Original Research Article

EFFECT OF TREADMILL EXERCISE ON HEART RATE VARIABILITY IN FIRST YEAR MEDICAL STUDENTS

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Abstract

Background: The transition into medical school presents a significant source of stress for first-year medical students, potentially impacting their cardiovascular health. This study examines the effects of treadmill exercise on heart rate variability (HRV), a non-invasive measure of autonomic nervous system function, to understand the impact of physical stress on this demographic.
Methods: Fifty first-year medical students from Sri Aurobindo Medical College and Postgraduate Institute participated in this study, which involved baseline and post-treadmill exercise HRV assessments. The exercise protocol aimed to induce sympathetic activation by reaching a heart rate of over 100 per minute. HRV parameters, including Mean heart rate, SDNN, LF, HF, and LF/HF ratio, were measured using an HRV analyzer. Statistical analysis involved descriptive statistics and paired t-tests to compare pre- and post-exercise HRV metrics.
Results: Post-exercise HRV analysis revealed significant changes indicative of sympathetic nervous system activation. Notably, Mean heart rate significantly increased ($p = 0.04$), VLF power percentage and LF power (ms^2) showed significant increases ($p = 0.001$ and $p = 0.01$, respectively), suggesting heightened sympathetic activity. Conversely, parameters associated with parasympathetic activity, such as HF power, showed no significant change, indicating a stable parasympathetic response to the exercise.
Conclusion: Treadmill exercise led to an evident shift towards sympathetic dominance in first-year medical students, as demonstrated by significant changes in HRV parameters. These findings suggest that physical stress from exercise induces a distinct autonomic response, highlighting the need for incorporating physical activity into medical students' routines to manage stress effectively and maintain cardiovascular health.
Keywords: Heart Rate Variability (HRV), Treadmill Exercise, Medical Students, Autonomic Nervous System, Stress Management.

Introduction

Stress at work is a major public health risk associated with cardiovascular morbidity. The initial journey through medical education is often a rigorous and demanding path, marked by high levels of stress and pressure that can have profound impacts on the well-being of medical students. Stress is a major contributor to many diseases and medical students are always under stress due to the various challenges they face including intensive academic workloads, clinical responsibilities, and the emotional toll of patient care. This stress, if not managed properly, can affect not only their academic performance and professional development but also their physical and mental health. Many researchers have shown that unrelieved stress would lead to health problems as chronic fatigue syndrome, autonomic nervous system (ANS) disorders, sleep disorders, depression etc. [1]. Heart rate variability is a non-invasive measure reflecting the variation over time of the period between consecutive heartbeats (RR intervals) and has been proved to be a reliable marker of ANS activity.

Heart rate variability (HRV) is ordinarily characterised by beat-to-beat variations in the time between peaks in the QRS complex of the ECG wave, i.e. by variations in the RR interval [2]. In 1996 a Task Force of the European Society of Cardiology (ESC) and the North American Society of Pacing and Electrophysiology (NASPE) defined and established standards of measurement, physiological interpretation and clinical use of HRV [3]. Time domain indices, geometric measures and frequency domain indices constitute nowadays the standard clinically used parameters. A formal set of signal analysis standards for measurement, interpretation and clinical application of HRV has been established comprising of time and frequency-domain methods and combinations thereof [4]. In the frequency domain, HRV analysis has classically been described for four distinct bands:

Table 1: Classification bands of HRV Analysis

Ultra-low frequency (ULF)	$f < 0.003$ Hz
Very-low frequency (VLF)	$0.003 \leq f < 0.04$ Hz
Low frequency (LF)	$0.04 \leq f < 0.15$ Hz
High frequency (HF)	$0.15 \leq f \leq 0.4$ Hz

Since the frequency f = 0.003 Hz at the border between the ULF and VLF bands corresponds to a time period of 333 s, short-term recordings of duration < 5 min are restricted to analysis of VLF, LF and HF characteristics, while the ULF band requires longer-term recording clinically, portable ECG monitors are employed which typically record for up to 24 h. It is also noted that HR signals may contain power at frequencies above 0.4 Hz, the upper bound of the HF range: consider a notional HR of 180 beats/min, which is 3 beats/s or f = 3 Hz.

It has been widely believed that HF power primarily reflects parasympathetic cardiac drive, that LF power has a predominantly sympathetic component, and that the LF/HF ratio can thus be used as a measure of sympatho-vagal balance [5], i.e. the relative contributions of sympathetic and parasympathetic activity. It has been proposed that ULF and VLF power might be predictors of cardiac health [6], but it has also been pointed out that understanding of the mechanisms involved is presently limited [7].

Although elucidation of the complex neural mechanisms of HRV and the associated implications for health needs further exploration, it is clear that HRV is an important phenomenon to be considered in the design of engineering systems employed in support of prescription and implementation of exercise training programmes: contemporary recommendations for exercise duration and intensity use HR for delineation of training regimes [8, 9]

The autonomic nervous system (ANS) is crucial in regulating the body's homeostatic functions related to visceral activities, including cardiovascular function, blood pressure, and body temperature management. As exercise intensity escalates, the ANS coordinates a response that enhances cardiac output and manages blood flow by decreasing parasympathetic activity and tilting the balance towards sympathetic dominance [10]. The extent and pace of the shift back to normal autonomic function, or sympathovagal balance, are indicative of the exercise's intensity. Notably, a prolonged state of sympathetic dominance and a sluggish return to parasympathetic activity post-exercise have been linked to a higher likelihood of experiencing acute cardiac incidents, such as ventricular arrhythmias. Consequently, monitoring ANS activity could provide valuable insights into the physiological stress imposed by different exercise intensities [11]

ANS activity can be evaluated noninvasively by heart rate variability (HRV) and invasively through circulating plasma catecholamines [12]. HRV is obtained through the quantification of the oscillations that occur between consecutive R-R intervals derived from an electrocardiogram (ECG). Circulating plasma catecholamines, epinephrine (E) and norepinephrine (NE), are sympathetic neurohormones that are released into circulation from the adrenal glands in response to stress. Essentially, heightened sympathetic activity is related to elevated circulating catecholamine levels and lowered HRV, whereas the opposite is observed during periods of parasympathetic dominance. The time courses of HRV recovery and catecholamine “clearance” are often studied to gauge the responsiveness of the ANS to acute bouts of exercise.

HRV has been successfully used to evaluate ANS functional recovery in young individuals [13] following exercise stress stimulation (i.e., treadmill test), which is a common approach to evaluating the cardiac response to stress [14]. Although sympathetic activation is typically reflected by the symptoms of stress (i.e., heart rate > 100 beats per minute with a rapid increase in respiratory rate) [15], ANS activities may vary with the levels of physical stress in different individuals [16]

In the current study, treadmill-induced sympathetic activation to a heart rate of over 100 per minute was used to investigate the effect of physical stress on heart rate variability (HRV) in first year medical students.

Material and Methods

The present study was carried out on 50 first year undergraduate medical students from a medical college. All research procedures were approved by the Institutional ethics committee. Inclusion of the participants were on a voluntary basis after being given full explanation regarding the purpose and the inclusion/exclusion criteria. Informed written consent was taken from all the participants prior to the current study. Inclusion criteria were from First year medical students with normal baseline ECG willing to participate in the study. Exclusion criteria included subjects with a history of clinical diagnoses of respiratory disorders, any history of hypertension and heart disease, abnormal baseline ECG, history of asthma, participants with a clinical diagnosis of mental illness.

All participants were first asked to rest on a clinical bed for 15 min, followed by baseline ECG and an assessment of their baseline ANS performance with an HRV analyzer (Recorders & Medicare Systems (P) Ltd, India) in a supine and relaxed position with the eyes open. The participants were then required to walk on a treadmill (zero degree inclination) with a structured increase in walking speed until reaching and holding required as well as a heartbeat rate over 100/min for 10 seconds. The participants were allowed to rest for 15 min in the same position as they did during their baseline assessment. Subsequently, the HRV analyzer was used to obtain the post-test (lying supine, eye open, and no activity) measurements. All activities were conducted in the same quiet, ambient temperature and humidity room (temperature 24˚C–26˚C; humidity, 50%–65%).

Five HRV parameters were collected as follows: **(1) Mean heart rate**: Average heart beat (beats per minute, BPM); **(2) SDNN**: The standard deviation of all the normal-to-normal intervals (SDNN) for time domain analysis, which is defined as the standard deviation of the RR interval sequence, is a standard parameter of the overall HRV that is influenced by both sympathetic and parasympathetic nervous activities. It represents the activation status of the ANS [17,18] and may be significantly reduced when an individual is overworked, stressed, or sick (particularly in diabetic patients) [19,20]; **(3) Low frequency band (LF)**: It signifies the result of a mixed modulation of sympathetic and parasympathetic activities. The power of the LF was computed in the range of 0.04–0.15 Hz, and the normalized values of LF (i.e., normalized LF) was calculated for statistical analysis; **(4) High frequency band (HF)**: It reflects the parasympathetic nervous activity. The power of the HF was computed in the range of 0.15–0.4Hz, and the normalized values of HF (i.e., normalized HF) was calculated for statistical analysis; **(5) LF/ HF**: The ratio of LF/HF denotes the sympathetic nervous activity relative to that of the parasympathetic nervous system. A ratio of "1" implies similar activities between the sympathetic and parasympathetic nerves, whereas the activation of the sympathetic system is higher than that of the parasympathetic system if the ratio exceeds 1.

Statistical analysis: Descriptive statistics was used to analyze the characteristic of the volunteers focusing on mean and standard deviation. Additionally, the paired t-test was used to analyze the variables to compare the means before and after the treadmill exercise with 0.95 level of significance (P<0.05).

Results

For analyzing the data, acquisition was done by computed software in RMS polyrite. Each data file was filtered in order to remove low-frequency composite oscillating waves. Since the QRS waves were high frequency waves, this filter made the QRS peaks in the electrocardiograph stand out more and facilitated selection in later parts of the program. The program then found the peaks of each graph, and other outliers caused by irregularities were eliminated through the use of a threshold.

The mean age of the subjects was 18.60 ± 0.84 years and various subject characteristics are given in the Table-2 below.

Table 2: Subject Characteristics (n=50)

Parameters	**Mean ± SD**
Age (years)	18.60 ± 0.84
Height (cm)	167. 28 ± 1.25
Weight (kg)	61.82 ± 14.30

The baseline heart rate variability (HRV) was measured using the HRV analyser, then the post-exercise HRV was measured. HRV parameters collected was as follows: (1) Mean heart rate (2) RR interval (3) SDNN (4) RMSSD (5) Very Low frequency band (VLF) (6) Low frequency band (LF) (7) High frequency band (HF) (8) LF/ HF Power%.

Table 3: Effect of Treadmill exercise on HRV parameters

No.	**Domain**	**Baseline**	**Post exercise**	**Paired t-test**
1.	**Mean Heart rate (bpm)**	81.83 ± 12.80	86.43 ± 11.73	0.04*
2.	**RR interval**	0.75± 0.12	0.70 ± 0.09	0.20
3.	**SDNN**	41.78 ± 17.58	40.86 ± 17.58	0.85
4.	**RMSSD**	30.64 ± 17.19	26.80 ± 14.92	0.29
5.	**VLFPOWER %**	44.12 ± 14.08	57.05 ± 16.09	0.001**
6.	**VLF POWER (ms^2)**	293.56 ± 135.99	400.52 ± 182.10	0.01*
7.	**LF POWER (n.u)**	52.80 ± 15.40	52.50 ± 16.71	0.94
8.	**LF POWER (ms^2)**	141.95 ± 63.81	183.26 ± 59.17	0.02*
9.	**HF POWER %**	27.42 ± 13.79	20.96 ± 13.62	0.11
10.	**HF POWER (n.u)**	47.21 ± 15.37	47.48 ± 16.72	0.95
11.	**HF POWER (ms^2)**	165.95 ± 63.77	133.08 ± 61.12	0.08
12.	**LF/HF POWER %**	1.38 ± 0.90	1.75 ± 2.42	0.48

**Significant (p< 0.05); **Highly significant (p< 0.001)*

From table 3, It is observed that most of the parameters have shown significant changes on exposure to treadmill exercise. The mean heart rate is increased significantly. The RR interval and SDNN has shown a reduction post-test though not significantly, indicating that treadmill exercise has resulted in physical stress in the participants.

The VLF power % and LF power % has increased significantly post exercise. The HF power % and HF power (ms^2) both have shown a reduction in post exercise values though not significantly. The LF/HF power % has increased but not significantly.

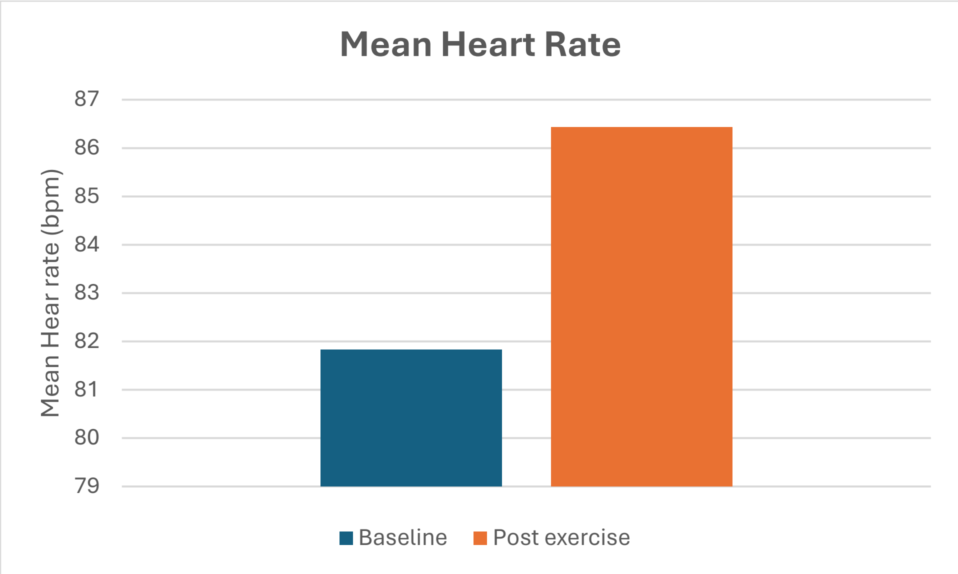

Figure 1: Effect of treadmill exercise on mean heart rate
Figure 1 shows that the mean heart rate is increased significantly post exercise.

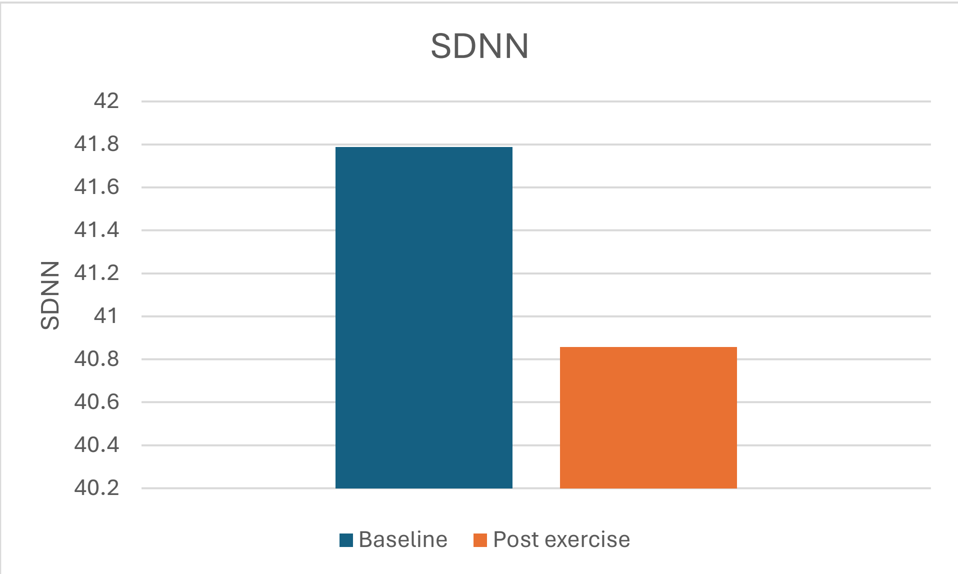

Figure 2: Effect of treadmill exercise on SDNN
SDNN has shown a reduction post-test though not significantly as depicted in figure 2.

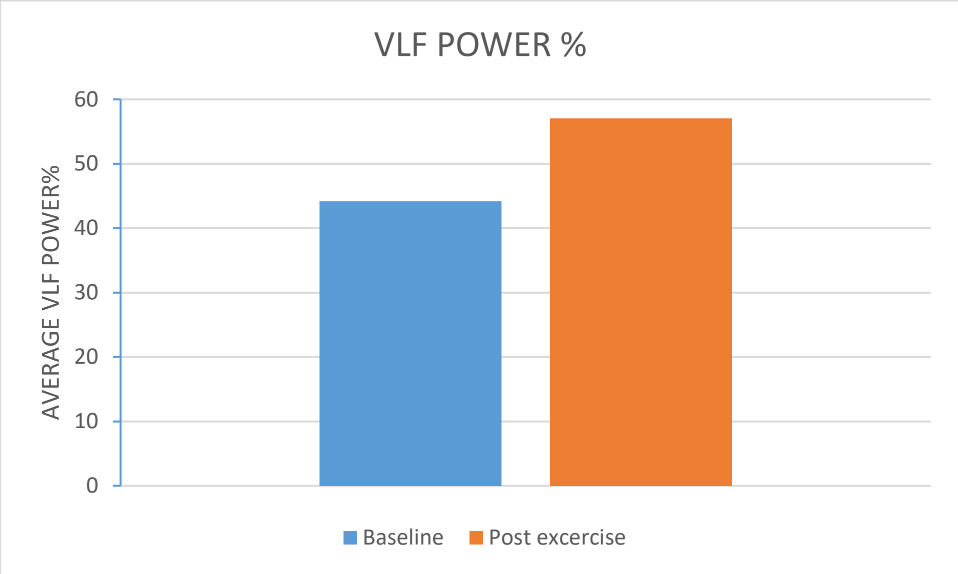

Figure 3: Effect of treadmill exercise on VLF power %

From the above figure3. it is found that the VLF power % has increased significantly post exercise indicating sympathetic system activation.

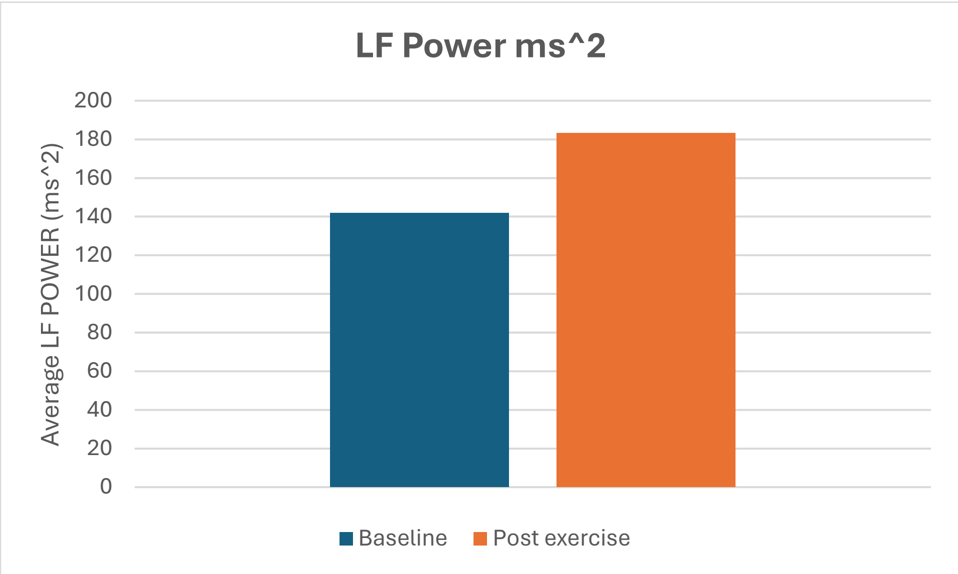

Figure 4: Effect of treadmill exercise on LF power(ms^2)

From the above figure 4. it is found that the LF power has increased significantly post exercise indicating sympathetic system activation.

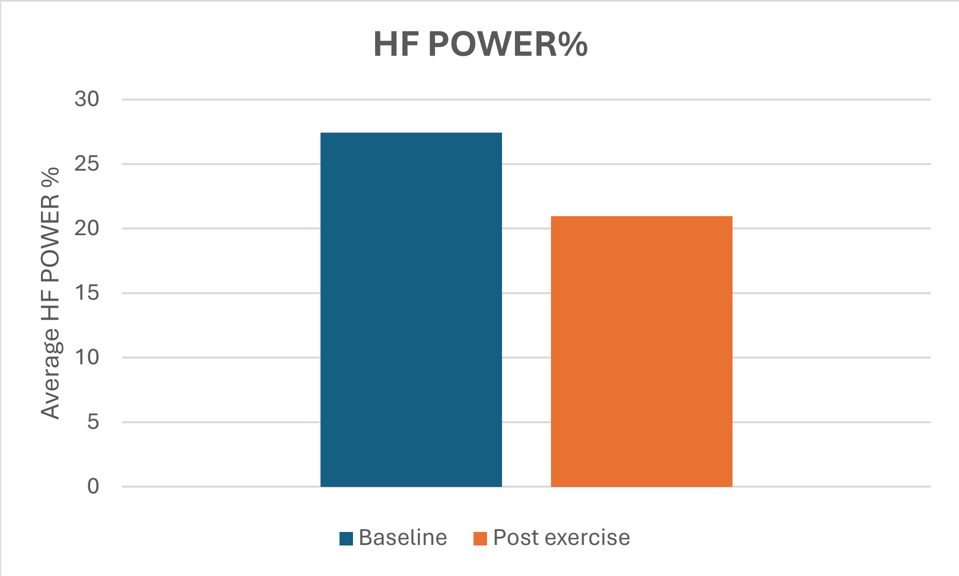

Figure 5: Effect of treadmill exercise on HF power %

The HF power % and HF power (ms^2) both have shown a reduction in post exercise values though not significantly as depicted in the Figures 5 and 6 .

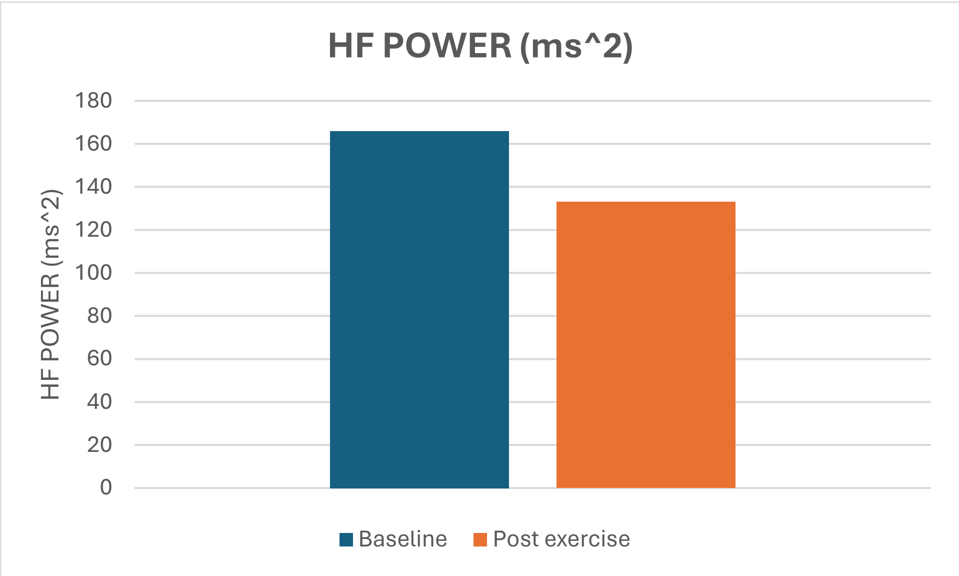

Figure 6: Effect of treadmill exercise on HF power (ms^2)

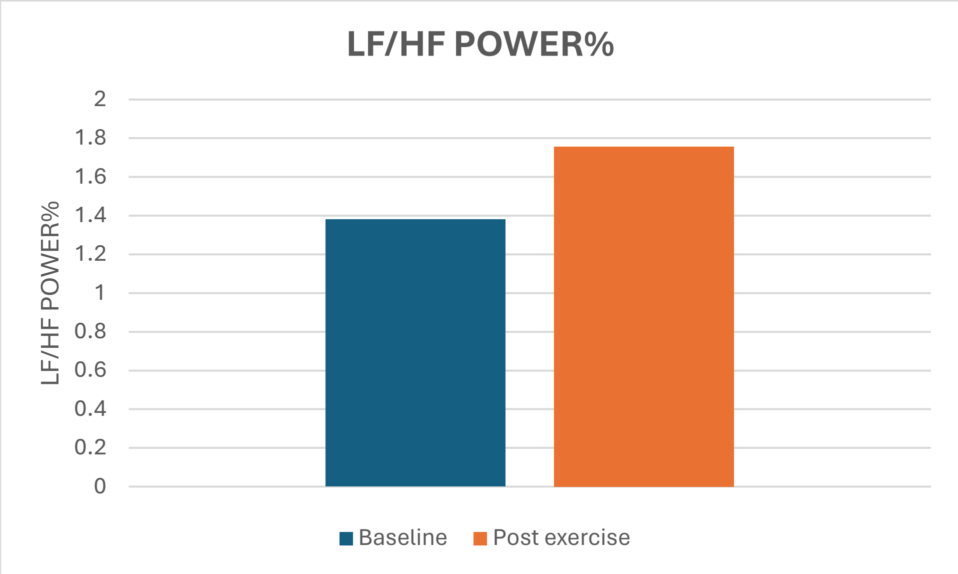

Figure 7: Effect of treadmill exercise on LF/HF power %
The ratio of LF/HF has increased as shown in the above figure 7 though not significantly.

Discussion

This study examined the autonomic nervous system's (ANS) response to exercise, as evidenced by changes in heart rate variability (HRV) and related metrics. Our findings demonstrate a significant exercise-induced increase in mean heart rate and a shift towards sympathetic dominance, as indicated by the significant changes in several HRV parameters. These results are consistent with the body's natural response to physical stress, where an increase in sympathetic activity and a reduction in parasympathetic activity are necessary to meet the metabolic demands of the body during exercise.

These results showcase the impact of exercise on various cardiovascular metrics, reflecting autonomic nervous system activity. The key findings are as follows:

1. **Mean Heart Rate:** Increased from 81.83 ± 12.80 bpm at baseline to 86.43 ± 11.73 bpm post-exercise, with a significant p-value (0.04*), indicating a statistically significant increase in heart rate due to exercise.
2. **RR Interval:** Decreased slightly from 0.75 ± 0.12 seconds to 0.70 ± 0.09 seconds, but the change was not statistically significant (p = 0.20).
3. **SDNN (Standard Deviation of NN intervals)**: Slightly decreased from 41.78 ± 17.58 ms to 40.86 ± 17.58 ms, with no significant change (p = 0.85), suggesting stable overall heart rate variability.
4. **RMSSD (Root Mean Square of Successive Differences)**: Decreased from 30.64 ± 17.19 ms to 26.80 ± 14.92 ms, not significantly (p = 0.29), indicating minor changes in vagal tone.
5. **VLFPOWER %**: Increased significantly from 44.12 ± 14.08% to 57.05 ± 16.09% (p = 0.001**), suggesting enhanced low-frequency oscillations in heart rate variability, potentially indicating increased sympathetic activity.
6. **VLF POWER (ms^2)**: Showed a significant increase from 293.56 ± 135.99 ms^2 to 400.52 ± 182.10 ms^2 (p = 0.01*), supporting the increase in sympathetic modulation.
7. **LF POWER (n.u) and LF POWER (ms^2)**: LF POWER in normalized units did not change significantly, but LF POWER in ms^2 increased significantly from 141.95 ± 63.81 ms^2 to 183.26 ± 59.17 ms^2 (p = 0.02*), indicating increased sympathetic activity.

8. **HF POWER % and HF POWER (n.u)**: Both measures showed no significant changes, suggesting that parasympathetic activity remained relatively stable.
9. **HF POWER (ms^2)**: Decreased from 165.95 ± 63.77 ms^2 to 133.08 ± 61.12 ms^2, but not significantly ($p = 0.08$), hinting at a reduction in vagal modulation.
10. **LF/HF POWER %**: Increased from 1.38 ± 0.90 to 1.75 ± 2.42, not significantly ($p = 0.48$), suggesting a trend towards increased sympathetic dominance.

In summary, these results indicate a significant shift towards sympathetic dominance and reduced parasympathetic activity in response to exercise, as evidenced by the significant changes in mean heart rate and various measures of heart rate variability (VLFPOWER %, VLF POWER, and LF POWER). The changes in RR interval, RMSSD, SDNN, HF POWER, and LF/HF ratio were not statistically significant, suggesting a nuanced autonomic response to exercise. The statistical significance is denoted by p-values, with * indicating $p < 0.05$ (significant) and ** indicating $p < 0.01$ (highly significant).

The significant increase in mean heart rate post-exercise ($p = 0.04$) aligns with existing literature [20] that documents the heart's accelerated activity under physical stress to facilitate increased blood flow and oxygen delivery to active muscles. This physiological response is crucial for sustaining exercise but also triggers broader autonomic adjustments.

Interestingly, the RR interval's decrease was not statistically significant ($p = 0.20$), suggesting that while the mean heart rate increased, the variability in heart rate timing did not change markedly with exercise. This may indicate a balance between the sympathetic and parasympathetic nervous system activities during the initial recovery phase, a finding that warrants further investigation for its implications on cardiac health and recovery kinetics.

The non-significant changes in SDNN and RMSSD further support the notion that overall heart rate variability remains relatively stable immediately after exercise, despite shifts in mean values. This stability in HRV parameters could be indicative of a well-maintained autonomic balance in the studied population, suggesting resilience of the cardiac autonomic function against the acute stress of exercise.

A noteworthy finding is the significant increase in VLFPOWER % and VLF POWER (ms^2) post-exercise, with p-values of 0.001 and 0.01, respectively. These increases are indicative of enhanced sympathetic activity, a necessary adaptation during exercise to mobilize energy reserves and support increased cardiovascular demands. The LF POWER (ms^2) also significantly increased ($p = 0.02$), corroborating the heightened sympathetic modulation to meet the physiological demands of exercise.

However, the HF POWER metrics, which are predominantly reflective of parasympathetic activity, did not show significant changes. This may suggest that while sympathetic activity increases to support exercise, parasympathetic activity does not markedly decrease in the immediate post-exercise period, possibly reflecting a protective mechanism to mitigate against excessive cardiac stress.

The LF/HF ratio, often used as an indicator of sympathovagal balance, showed an increase, although not statistically significant ($p = 0.48$). This trend towards sympathetic predominance is consistent with the physiological response to exercise but indicates that further research is needed to understand the complexities of autonomic regulation during different phases of exercise and recovery. Similar studies show Cardiac sympatho-excitation due to a physical stressor such as orthostatism is known to be associated with a reduction in total variability, along with alteration of the LF/HF ratio.

In conclusion, our study adds to the growing body of evidence suggesting that exercise induces significant autonomic shifts, primarily characterized by increased sympathetic activity. These findings underscore the importance of considering individual variations in autonomic response when designing exercise programs, especially for populations at risk of cardiovascular events. Future studies should explore the long-term implications of these autonomic responses to exercise, including their relationship with cardiovascular health and exercise adaptation.

Conclusion

This study set out to explore the impact of treadmill exercise on heart rate variability (HRV) among first-year medical students, aiming to understand how physical stress influences autonomic nervous system (ANS) regulation in this specific demographic.

Our findings reveal that treadmill exercise leads to a significant increase in mean heart rate and a pronounced shift towards sympathetic dominance, as evidenced by changes in various HRV parameters. Notably, the exercise regimen resulted in an enhanced sympathetic modulation, indicated by significant increases in VLFPOWER %, VLF POWER (ms^2), and LF POWER (ms^2), without causing marked alterations in parasympathetic indicators such as HF POWER metrics.

These results underscore the physiological adaptability of first-year medical students to the acute stress imposed by treadmill exercise, highlighting an effective autonomic response that balances the increased cardiovascular demands. Despite the heightened sympathetic activity, the stability in parasympathetic output suggests a protective autonomic mechanism, potentially safeguarding against excessive cardiac stress during and after exercise.

Furthermore, the absence of significant changes in the RR interval, SDNN, and RMSSD post-exercise indicates that while the heart rate increases to meet the exercise challenge, overall heart rate variability remains relatively unaffected. This could reflect a well-maintained autonomic function, suggesting that regular physical activity might contribute to cardiovascular resilience among medical students.

Our study contributes valuable insights into the cardiovascular and autonomic effects of physical exercise on first-year medical students, a group that may experience unique physiological and psychological stressors. The findings advocate for the inclusion of regular, moderated physical activity in the lifestyle of medical students to support not only their physical well-being but also their academic performance and stress management.

In conclusion, treadmill exercise induces significant autonomic shifts towards sympathetic dominance in first-year medical students, without compromising heart rate variability or parasympathetic function. These insights pave the way for further research into optimal exercise regimens that promote health and well-being in medical students, potentially informing policies and programs that support their academic journey and overall health.

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