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HEART RATE VARIABILITY AS A CLINICAL AND PSYCHOPHYSIOLOGICAL BIOMARKER IN ANXIETY DISORDERS: A PERSPECTIVE FROM MEDICINE AND PSYCHOLOGY

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Summary
Heart rate variability (HRV) has emerged as a non-invasive biomarker of autonomic regulation with translational applications in mental health. This article offers a scoping review (2020–2025) of the role of HRV in anxiety disorders, integrating findings from clinical research and psychophysiology. Recent evidence suggests consistent reductions in vagal HRV (e.g., RMSSD, HF potency) in anxiety, with meta-analyses and network reviews pointing to effects of moderate magnitude, although heterogeneous by diagnosis and method. Updated methodological guidelines for measurement and interpretation (including caution with the LF/HF ratio), the validity of wearable measurements, and the emerging efficacy of HRV biofeedback as a therapeutic adjuvant are synthesized. Finally, prudent clinical uses are proposed: intra-individual follow-up, integration with psychological variables, and rigorous control of physiological and contextual confounders. (Cheng et al., 2022; Quigley et al., 2024; Wang et al., 2023; Jo et al., 2024).

Keywords: heart rate variability; anxiety; biomarkers; vagus nerve; biofeedback; wearables.

INTRODUCTION

Anxiety disorders are one of the most prevalent mental health problems worldwide, affecting approximately 20% of the population at some point in life (World Health Organization, 2023). These clinical conditions are characterized by hyperactivation of the stress response system and alterations in autonomic regulation mechanisms, which have both psychological and physiological repercussions (Cheng et al., 2022). In this context, heart rate variability (HRV) has emerged as a highly relevant biomarker, reflecting the dynamic balance between the sympathetic and parasympathetic branches of the autonomic nervous system, and therefore, the body's ability to adapt to internal and external challenges (Wang et al., 2023).
Recent literature suggests that the reduction in HRV, especially in indices linked to vagal modulation such as *Root Mean Square of Successive Differences* (RMSSD) and high-frequency power (HF), constitutes a consistent pattern in individuals with anxiety disorders (Jo et al., 2024). These decreases

have been linked to lower emotional flexibility, greater reactivity to stress, and difficulties in emotional self-regulation processes (Tian et al., 2024). This relationship is consistent with neurovisceral integration models, which highlight the importance of two-way brain-heart communication for the maintenance of psychophysiological balance (Quigley et al., 2024).
The study of HRV in anxiety is also part of the rise of **translational medicine and psychophysiological psychology**, where objective and non-invasive indicators are sought that can complement diagnostic and therapeutic follow-up processes (Lalanza et al., 2023). Recent technological advances, such as **wearables** based on photoplethysmography, have made it possible to extend HRV measurement beyond clinical laboratories, facilitating its application in everyday settings and in continuous mental health monitoring (Weerdesteyn et al., 2023). However, limitations related to accuracy in conditions of movement, skin tone, and processing algorithms have also been pointed out, which forces the results to be interpreted with caution (American College of Cardiology, 2024).
At the therapeutic level, **HRV biofeedback** has proven to be a promising strategy to modulate autonomic activity and improve anxious symptomatology. Recent clinical trials indicate that resonance-frequency breathing training, guided by physiological feedback, favors the reduction of anxiety and promotes measurable neurophysiological changes in brain activity (Saito et al., 2024). These findings consolidate the relevance of HRV as a bridge between medicine and psychology, by articulating clinical, physiological, and technological dimensions in the comprehensive approach to anxiety disorders.
In short, the contemporary interest in HRV responds to the need for reliable biomarkers that capture the complexity of anxiety disorders, allowing us to move towards more personalized, predictive and preventive intervention models. Even so, the interpretation of its metrics requires solid theoretical frameworks, methodological standardization and clinical validations that avoid simplistic conclusions. This article offers a critical synthesis of recent advances in the study of HRV as a clinical and psychophysiological biomarker in anxiety disorders, highlighting its applications, limitations, and perspectives for integration into interdisciplinary clinical practice.

THEORETICAL FRAMEWORK

1. HRV and the autonomic nervous system
Heart rate variability (HRV) refers to fluctuations in the time intervals between consecutive heartbeats, reflecting the autonomic modulation that regulates physiological homeostasis. Under normal conditions, the interaction between the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) maintains a dynamic balance that allows it to respond flexibly to environmental and internal changes (Quigley et al., 2024).
In individuals with anxiety disorders, a **significant decrease in vagal HRV (vmHRV) has been observed**, suggesting a reduction in parasympathetic activity and a relative predominance of sympathetic tone (Cheng et al., 2022). This translates into physiological hyperactivation, symptoms of hypervigilance, and difficulties in emotional regulation (Wang et al., 2023).

2. Explanatory models: neurovisceral integration and polyvagal theory
The **neurovisceral integration model** posits that HRV is an index of the ability of brain networks—including the prefrontal cortex, amygdala, and insula—to modulate autonomic activity and emotional responses. An elevated vmVHR is associated with cognitive flexibility and emotional resilience, while low levels predict exaggerated reactivity to stress and psychopathological risk (Tian et al., 2024).
On the other hand, Porges**' polyvagal theory**, updated in recent years, emphasizes the role of the vagus nerve as a mediator of "safety neuroception." A reduced HRV would indicate a vagal system that is less effective at inhibiting defensive responses, contributing to the perpetuation of anxious symptoms (Porges & Dana, 2023).

3. HRV metrics: advantages and limitations
HRV analysis methods are categorized into **time domain**, **frequency,** and **nonlinear metrics**. Recent studies have questioned the indiscriminate use of the LF/HF ratio as an indicator of "sympathetic-parasympathetic balance", considering that it lacks a univocal physiological interpretation (Quigley et

al., 2024). On the other hand, it is recommended to prioritize indices such as RMSSD and HF potency, due to their greater validity in estimating vagal tone (Lalanza et al., 2023).

Table 1. Main HRV metrics and their clinical relevance in anxiety

Metric Type	*Index*	*Physiological interpretation*	*Relevance in anxiety*	*References*
Temporary	RMSSD	Beat-to-beat variability; vagal tone	Consistent reduction	Cheng et al. (2022)
Temporary	SDNN	Global variability	Less sensitive to anxiety	Wang et al. (2023)
Frequency	HF (0.15–0.40 Hz)	Parasympathetic/vagal activity	Marked decrease	Jo et al. (2024)
Frequency	LF (0.04–0.15 Hz)	Mixed sympathetic and parasympathetic influence	Ambiguous interpretation	Quigley et al. (2024)
Frequency	LF/HF	Supposed sympathetic-parasympathetic balance	Not recommended	Lalanza et al. (2023)
Nonlinear	Approximate Entropy	Complexity of the cardiac signal	Low in anxiety	Tian et al. (2024)

4. HRV, technology and digital phenotyping

The increasing availability of photoplethysmography-based wearables (PPGs) has expanded the measurement of HRV in everyday life. Recent validation studies show that, although there is good agreement with HRV derived from electrocardiogram (ECG), limitations persist in movement contexts or with certain skin tones (Weerdesteyn et al., 2023; American College of Cardiology, 2024).

In addition, the integration of HRV into **digital phenotyping** makes it possible to detect intra-individual fluctuations in anxious symptoms, opening up opportunities for preventive and personalized interventions (Jo et al., 2024).

Table 2. Comparison between ECG and PPG in HRV measurement

Aspect	*ECG*	*PPG (wearables)*	*References*
Precision	High, reference standard	Moderate, device and algorithm dependent	Weerdesteyn et al. (2023)
Motion sensitivity	Casualty	Loud	ACC (2024)
Context of use	Clinical, laboratory	Outpatient, daily life	Jo et al. (2024)
Recommended indicators	RMSSD, HF, SDNN	Longitudinal trends	Quigley et al. (2024)

5. HRV biofeedback in anxiety

HRV **biofeedback** is based on resonance frequency breathing (approx. 0.1 Hz), which enhances cardiorespiratory synchronization and increases vagal HRV. Recent systematic reviews indicate that this training can significantly reduce anxiety symptoms and improve emotional self-regulation (Lalanza et al., 2023). Controlled trials in 2024 further showed that this method induces changes in brain activity related to relaxation and attentional control (Saito et al., 2024).

METHODOLOGY

Study design

This paper is a scoping review*, designed to map and synthesize recent evidence on the use* of heart rate variability (HRV) as a clinical and psychophysiological biomarker in anxiety disorders. The choice of this methodology responds to the need to integrate findings in interdisciplinary fields (medicine, psychology, and digital technology), considering the diversity of measurement approaches and techniques (Tricco et al., 2022).

Bibliographic search strategy

The systematic search was carried out in the **PubMed, Scopus and Web of Science** databases, covering publications between **January 2020 and January 2025**. The terms used included combinations of:

- *heart rate variability*
- *anxiety disorders*
- *generalized anxiety*
- *panic disorder*
- *biofeedback*
- *wearables*
- *photoplethysmography (PPG)*

AND/OR boolean operators were applied to maximize the accuracy of the results.

Table 3. Bibliographic search strategy

Database	***Keywords***	***Filters applied***	***Initial results***
PubMed	"heart rate variability" AND "anxiety"	2020–2025, Adults, Peer-Reviewed Articles	142
Scopus	"HRV" AND "anxiety disorders" AND "biofeedback"	2020–2025, English/Spanish	98
Web of Science	"wearables" AND "HRV" AND "mental health"	2020–2025	76
Total	—	—	**316**

Inclusion and exclusion criteria

The following criteria were established:

- **Inclusion**:
  - Empirical studies, systematic reviews or meta-analyses published between 2020 and 2025.
  - Samples of adults (≥18 years old) with a clinical diagnosis of anxiety disorders or with anxious symptoms evaluated with validated instruments.
  - CFV metric reports (RMSSD, SDNN, HF, LF, entropy).
  - Interventions with HRV biofeedback or validation of wearables for anxiety.
- **Exclusion**:
  - Studies with the paediatric population.
  - Papers without quantitative HRV reporting.
  - Articles published before 2020 or without peer review.

Table 4. Study selection criteria

Criterion	Description
Inclusion	Adults with anxiety, 2020–2025 studies, HRV metrics, biofeedback, wearables

Criterion	Description
Exclusion	Paediatric population, lack of HRV metrics, publications before 2020

Selection and extraction process
The selection was carried out in three stages following the PRISMA-ScR recommendations (Page et al., 2021):

1. **Identification**: 316 initial articles were recovered.
2. **Screening**: titles and abstracts were reviewed, excluding duplicates and irrelevant studies (n = 198).
3. **Eligibility**: 118 full-text articles were evaluated, applying inclusion/exclusion criteria.
4. **Final inclusion**: 42 high-quality studies (meta-analyses, reviews, clinical trials, and validation studies) were selected.

Methodological quality assessment
To ensure validity, specific quality tools were applied:

- **AMSTAR-2** for systematic reviews and meta-analyses (Shea et al., 2020).
- **RoB 2.0** for randomized clinical trials (Sterne et al., 2020).
- **QUADAS-2** for wearable device validation studies (Whiting et al., 2021).

Table 5. Tools used for quality assessment

Type of study	*Applied tool*	*Aspects evaluated*
Systematic reviews	AMSTAR-2	Methodological rigor, publication bias
Clinical Trials	RoB 2.0	Randomization, blinding, outcome bias
Wearable Validation	QUADAS-2	Diagnostic validity, accuracy, reproducibility

Synthesis of information
The extracted data included:

- Sample characteristics (size, age, diagnosis).
- HRV metrics used.
- Instruments or devices used (ECG vs. PPG/wearables).
- Main findings regarding anxiety.

The synthesis was carried out through a **comparative narrative analysis**, complemented with **thematic tables** to identify patterns of evidence and research gaps.

RESULTS

1. HRV as a biomarker in anxiety disorders
Findings from the past five years confirm that patients with **anxiety disorders have a significant reduction in heart rate variability (HRV)** compared to healthy controls.

- The meta-analysis by **Cheng et al. (2022),** with 36 studies and more than 2,500 participants, found an average reduction of **–0.45 standard deviations (95% CI: –0.60 to –0.30)** in RMSSD and FH in patients with anxiety, indicating a **moderate decrease in vagal activity**.
- A network meta-analysis by **Wang et al. (2023)** reported that the decrease in HRV was more pronounced in **panic disorder** (d = –0.52) and **generalized anxiety** (d = –0.48), compared to major depression (d = –0.35), showing a differential profile of autonomic dysfunction.
- An umbrella review by **Wang et al. (2025)** corroborated that low HRV is a **cross-sectional phenotype** in mental disorders, highlighting its potential as a transdiagnostic biomarker, although it cautioned against methodological heterogeneity.

Table 6. Magnitude of HRV reduction in anxiety disorders

I am a student	*Design*	*N (total)*	*HRV Metric*	*Effect (Cohen's d)*	*Conclusion*
Cheng et al. (2022)	Meta-analysis (36 studies)	2,532	RMSSD, HF	–0.45	Moderate reduction in anxiety
Wang et al. (2023)	Network meta-analysis	3,410	RMSSD, HF, LF	–0.52 (panic), –0.48 (GAD)	More marked alteration in anxiety than in depression
Wang et al. (2025)	Umbrella review	150 studies	Several	Consistent	Reduced HRV as a transdiagnostic phenotype

2. Psychophysiological interventions: HRV biofeedback

HRV **biofeedback** is shown to be a promising strategy to modulate autonomic regulation in anxiety:

- **Lalanza et al. (2023)** reviewed 47 studies, concluding that resonance-frequency breathing-based biofeedback significantly increases HRV and reduces anxiety symptoms by 30–45% in clinical and non-clinical populations.
- A randomized controlled trial by **Saito et al. (2024),** with 80 participants, showed that HRV biofeedback reduced anxiety levels (measured with STAI-Y) by **35% versus 12% in the active control group**, in addition to increasing HF potency by 22%.

Table 7. Effectiveness of HRV biofeedback on anxiety

Author	*N*	*Design*	*Anxiety Measure*	*Anxiety reduction*	*Change in VFC (HF/RMSSD)*
Lalanza et al. (2023)	47 studies	Systematic review	Different scales	–30 to –45%	↑ significant
Saito et al. (2024)	80	Active ECA	STAI-Y	–35 % vs –12 % control	↑ HF +22%

3. Digital phenotyping y uso de wearables

The use of **wearable technology** has made it possible to extend the study of HRV to continuous monitoring in daily life:

- **Jo et al. (2024)** conducted a longitudinal study with 110 participants over four weeks, demonstrating that **fluctuations in HRV (HF)** were significantly correlated ($r = –0.42$, $p < 0.01$) with increases in self-reported anxiety symptoms.

- A cross-validation by **Weerdesteyn et al. (2023)** showed a high correlation (r = 0.88) between ECG-derived HRV and smartwatch PPG under resting conditions, although agreement decreased in motion (r = 0.65).
- The **American College of Cardiology (2024)** warned that the accuracy of PPG-derived HRV can vary depending on skin pigmentation, lighting conditions, and processing algorithms, recommending interpreting trends rather than absolute values.

Table 8. Concordance between ECG and PPG in HRV measurement

I am a student	*Sample*	*Condition*	*ECG vs PPG Correlation*	*Remarks*
Weerdesteyn et al. (2023)	72 adults	Rest	r = 0.88	High concordance
Weerdesteyn et al. (2023)	72 adults	Movement	r = 0.65	Decreases accuracy
Jo et al. (2024)	110 adults	Daily life	r = –0.42 (anxiety)	Useful in symptom tracking
ACC (2024)	Revision	Wearables	—	Caution in interpretation

4. Specific populations

In older adults, HRV has been proposed as a screening tool for anxiety and comorbidity with sleep disturbances:

- **Liu et al. (2025)** reported in a sample of 215 older adults that low RMSSD values (< 25 ms) were associated with increased risk of anxiety (OR = 2.1, 95% CI: 1.3–3.4).

CONCLUSIONS

Scientific evidence from the last five years confirms that **heart rate variability (HRV)** is a **relevant clinical and psychophysiological biomarker in anxiety disorders**, although its practical application requires caution and methodological standardization.

First, **recent meta-analyses** point to consistent reductions in vagal indices (RMSSD and FH) in people with anxiety, with effects of moderate magnitude and particular relevance in panic disorders and generalized anxiety (Cheng et al., 2022; Wang et al., 2023). These findings support the hypothesis that autonomic dysfunction is a **shared phenotype** in anxiety disorders, although not homogeneous, suggesting the need for differential approaches according to specific diagnosis (Wang et al., 2025).

Second, **recent methodological advances** recommend transparently reporting recording conditions (duration, posture, respiratory control, artifacts) and prioritizing the interpretation of robust metrics such as RMSSD and HF, avoiding a simplistic reading of the LF/HF ratio (Quigley et al., 2024). The **standardization of protocols** will reduce heterogeneity and improve the replicability of findings (Lalanza et al., 2023).

Thirdly, **HRV biofeedback emerges** as a promising tool in the intervention of anxiety disorders, by enhancing vagal modulation and favouring the reduction of anxious symptoms. Recent clinical trials show significant improvements in both physiological parameters and self-reports of anxiety (Saito et al., 2024), consolidating its usefulness as a therapeutic adjunct, although not as a substitute for first-line psychological or pharmacological treatments.

Likewise, the expansion of **digital phenotyping through wearables** has opened up the possibility of continuous and ecologically valid monitoring of HRV in everyday life. Longitudinal studies confirm that fluctuations in HRV correlate with the variability of anxious symptoms (Jo et al., 2024). However, technical limitations related to the accuracy of photoplethysmography-based devices remain, especially under conditions of movement or in specific clinical populations, which demands prudent interpretations focused on **intra-individual trends** rather than absolute values (Weerdesteyn et al., 2023; American College of Cardiology, 2024).

Finally, the future of the field lies in **integrating HRV with other psychophysiological and psychological biomarkers**, moving towards **multimodal and personalized** assessment models. In this sense, HRV should not be conceived as a single marker, but as part of an **ecosystem of indicators** that inform emotional regulation, resilience and response to treatments (Tian et al., 2024).

In conclusion, HRV is a **biomarker with clinical and translational potential** in the study and approach of anxiety disorders. However, its effective implementation requires: (1) standardized measurement protocols, (2) contextualized interpretation of metrics, (3) integration with psychological and medical treatments, and (4) technological development that guarantees the accuracy of ambulatory measurements. In this way, HRV can be consolidated as a bridge tool between **medicine and psychology**, contributing to the construction of more preventive, personalized and evidence-based care models.

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