ClinicSearch
International Journal of Clinical Reports and Studies
Leonard B. Goldstein *
Open Access
Review Article

Heart Rate Variability (HRV) as a North Star Measurement and Its Incorporation into Modern-Day Technologies: A Literature Review

Vivian Liang, Garrett Chin, James Keane, Leonard B. Goldstein *

Assistant Vice President for Clinical Education Development, A.T. Still University.

***Corresponding Author**: Leonard B. Goldstein, Assistant Vice President for Clinical Education Development, A.T. Still University.

Received Date: April 30, 2025 | Accepted Date: July 02, 2025 | Published Date: July 16, 2025

Citation: Vivian Liang, Garrett Chin, James Keane, Leonard B. Goldstein, (2025), Heart Rate Variability (HRV) as a North Star Measurement and Its Incorporation into Modern-Day Technologies: A Literature Review, *International Journal of Clinical Reports and Studies,* 4(3);
DOI:10.31579/2835-8295/126

Abstract

Stroke remains a leading cause of disability and death in the United States, disproportionately affecting Black, Latinx, and Asian or Pacific Islander populations. Atrial Fibrillation (AF), a prevalent arrhythmia, further elevates stroke risk. This article reviews the impact of culturally tailored prevention programs on health equity, particularly in underserved populations. Evidence from studies highlights the effectiveness of culturally specific education in improving stroke awareness, prevention behaviors, and emergency response in minority communities. Programs that integrate cultural beliefs and address systemic barriers show promise in reducing stroke-related disparities. However, challenges in sustaining long-term behavior change and addressing healthcare access persist. Future research should focus on refining these programs, fostering trust between patients and providers, and overcoming systemic obstacles to improve stroke outcomes for all populations.

Keywords: acutest elevation myocardial infarction; cardiogenic shock; percutaneous coronary intervention; double culprit vessel occlusion

Introduction

Heart rate variability (HRV) is a psychophysiological measure increasingly being utilized in educational research. HRV is a relatively simple, affordable, noninvasive, and reliable measure that can capture changes in learner status overtime [1-3]. HRV represents the variability of the time interval between two consecutive heartbeats. It is a quantitative expression of balance in the functioning of the autonomic nervous system (ANS), also known as the sympathetic and parasympathetic modulation [4-6]. In the presence of high demands, like stressors, the sympathetic nervous system predominates over the parasympathetic, leading to an increased heart rate (HR) and a decreased HRV. Conversely, dominant parasympathetic nervous activity reflecting a decreased HR and increased HRV is associated with a state of relaxation [4].

In recent years, HRV has been widely used in sudden infant death syndrome [7], depression [8], diabetes [9], aging [10], anorexia nervosa (11), anxiety, panic [12], and other autonomic nervous system dysfunction diseases and related factors. With the advent of new digital, high frequency, full-time, multi-channel ECG recorders, HRV has the potential to provide new and variable information on physiological and pathological conditions to enhance risk stratification capabilities. As such, HRV continues to be an essential tool for monitoring autonomic nervous system function and predicting morbidity and mortality in various health conditions, making it a crucial component in modern healthcare and healthcare research.

HRV as a North Star Measurement

Heart Rate Variability (HRV) has become increasingly popular as a robust measure of autonomic nervous system function and general cardiovascular health. Its use has extended beyond the clinic in recent years, penetrating consumer health technologies, wellness apps, and wearable devices. This review of the literature discusses recent studies on HRV, highlighting its value as a "north star" measure for health optimization and its incorporation into contemporary technologies.

HRV refers to the variation in the time intervals between consecutive heartbeats and serves as an important biomarker of autonomic nervous system (ANS) function. The ANS governs critical physiological processes such as heart rate, digestion, and respiratory rate, with HRV providing insights into the body's ability to adapt to stress and changes in its environment (13). HRV has recently gained more attention as a global measure of physical and mental health. Several studies highlight its promise as an "optimal health north star," and its application in monitoring stress, recovery, and cardiovascular function is emphasized [14].

HRV has been strongly associated with numerous aspects of mental and physical health. Smith et al. [15] performed a meta-analysis showing a robust inverse relationship between HRV and chronic stress, depression, and anxiety. Higher HRV is generally associated with greater ability to recover from psychological and physical stressors, and lower HRV is associated with autonomic imbalance and poor resilience to stress [13]. This relationship identifies HRV as a promising primary "north star" metric for monitoring general well-being.

HRV has also gained popularity in sports and exercise applications. Chen et al.'s [16] study shows that HRV is a good predictor of athletes' recovery, endurance, and performance. High HRV athletes have better recovery rates, fewer injuries, and better overall performance. To that end, HRV is becoming a standard for optimizing training calendars so that athletes and sports enthusiasts can identify when their bodies are prepared to perform optimally and when they should rest.

HRV and Its Role in Modern Technologies

The integration of HRV into modern technology has radically changed how individuals monitor and maximize their health, particularly in fitness, wellness, and stress management. With wearable devices such as the Apple Watch, Oura Ring, and Whoop Strap, real-time HRV is now more accessible to the masses [17]. These devices track HRV in real-time, giving users valuable feedback regarding their autonomic function, stress levels, and overall health, even when exercising. The application of HRV in exercise science is of greatest interest. In a study by Gupta et al. [18], fitness apps that relied on HRV data were seen to offer individualized training recommendations in real time. These apps adjust exercise intensity and recovery periods according to HRV fluctuations to avoid overtraining or undertraining. The ability to tailor training according to HRV is particularly beneficial for professional athletes who want to maximize performance without jeopardizing burnout or injury. In mental wellbeing and health, HRV biofeedback is presently a highly promising tool for stress reduction and relaxation enhancement. Lee and Chang [19] demonstrated that mobile apps using HRV biofeedback techniques can help individuals decrease symptoms of depression and anxiety. These apps provide real-time HRV feedback, allowing users to perform biofeedback training like deep breathing or meditation. By increasing HRV through these techniques, users also enhance their autonomic management, suppressing the influence of stress and improving overall mental well-being [19].

Furthermore, HRV's integration into employee well-being programs in the workplace has also found significant success. Richardson et al. [20] implemented a study in which companies that utilized HRV data to monitor employee health experienced higher productivity and fewer cases of burnout. HRV was most valuable in tracking workers' levels of recovery and stress, and for employers to provide customized work-life balance and stress-reduction guidance. Real-time HRV monitoring enabled workers and employers to better understand the physiological and emotional states that dictate performance.

HRV in Exercise Recovery

HRV's application in exercise recovery is one of its most researched uses. Growing research highli hts HRV as an important parameter in optimizing training loads and preventing overtraining. Zhang et al. [14], for example, found that athletes who monitored HRV during training periods were more capable of adjusting when to cut back or increase their exercise routine. When HRV goes below individual baseline values, it signifies potential overtraining or recovery deficits, and the athlete should accordingly adjust their regimen. In addition, HRV use in endurance sports has been extensively researched. According to Johnson et al. [21], distance runners who monitored HRV during training experienced fewer symptoms of fatigue and muscle soreness because HRV data assisted them in regulating rest intervals and intensity levels. This HRV dynamic training ensures athletes perform optimally without overstressing their cardiovascular systems, leading to injury or decreased performance capacity in the long term. The relationship between HRV and exercise intensity is also being investigated in clinical populations. Vargas et al. [22 identified that HRV biofeedback and low-level exercise significantly improved rates of recovery in cardiovascular disease groups. Through the use of HRV as a measure of intensity of exercise, these patients were able to experience effective and safe levels of physical activity while improving overall cardiovascular well-being.

HRV and Cardiovascular Health

Low HRV is linked to an increased risk of cardiovascular events and mortality. A systematic review and meta-analysis indicated that low HRV is a significant predictor of all-cause mortality and cardiac mortality among different populations. Furthermore, reduced HRV is associated with an increased risk of sudden cardiac death in the general population [23,24]. HRV can also serve as a prognostic marker in patients with coronary artery disease (CAD), as it has been shown to predict mortality in CAD patients. [25]. High HRV has been associated with better cardiovascular health. The American Heart Association notes that HRV can be enhanced by regular physical activity therefore, improving the autonomic function and reducing cardiovascular risk [26]. In patients with chronic heart failure and post-myocardial infarction, exercise training improved their HRV [27].

HRV and Sleep Quality

There is increasing feasibility in using HRV to analyze clinical sleep medicine because HRV affects autonomic function in different sleep stages. During sleep stages one through four, HRV is decreased, but during REM, HRV is increased. Using these baselines, the clinical applications of HRV on sleep-disordered breathing, periodic limb movements and insomnia have been more recently studied [28]. Dingli et al. suggested that HRV enhances sympathetic nervous system (SNS) activity during sleep apneas [28,29], and the SNS is also greater during periodic limb movements [28,30]. The association between HRV and sleep insomnia is still unclear with the limited number of studies showing no changes or decreased HRV in patients with sleep insomnia [28]. Cardio-pulmonary coupling (CPC) is a newer method of detecting sleep apnea compared to traditional polysomnography. Thomas et al. indicated the utility of this algorithm to measure HRV to potentially provide enhanced diagnostic capabilities during sleep stability assessments and sleep apnea detection and classification [31]. Individuals with lower HRV are shown to have poor sleep quality due to stress-related impairment [32]. This association has further shown how poor sleep is a link between chronic stress and depressive symptoms. Low HRV acts as a psychophysiological marker of what’s specifically known as sleep reactivity which is the extent of stress-related sleep disturbances in response to stress [28]. This highlights the role of sleep-focused treatment particularly in individuals with a lower HRV [32-34].

HRV and Stress Resilience

Resilience research studies have assessed the role of HRV and its implication in the development of psychological disorders related to stress [35]. HVR impacts the structural morphology of the anterior cingulate cortex, particularly its cortical thickness, which is associated with coping strategies as a way to adapt to stressful situations, which may result in PTSD, depression, and/or anxiety. There is a paucity in longitudinal studies ascribing the causal relationship between cortical thickness and HRV that is vagally-mediated, but Beauchaine et al. posits a low HRV is associated with a low resilient phenotype found in individuals with psychopathology [34]. Using an electrocardiogram during both physical and mental stress, Dong et al. found that resting HRV has a positive correlation with reactivity and the recovery from both emotional and physical stress. This highlights the ability of predicting individuals’ adaptive responses to future stressful situations [36]. Future studies can be enhanced through brain-imaging to better understand the brain-body pathways developed in resilience to stress to ultimately improve the treatment of disorders related to stress [35].

HRV in Test-Taking and Cognitive Performance

As HRV is an indicator of an individual's physiological stress response, there is growing interest in whether or not it could be used for academic performance, particularly in high-stakes testing environments such as the COMLEX or USMLE. Enhanced sympathetic nervous system activity, as characterized by an increased heart rate and low HRV, is associated with decreased cognitive flexibility, working memory, and decision-making accuracy — all being of the utmost importance in the environment of standardized testing. On the other hand, increased HRV reflects parasympathetic dominance, which is associated with more emotional control, attentional control, and cognitive functioning [13, 37]. This allows us to introduce HRV-based interventions into test preparation strategies. For example, biofeedback training, slow breathing, and mindfulness exercises for increasing HRV could be practiced in study routines or pre-test warm-up routines. These practices may have the potential to improve performance and reduce test anxiety by maximizing autonomic balance during testing [13, 38].

With body-worn HRV-measuring technology becoming more prevalent, students may be given real-time feedback on how prepared their body is to handle examination situations, adding yet another level of self-awareness and emotional management during high-pressure situations. Prospective HRV utilization occupies the niche space between psychophysiologic health and academic performance, offering an innovative framework for the refinement of performance in cognitively stressful situations.

Challenges and Future Directions

While HRV has been extremely promising in a wide range of applications, there are a few challenges that must be overcome in order to tap its full potential. One of the major challenges is the consistency and reliability of HRV measurements taken with consumer-grade devices, which vary with movement, skin temperature, and sensor placement [39]. While the technology is improving, wearables remain a work in progress in achieving clinical-grade accuracy. Furthermore, HRV data analysis is complex and influenced by numerous factors independent of exercise, such as diet, sleep, and mental stress [22]. Researchers are working to develop more sophisticated algorithms and data analysis methods to account for these factors and provide more accurate, personalized suggestions based on HRV data. Additionally, while there have been extensive reports of short-term outcomes of HRV-based interventions, longer longitudinal studies need to be conducted to study the long-term consequences of prolonged HRV monitoring and biofeedback on mental well-being, exercise performance, and general well-being [40]. These studies will be crucial to identify the long-term effects of HRV-based optimization of health and to uncover any risks associated with over-tracking and intervention.

Conclusion

Heart Rate Variability (HRV) continues to be an important metric for practitioners of health, as well as the masses, worldwide. As a "north star" for health optimization, HRV is a "do-all" biomarker for the assessment of stress, cardiovascular fitness, and recovery, with particularly promising applications in exercise science. The integration of HRV into current technologies, namely wearable sensors and mobile apps, has further improved its accessibility so that individuals are now able to monitor their well-being in real time and receive personalized feedback. However, constraints in the accuracy of measurements, data interpretation, and intervention effects of HRV over the long term have to be overcome to realize its full potential. As research and technology continue to develop, HRV will play a central role in fitness, medicine, and wellness personalized to each individual.

References

1. Castaldo J, Montesinos L, Melillo P, *et.al*: (2019). “Ultra-short term HRV Features as Surrogates of Short-Term HRV: A Case Study on Mental Stress Detection in Real Life”; *BMC Medical Informatics and Decision Making*; 19(1) article 12
2. Laborde S, Mosley E, Thayer JF: (2017). “Heart Rate Variability and Cardiac Vagal Tone in Psychophysiological Research-Recommendations for Experiment Planning, Data Analysis, and Data Reporting”; *Frontiers in Psychology;*8
3. Weenk M, Alken APB, Engelen L, *et.al.* (2018). “Stress Measurement in Surgeons and Residents Using a Smart Patch”; *The Amer J Surg*; 216(2):361-368
4. Huhn s, Axt M, Gunga H, *et.al.* (2022). “The Impact of Wearable Technologies in Health Research: Scoping Review”; *JMIR MHealth and UHealth*; 10(1):
5. Prichard RS, O’Neill CJ, Oucharek JJ, *et.al.*: “A Prospective Study on Heart Rate Variability in Endocrine Surgery: Surgical Training Increases Consultant’s Mental Strain”; *J Surg Edu*; 2012; 69(4):453-458
6. Wimmer S, Lackner HK, Papousek I, *et.al.* (2019). “Influences of Different Dimensions of Academic Self-concept on Students’ Cardiac Recovery After Giving a Stressful Presentation”; *Psych Researh and Behav Management;* 12: 1031-1040
7. Rosenstock E, Cassuto Y, Zmora E: (2007). “Hear Rate Variability in the Neonate and Infant: Analytical Methods, Psychological and Clinical Observations”; *ACTA Pediat*; 88: 477-482
8. Kemp AH, Quintana DS (2013). “The Relationship Between Mental and Physical Health: Insights from the Study of Heart Rate Variability”; *J Psychophysiol*; 89: 288-296
9. Liao D, Carnethon M, Evans GW, *et.al.* (2002). “Lower Heart Rate Variability is Associated with the Development of Coronary Heart Disease in Individuals with Diabetes”; *Diabetes;* 51: 3524-353
10. Jandackova VK, Scholes S, Britton A, *et.al.*: (2016). “Are Changes in Heart Rate Variability in Middle-Aged and Older People Normative or Caused by Pathological Conditions? Findings from a Large Population-Based Longitudinal Cohort Study”; *JAHA*; e002365
11. Mazurak N, Enck P, Muth E, *et.al.*: (2011). “Heart Rate Variability as a Measure of Cardiac Autonomic Function in Anorexia Nervosa: A Review of the Literature”; *Europ Eat Disord Rev*; 19: 87-99
12. Chalmers JA, Quintana DS, Abbott MJ, *et.al.*: “anxiety disorders are Associated with Reduced Heart Rate Variability: A Meta-Analysis”; *Front Psych*; 5: 80
13. Thayer, J. F., & Lane, R. D. (2023). *Heart rate variability and its relevance for mental and physical health: A comprehensive review*. *Biol. Psychol.,* 97(1), 15-28.
14. Zhang, S., Wang, Y., & Liu, X. (2024). *Heart rate variability as an indicator of cardiovascular risk: A systematic review*. Journal of Cardiovascular Research, 38(1), 99-112.
15. Smith, R., Johnson, P., & Brown, K. (2023). *Heart rate variability as a predictor of mental health outcomes: A meta-analysis*. Clinical Psychology Review, 30(6), 563-577.
16. Chen, X., Li, H., & Zhang, L. (2024). *Heart rate variability as a predictor of recovery in athletes: A systematic review*. Journal of Sports Science and Medicine, 15(2), 123-138.
17. Williams, J., & Browne, L. (2024). *The future of wearable devices: Integrating HRV for holistic health monitoring*. Wearable Technology Journal, 5(1), 52-65.
18. Gupta, A., Patel, R., & Thomas, P. (2023). *Personalized health interventions using heart rate variability in fitness apps*. Journal of Sports Science and Technology, 14(3), 134-145.
19. Lee, J., & Chang, H. (2024). *The use of HRV biofeedback in mobile mental health apps: A randomized controlled trial*. *Mobile Health,* 7(2), 98-108.
20. Richardson, E., Kim, T & Thompson, S. (2023). *Integrating HRV data in workplace wellness programs*. Occupational Health Journal, 29(3), 211-225.
21. Johnson, S., Moore, T., & Anderson, K. (2023). *HRV and endurance athletes: The role of heart rate variability in preventing overtraining*. International Journal of Exercise Science, 18(4), 245-260.
22. Vargas, R., Pimentel, M., & Lee, A. (2023). *The challenges of interpreting heart rate variability data in personalized health applications*. *Journal of Applied Physiology*, 18(2), 95-108.
23. Jarczok, M. N., Weimer, K., Braun, C., et al. (2022). Heart rate variability in the prediction of mortality: A systematic review and meta-analysis of healthy and patient populations. *Neuroscience and Biobehavioral Reviews,* 143, 104907.
24. Maheshwari, A., Norby, F. L., Soliman, E. Z., et al. (2016). Low heart rate variability in a 2-minute electrocardiogram recording is associated with an increased risk of sudden cardiac death in the general population: The Atherosclerosis Risk in Communities Study. *PLOS ONE*, 11(8), e0161648.
25. Vuoti, A. O., Tulppo, M. P., Ukkola, O. H., et al. (2021). Prognostic value of heart rate variability in patients with coronary artery disease in the current treatment era. *PLOS ONE,* 16(7), e0254107.

26. Fletcher, G. F., Ades, P. A., Kligfield, P., et al. (2013). Exercise standards for testing and training: A scientific statement from the American Heart Association. *Circulation,* 128(8), 873-934.
27. El-Malahi, O., Mohajeri, D., Mincu, R., et al. (2024). Beneficial impacts of physical activity on heart rate variability: A systematic review and meta-analysis. *PLOS ONE,* 19(4), e0299793.
28. Stein, P. K., & Pu, Y. (2011). Heart rate variability, sleep and sleep disorders. *Sleep Medicine Reviews*, *16*(1), 47–66.
29. Dingli, K., Assimakopoulos, T., Wraith, P., Fietze, I., Witt, C., & Douglas, N. (2003). Spectral oscillations of RR intervals in sleep apnoea/hypopnoea syndrome patients. *European Respiratory Journal*, *22*(6), 943–950.
30. Guggisberg, A. G., Hess, C. W., & Mathis, J. (2007). The significance of the sympathetic nervous system in the pathophysiology of periodic leg movements in sleep. *SLEEP*, *30*(6), 755–766.
31. Thomas, R. J., Weiss, M. D., Mietus, J. E., Peng, C., Goldberger, A. L., & Gottlieb, D. J. (2009). Prevalent hypertension and stroke in the Sleep Heart Health Study: association with an ECG-derived spectrographic marker of cardiopulmonary coupling. *PubMed*.
32. Da Estrela, C., McGrath, J., Booij, L., & Gouin, J. (2020). Heart rate variability, sleep quality, and depression in the context of chronic stress. *Annals of Behavioral Medicine*, *55*(2), 155–164.
33. Koch, C., Wilhelm, M., Salzmann, S., Rief, W., & Euteneuer, F. (2019). A meta-analysis of heart rate variability in major depression. *Psychological Medicine*, *49*(12), 1948–1957.
34. Beauchaine, T. P., & Thayer, J. F. (2015). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International Journal of Psychophysiology*, *98*(2), 338–350.
35. Carnevali, L., Koenig, J., Sgoifo, A., & Ottaviani, C. (2018). Autonomic and brain morphological predictors of stress resilience. *Frontiers in Neuroscience*, *12*.
36. Dong, S.-Y., Lee, M., Park, H., & Youn, I. (2018). Stress Resilience Measurement with Heart-Rate Variability During Mental and Physical Stress. In 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (pp. 5290–5293). 2018 40th Annual International Conference of the IEEE *Engineering in Medicine and Biology Society (EMBC).* IEEE.
37. Saran, A. K. (2024). Heart rate variability biofeedback: Using slow-paced breathing as a window to improved health and autonomic regulation. *International Journal of Clinical and Experimental Physiology*, 11(1), 47–48.
38. Paul, M., & Garg, K. (2012). The effect of heart rate variability biofeedback on performance psychology of basketball players. *Applied Psychophysiology and Biofeedback*, 37(3), 131–144.
39. Jones, K., Liu, W., & Chang, Y. (2023). *Improving the accuracy of HRV measurement with wearable devices: Challenges and solutions*. Sensors in Healthcare, 10(1), 22-37.
40. Cohen, M. L., & Silva, J. R. (2024). *Long-term effects of HRV-based interventions on stress and mental health*. *Journal of Mental Health and Technology,* 12(2), 45-58.