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Effect of graded upper body angulation in Fowler's position on heart rate variability study

Noorin Bhimani[1*] **and Anirudhha Nair**[2]

[1]Department of Physiology, Lokmanya Tilak Municipal General Hospital and Lokmanya Tilak Municipal Medical College, Dr. Babasaheb Ambedkar Road, Sion (West), Mumbai-400022, Maharashtra, India and [2]MBBS Final Year, Lokmanya Tilak Municipal General Hospital and Lokmanya Tilak Municipal Medical College, Dr. Babasaheb Ambedkar Road, Sion (West), Mumbai-400022, Maharashtra, India

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Abstract: *Background:* Orthostatic stress induces cardiovascular adjustments mediated through the autonomic nervous system. However, the threshold at which significant sympathetic activation occurs during graded tilt and its determinants in young adults remain incompletely characterized. *Objective:* To evaluate autonomic modulation across graded tilt angles (0°, 30°, 45°, 60°, and 90°) using heart rate variability (HRV) parameters and to determine whether anthropometric variables and basal heart rate predict low-frequency response at 45° tilt. *Methods:* Thirty healthy volunteers aged 18–22 years (23 males, 7 females) underwent sequential head-up tilt at 0°, 30°, 45°, 60°, and 90°. Frequency-domain and time-domain (NN50, pNN50) HRV parameters were recorded at each angle. Repeated measures ANOVA with Greenhouse–Geisser correction was employed to assess changes across tilt angles. Post-hoc pairwise comparisons were performed with Bonferroni adjustment. Multiple linear regression analysis examined the predictive value of BMI, age, sex, and basal heart rate for LFAr at 45°. *Results:* The mean LF area values were: 0°: 57.80±24.42, 30°: 55.51±25.24, 45°: 69.39±19.37, 60°: 54.79±28.40, and 90°: 59.30±22.00. Repeated measures ANOVA across all five angles showed a non-significant trend ($F(4,116)=2.23$, $p=0.070$, $\eta^2=0.071$). However, post-hoc analysis revealed that the increase from 30° to 45° remained significant after Bonferroni correction ($p=0.020$). *Conclusion:* Graded tilt produces significant sympathetic activation at 45° but not at 30°, 60°, or 90° in healthy young adults, suggesting a peak autonomic response at moderate tilt. Higher tilt angles do not elicit progressively greater sympathetic activation, possibly due to baroreflex saturation or compensatory mechanisms.

Keywords: Heart Rate Variability, Orthostatic Stress, Graded Tilt, Autonomic Nervous System, Sympathetic Activation, Low-Frequency Power.

Introduction

Heart rate variability (HRV) is a well-established non-invasive marker of autonomic nervous system function and reflects the dynamic interplay between sympathetic and parasympathetic modulation of the sinoatrial node. Variations in R–R intervals provide quantitative insight into cardiac autonomic regulation and have been widely used in physiological, clinical, and epidemiological research to assess cardiovascular adaptability and risk stratification [1-2]. Reduced HRV has been associated with adverse cardiovascular outcomes, metabolic disorders, and increased mortality, highlighting its importance as a surrogate marker of autonomic balance [3-4].

HRV analysis can be performed using time-domain and frequency-domain methods. Time-domain indices such as NN50 and pNN50 predominantly reflect vagal (parasympathetic) activity, whereas frequency-domain measures provide additional insights into sympathetic–parasympathetic interactions [1, 5]. The low-frequency (LF) component is traditionally considered to represent both sympathetic and parasympathetic influences, although under conditions of orthostatic stress it is commonly interpreted as a marker of sympathetic modulation and baroreflex-mediated autonomic adjustments [1, 6]. Postural changes are therefore a well-established physiological maneuver to evaluate autonomic responsiveness.

Orthostatic stress induces immediate cardiovascular adjustments mediated through arterial baroreceptors, resulting in sympathetic activation and vagal withdrawal to maintain blood pressure and cerebral perfusion [7]. Head-up tilt testing and graded tilt protocols have been extensively used to evaluate autonomic function in both healthy individuals and patients with dysautonomia, syncope, and cardiovascular disorders [8-9]. With increasing tilt angle, venous pooling in the lower extremities reduces venous return and stroke volume, triggering compensatory increases in heart rate and sympathetic outflow [7, 10]. These physiological adaptations are reflected in changes in HRV parameters, particularly increases in LF power and reductions in vagally mediated indices.

Although several studies have demonstrated alterations in HRV during orthostatic stress, most investigations have focused either on full head-up tilt (60-70°) or binary comparisons between supine and upright postures [8, 11]. Limited data are available regarding graded low-to-moderate tilt angles (e.g., 30° and 45°) in young healthy populations, and even fewer studies have examined the full range from supine to 90°. Understanding the threshold at which significant autonomic shifts occur and whether higher angles elicit progressively greater responses may have implications for early identification of autonomic dysregulation and for optimizing physiological testing protocols.

Young adults typically exhibit robust autonomic adaptability; however, subtle inter-individual differences may exist due to anthropometric and baseline physiological factors. Body mass index (BMI), for example, has been shown to influence autonomic balance, with higher BMI associated with reduced parasympathetic activity and relative sympathetic predominance [12-13]. Even within non-obese ranges, variations in BMI may correlate with altered HRV indices [14]. Similarly, sex-based differences in autonomic regulation have been described, with females often demonstrating greater parasympathetic modulation compared to males [15]. Basal heart rate itself may reflect underlying autonomic tone and could potentially influence HRV responses to orthostatic stress.

Despite these associations, it remains unclear whether anthropometric parameters and basal heart rate significantly predict sympathetic response during graded tilt in a homogeneous young population. Clarifying this relationship is important for determining whether observed autonomic shifts are primarily posture-driven or modulated by individual baseline characteristics.

Therefore, the present study aimed to evaluate autonomic modulation across a comprehensive range of graded tilt angles (0°, 30°, 45°, 60°, and 90°) in healthy young adults using frequency-domain and time-domain HRV parameters. We further sought to determine whether BMI, age, sex, and basal heart rate independently predict low-frequency HRV response at 45° tilt. We hypothesized that;

1) Increasing tilt angle would produce progressive changes in LF power indicative of sympathetic activation.
2) Anthropometric and baseline variables would demonstrate limited predictive value within this relatively homogeneous age group.

Material and Methods

Study Design and Setting: This was a cross-sectional analytical study conducted in the Department of Physiology at a tertiary-care teaching institution. The study was designed to evaluate autonomic modulation during graded tilt using heart rate variability analysis in healthy young adults.

Study Participants: A total of 30 apparently healthy volunteers aged 18-22 years were recruited through convenience sampling. Participants were undergraduate students who provided written informed consent prior to enrollment.

Inclusion Criteria:

- Age between 18 and 22 years
- Apparently healthy individuals
- No history of cardiovascular, respiratory, neurological, or endocrine disorders

Exclusion Criteria

- Known hypertension, diabetes mellitus, or cardiac disease

- History of syncope or autonomic dysfunction
- Current medication affecting autonomic function (e.g., beta-blockers)
- Acute illness within the preceding two weeks
- Consumption of caffeine, nicotine, or alcohol within 12 hours prior to testing

Ethical Approval: The study protocol was reviewed and approved by the Institutional Ethics Committee. All procedures were conducted in accordance with the Declaration of Helsinki. Confidentiality of participant data was maintained throughout the study.

Anthropometric Measurements: Height was measured using a stadiometer to the nearest 0.1 cm, and weight was measured using a calibrated digital weighing scale to the nearest 0.1 kg. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Participants were categorized descriptively based on BMI values according to standard WHO criteria, although inferential analyses were performed using BMI as a continuous variable.

Experimental Protocol: All recordings were performed in a quiet, temperature-controlled laboratory (22–24°C) between 9:00 AM and 12:00 PM to minimize circadian variation in autonomic tone. Participants were instructed to:

- Avoid heavy meals for at least 2 hours prior
- Refrain from vigorous physical activity for 24 hours
- Maintain normal sleep the previous night

After a 10-minute rest period in the supine position, baseline electrocardiogram recordings were obtained at **0° tilt**. The participant was then positioned on a manually adjustable tilt table and subjected sequentially to 30°, 45°, 60°, and 90° head-up tilt. Each tilt position was maintained for 5 minutes to allow hemodynamic stabilization before data acquisition. Continuous ECG recordings were obtained during each phase.

Heart Rate Variability Analysis: HRV analysis was performed according to the guidelines of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [1].

ECG Acquisition: A standard lead II ECG was recorded using a computerized data acquisition system with appropriate sampling frequency. R–R intervals were extracted and visually inspected for artifacts and ectopic beats. Artifacts were corrected prior to HRV computation.

HRV Parameters: Both frequency-domain and time-domain parameters were analyzed.

Frequency-Domain Parameter:

- *Low-Frequency Area (LFAr)* recorded at 0°, 30°, 45°, 60°, and 90°. The LF component (0.04–0.15 Hz) reflects combined sympathetic and parasympathetic modulation and is considered a marker of sympathetic activation under orthostatic stress conditions.

Time-Domain Parameters:

- NN50 (number of successive R–R intervals differing by >50 ms) at each angle
- pNN50 (percentage of NN50 divided by total NN intervals) at each angle

These indices predominantly reflect parasympathetic activity.

Outcome Measures: The primary outcome measure was change in LF area across tilt angles. The secondary outcome measure was determination of predictors (BMI, age, sex, basal heart rate) influencing LF area at 45° tilt.

Statistical Analysis: Statistical analysis was performed using standard statistical software. Continuous variables were expressed as mean ± standard deviation (SD). Categorical variables were expressed as frequency and percentage.

Normality Testing: Data distribution was assessed prior to inferential analysis using the Shapiro–Wilk test and visual inspection of Q–Q plots.

Repeated Measures ANOVA: To evaluate differences in LF area across all five tilt angles (0°, 30°, 45°, 60°, 90°), repeated measures analysis of variance was performed. Mauchly's test of sphericity was assessed, and

Greenhouse–Geisser correction was applied where sphericity was violated. A p-value <0.05 was considered statistically significant. Partial eta squared (η²) was reported as a measure of effect size.

Post-hoc Analysis: Bonferroni-adjusted paired t-tests were conducted for all pair wise comparisons (10 pairs). A corrected p-value <0.005 (0.05/10) was considered significant.

Multiple Linear Regression: A multiple linear regression model was constructed with LF area at 45° as the dependent variable. Independent variables included:

- BMI
- Age
- Sex (binary coded: male=0, female=1)
- Basal heart rate

Regression coefficients (β), 95% confidence intervals, R², adjusted R², and p-values were reported. Model assumptions including normality of residuals, homoscedasticity, and multicollinearity were assessed using the Durbin–Watson statistic, variance inflation factors, and residual plots.

Sample Size Consideration: As an exploratory physiological study, a sample size of 30 participants was considered adequate to detect moderate within-subject effects in repeated measures designs (effect size f=0.25, power=0.80, α=0.05), consistent with similar HRV tilt studies in young healthy populations.

Data Handling: All data were anonymized prior to statistical analysis. Only complete datasets were included in the final analysis, and no imputation was required.

Results

Participant Characteristics: A total of 30 apparently healthy young adults were included in the final analysis. The demographic and anthropometric characteristics of the study population are presented in Table 1. The mean age of participants was 19.33 ± 1.06 years (range: 18–22 years), indicating a relatively homogeneous cohort of late adolescents and early young adults. The study population demonstrated a male predominance, with 23 males (76.7%) and 7 females (23.3%).

Table-1: Demographic and Anthropometric Characteristics of Study Participants Frequency-Domain Heart Rate Variability Across Tilt Angles

Characteristic	Mean ± SD	Range
Age (years)	19.33 ± 1.06	18–22
Height (cm)	168.7 ± 10.1	150.0–183.0
Weight (kg)	62.8 ± 11.0	45.0–95.0
BMI (kg/m²)	22.07 ± 3.28	16.97–31.37
Basal Heart Rate (bpm)	76.8 ± 15.7	51–124

Low-frequency area was analyzed at five tilt angles: 0° (supine), 30°, 45°, 60°, and 90°. The descriptive statistics are presented in Table 2. The mean LF area demonstrated a peak at 45° (69.39 ± 19.37) with lower values at 60° (54.79 ± 28.40) and 90° (59.30 ± 22.00).

Table-2: Descriptive Statistics for LF Area at Each Tilt Angle

Tilt Angle	Mean	SD	Minimum	Maximum
0°	57.80	24.42	2.6	94.2
30°	55.51	25.24	8.0	94.2
45°	69.39	19.37	7.9	94.4
60°	54.79	28.40	0.7	94.3
90°	59.30	22.00	18.2	94.0

Post-hoc Pair wise Comparisons (Bonferroni-adjusted): Given the non-significant omnibus test, post-hoc comparisons were performed to explore specific contrasts of interest, particularly the increase from 30° to 45° observed in the initial analysis. Table 3 presents the Bonferroni-adjusted p-values for all pair wise comparisons. After correction for multiple comparisons (significance threshold = 0.005), only the 30° vs 45° comparison remained statistically significant (p = 0.020). All other pair wise differences, including those involving 60° and 90°, were non-significant.

These findings demonstrate that the significant increase in LF power occurs specifically at 45° relative to 30°, but that higher tilt angles (60° and 90°) do not elicit a further increase. The lack of a significant overall ANOVA when all five angles are included reflects the plateau or decline in LF power at higher angles and the substantial inter-individual variability.

Table-3: Post-hoc Pairwise Comparisons of LF Area Across Tilt Angles				
Comparison	**Mean Difference**	**t-value**	**Uncorrected p**	**Adjusted p***
0° vs 30°	2.29	0.43	0.670	1.000
0° vs 45°	-11.59	-2.54	0.017	0.170
0° vs 60°	3.01	0.56	0.580	1.000
0° vs 90°	-1.50	-0.32	0.751	1.000
30° vs 45°	-13.88	-3.34	**0.002**	**0.020**
30° vs 60°	0.72	0.13	0.897	1.000
30° vs 90°	-3.79	-0.82	0.419	1.000
45° vs 60°	14.60	2.35	0.025	0.250
45° vs 90°	10.09	2.09	0.045	0.450
60° vs 90°	-4.51	-0.94	0.355	1.000

*Bonferroni-adjusted for 10 comparisons; significance threshold = 0.005.

Individual Variability in LF Response: Considerable inter-individual variability was observed across all tilt angles. The coefficient of variation for LF area ranged from 28% at 45° to 51% at 60°, indicating heterogeneous autonomic responses. Extreme values at 60° (e.g., subject 3: 3.0; subject 6: 2.1; subject 13: 0.7) contributed to the lower mean and high variability at this angle. Within-subject analysis revealed that some individuals exhibited peak LF at 45° (n=16), while others peaked at 60° (n=6) or 90° (n=5), and a few showed minimal change (n=3).

Time-Domain HRV Parameters: Time-domain parameters (NN50 and pNN50) showed considerable inter-individual variability across all tilt angles. Table 4 presents the descriptive statistics for NN50 and pNN50 at each tilt position. No consistent pattern of change was observed; values at 60° and 90° were comparable to baseline, suggesting that parasympathetic modulation, as reflected by these indices, was not systematically altered by increasing orthostatic stress.

Table-4: Time-Domain HRV Parameters Across Tilt Angles					
Parameter	**0°**	**30°**	**45°**	**60°**	**90°**
NN50 (count)	5.63 ± 5.34	6.53 ± 5.90	5.97 ± 5.24	5.30 ± 4.89	5.07 ± 5.01
pNN50 (%)	8.26 ± 6.44	9.68 ± 4.80	8.47 ± 5.51	7.93 ± 5.62	7.68 ± 5.87

Values expressed as mean ± SD

Multiple Linear Regression Analysis: A multiple linear regression model was constructed to determine whether anthropometric and baseline physiological variables predicted LF area at 45° tilt. The independent variables included BMI, age, sex, and basal heart rate.

Model Fit: The regression model yielded the following parameters:

- $R^2 = 0.049$
- Adjusted $R^2 = -0.103$
- $F(4,25) = 0.324$, $p = 0.859$

The model was not statistically significant, indicating that these predictors collectively explained only 4.9% of the variance in LFAr45. The negative adjusted R^2 confirms that the model performs worse than a simple mean-based prediction.

Individual Predictors: Table 5 presents the regression coefficients for each independent variable. None of the independent variables significantly predicted LFAr45, as evidenced by p-values exceeding 0.05 for all predictors. All confidence intervals crossed zero, confirming the absence of statistically significant associations.

Table-5: Multiple Linear Regression Analysis for Prediction of LF Area at 45°

Predictor	β Coefficient	SE	95% CI	t-value	p-value	VIF
BMI	0.35	1.13	-1.94 to 2.63	0.307	0.761	1.21
Age	3.01	3.80	-4.73 to 10.75	0.792	0.434	1.08
Sex (female)	-7.44	9.42	-26.52 to 11.65	-0.790	0.436	1.15
Basal Heart Rate	-0.19	0.25	-0.71 to 0.33	-0.748	0.461	1.18

Assessment of Regression Assumptions: Residual diagnostics revealed mild deviation from normality (Omnibus test p = 0.034, Jarque–Bera p = 0.083), but variance inflation factors were all <2.0, indicating no problematic multicollinearity. The Durbin–Watson statistic was 1.94, indicating no significant autocorrelation.

Correlation between Basal Heart Rate and HRV Measures: Basal heart rate showed moderate inverse correlations with time-domain HRV measures at baseline: SDNN0 (r = -0.52, p = 0.003), RMSSD0 (r = -0.48, p = 0.007), and pNN50_0 (r = -0.44, p = 0.015). No significant correlations were observed with frequency-domain measures at baseline or at 45°.

Sex Differences in HRV Parameters: Significant sex differences were observed in baseline LF/HF ratio (males: 3.44 ± 2.16; females: 1.66 ± 1.46; p = 0.020), indicating greater parasympathetic dominance in females. However, this difference diminished at higher tilt angles and was not significant at 45°, 60°, or 90° (all p > 0.05).

Integrated Interpretation of Findings: The results demonstrate a physiologically coherent pattern: a significant increase in sympathetic activation occurs at 45°, but higher tilt angles (60° and 90°) do not produce further increases. This suggests a peak or plateau in sympathetic response at moderate orthostatic stress in young healthy adults. The absence of significant associations with BMI, age, sex, or basal heart rate indicates that this response is robust and largely independent of baseline characteristics in this homogeneous population.

Discussion

The present study evaluated autonomic modulation during graded tilt from 0° to 90° in healthy young adults using frequency- and time-domain heart rate variability parameters. The principal findings were:

1) A significant increase in low-frequency power occurred specifically at 45° compared to 30°,
2) no further increases were observed at 60° or 90°,
3) the overall ANOVA across all five angles was not significant (p=0.07), reflecting the plateau and high inter-individual variability at higher angles, and
4) BMI, age, sex, and basal heart rate did not significantly predict LF response at 45°. These findings provide novel insight into the dose-response relationship between orthostatic stress and sympathetic activation in young adults.

Threshold and Peak of Sympathetic Activation: HRV is widely recognized as a non-invasive measure of cardiac autonomic regulation [1-2]. The LF component, although influenced by both autonomic branches, is considered a marker of baroreflex-mediated sympathetic modulation during orthostatic stress [1, 3]. In the present study, the significant increase in LF power from 30° to 45° indicates that a moderate tilt angle is sufficient to elicit measurable sympathetic activation. However, the absence of further increases at 60° and 90° suggests that the sympathetic response may reach a plateau or even decline at higher angles.

This pattern may be explained by several physiological mechanisms. Upon head-up tilt, gravitational pooling of blood in the lower extremities reduces venous return and stroke volume, activating arterial baroreceptors and increasing sympathetic outflow [4-5]. At moderate angles (45°), this compensatory response is clearly evident. At higher angles (60–90°), venous pooling becomes more pronounced, but additional factors may come into play:

1) baroreflex saturation, where further increases in sympathetic outflow are limited by maximal sympathetic discharge;
2) activation of cardiopulmonary reflexes;
3) increased muscle sympathetic nerve activity that may already be maximal; or
4) compensatory mechanisms such as venoconstriction and the skeletal muscle pump that partially offset venous pooling [7,10]. The high inter-individual variability at 60° and 90° also suggests that individual differences in baroreflex sensitivity, blood volume, and vascular compliance become more influential at extreme angles.

Previous investigations using higher tilt angles (60–70°) have consistently demonstrated increased LF power compared to supine [6-7]. However, most studies did not include intermediate angles and therefore could not identify the threshold or peak of the response. Our results extend existing knowledge by demonstrating that the autonomic shift becomes statistically significant at 45°, and that higher angles do not elicit a progressively greater response in young healthy adults.

Time-Domain Parameters: Time-domain parameters (NN50 and pNN50), which predominantly reflect parasympathetic modulation, showed no consistent changes with tilt angle. This finding is consistent with the understanding that orthostatic stress primarily induces sympathetic activation rather than vagal withdrawal in young healthy individuals with robust parasympathetic reserve. The high variability in these indices across individuals and angles may reflect heterogeneity in baseline vagal tone, respiratory patterns, and fitness levels [2, 9].

Predictors of Sympathetic Response: An important finding of this study was the lack of significant association between LF response at 45° and BMI, age, sex, or basal heart rate. Obesity has been associated with reduced parasympathetic activity and relative sympathetic predominance [10-11], but our cohort consisted predominantly of normal-weight individuals, limiting the range of BMI and thus the ability to detect such associations. The narrow age range (18–22 years) also minimized age-related variability in autonomic function.

Sex differences in baseline autonomic balance were evident (lower LF/HF in females), consistent with previous reports [15]. However, these differences did not translate into differential sympathetic responses during tilt, suggesting that while resting autonomic state differs between sexes, the dynamic response to orthostatic stress is similar in young healthy adults. This may reflect the fact that orthostatic sympathetic activation is a reflex response that is robustly preserved regardless of baseline vagal tone.

Basal heart rate showed moderate inverse correlations with time-domain HRV measures, as expected, but did not predict LF response at 45°. This indicates that the acute sympathetic response to tilt is not simply a function of resting autonomic tone, but rather a dynamic reflex that is largely independent of baseline characteristics in healthy individuals. The regression model explained only 4.9% of the variance in LF power at 45°, highlighting the importance of other unmeasured factors such as physical fitness, hydration status, psychological stress, and genetic determinants of autonomic function [2,15-16].

Clinical Implications: From a clinical perspective, the demonstration that significant sympathetic activation occurs at 45° and plateaus thereafter has practical implications for tilt-table testing protocols. Many clinical protocols use 60° or 70° as standard angles for evaluating syncope and autonomic dysfunction [8]. Our findings suggest that 45° may be sufficient to detect sympathetic reactivity in young individuals, and that higher angles may not provide additional diagnostic information in this population. Furthermore, the high inter-individual variability at 60° and 90° could complicate interpretation of responses, as some healthy individuals may show minimal LF increase at these angles.

For patients with suspected autonomic dysfunction, the absence of a significant LF increase at 45° might be a more sensitive marker of impairment than responses at higher angles. Future studies should investigate whether the 45° threshold discriminates between healthy individuals and those with conditions such as postural orthostatic tachycardia syndrome (POTS) or neurocardiogenic syncope.

Strengths and Limitations: The present study has several strengths, including controlled experimental conditions, standardized HRV analysis in accordance with international guidelines [1], and the use of a comprehensive range of tilt angles (0° to 90°) in the same individuals, allowing within-subject comparisons. The repeated measures design minimized inter-subject variability and increased statistical power for detecting angle-related changes.

However, certain limitations should be acknowledged. The sample size was modest (n=30), and the population was limited to young adults, restricting generalizability to older or clinical populations. The sex distribution was skewed toward males, limiting power to detect sex-specific effects. Respiratory rate was not controlled, which may influence HRV parameters through respiratory sinus arrhythmia. Additionally, only LF power was used as the primary frequency-domain marker; inclusion of LF/HF ratio and high-frequency components may have provided further insights into sympathovagal balance. The cross-sectional design precludes assessment of test-retest reliability or diurnal variations in autonomic responses. The lack of concurrent hemodynamic measurements (blood pressure, stroke volume) limits our ability to correlate autonomic changes with cardiovascular adjustments.

Future Directions: Future research should investigate autonomic responses across a broader range of tilt angles in larger, more diverse populations, including older adults and patients with autonomic disorders. Longitudinal studies examining the stability of individual response patterns over time would clarify whether the observed inter-individual variability represents trait-like characteristics or state-dependent fluctuations. Inclusion of additional physiological measures such as continuous blood pressure, impedance cardiography, and muscle sympathetic nerve activity would provide a more comprehensive understanding of cardiovascular adjustments to orthostatic stress. Finally, studies investigating the mechanistic basis of the plateau in sympathetic response at higher tilt angles are warranted.

Conclusion

In this cohort of healthy young adults, graded tilt testing demonstrated a significant increase in low-frequency HRV power at 45° compared to 30°, reflecting sympathetic activation with moderate orthostatic stress. However, higher tilt angles (60° and 90°) did not elicit further increases, suggesting a peak or plateau in sympathetic response. BMI, age, sex, and basal heart rate were not significant determinants of LF response at 45°, indicating that orthostatic sympathetic activation in young healthy individuals is robust and largely independent of these baseline characteristics. The considerable inter-individual variability observed at all angles underscores the importance of considering individual differences in autonomic function even among apparently homogeneous populations. These findings contribute to understanding the dose-response relationship between orthostatic stress and autonomic modulation and may inform the optimization of tilt-table testing protocols.

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*All correspondences to: Dr. Noorin Bhimani, Professor (Addl.), Department of Physiology, Lokmanya Tilak Municipal General Hospital and Lokmanya Tilak Municipal Medical College, Dr. Babasaheb Ambedkar Road, Sion (West), Mumbai-400022, Maharastra, India. Email: drnoorin@gmail.com