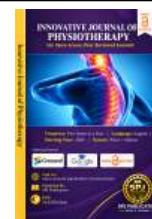




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Original Research

Inter-Parameter Correlation Structure of Heart Rate Variability Indices in Collegiate Students with Chronic Neck Pain

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ABSTRACT

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Background: Chronic neck pain (CNP) is a prevalent musculoskeletal condition associated with functional impairment and alterations in autonomic nervous system (ANS) regulation. Heart rate variability (HRV) provides a non-invasive method for assessing autonomic function; however, relationships among HRV indices in individuals with CNP remain insufficiently explored.

Objective: To investigate the correlation structure among HRV indices in college students with chronic neck pain.

Methods: This cross-sectional observational study included 100 college students aged 18 to 30 years with CNP. HRV was assessed under standardized resting conditions using a validated system during a 5-minute ECG recording. The time-domain parameter RMSSD and frequency-domain parameters LF, HF, and LF/HF ratio were analyzed. Data normality was assessed using the Shapiro-Wilk test, followed by Pearson correlation analysis.

Results: Considerable inter-individual variability was observed across all HRV measures. A significant positive correlation was found between RMSSD and HF ($r = 0.736$, $p < 0.01$). Moderate positive correlations were observed between RMSSD and LF ($r = 0.478$, $p < 0.01$) and between LF and HF ($r = 0.583$, $p < 0.01$). The LF/HF ratio demonstrated significant negative correlations with HF ($r = -0.330$, $p < 0.01$) and RMSSD ($r = -0.417$, $p < 0.01$). Among demographic and cardiovascular parameters, BMI showed a moderate positive correlation with LF/HF ($r = 0.244$, $p < 0.05$).

Conclusion: HRV indices demonstrated significant interrelationships, with the strongest correlation observed between RMSSD and HF. These findings suggest consistency in autonomic measures among college cadets with CNP and contribute to understanding autonomic regulation in this population. Further controlled longitudinal studies are warranted.

Keywords: Chronic Neck Pain, Heart Rate Variability, Autonomic Nervous System, RMSSD, LF/HF Ratio, Parasympathetic Activity.

INTRODUCTION

Chronic neck pain (CNP) is a common musculoskeletal condition that can result in persistent pain, functional limitations, and reduced quality of life. Beyond physical symptoms, CNP is frequently associated with psychological comorbidities, including anxiety and depression, which may increase the psychological burden on patients and contribute to greater healthcare utilization and costs. ^[1] The prevalence of CNP has increased across various age groups and occupational populations, partly due to sedentary lifestyles, prolonged use of digital devices, and inadequate ergonomic practices. These factors make CNP an important health concern among younger adults, particularly college students. CNP is generally defined as neck pain persisting for more than three months following its onset, extending beyond the expected period of tissue healing. ^[2] When an identifiable underlying pathology is present, the condition may be distinguished from chronic non-specific neck pain. Contemporary research increasingly conceptualizes CNP within a biopsychosocial framework, recognizing the combined influence of biological, psychological, and social factors on the development, persistence, and severity of symptoms. ^[3-5] The pathophysiology of CNP is multifactorial and may involve mechanical, degenerative, neuromuscular, and psychosocial factors. Repetitive mechanical stress, prolonged forward-head posture, and sustained cervical muscle

loading may contribute to soft-tissue injury, ligamentous dysfunction, altered cervical biomechanics, and persistent symptoms. [6-8] Traumatic events, including whiplash-associated disorders (WAD), may similarly result in soft-tissue injury, ligamentous disruption, and altered cervical biomechanics, potentially contributing to chronic symptoms. [9] Neuromuscular dysfunction is an important component of CNP. Individuals with CNP may demonstrate reduced activation of the deep cervical flexor muscles accompanied by increased activity of superficial muscles, including the upper trapezius and sternocleidomastoid. [10] Such muscular imbalance may compromise cervical stability and increase mechanical loading of the cervical spine. Psychological factors, including stress, anxiety, depression, and inadequate coping strategies, may further contribute to the persistence of chronic pain. In addition, central nervous system sensitization, increased neuronal excitability, hyperalgesia, and allodynia may contribute to the maintenance and amplification of pain symptoms. [11-13]

In recent years, increasing attention has been directed toward the role of the autonomic nervous system (ANS) in chronic pain conditions, including CNP. [14] The ANS regulates essential physiological functions such as heart rate, blood pressure, and responses to stress. Chronic pain has been associated with alterations in autonomic regulation, often characterized by increased sympathetic activity and reduced parasympathetic or vagal modulation. Such autonomic dysregulation may contribute to sustained physiological stress, impaired tissue recovery, and enhanced pain perception. Reduced heart rate variability (HRV), generally reflecting diminished parasympathetic influence on cardiac function, has been associated with several chronic health conditions, including chronic pain disorders. [15] HRV can be evaluated using time-domain, frequency-domain, and non-linear methods. Among frequency-domain measures, low-frequency (LF) power reflects influences from both sympathetic and parasympathetic activity, particularly in relation to baroreflex mechanisms, whereas high-frequency (HF) power is closely associated with vagal modulation and respiratory sinus arrhythmia. The LF/HF ratio has historically been interpreted as an indicator of sympathovagal balance; however, this interpretation remains subject to methodological debate. [16] Previous studies have reported reduced HRV among individuals with chronic pain, which has commonly been interpreted as indicative of altered autonomic regulation and reduced parasympathetic activity [17-22] Although HRV research in chronic pain populations has increased, previous studies have predominantly focused on comparisons of individual HRV measures between healthy individuals and patients with pain. Comparatively less attention has

been given to the internal correlation structure of HRV, particularly the relationships among individual indices. Examining the associations between RMSSD, LF, HF, and the LF/HF ratio may provide additional insight into the integrated regulation of the ANS and improve the interpretation of HRV measures in clinical settings. [23,25] Understanding these relationships may also contribute to the identification of specific autonomic patterns that could inform physiologically oriented approaches to assessment and management. College students represent an important population for investigating these relationships because prolonged screen exposure, academic stress, physical inactivity, and poor posture are common characteristics that may contribute to the development and persistence of neck pain. Therefore, the present study aimed to investigate the inter-parameter correlation structure among HRV indices, specifically RMSSD, LF, HF, and the LF/HF ratio, in college students with chronic neck pain. Clarifying these relationships may enhance understanding of autonomic regulation in CNP and support the development of more comprehensive, physiologically informed assessment and management strategies. [26-28]

METHODS

Study Design and Participants: A cross-sectional observational study was conducted among college students with chronic neck pain (CNP). Participants aged 18–30 years were recruited following approval from the relevant university departments and institutional authorities. Recruitment was conducted through institutional emails, student portals, social media announcements, and faculty-approved classroom briefings. Participants underwent questionnaire-based screening followed by a brief clinical assessment.

Sample Size: Sample size was calculated using G-Power for correlation analysis, assuming a moderate effect size ($r = 0.30$), $\alpha = 0.05$, two-tailed testing, and 80% statistical power. The minimum required sample was approximately 100 participants. The target sample was increased to 115 to account for potential artefacts, missing data, or participant withdrawal.

Eligibility and Recruitment: Participants were included if they were 18–30 years old, currently enrolled in college, had CNP for at least three months, reported cervical-region pain with or without mild radiation, and were able to understand the study procedures and provide written informed consent. Both male and female participants were eligible. Participants were excluded if they had cervical trauma, surgery, structural deformity, neurological or cardiovascular conditions affecting autonomic function, or used ANS-modifying medications such as beta-blockers or antidepressants. Acute musculoskeletal or inflammatory conditions,

caffeine, nicotine, or alcohol consumption within 12 hours, vigorous exercise within 24 hours, and fewer than five hours of sleep the preceding night were also exclusion criteria.

HRV Assessment Procedure: Participants underwent no intervention. Following verification of pre-assessment requirements, participants rested for 10–15 minutes in a quiet, temperature-controlled room maintained at 22–25°C. HRV was recorded in the supine position using a validated ECG system (AD Instruments with Lab Chart software). Participants remained still, avoided speaking, and maintained steady breathing during recording. A standardized 5-minute resting ECG recording was obtained. Surface electrodes were positioned according to standard ECG guidelines. ECG signals were visually inspected for artefacts, and ectopic beats were corrected using the software's filtering algorithms. Only recordings containing at least 95% normal sinus rhythm were included. The analyzed HRV parameters were RMSSD, LF power (0.04–0.15 Hz), HF power (0.15–0.40 Hz), and the LF/HF ratio.

Outcome Measures: The primary outcomes were RMSSD, LF, HF, and LF/HF ratio, representing complementary aspects of autonomic regulation. RMSSD was used as a time-domain measure of vagally mediated cardiac modulation. HF power (0.15–0.40 Hz) was interpreted primarily as reflecting vagal modulation, whereas LF power (0.04–0.15 Hz) was interpreted as an indicator of integrated autonomic modulation and baroreflex-related activity rather than an exclusive marker of sympathetic activity. The LF/HF ratio was included as a supplementary index, with recognition of its methodological limitations. The inter-parameter correlations among RMSSD, LF, HF, and LF/HF ratio were specifically examined to assess their relationships and provide a more integrated interpretation of autonomic regulation.

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean $\pm$ standard deviation (SD). Normality was assessed using the Shapiro–Wilk test. RMSSD, LF, HF, and LF/HF ratio demonstrated approximately normal distributions ($p > 0.05$); therefore, Pearson's correlation coefficient was used to assess inter-parameter relationships. Statistical significance was set at $p < 0.05$.

RESULTS

A total of 100 participants were included in the final analysis. The mean age was 24.35 ± 3.17 years, and the mean BMI was 22.22 ± 1.54 kg/m². Mean height and weight were 155.90 ± 11.99 cm and 54.62 ± 11.18 kg, respectively. Resting cardiovascular parameters were within normal ranges, with mean systolic blood pressure

(SBP) of 122.44 ± 9.19 mmHg, diastolic blood pressure (DBP) of 79.48 ± 7.90 mmHg, and resting heart rate (HR) of 89.32 ± 7.55 beats/min. Detailed descriptive statistics are presented in Table 1.

Table 1. Descriptive Statistics of Demographic, Anthropometric and Heart Rate Variability (HRV) Parameters of the Participants (Mean $\pm$ SD)

Variable	Mean $\pm$ SD
Age (years)	24.35 ± 3.17
Height (cm)	155.90 ± 11.99
Weight (kg)	54.62 ± 11.18
BMI (kg/m ²)	22.22 ± 1.54
Systolic BP (mmHg)	122.44 ± 9.19
Diastolic BP (mmHg)	79.48 ± 7.90
Heart Rate (bpm)	89.32 ± 7.55
HRV–RMSSD (ms)	59.37 ± 38.25
HRV–LF (ms ²)	1015.48 ± 840.72
HRV–HF (ms ²)	1731.70 ± 2313.80
HRV–LF/HF	1.53 ± 2.11

Note: Values are presented as mean $\pm$ standard deviation. BMI = Body Mass Index; BP = Blood Pressure; bpm = beats per minute; HRV = Heart Rate Variability; RMSSD = Root Mean Square of Successive Differences; LF = Low Frequency; HF = High Frequency; LF/HF = Low-to-High Frequency ratio.

Substantial inter-individual variability was observed across HRV measures. Mean RMSSD was 59.37 ± 38.25 ms, while mean LF and HF powers were 1015.48 ± 840.72 ms² and 1731.70 ± 2313.80 ms², respectively. The standard deviation of HF exceeded its mean, indicating marked variability in vagally mediated modulation. The mean LF/HF ratio was 1.53 ± 2.11 , demonstrating considerable heterogeneity in sympathovagal modulation. Pearson correlation analysis identified significant associations among anthropometric and cardiovascular variables (Table 2).

Table 2. Pearson Correlation Matrix Among Demographic, Anthropometric and Heart Rate Variability (HRV) Parameters of the Participants

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Age	—										
2. Height	.33*	—									

3. W e i g h t	.4 7 4 * *	.9 5 9 * *	—							
4. B M I	.6 2 3 * *	.5 2 3 * *	.7 3 7 * *	—						
5. S y s B P	.4 5 8 * *	.7 7 4 * *	.8 0 0 * *	.5 5 6 * *	—					
6. D i a B P	.3 6 3 * *	.6 6 3 * *	.7 0 0 * *	.5 0 3 * *	.8 1 8 * *	—				
7. H R	.3 5 8 * *	.5 4 8 * *	.6 0 7 * *	.5 0 8 * *	.6 9 7 * *	.6 5 5 * *	—			
8. R M S S D	- .0 3 4	.0 8 2	.0 5 5	- .0 2 6	.0 1 2	.0 2 3	- .0 9 9	—		
9. L F	- .0 6 3	- .0 9 1	- .0 7 1	- .0 0 3	- .0 2 2	- .0 4 7	- .1 1 4	.4 7 8 * *	—	
10. H F	- .0 5 9	.0 4 0	.0 1 5	- .0 3 7	.0 0 7	.0 5 3	- .0 7 3	.7 3 6 * *	.5 8 3 * *	—
11. L F /H F	.1 6 0	.0 1 1	.0 8 3	.2 4 4 *	.0 4 4	- .0 1 3	.1 0 6	- .4 1 7 * *	.0 4 2	- .3 0 * *

Note: Values represent Pearson's correlation coefficients (r). BMI = Body Mass Index; BP = Blood Pressure; HRV = Heart Rate Variability; RMSSD = Root Mean Square of Successive Differences; LF = Low Frequency; HF = High Frequency; LF/HF = Low-to-High Frequency ratio. *p < 0.05; **p < 0.01.

Height and weight showed the strongest correlation ($r = 0.959$, $p < 0.01$). BMI was significantly correlated with

weight ($r = 0.737$, $p < 0.01$) and height ($r = 0.523$, $p < 0.01$). Age was positively correlated with BMI ($r = 0.623$, $p < 0.01$), weight ($r = 0.474$, $p < 0.01$), and SBP ($r = 0.458$, $p < 0.01$). SBP was strongly correlated with DBP ($r = 0.818$, $p < 0.01$) and HR ($r = 0.697$, $p < 0.01$) (Figure-1).

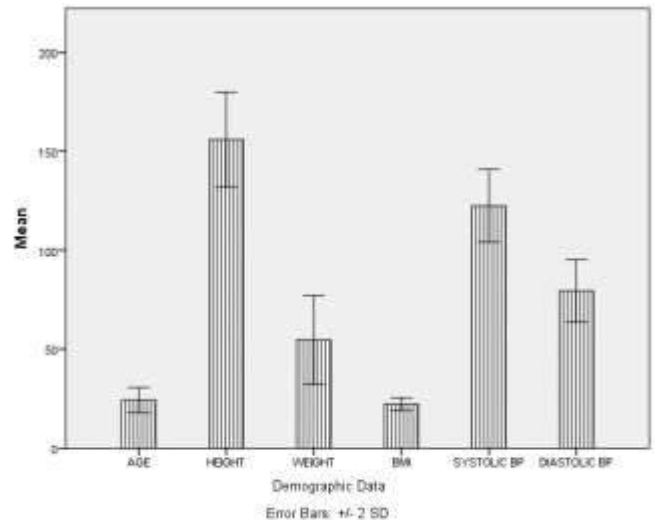


Figure 1. Mean Values of Demographic and Anthropometric with Error Bars

Significant interrelationships were also observed among HRV parameters in Figure-2.

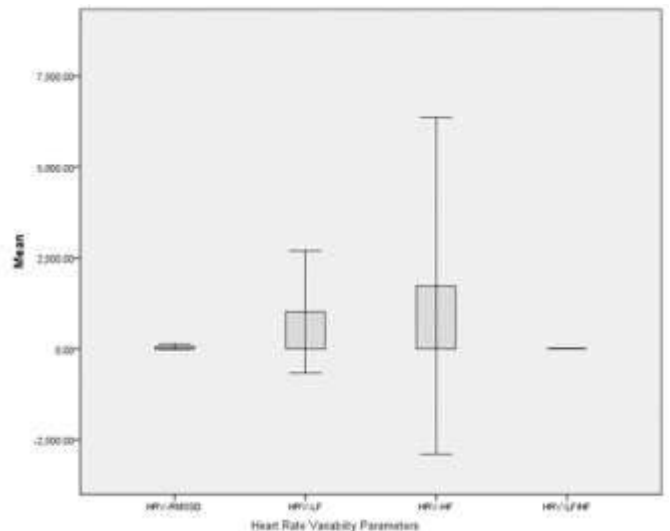


Figure 2. Mean Values of Heart Rate Variability (HRV) Parameters with Error Bars

RMSSD demonstrated the strongest correlation with HF ($r = 0.736$, $p < 0.01$), followed by LF ($r = 0.478$, $p < 0.01$). LF and HF were moderately correlated ($r = 0.583$, $p < 0.01$). The LF/HF ratio showed significant negative correlations with RMSSD ($r = -0.417$, $p < 0.01$) and HF ($r = -0.330$, $p < 0.01$). No significant correlations were observed between RMSSD, LF, or HF and demographic or cardiovascular variables ($p > 0.05$), except for a

modest positive correlation between BMI and LF/HF ratio ($r = 0.244$, $p < 0.05$).

DISCUSSION

The present study investigated the inter-parameter relationships among HRV indices in college students with chronic neck pain (CNP). Rather than focusing only on absolute HRV values, the study examined the associations among RMSSD, LF, HF, and the LF/HF ratio, providing insight into autonomic regulation in chronic pain. Considerable inter-individual variability was observed, particularly in HF and LF power, suggesting heterogeneous parasympathetic and autonomic responses among participants. Such variability may reflect differences in pain characteristics, psychological stress, lifestyle, and coping strategies, supporting the multifactorial nature of CNP.^[23] A strong positive correlation was observed between RMSSD and HF ($r = 0.736$, $p < 0.01$), consistent with their established association with parasympathetic cardiac modulation. This finding supports the use of RMSSD as a practical measure of vagal activity, particularly because it can be obtained without complex spectral analysis.

Moderate positive correlations between LF and RMSSD ($r = 0.478$, $p < 0.01$) and LF and HF ($r = 0.583$, $p < 0.01$) further support the contemporary interpretation of LF as an integrated autonomic measure rather than a direct indicator of sympathetic activity. LF is influenced by both sympathetic and parasympathetic mechanisms, particularly through baroreflex regulation.^[21,27] The LF/HF ratio showed significant negative correlations with RMSSD ($r = -0.417$, $p < 0.01$) and HF ($r = -0.330$, $p < 0.01$), indicating an association between higher LF/HF values and reduced vagal activity.

However, the LF/HF ratio should be interpreted cautiously because its validity as a direct measure of sympathovagal balance remains debated.^[19,22] Most demographic and cardiovascular variables, including age, height, weight, blood pressure, and resting heart rate, were not significantly associated with HRV measures. BMI showed a modest positive correlation with LF/HF ratio ($r = 0.244$, $p < 0.05$), consistent with evidence linking increased BMI with altered autonomic regulation. Overall, these findings support the presence of altered autonomic regulation in college students with CNP and demonstrate meaningful relationships among HRV parameters, particularly those reflecting vagal activity. The findings also emphasize the importance of interpreting HRV indices collectively rather than in isolation. Further longitudinal studies incorporating pain severity, psychological factors, and standardized HRV protocols are warranted to clarify the role of autonomic dysfunction in chronic neck pain.

Limitations: The cross-sectional design limits causal inference. Convenience sampling and the absence of a healthy control group may restrict generalizability. Uncontrolled factors such as stress, sleep, and physical activity may have influenced HRV. The LF/HF ratio should also be interpreted cautiously because its physiological validity remains debated.

Future Directions: Future studies should use longitudinal designs with matched healthy controls to clarify the relationship between autonomic regulation and chronic neck pain. Integrating HRV with psychological and functional measures, along with nonlinear and machine-learning approaches, may improve understanding and prediction of autonomic alterations.

CONCLUSION

The study demonstrates significant interrelationships among HRV parameters in college students with chronic neck pain, particularly between RMSSD and HF, reflecting their shared parasympathetic basis. The inverse associations of the LF/HF ratio with vagally mediated indices further suggest altered autonomic regulation. Overall, HRV may serve as a useful non-invasive tool for assessing autonomic patterns in chronic neck pain and may support more targeted clinical assessment and management.

DECLARATIONS

Funding: No specific funding was received from public, private, or nonprofit organizations for this study.

Conflict of Interest: The authors declare no conflicts of interest, financial or otherwise, that could have influenced this work.

Ethical Approval: The study was approved by the Institutional Ethics Committee of Hamdard Institute of Medical Sciences and Research (HIMSR), Jamia Hamdard, New Delhi (Approval No. HIMSR/IEC(004)/2023; approved 02 February 2023). The study was conducted in accordance with the Declaration of Helsinki (2013 revision).

Informed Consent: Written informed consent was obtained from all participants before study procedures commenced.

Author Contributions: A.L. Khabir: Conceptualization, methodology, data collection, formal analysis, and original manuscript preparation. M.I. Alam: Study design, manuscript review and editing, and intellectual content review. S. Gautam: Methodological support, manuscript review and editing, and critical revision. All authors approved the final manuscript and accept responsibility for all aspects of the work.

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Data Availability: The data generated and analyzed during this study are available from the corresponding author upon reasonable request.

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