

Resting Heart Rate Variability in Relation to Body Mass Index and Physical Activity in Young Adults: A Cross-Sectional Study

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ABSTRACT

Background: Heart rate variability (HRV) provides a non-invasive window into cardiac autonomic modulation. Excess body weight and low habitual physical activity may alter autonomic balance even in otherwise healthy young adults. This study examined the relationship of resting HRV with body mass index (BMI) and self-reported physical activity.

Methods: A cross-sectional observational study was conducted among 140 apparently healthy young adults aged 18–25 years from March 2025 to February 2026. Height and weight were measured using standard anthropometric methods, and body mass index (BMI) was calculated as weight in kilograms divided by height in metres squared. Habitual physical activity was assessed using the International Physical Activity Questionnaire–Short Form (IPAQ-SF). After 10 minutes of supine rest, a 5-minute electrocardiogram was recorded under standardized laboratory conditions. RMSSD and SDNN were derived as time-domain indices of heart rate variability. Group differences were assessed using one-way analysis of variance, and linear associations were examined using Pearson correlation. Statistical significance was set at $p < 0.05$.

Results: Resting HRV decreased progressively across increasing BMI categories and increased with greater physical activity. RMSSD declined from 42.3 ± 5.8 ms in the underweight category to 28.4 ± 6.5 ms in the obese category, while SDNN declined from 55.2 ± 7.1 to 39.9 ± 8.0 ms. BMI-group differences were significant for RMSSD ($F=23.90$, $p < 0.001$, $\eta^2=0.345$) and SDNN ($F=20.31$, $p < 0.001$, $\eta^2=0.309$). RMSSD and SDNN also increased significantly across low, moderate and high physical-activity groups ($F=42.54$ and 37.82 , respectively; both $p < 0.001$). BMI correlated inversely with RMSSD ($r=-0.51$) and SDNN ($r=-0.47$), whereas physical activity correlated positively with RMSSD ($r=0.48$) and SDNN ($r=0.53$); all correlations were statistically significant ($p < 0.001$). **Conclusion:** Within the limits of a cross-sectional design, higher BMI was associated with lower resting HRV, while greater physical activity was associated with more favorable autonomic indices. These findings support early lifestyle-based cardiovascular risk reduction in young adults, although causal inference requires longitudinal or interventional research.

Keywords: heart rate variability; body mass index; physical activity; autonomic nervous system; RMSSD; SDNN; young adults

INTRODUCTION

Heart rate variability (HRV) describes beat-to-beat variation in normal cardiac intervals and is widely used to characterize autonomic modulation of the heart. Short-term recordings are particularly suited to controlled laboratory studies because indices such as the root mean square of successive differences (RMSSD) are

strongly influenced by vagal modulation, whereas the standard deviation of normal-to-normal intervals (SDNN) reflects overall variability during the recording period [1–3]. HRV is sensitive to age, respiration, posture, recording duration, physical conditioning and cardiometabolic status, making standardized acquisition

essential when comparisons are made between groups [1–3].

Body composition and physical activity are two potentially modifiable correlates of autonomic function. Excess adiposity is associated with metabolic and inflammatory changes that may shift cardiac autonomic regulation toward lower vagal modulation and reduced HRV [4,6,7]. Conversely, regular physical activity and higher cardiorespiratory fitness are generally associated with more favorable HRV profiles, although the magnitude of association varies with activity measurement, training status and HRV methodology [8–11].

Young adulthood is an important period for prevention because weight gain and sedentary behavior may emerge before overt cardiometabolic disease. Detecting autonomic differences in apparently healthy individuals may therefore identify early physiological changes that are not apparent from resting heart rate alone. The present study was designed to examine BMI and habitual physical activity concurrently in relation to resting RMSSD and SDNN among adults aged 18–25 years.

The primary objective was to assess the correlation of resting HRV with BMI and physical activity level. A secondary objective was to compare RMSSD and SDNN across BMI and IPAQ-SF activity categories.

MATERIALS AND METHODS

Study design and setting

A cross-sectional observational study was conducted in the Department of Physiology, Shadan Institute of Medical Sciences, Hyderabad, Telangana, from March 2025 to February 2026. The study evaluated the relationship of resting heart rate variability with body mass index and habitual physical activity in apparently healthy young adults. The study was undertaken after approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants before enrolment and assessment.

Participants

A total of 140 apparently healthy undergraduate and postgraduate students aged 18–25 years were recruited by convenience sampling. Participants were eligible if they were 18–25 years of age, had a resting heart rate between 60 and 100 beats/min, and had no known chronic medical or psychiatric illness. Individuals receiving medications known to influence cardiovascular or autonomic function were excluded. Participants with a history of smoking or alcohol consumption, recent infection, irregular sleep pattern, or athletic training exceeding 6 hours per week were also excluded.

Anthropometric assessment

Height was measured to the nearest practical unit using a stadiometer, and body weight was measured using a digital weighing scale. Body mass index was calculated as weight in kilograms divided by the square of height in metres (kg/m^2). For the group-wise analysis, BMI was categorized as underweight ($<18.5 \text{ kg/m}^2$), normal ($18.5\text{--}24.9 \text{ kg/m}^2$), overweight ($25.0\text{--}29.9 \text{ kg/m}^2$), and obese ($\geq 30.0 \text{ kg/m}^2$), corresponding to the categories used in the reported HRV comparisons.

Assessment of Physical Activity

Habitual physical activity was assessed using the International Physical Activity Questionnaire–Short Form (IPAQ-SF), which recorded walking, moderate-intensity activity, vigorous-intensity activity, and sitting time during the preceding 7 days [5]. Responses were scored according to the standard IPAQ procedure and expressed as metabolic equivalent task minutes per week (MET-min/week). Participants were subsequently classified into low, moderate, or high physical-activity categories.

Resting HRV recording

Heart rate variability was recorded in a quiet, temperature-controlled laboratory maintained at approximately $22\text{--}24^\circ\text{C}$. Participants were instructed to rest in the supine position for 10 minutes before recording. A 5-minute electrocardiogram was then obtained using a standard three-lead configuration between 09:00 and 11:00 hours to minimize the influence of circadian variation. Normal-to-normal RR intervals were analyzed using validated HRV software. The root mean square of successive differences (RMSSD) and the standard deviation of normal-to-normal intervals (SDNN) were calculated in milliseconds as the principal time-domain HRV measures [1,3].

Statistical analysis

Continuous variables were expressed as mean $\pm$ standard deviation, whereas categorical variables were summarized as frequencies and percentages. Distributional normality was assessed using the Shapiro–Wilk test. Differences in RMSSD and SDNN across BMI categories and physical-activity levels were evaluated using one-way analysis of variance (ANOVA). Tukey post-hoc comparisons were planned when the overall ANOVA was significant. Pearson correlation coefficients were calculated to assess the relationships of BMI and physical-activity score with RMSSD and SDNN. Statistical significance was defined as $p < 0.05$, and 95% confidence intervals were reported where applicable. F statistics and eta-squared (η^2) effect sizes for the group comparisons were calculated from the

available group size, mean, and standard deviation values. No missing individual observations were imputed for these calculations.

RESULTS

Participant characteristics

The study enrolled 140 young adults with a mean age of 21.8 ± 1.5 years. Men accounted for 54% (81/140) and women for 46% (69/150). Mean BMI was 23.6 ± 2.9 kg/m² and mean resting heart rate was 72.4 ± 8.1 beats/min (Table 1).

Table 1. Baseline characteristics of the study participants

Characteristic	Value
Age, years	21.8 ± 1.5
Male sex	81 (58.86%)
Female sex	59 (42.14%)
BMI, kg/m ²	23.6 ± 2.9
Resting heart rate, beats/min	72.4 ± 8.1

Values are mean $\pm$ SD or n (%). BMI, body mass index; SD, standard deviation

HRV across BMI categories

Both HRV indices decreased stepwise across the reported BMI categories (Table 2 and Figure 1). RMSSD fell from 42.3 ± 5.8 ms in the underweight group to 28.4 ± 6.5 ms in the obese group. The corresponding SDNN values declined from 55.2 ± 7.1 to 39.9 ± 8.0 ms. Based on the reported summary statistics, between-group variation was significant for RMSSD ($F(3,136)=23.90$, $p<0.001$, $\eta^2=0.345$) and SDNN ($F(3,136)=20.31$, $p<0.001$, $\eta^2=0.309$). These effect sizes indicate that roughly one-third of the observed variance in each HRV index was associated with BMI-category membership in this sample.

Table 2. Resting HRV according to reported BMI category

BMI category	n	RMSSD, ms	SDNN, ms
Underweight (<18.5)	20	42.3 ± 5.8	55.2 ± 7.1
Normal (18.5–24.9)	60	38.5 ± 6.1	51.4 ± 6.9
Overweight (25–29.9)	40	32.1 ± 7.0	45.6 ± 7.5
Obese (≥ 30)	20	28.4 ± 6.5	39.9 ± 8.0

BMI-category counts available for the group comparison totaled 140 participants. ANOVA based on the reported group summaries showed significant differences for RMSSD, $F(3,136)=23.90$, $p<0.001$, $\eta^2=0.345$, and SDNN, $F(3,136)=20.31$, $p<0.001$, $\eta^2=0.309$

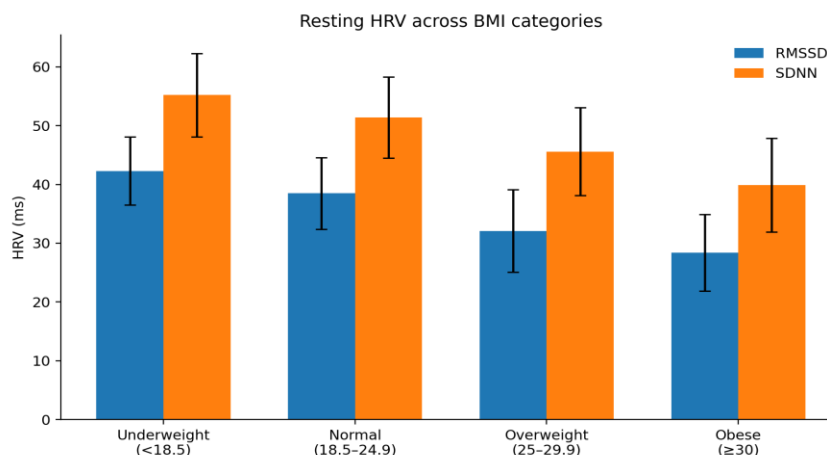


Figure 1: Mean resting RMSSD and SDNN across reported BMI categories. Error bars represent ± 1 SD

HRV across physical activity categories

A complementary pattern was observed for physical activity (Table 3 and Figure 2). Mean RMSSD increased from 31.2 ± 6.7 ms in the low-activity group to 44.1 ± 6.3 ms in the high-activity group. SDNN increased from 43.1 ± 6.9 to 56.8 ± 7.0 ms. Summary-statistic ANOVA showed marked differences across activity categories for RMSSD ($F(2,137)=42.54$, $p<0.001$, $\eta^2=0.383$) and SDNN ($F(2,137)=37.82$, $p<0.001$, $\eta^2=0.356$).

Table 3: Resting HRV according to physical activity level

Physical activity	n	RMSSD, ms	SDNN, ms
Low	35	31.2 ± 6.7	43.1 ± 6.9
Moderate	60	37.5 ± 5.9	49.3 ± 7.2
High	45	44.1 ± 6.3	56.8 ± 7.0

Physical-activity category counts available for the group comparison totaled 140 participants. ANOVA based on the reported group summaries showed significant differences for RMSSD, $F(2,137)=42.54$, $p<0.001$, $\eta^2=0.383$, and SDNN, $F(2,137)=37.82$, $p<0.001$, $\eta^2=0.356$

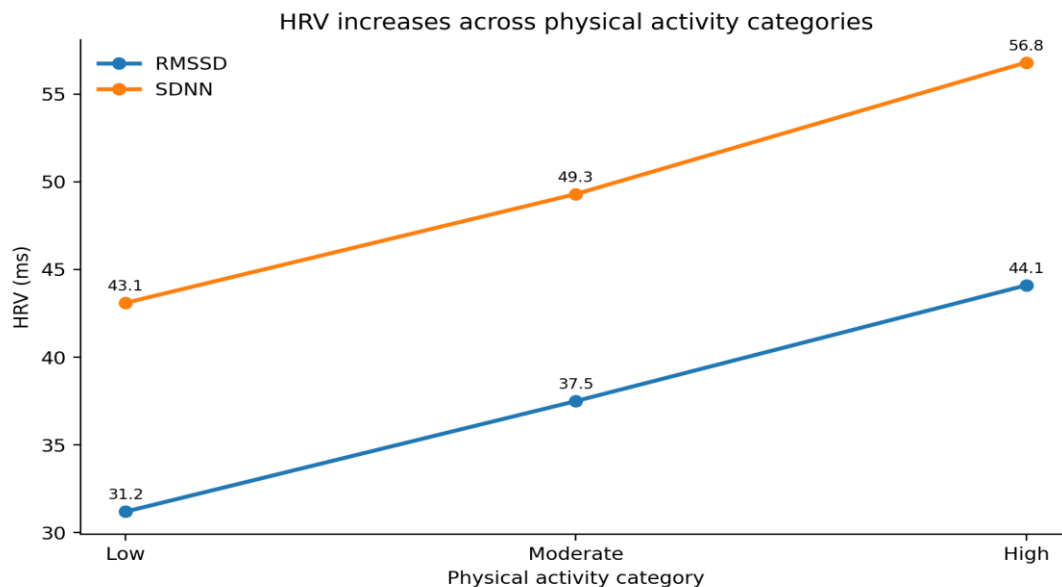


Figure 2: Reported mean RMSSD and SDNN across low, moderate and high physical activity categories

Correlations of BMI and physical activity with HRV

Correlation analysis supported the group-based findings (Table 4 and Figure 3). BMI showed moderate inverse associations with RMSSD ($r=-0.51$, 95% CI -0.63 to -0.37) and SDNN ($r=-0.47$, 95% CI -0.59 to -0.33), both $p<0.001$. Physical activity score showed moderate positive associations with RMSSD ($r=0.48$, 95% CI 0.33 to 0.61) and SDNN ($r=0.53$, 95% CI 0.39 to 0.65), both $p<0.001$. Thus, higher BMI and lower activity were each aligned with a less favorable resting HRV profile.

Table 4: Correlation of BMI and physical activity score with HRV indices

HRV index	Correlate	Pearson r	95% CI	p value
RMSSD	BMI	-0.51	-0.63 to -0.37	<0.001
SDNN	BMI	-0.47	-0.59 to -0.33	<0.001
RMSSD	Physical activity score	0.48	0.33 to 0.61	<0.001
SDNN	Physical activity score	0.53	0.39 to 0.65	<0.001

CI, confidence interval; BMI, body mass index; RMSSD, root mean square of successive differences; SDNN, standard deviation of normal-to-normal intervals

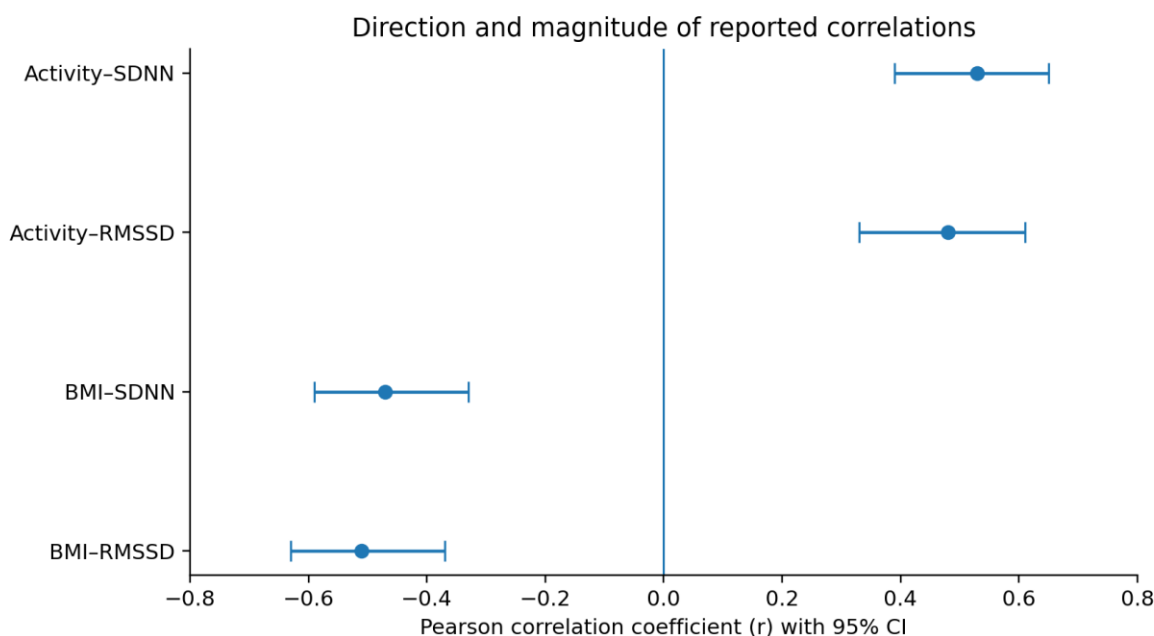


Figure 3: Reported Pearson correlations with 95% confidence intervals. Values to the left of zero indicate inverse associations; values to the right indicate positive associations

DISCUSSION

This study identified two convergent associations in apparently healthy young adults: resting HRV decreased as BMI increased, while HRV increased with greater habitual physical activity. The patterns were evident for both RMSSD and SDNN and were supported by moderate correlation coefficients. Because RMSSD is predominantly sensitive to short-term vagal modulation and SDNN reflects overall variability over the recording window, the parallel findings suggest that the observed differences were not confined to a single time-domain metric [1–3].

The inverse relationship between BMI and HRV is biologically plausible and broadly consistent with prior literature. Nagai et al. reported lower autonomic activity in obese school children compared with non-obese peers, with autonomic differences related to the development of obesity [6]. Broader cardiovascular literature also links reduced HRV with adverse risk profiles and autonomic imbalance [7,12]. In the present study, the monotonic decline in RMSSD and SDNN from the lowest to highest BMI category supports the possibility that autonomic changes may be detectable before the development of overt cardiovascular disease.

Physical activity showed the opposite relationship. Participants in the high-activity category had the highest RMSSD and SDNN values, and activity score correlated positively with both indices. Reviews and training studies have generally shown that regular exercise can improve HRV, particularly indices related to vagal

modulation [8–10,13]. A recent meta-analysis of randomized trials in healthy adults reported significant improvements in both RMSSD and SDNN after exercise training, strengthening the physiological interpretation of the cross-sectional pattern observed here [13].

The findings should not be interpreted to mean that HRV alone is a direct measure of “fitness” or “fatness.” BMI is an anthropometric proxy and does not distinguish fat mass from lean mass, while IPAQ-SF is a self-reported activity measure rather than an objective measure of cardiorespiratory fitness. The revised title therefore describes the measured exposures directly. This distinction improves construct validity and avoids overstating what can be inferred from the available measurements.

Several methodological strengths deserve mention. HRV was recorded after a standardized supine rest period, within a restricted morning time window and in a temperature-controlled setting, reducing important records of short-term variability. The use of two established time-domain HRV measures and a validated physical-activity questionnaire also improves interpretability [1,5]. In addition, reporting 95% confidence intervals for correlations and effect sizes for group comparisons gives a clearer indication of the magnitude and precision of associations than p values alone.

Limitations

The cross-sectional design precluded conclusions about causality or temporal direction. Convenience sampling from students may have limited generalizability. Physical activity was self-reported and was therefore susceptible to recall and social-desirability bias. BMI did not directly quantify body fat or fat distribution. Potential confounders such as sex-specific autonomic differences, menstrual-cycle phase, sleep duration, caffeine intake, dietary status, psychological stress, and objectively measured cardiorespiratory fitness were not included as adjusted covariates. The analysis was limited to time-domain HRV and did not include frequency-domain or non-linear indices. In addition, the available category-specific counts for both BMI and physical activity totaled 140, whereas 150 participants were included in the overall study population; this should be verified against the study records before final submission.

CONCLUSION

Among healthy adults aged 18–25 years, higher BMI was associated with lower resting RMSSD and SDNN, whereas greater habitual physical activity was associated with higher values of both HRV indices. The results are compatible with early modulation of cardiac autonomic function by lifestyle-related factors. Longitudinal studies incorporating direct measures of adiposity and cardiorespiratory fitness, objective activity monitoring and multivariable adjustment are needed to determine whether the observed associations predict later cardiometabolic risk.

Declarations

Ethics approval and consent to participate: The study was conducted after approval from the Institutional Ethics Committee, and written informed consent was obtained from all participants before enrolment.

Conflicts of interest: The authors declared no conflicts of interest.

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