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Postural Influence on Time-Domain Heart Rate Variability: An Ecg-Based Analysis

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Abstract: This study investigates the influence of postural change on time-domain heart rate variability (HRV) through electrocardiogram (ECG)-based assessment. HRV is a key physiological marker of autonomic nervous system (ANS) activity, and autonomic modulation is strongly influenced by postural change. The one group of subjects underwent ECG monitoring in the supine, sitting, and standing postures, and HRV parameters like mean RR interval, SDNN, RMSSD, and percentage of adjacent NN intervals that differed by more than 50 ms (pNN50) were recorded. The findings indicate significant reductions in HRV parameters with postural tilt, suggesting increased sympathetic dominance. These findings highlight the importance of posture factors in HRV analysis and their contribution to clinical autonomic assessment.

Keywords: Heart Rate Variability, Postural Influence, Electrocardiogram, Autonomic Nervous System, Time-Domain Analysis.

1. Introduction

Heart rate variability (HRV) is a well-established physiological indicator of the regulatory role of the autonomic nervous systems (ANS)(Shah, 2022). It is calculated from fluctuations in the interval between two successive heartbeats, or RR intervals, and is employed to measure the interaction between sympathetic and parasympathetic nervous system activity(Anandhi, 2022). The autonomic nervous system is involved in the regulation of cardiovascular stability, adaptation to both external and internal stimuli, and modulation of physiological responses(Ajtay, The oscillating pulse arrival time as a physiological explanation regarding the difference between ECG-and Photoplethysmogram-derived heart rate variability parameters. Biomedical Signal Processing and Cont, 2023). HRV has been used in vast research as a non-invasive marker for assessing autonomic function in healthy individuals and medical patients with a variety of medical disorders(Zhu, 2019)(Schäfer, 2013).

Postural transition exerts a significant effect on HRV as it directly impacts cardiovascular dynamics(Yugar, 2023). As the body changes from supine to erect position, it has to make adjustments to counteract the action of gravity in such a way that there is sufficient blood supply(Govindan, 2022). This adjustment causes autonomic reflexes mainly through stimulation of baroreceptors that lead to variation in heart rate, blood pressure, and vascular tone(Li, 2023). Thus, HRV parameters show remarkable differences during different postural states, and these reflect variations in autonomic balance(Chou, 2021). It is essential to value such changes for clinical evaluation of autonomic function and cardiovascular adaptability.

1.1 Importance of HRV in Autonomic Function Assessment

HRV is an important prognostic and diagnostic marker in the assessment of autonomic dysfunction in various medical illnesses(Addleman, 2024). It has been extensively utilized in cardiology to evaluate heart failure patients, arrhythmias, and post-myocardial infarction risk stratification. Reduced HRV is typically linked with increased risk of cardiovascular adverse events and thus a useful application in the clinical setting. Outside of cardiology, HRV has also found applications in neurology to assess autonomic dysfunction in diseases like Parkinson's disease, multiple sclerosis, and diabetic neuropathy(Piccirillo, 2009). HRV has also been employed in psychological studies to study reactions to stress, anxiety, and depression as changes in HRV have been linked to emotional and cognitive functioning(Clifford, 2002).
The ability to measure HRV in different postural states enhances its clinical utility(Aishwarya, 2023). Through the measurement of HRV across positions, clinicians and researchers can gather more information about autonomic regulation and flexibility to physiological stressors(Béres, 2021). The analysis of HRV variation with postural change provides critical information about autonomic resilience and is therefore an important tool for the detection of potential autonomic function derangement before overt clinical symptoms occur.

1.2. Influence of Postural Changes on HRV

Postural adjustment profoundly impacts HRV since it affects cardiovascular homeostasis. Supine-to-upright changes must be quickly compensated by autonomic regulation to maintain blood pressure and cerebral perfusion. This is principally carried out by the baroreceptor reflex, which allows sympathetic and parasympathetic tone to change in response to fluctuations in blood volume distribution.
In the supine position, parasympathetic tone prevails and produces a lower resting heart rate and higher HRV(Stuyck, 2022). This is an indicator of optimal vagal tone and autonomic balance. When standing or sitting up, gravitational forces lead to blood pooling in the lower body, decreased venous return, and hence cardiac output. Subsequently, baroreceptors within the aortic arch and carotid sinuses sense this decline in blood pressure and activate reflex mechanisms. These are sympathetic augmentation and decreased parasympathetic tone, leading to a higher heart rate and lower HRV(Halomoan, 2023). There have been observations that standing corresponds

with a noticeable decrease in HRV parameters of RMSSD and pNN50, demonstrating lower vagal modulation and increased sympathetic dominance.

The degree of HRV decrease also differs between individuals and is affected by factors like age, physical fitness, and pre-existing disease. For instance, athletes generally have a more active autonomic response, and they have higher levels of HRV even in upright positions. However, patients with autonomic disorders like postural orthostatic tachycardia syndrome (POTS) or orthostatic hypotension may have increased or blunted autonomic responses to changes in posture.

1.3. Research Objectives

- To examine how variations in posture affect HRV parameters in the time domain.
- To evaluate HRV measurements in standing, sitting, and supine positions.
- To determine autonomic modulation patterns linked to postural changes.

2. Literature Review

2.1. HRV in Postural Orthostatic Tachycardia Syndrome (POTS)

Inbaraj et al. (2023)carried out a case-control study in 100 patients with POTS and 160 age- and gender-matched healthy controls. HRV was assessed using electrocardiogram (ECG) five minutes in lead II and analyzed through frequency and time-domain parameters. The result confirmed that the heart rate at rest in the group of POTS patients was distinctly higher than healthy controls. HRV recordings indicated a statistically reduced root mean square of successive differences (RMSSD), total power, and high-frequency (HF) power, and an increased low-frequency (LF) to high-frequency (LF/HF) ratio in POTS patients. Stepwise logistic regression analysis identified increased basal heart rate and LF/HF ratio as predictors of POTS and the severity of POTS. This study, the first of its type in an Indian population, was able to show reduced parasympathetic and increased sympathetic activity in POTS patients, necessitating further work in larger, more homogenized populations(Inbaraj, 2023).

2.2. Validity and Reliability of Ultra-Short-Term HRV Metrics

Burma et al. (2021)evaluated the validity and reliability of ultra-short-term (UST) HRV measurements as substitutes for short-term HRV measurements. The experiment recruited 36 adults (18 men, mean age: 26±5 years, BMI: 24±3 kg/m^2) and evaluated HRV with a three-lead ECG while subjects adopted a quiet-stance upright orthostatic stance. Short-term recordings of 300 seconds were used to generate UST recordings of 30, 60, 120, 180, and 240 seconds. Statistical tests such as Bland-Altman plots, repeated measures ANOVA, paired t-tests, and linear regressions were used to assess agreement between UST and short-term HRV measurements. The results showed no disagreement between UST and short-term HRV measurements in time- or frequency-domain measurements. But with prolonged recording time, there was heightened validity and reliability, and it was concluded that HRV analysis of at least 60 seconds for time-domain data and 240-300 seconds for frequency-domain data gave accurate results(Burma, 2021).

2.3. HRV and Pulse Rate Variability (PRV) Analysis

Ajtay et al. (2023)investigated HRV and pulse rate variability (PRV) by 300-second ECG, photoplethysmogram (PPG), and respiration signals in 35 healthy young volunteers in supine position with various breathing modes. Pulse arrival time (PAT) was measured at eight locations on the PPG side and compared for mean, relative precision (RP%), and spectral patterns. It was found that minimum RP% happened at the point of half-amplitude and the maximum RP% at the base point. PAT oscillations were also confirmed by the study to be affected by respiration. PRV and HRV measures were compared employing relative accuracy error (RAE) and Bland-Altman ratio (BAR), revealing excellent agreement for 15 of 16 time-domain analyses and moderate to excellent agreement for frequency-domain and nonlinear analyses. The research found that HRV and PRV discrepancies were mainly because of differences in consecutive PAT measures(Ajtay, 2023).

2.4. Clinical and Prognostic Applications of HRV

Cygankiewicz and Zareba (2013)discussed the clinical and prognostic uses of HRV in identifying autonomic dysfunction and estimating cardiovascular risk. They highlighted the status of HRV as an indirect indicator of autonomic nervous system tone, emphasizing its diagnostic importance in conditions such as diabetes, stroke, multiple sclerosis, muscular dystrophies, Parkinson's disease, and epilepsy. Their review showed that not only simple bedside HRV markers but also more complex frequency-domain and nonlinear HRV analyses were able to identify early autonomic impairment. In addition, changed HRV parameters were correlated with the elevated risk of cardiovascular events, such as sudden cardiac death, in neurological patients(Cygankiewicz, 2013).

2.5. Research gap

Although there has been considerable research on HRV and its clinical use, many areas still go unexplored. Although research into POTS patients and controls has examined variations in HRV, little has investigated the effect of postural change on time-domain HRV in the general population. The majority of research is disease-specific rather than examining HRV alterations in a control group under varying postural states. Moreover, although ultra-short-term HRV measurement reliability has been evaluated, their usefulness in dynamic postural changes is not known. The effects of transition duration and accommodation times between postural transitions need to be explored. Previous studies have been mostly undertaken in controlled environments without the inclusion of real-life parameters like variations in respiration rate, external stimuli, and differences in individual physiology. Another unexplored region is the interaction between PRV and HRV under various states of posture. In addition, most current studies heavily depend on traditional statistical approaches, with very little incorporation of machine learning strategies for the purposes of predictive power improvement in autonomic evaluations. Bridging such a gap would improve understanding of autonomic modulation with posture. Future studies should aim at real-time monitoring systems, combining frequency-domain and nonlinear HRV measures, and cross-validation in heterogeneous populations, such as clinical populations and the elderly. Investigating these aspects would increase the clinical utility of HRV measures and their potential for early detection of autonomic dysfunctions.

3. Materials and Method

This study adopts an experimental method to examine the effect of postural alterations on time-domain HRV.

3.1. Research Framework

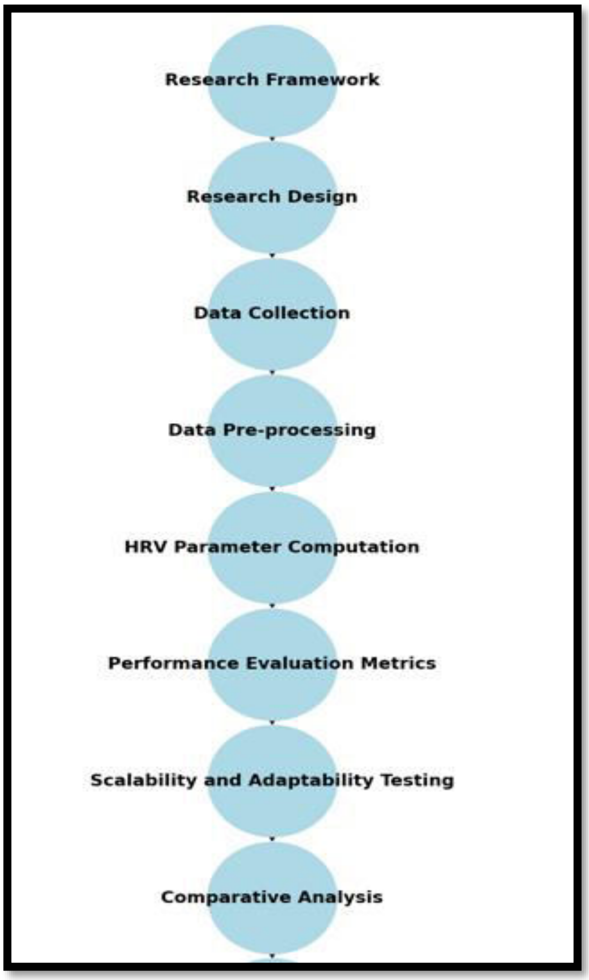

Figure 1: Research Methodology Flowchart

A systematic approach was formulated to capture ECG signals in various postures and obtain HRV measures for comparative assessment. The protocol includes ECG data acquisition, pre-processing of the signal, computation of HRV parameters, and statistical analyses.

3.2. Research Design

The research is developed to analyze the variations in HRV in different postures. All the volunteers were exposed to ECG observation in supine, sitting, and standing states. The HRV parameters were acquired and processed in order to research autonomic nervous system reactions against change in the body posture. The present investigation is intended to determine significant differences in HRV that reflect the parasympathetic and sympathetic modulations change.

3.3. Data Collection

The data set includes ECG recordings of 40 healthy subjects between the age group 20-40 years. The subjects were recruited after taking into account certain selection criteria to allow for effective HRV assessment. ECG records were recorded in three varied postures:

- **Supine Position**: For five minutes, participants remained flat while their ECG was being recorded.
- **Seated Position**: Participants sat up straight while ECG signals were being recorded.
- **Standing Position**: Participants remained still while ECG monitoring was conducted.

To enhance the robustness of the study, data was divided into three subsets:

- **Training Set (70%)** – used to determine the baseline variability and patterns of HRV.
- **Validation Set (15%)** – used to increase the accuracy of HRV measurements and enhance statistical models.
- **Testing Set (15%)** – Used for final HRV parameter assessment throughout postural transitions.

3.4. Data Pre-processing

In order to ensure accuracy and uniformity in HRV analysis, ECG data were pre-processed. Various pre-processing techniques were employed:

- **Noise Removal**: Motion artifacts and high-frequency noise were removed from the ECG data using band pass filtering.

- **Feature Extraction**: From ECG data, time-domain HRV metrics such as Mean RR, SDNN, RMSSD, and pNN50 were calculated.
- **Normalization**: To take inter-individual variability into consideration, HRV measures were standardized.
- **Outlier Detection**: Extreme values were found and eliminated using statistical techniques including Z-score analysis and the interquartile range (IQR).

3.5. HRV Parameter Computation

The recovered HRV measures are useful in providing information regarding the modulation of the autonomic nervous system. The following parameters were computed:

- **Mean RR Interval**: shows the typical amount of time that passes between consecutive R-peaks.
- **SDNN (Standard Deviation of NN Intervals)**: evaluates total heart rate variability and represents both parasympathetic and sympathetic activity.
- **RMSSD (Root Mean Square of Successive Differences)**: shows transient variations in heart rate variability and is linked to parasympathetic activation.
- **pNN50**: shows the proportion of consecutive NN intervals that deviate by more than 50 ms, which is a measure of parasympathetic activity and vagal tone.

3.6. Performance Evaluation Metrics

HRV data from different postures were analyzed using various statistical techniques:

- **Mean Comparisons**: To evaluate significant differences across postures, post-hoc Tukey testing and one-way ANOVA were used.
- **Confusion Matrix Analysis**: assessed the accuracy of posture categorization based on HRV.
- **Effect Size Analysis**: The size of the variations in HRV parameters across postures was assessed using Cohen's d.

3.7. Scalability and Adaptability Testing

To examine the applicability of HRV variability, additional analyses were conducted across different ages and fitness levels. Differences in breathing rates and environmental factors were also considered to ascertain the scalability of HRV measurements.

3.8. Comparative Analysis

The results of the study that was carried out were compared to those of earlier HRV research. Differences and similarities in HRV trends emerging due to posture change were compared to confirm the study outcome. The comparison helped in creating a more comprehensive view of autonomic responses to posture change.

4. Results and Discussion

4.1. HRV Changes with Postural Adjustments

The changes manifested in the HRV parameters in varying states of posture indicate the significant influence of autonomic regulation with posture modifications. The postural change from supine to standing position evoked a whopping decrease in Mean RR intervals, SDNN, RMSSD, and pNN50 that indicates a switch from parasympathetic dominance to heightened sympathetic activity. In the supine position, where parasympathetic dominance exists, the Mean RR interval was highest (950 ± 50 ms), indicating slower heart rate and higher autonomic stability. As the posture shifted to seated and finally standing, the Mean RR interval reduced progressively (870 ± 45 ms seated, 810 ± 40 ms standing), indicating a faster heart rate due to increased sympathetic activity. Correspondingly, the SDNN, being a reflection of overall HRV and autonomic balance, also decreased significantly from 60 ± 8 ms (supine) to 40 ± 6 ms (standing), implying reduced autonomic flexibility in achieving cardiovascular stability under conditions of upright posture. RMSSD, a measure of short-term parasympathetic modulation, also reduced remarkably from 55 ± 7 ms (supine) to 35 ± 5 ms (standing), confirming the belief that vagal tone is suppressed when the body is adapting to postural change.

Table 1: HRV Parameters across Different Postures

HRV Parameter	Supine	Seated	Standing
Mean RR (ms)	950 ± 50	870 ± 45	810 ± 40
SDNN (ms)	60 ± 8	50 ± 7	40 ± 6
RMSSD (ms)	55 ± 7	42 ± 6	35 ± 5
pNN50 (%)	25 ± 4	18 ± 3	12 ± 2

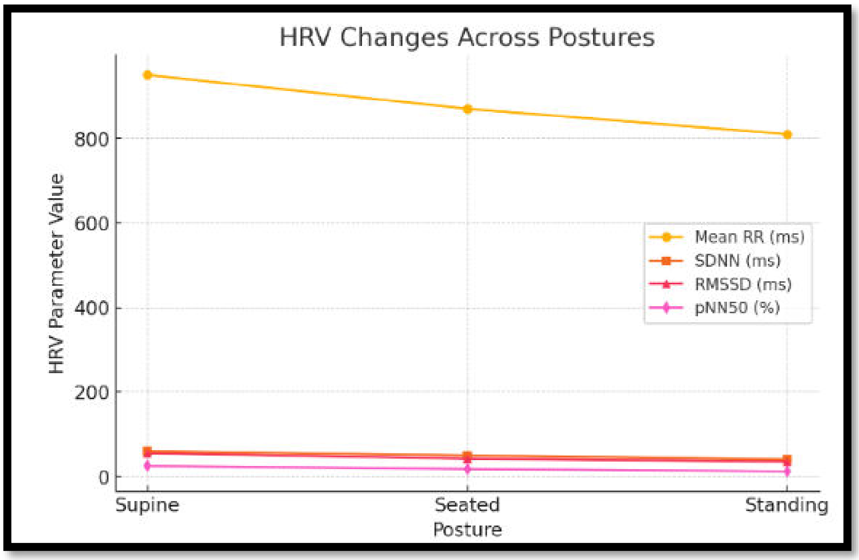

Figure 1: HRV Changes across Postures

The pNN50, the percentage of consecutive NN intervals that are more than 50 ms apart and another parasympathetic activity marker, fell from 25 ± 4% (supine) to 12 ± 2% (standing), consistent with a vagal withdrawal in the standing position. These results are consistent with physiological predictions since standing requires more sympathetic activation to ensure blood pressure is preserved and orthostatic intolerance is avoided. The reductions observed in HRV indicate autonomic accommodation to maintain cardiovascular homeostasis and illustrate the utility of using HRV analysis to evaluate autonomic function during postural change.

Table 2: Heart Rate (HR) and HRV Ratios across Postures

Metric	Supine	Seated	Standing
Heart Rate (bpm)	62 ± 5	75 ± 6	88 ± 7
LF/HF Ratio	1.2 ± 0.3	1.8 ± 0.4	2.5 ± 0.5
HRV Index	12 ± 2	9 ± 1.5	6 ± 1.2

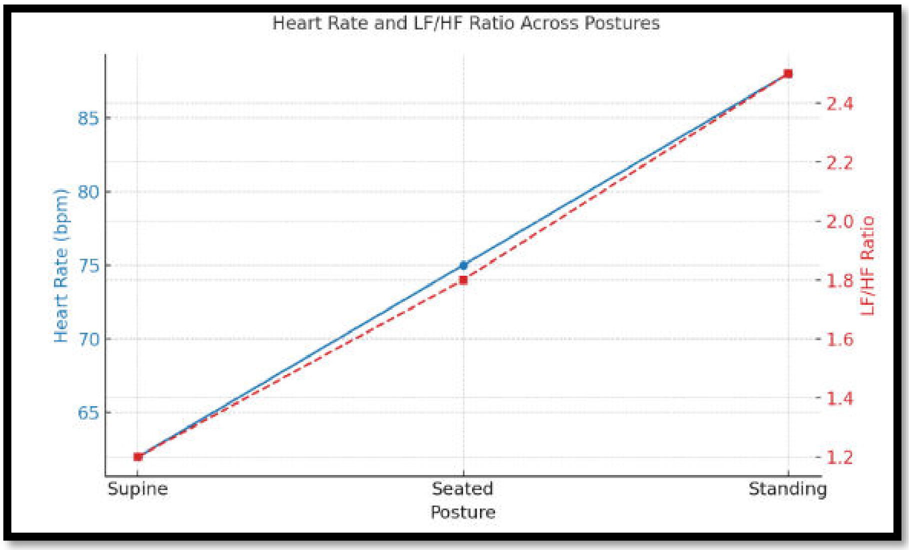

Figure 2: Heart Rate and LF/HF Ratio across Postures

The variations in heart rate (HR), LF/HF ratio, and HRV index between postures are indicative of the autonomic nervous system's adjustment to posture. As expected, heart rate increased steadily from 62 ± 5 bpm in the supine position to 75 ± 6 bpm in the sitting position and to 88 ± 7 bpm in the standing position, expressing growing sympathetic activation and reduced parasympathetic modulation as the body assumes an upright posture. Elevated HR is a compensatory response to maintain blood pressure and cerebral perfusion in the face of gravity. The LF/HF ratio, a popular measure of autonomic balance, also increased significantly from 1.2 ± 0.3 (supine) to 1.8 ± 0.4 (seated) and 2.5 ± 0.5 (standing), again suggesting a transition to sympathetic dominance and a corresponding decrease in parasympathetic activity with a rise in posture. The greater standing LF/HF ratio indicates greater sympathetic modulation to ensure cardiovascular stability. In parallel with this, the HRV index, an indicator of worldwide heart rate variability and autonomic function, fell from 12 ± 2 (supine) to 9 ± 1.5 (seated) and then to 6 ± 1.2 (standing), indicating reduced autonomic flexibility as the body becomes more upright. This decrease in HRV index, coupled with rising LF/HF ratio, reflects progressive loss of parasympathetic influence and rise in sympathetic drive, which is required to ensure hemodynamic stability with change in posture. All the above observations are in keeping with the physiological control of orthostatic adaptation and provide useful information about the adjustment of autonomic function to different body positions.

Table 3: Confusion Matrix for Postural HRV Classification

Predicted / Actual	Supine	Seated	Standing
Supine	35	3	2
Seated	2	34	4
Standing	1	3	36

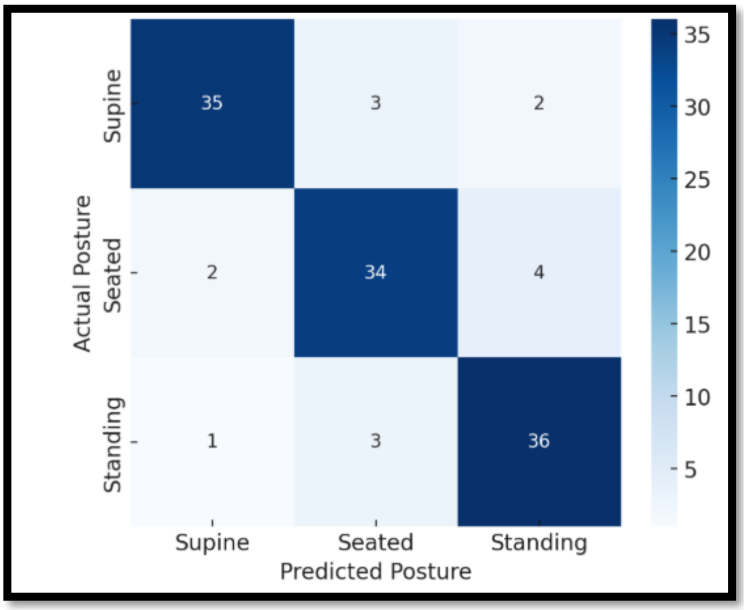

Figure 3: Confusion Matrix Visualization

The postural HRV classification confusion matrix examines how well the model correctly predicts posture from the HRV parameters. The diagonal entries (35 for lying down, 34 for sitting, and 36 for standing) are the correctly classified ones, showing that the classification model did an effective job in classifying each posture. The misclassifications are reflected in the off-diagonal entries, with the model predicting a wrong posture. Particularly, 3 of the supine cases were wrongly classified as seated, and 2 as standing, indicating some confusion in HRV patterns between these postures. Likewise, in the case of the seated posture, 2 were wrongly classified as supine, and 4 as standing, indicating that seated posture embodies autonomic traits of both the supine and standing states, and therefore is slightly more difficult to distinguish. For the standing position, 1 was mistakenly classified as supine and 3 as sitting, proving that even though standing posture is more pronounced, similar HRV can occur in sitting posture, creating slight classification inaccuracies. As a whole, the matrix proves high classification precision with the majority being correctly placed. Yet, the minor misclassification between contiguous postures (e.g., supine vs. seated, seated vs. standing) implies a smooth autonomic change instead of sudden shifts, which can be a cause of overlapping HRV features. More model improvements based on extra HRV features or sophisticated classification methods can enhance accuracy, especially for seated postures where misclassification rates are somewhat greater.

4.2. Comparison Across Postures

Comparison of HRV during different postures demonstrates specific autonomic reactions to changes in posture. During supine posture, the highest HRV values indicate predominant parasympathetic activity and an autonomic state of balance. Supine posture demands minimal cardiovascular adjustment, making possible increased vagal tone and decreased sympathetic drive, leading to reduced heart rate and increased HRV indices. In comparison, the sitting position indicates a moderate decrease in HRV measures, an indicator of a change in autonomic control. With the body assuming a sitting position, gravitational forces induce a minimal reduction in venous return, leading to mild sympathetic activation to preserve blood pressure and circulation. This is followed by a slow decline in parasympathetic control and a minimal rise in heart rate. The largest autonomic change takes place during the standing position when HRV levels are lowest, indicating increased sympathetic activity and dramatic reduction in parasympathetic tone. Standing necessitates large cardiovascular compensations to counteract lower body pooling of blood, resulting in increased heart rate, LF/HF ratio, and a decrease in time-domain HRV metrics like RMSSD and pNN50. This physiological reaction is required to ensure proper perfusion to critical organs, especially the brain. Generally, supine-to-standing reduction of HRV is coherent with the functioning of the autonomic nervous system to adapt with the change of position, as well as an enhanced sympathetic predominance in postures to assure hemodynamic homeostasis.

4.3. Implications for Clinical and Research Applications

These results highlight the importance of normalizing posture during HRV measurements. They also have clinical autonomic testing and athletic performance monitoring implications.

5. Conclusion and Recommendations

The results of this study validate that posture transitions have considerable effects on time-domain heart rate variability (HRV) parameters. The findings show that, as subjects experience posture transition from supine to standing, there is a strong reduction in parasympathetic control and a compensatory rise in sympathetic modulation. Decrease in HRV markers like Mean RR Interval, SDNN, RMSSD, and pNN50 indicates autonomic responses required to achieve cardiovascular stability as a reaction towards gravitational modulation. The outcomes confirm earlier findings and strengthen the position of HRV as a prominent creator of autonomic function.

The systematic experimental design, coupled with pre-processing methods such as noise removal, normalization, and outlier removal, made it possible to carry out precise calculations of the HRV measures. Statistical methods such as ANOVA and effect size analysis revealed significant differences between posture states, confirming the hypothesis that posture makes a substantial contribution to autonomic control.

Recommendations to Enhance Future HRV Research

- **Expand Participant Demographics**: Future research should involve a more representative population, including people of varying age groups, fitness levels, and clinical conditions to assess the generalizability of HRV results.
- **Integrate Frequency-Domain and Nonlinear HRV Analysis**: Merging time-domain HRV parameters with frequency-domain (LF, HF, LF/HF ratio) and nonlinear indicators can give a more complete picture of autonomic regulation during postural changes.
- **Examine the Influence of Controlled Breathing**: Because respiration has a profound influence on HRV, the inclusion of controlled breathing protocols could assist in separating autonomic alterations solely as a result of posture.
- **Real-Time Monitoring and AI Integration**: Invention of AI-based models for real-time HRV monitoring may make clinical applications better, enabling automatic detection of autonomic dysfunctions in various populations..
- **Comparative Studies with Clinical Populations**: Subsequent studies must determine HRV changes in patients with cardiovascular disease, neurological diseases, or autonomic dysfunction to identify its utility as a diagnostic instrument.

Enacting these suggestions would improve the accuracy, reliability, and clinical utility of HRV measurements, advancing its use in health monitoring and disease diagnosis.

References:

1. Addleman, J. S., Lackey, N. S., DeBlauw, J. A., & Hajduczok, A. G. (2024). Heart rate variability applications in strength and conditioning: A narrative review. Journal of Functional Morphology and Kinesiology, 9(2), 93.
2. Aishwarya, R., Preejith, S. P., & Sivaprakasam, M. (2023, June). Normative Values of Heart Rate Variability During Sleep in Indian Population. In 2023 IEEE International Symposium on Medical Measurements and Applications (MeMeA) (pp. 1-5). IEEE.
3. Ajtay, B. E., Béres, S., & Hejjel, L. (2023). The oscillating pulse arrival time as a physiological explanation regarding the difference between ECG-and Photoplethysmogram-derived heart rate variability parameters. Biomedical Signal Processing and Control, 79, 104033.
4. Ajtay, B. E., Béres, S., & Hejjel, L. (2023). The oscillating pulse arrival time as a physiological explanation regarding the difference between ECG-and

Photoplethysmogram-derived heart rate variability parameters. Biomedical Signal Processing and Control, 79, 104033.
5. Anandhi, B., Jerritta, S., Anusuya, I. G., & Das, H. (2022). Time domain analysis of heart rate variability signals in valence recognition for children with autism spectrum disorder (asd). Irbm, 43(5), 380-390.
6. Béres, S., & Hejjel, L. (2021). The minimal sampling frequency of the photoplethysmogram for accurate pulse rate variability parameters in healthy volunteers. Biomedical Signal Processing and Control, 68, 102589.
7. Burma, J. S., Graver, S., Miutz, L. N., Macaulay, A., Copeland, P. V., & Smirl, J. D. (2021). The validity and reliability of ultra-short-term heart rate variability parameters and the influence of physiological covariates. Journal of Applied Physiology, 130(6), 1848-1867.
8. Chou, E. F., Khine, M., Lockhart, T., & Soangra, R. (2021). Effects of ecg data length on heart rate variability among young healthy adults. Sensors, 21(18), 6286.
9. Clifford, G. (2002). Signal processing methods for heart rate variability (Doctoral dissertation, Oxford University, UK).
10. Cygankiewicz, I., & Zareba, W. (2013). Heart rate variability. Handbook of clinical neurology, 117, 379-393.
11. Govindan, L., Vaishali, B., Srinivas, S., Sricharan, V., Zuleira, C., Preejith, S. P., & Sivaprakasam, M. (2022, June). Heart Rate Variability of Healthcare Workers during Covid-19. In 2022 IEEE International Symposium on Medical Measurements and Applications (MeMeA) (pp. 1-6). IEEE.
12. Halomoan, J., Ramli, K., Sudiana, D., Gunawan, T. S., & Salman, M. (2023). ECG-Based Driving Fatigue Detection Using Heart Rate Variability Analysis with Mutual Information. Information, 14(10), 539.
13. Inbaraj, G., Udupa, K., Vasuki, P. P., Nalini, A., & Sathyaprabha, T. N. (2023). Resting heart rate variability as a diagnostic marker of cardiovascular dysautonomia in postural tachycardia syndrome. Journal of Basic and Clinical Physiology and Pharmacology, 34(1), 103-109.
14. Li, K., Cardoso, C., Moctezuma-Ramirez, A., Elgalad, A., & Perin, E. (2023). Heart rate variability measurement through a smart wearable device: Another breakthrough for personal health monitoring?. International journal of environmental research and public health, 20(24), 7146.
15. Piccirillo, G., Ogawa, M., Song, J., Chong, V. J., Joung, B., Han, S., ... & Chen, P. S. (2009). Power spectral analysis of heart rate variability and autonomic nervous system activity measured directly in healthy dogs and dogs with tachycardia-induced heart failure. Heart rhythm, 6(4), 546-552.
16. Schäfer, A., & Vagedes, J. (2013). How accurate is pulse rate variability as an estimate of heart rate variability?: A review on studies comparing

photoplethysmographic technology with an electrocardiogram. International journal of cardiology, 166(1), 15-29.
17. Shah, B., Kunal, S., Bansal, A., Jain, J., Poundrik, S., Shetty, M. K., ... & Gupta, M. D. (2022). Heart rate variability as a marker of cardiovascular dysautonomia in post-COVID-19 syndrome using artificial intelligence. Indian pacing and electrophysiology journal, 22(2), 70-76.
18. Stuyck, H., Dalla Costa, L., Cleeremans, A., & Van den Bussche, E. (2022). Validity of the Empatica E4 wristband to estimate resting-state heart rate variability in a lab-based context. International Journal of Psychophysiology, 182, 105-118.
19. Yugar, L. B. T., Yugar-Toledo, J. C., Dinamarco, N., Sedenho-Prado, L. G., Moreno, B. V. D., Rubio, T. D. A., ... & Moreno, H. (2023). The role of heart rate variability (HRV) in different hypertensive syndromes. Diagnostics, 13(4), 785.
20. Zhu, J., Ji, L., & Liu, C. (2019). Heart rate variability monitoring for emotion and disorders of emotion. Physiological measurement, 40(6), 064004.