levels in University Students During Examination Periods. Braz J Clin Med Rev. 2024 Jun 9. doi:10.52600/2965-0968.bjcmr.2025.3.1.bjcmr3

16. Obi A, Nwobodo E, Dimkpa U, Maduka S, Fintan E. Assessment of Stress Level of Young Undergraduates Before and After a Degree Examination Using Heart Rate Variability Analysis. Eur J Med Health Sci. 2021 Sep 14. doi:10.24018/ejmed.2021.3.5.1008

17. Sancinelli S. Heart Rate Variability as an Indicator of Stress in Students' Athletes. Open J Med Psychol. 2023 Jan 1. doi:10.4236/ojmp.2023.123009

18. DiPasquale S, Wood M, Edmonds R. Heart rate variability in a collegiate dance environment: insights on overtraining for dance educators. Res Dance Educ. 2021 Jan 2;22:108–25. doi:10.1080/14647893.2021.1884673

19. Kim HG, Cheon E, Bai D, Lee YH, Koo B. Stress and Heart Rate Variability: A Meta-Analysis and Review of the Literature. Psychiatry Investig. 2018 Feb 28;15:235–45. doi:10.30773/pi.2017.08.17

20. Belyaeva V. Stress before exams as a risk factor causing functional disorders in the cardiovascular system in students with different metabolic status. Health Risk Anal. 2020 Dec 1. doi:10.21668/health.risk/2020.4.17

21. Bagri D, Gupta A, Dube A, Gupta R. Assessment Of Examination Stress And HRV in Adolescents. Natl J Integr Res Med. 2016 Jul 1;7:1–7.

22. Krivobokova V, Kiseleva M, Gryaznykh A. Analysis of the emotional strain influence on the indicators of the heart rhythm variability in students. In. 2020. Available from: https://consensus.app/papers/analysis-of-the-emotional-strain-influence-on-the-krivobokova-kiseleva/3a33e29ccf685020984c93a7009c95e1/ doi:10.1051/bioconf/20202600004

23. Gellisch M, Bablok M, Morosan-Puopolo G, Schäfer T, Brand-Saberi B. Autonomic stress responses in oral examination simulations: Neuroscientific insights from comparing peer-led and lecturer-led approaches. Trends Neurosci Educ. 2025 Sep 1;40:100270. doi:10.1016/j.tine.2025.100270

24. Sánchez-Conde P, Clemente-Suárez V. Autonomic Stress Response of Nurse Students in an Objective Structured Clinical Examination (OSCE). Sustainability. 2021 May 21;13:5803. doi:10.3390/su13115803

25. Vageesh V, Bharath T. Effect of Stress on Heart Rate Variability in Medical Students: A Cross-sectional Study. J Clin Diagn Res. 2022 Jan 1. doi:10.7860/jcdr/2022/53713.16678

26. Woranush W, Sedghi A, Moskopp M, Japtok J, Ziegler C, Barlinn J, et al. Effects of digitalized university curriculum-associated teaching on the equilibrium of autonomic neurophysiology and disposition of learners in medical school (EDUCATE-AND-LEARN): protocol for a randomized crossover study. Ann Med. 2021 Jan 1;53:1981–8. doi:10.1080/07853890.2021.1996626

27. Grabo LM, Schulz A, Bellingrath S. Vagally-mediated heart rate variability longitudinally predicts test anxiety in university students. Anxiety Stress Coping. 2025 Feb 2;38:409–22. doi:10.1080/10615806.2025.2460230

28. Kim H, Park Y, Lee J. The Validity of Heart Rate Variability (HRV) in Educational Research and a Synthesis of Recommendations. Educ Psychol Rev. 2024 Apr 11;36. doi:10.1007/s10648-024-09878-x

29. T. R, Ye. B, L A, F. P. The Effect of Exam Stress on Age Dynamics of Vegetative Indicators of Choleric Students. Bull Sci Pract. 2024 Nov 11. doi:10.33619/2414-2948/108/20

30. Zallocco L, Giusti L, Ronci M, Mussini A, Trerotola M, Mazzoni M, et al. Salivary Proteome Changes in Response to Acute Psychological Stress Due to an Oral Exam Simulation in University Students: Effect of an Olfactory Stimulus. Int J Mol Sci. 2021 Apr 21;22. doi:10.3390/ijms22094295

31. Rubio-López A, García-Carmona R, Zarandieta-Román L, Rubio-Navas A, González-Pinto Á, Cardinal-Fernández P. Analysis of stress responses in medical students during simulated pericardiocentesis training using virtual reality and 3D-printed mannequin. Sci Rep. 2025 Mar 4;15. doi:10.1038/s41598-025-92221-3

32. Bhaskaran D, Anagppan S, Vijayagopal L, Subramanian A, Mourali C, Merlin DD. Autonomic echoes of student life: a mixed-method inquiry with meta-inferential integration of autonomic function, lifestyle narratives, and health behaviours among medical students. Arch Ind Hyg Toxicol. 2026 Mar 1;77:49–56. doi:10.2478/aiht-2026-77-4057

33. Eslami A, Nassif N, Lal S. Evaluating High and Low Heart Rate Variability Response and Neurocognitive Performance in Workers: An Exploratory Study. Behav Sci. 2023 Sep 1;13. doi:10.3390/bs13090742

34. Van Den Houte M, Ramakers I, Van Oudenhove L, Van Den Bergh O, Bogaerts K. Comparing autonomic nervous system function in patients with functional somatic syndromes, stress-related syndromes and healthy controls. J Psychosom Res. 2024 Dec 1;189:112025. doi:10.1016/j.jpsychores.2024.112025

35. Roy T, Saroka K, Hossack V, Dotta B. The Effects of Exam-Induced Stress on EEG Profiles and Memory Scores. Behav Sci. 2023 May 1;13. doi:10.3390/bs13050373

36. Deschodt-Arsac V, Lalanne R, Spiluttini B, Bertin C, Arsac L. Effects of heart rate variability biofeedback training in athletes exposed to stress of university examinations. PLoS ONE. 2018 Jul 26;13. doi:10.1371/journal.pone.0201388

37. Bian W, Zhang X, Dong Y. Autonomic Nervous System Response Patterns of Test-Anxious Individuals to Evaluative Stress. Front Psychol. 2022 Feb 28;13. doi:10.3389/fpsyg.2022.824406

38. Sharma M, Sharma M, MathurK C, OihaK C, Binawara B, DeoraD K. A STUDY OF STRESS AND AUTONOMIC FUNCTION TEST IN MEDICAL STUDENTS. J Evol Med Dent Sci. 2014 Feb 13;3:1672–80. doi:10.14260/jemds/2014/2041

39. Saboo N, Kacker S, Sorout J. A study to correlate stress score with heart rate variability among MBBS students at a tertiary care center, Jaipur. Acta Medica Int. 2023 Jul 1;10:148–54. doi:10.4103/amit.amit_66_23

40. Thomas B, Viljoen M. Heart Rate Variability and Academic Performance of First-Year University Students. Neuropsychobiology. 2019 Jul 2;78:175–81. doi:10.1159/000500613

41. Pillon A, Ulbricht V, De Souza MV, Fontenele AFGT. Heart Rate Variability Analysis to track stress level while learning Mathematics. In. 2023. p. 1–6. Available from: https://consensus.app/papers/heart-rate-variability-analysis-to-track-stress-level-

pillon-ulbricht/0bbde035f6f455249282213c514d8037/ doi:10.23919/cisti58278.2023.10211300

42. Nakayama N, Arakawa N, Ejiri H, Matsuda R, Makino T. Heart rate variability can clarify students' level of stress during nursing simulation. PLoS ONE. 2018 Apr 5;13. doi:10.1371/journal.pone.0195280

43. Loftness B, Hidalgo J, Cherian J, Mascia G, McGinnis R, McGinnis E. Longitudinal Profiles of Heart Rate Variability in First-Year College Students Using Wearables. In. 2024. p. 1–4. Available from: https://consensus.app/papers/longitudinal-profiles-of-heart-rate-variability-in-loftness-hidalgo/48410085466b5a088b6e073d52dc27ad/ doi:10.1109/bsn63547.2024.10780775

44. Mascia G, McGinnis E, Fudolig M, Bloomfield L, Price M, McGinnis R. Nightly Heart Rate Variability as a Biomarker of Mental Health Changes in College Students. In. 2024. p. 1–4. Available from: https://consensus.app/papers/nightly-heart-rate-variability-as-a-biomarker-of-mental-mascia-mcginnis/252ba33a0e8150af8348c940e71cde23/ doi:10.1109/bsn63547.2024.10780647

45. Bobrisheva-Pushkina N, Kusnetsova L, Popova O. EXAMINATION STRESS AMONG MEDICAL STUDENTS: PREVALENCE CAUSES AND PREVENTION. Vol. 97. 2018 May 15;97:456–60. doi:10.18821/0016-9900-2018-97-5-456-460

46. Sancinelli S. Heart Rate Variability as an Indicator of Stress in Students' Athletes. Open J Med Psychol. 2023 Jan 1. doi:10.4236/ojmp.2023.123009

47. Kumar Y, Agarwal V, Gautam S. Heart Rate Variability During Examination Stress in Medical Students. Int J Physiol. 2013 Jan 1;1:83–6.

48. Immanuel S, Teferra M, Baumert M, Bidargaddi N. Heart Rate Variability for Evaluating Psychological Stress Changes in Healthy Adults: A Scoping Review. Neuropsychobiology. 2023 Jun 8;82:187–202. doi:10.1159/000530376

49. Pandey KR, Khadka R, Panday D, Agrawal K, Paudel B. Influence of acute mental stress on blood pressure, heart rate and heart rate variability in male medical students: An experimental study from tertiary care hospital, Nepal. J Biomed Sci. 2020 Jul 3;7:11–7. doi:10.3126/jbs.v7i1.29848

50. Tashchuk V, Rusnak I, Amelina T, Hinhuliak O, Korbut BA. HEART RATE VARIABILITY: CLINICAL OPPORTUNITIES AND CONTROL. Clin Exp Pathol. 2025 May 24. doi:10.24061/1727-4338.xxiv.1.91.2025.14

51. Grabo LM, Schulz A, Bellingrath S. Vagally-mediated heart rate variability longitudinally predicts test anxiety in university students. Anxiety Stress Coping. 2025 Feb 2;38:409–22. doi:10.1080/10615806.2025.2460230

52. LeBlanc V, Mastoras G, Hicks C, MacGregor P, O'Rielly C, Petrosoniak A, et al. The stressed heart: Validity evidence supporting mobile heart rate variability applications to detect psychological stress in healthcare learners. Med Educ. 2025 Feb 24;59:729–38. doi:10.1111/medu.15629

53. Magomedova Z, Zakhkieva R, Abumuslimov S. The relationship between heart rate variability and school performance. In. 2021. Available from: https://consensus.app/papers/the-relationship-between-heart-rate-variability-and-magomedova-zakhkieva/0ddac5c2aa3a5d9ba3f68136bfa243af/ doi:10.1063/5.0075433

54. Shaffer F, Ginsberg J. An Overview of Heart Rate Variability Metrics and Norms. Front Public Health. 2017 Sep 28;5. doi:10.3389/fpubh.2017.00258

55. Nashiro K, Yoo H, Cho C, Min J, Feng T, Nasseri P, et al. Effects of a Randomised Trial of 5-Week Heart Rate Variability Biofeedback Intervention on Cognitive Function: Possible Benefits for Inhibitory Control. Appl Psychophysiol Biofeedback. 2022 Aug 28;48:35–48. doi:10.1007/s10484-022-09558-y

56. Luque-Casado A, Zabala M, Morales E, Mateo-March M, Sanabria D. Cognitive Performance and Heart Rate Variability: The Influence of Fitness Level. PLoS ONE. 2013 Feb 20;8. doi:10.1371/journal.pone.0056935

57. Pillon A, Ulbricht V, De Souza MV, Fontenele AFGT. Heart Rate Variability Analysis to track stress level while learning Mathematics. In. 2023. p. 1–6. Available from: https://consensus.app/papers/heart-rate-variability-analysis-to-track-stress-level-pillon-ulbricht/0bbde035f6f455249282213c514d8037/ doi:10.23919/cisti58278.2023.10211300

58. Warren J, Ni L, Fry B, Stowell M, Gardiner C, Whittaker R, et al. Predicting Heart Rate Variability from Heart Rate and Step Count for University Student Weekdays. In. 2024. p. 1–4. Available from: https://consensus.app/papers/predicting-heart-rate-variability-from-heart-rate-and-step-warren-ni/7d1896480774500a8c5f13633c335732/ doi:10.1109/embc53108.2024.10781904

59. Loftness B, Hidalgo J, Cherian J, Mascia G, McGinnis R, McGinnis E. Longitudinal Profiles of Heart Rate Variability in First-Year College Students Using Wearables. In. 2024. p. 1–4. Available from: https://consensus.app/papers/longitudinal-profiles-of-heart-rate-variability-in-loftness-hidalgo/48410085466b5a088b6e073d52dc27ad/ doi:10.1109/bsn63547.2024.10780775

60. Rice D, Gatzke-Kopp L, Fisher Z. Developmental Changes in the Association Between Heart Rate Variability and Peer Success Across Early Elementary School. Psychophysiology. 2025 Sep 1;62. doi:10.1111/psyp.70156

61. Yoo H, Yune S, Im S, Kam B, Lee SY. Heart Rate Variability-Measured Stress and Academic Achievement in Medical Students. Med Princ Pract. 2020 Dec 16;30:193–200. doi:10.1159/000513781

62. Derby C, Qin J, Liu G, Wang C, Sloan R. Heart Rate Variability, Cognitive Performance and Cognitive Impairment in Older Adults: Cross-Sectional Results From the Einstein Aging Study. Health Sci Rep. 2025 Aug 1;8. doi:10.1002/hsr2.71152

63. Zeng J, Meng J, Wang C, Leng W, Zhong X, Gong A, et al. High vagally mediated resting-state heart rate variability is associated with superior working memory function. Front Neurosci. 2023 Feb 20;17. doi:10.3389/fnins.2023.1119405

64. Федерация Р, Новгород Н. Students' Dynamics of Heart Rate Variability during Virtual Reality Class. Exp Psychol Russ. 2022 Jan 1. doi:10.17759/exppsy.2022150205

65. Hong H, Huang WL, Twu S. Study on Effcet of Computer Assisted Instruction Via Analysis of Heart Rate Variation. In. 2022. p. 412–5. Available from: https://consensus.app/papers/study-on-effcet-of-computer-assisted-instruction-via-hong-huang/4708bcfdc4e45f298ba6db8707a976bd/ doi:10.1109/ecei53102.2022.9829528

66. Ziyadidegan S, Javid A, Sasangohar F. Investigating Stress-Related Heart Rate Behavior and Rhythm in College Students Using Trend Analysis Methods. Sensors. 2026 Apr 1;26. doi:10.3390/s26082391

67. Forte G, Casagrande M. The intricate brain-heart connection: The relationship between heart rate variability and cognitive functioning. Neuroscience. 2024 Dec 1. doi:10.1016/j.neuroscience.2024.12.004

68. Benítez-Agudelo J, Restrepo D, Navarro-Jiménez E, Clemente-Suárez V. Longitudinal effects of stress in an academic context on psychological well-being, physiological markers, health behaviors, and academic performance in university students. BMC Psychol. 2025 Jul 8;13. doi:10.1186/s40359-025-03041-z

69. Orellana CS, Coria GD, Osorio VG, Santos AD, Roca LB. Relación de la variabilidad de la frecuencia cardiaca y el yo-yo test en deportistas universitarios. Retos. 2025 Dec 4. doi:10.47197/retos.v75.117688

70. Matyevich M, Kingsley M, Bice R, Mortimer M, Horan B, Piantella S, et al. Reliability and reactivity of heart rate variability and pupillometry in response to controlled autonomic perturbations in university students. Behav Res Methods. 2025 Aug 19;57. doi:10.3758/s13428-025-02793-1

71. Liu K, Elliott T, Knowles M, Howard R. Heart rate variability in relation to cognition and behavior in neurodegenerative diseases: A systematic review and meta-analysis. Ageing Res Rev. 2021 Dec 6;73. doi:10.1016/j.arr.2021.101539