

Comparative Cross-Sectional Study of Heart Rate Variability among Swimmers, Runners, and Sedentary Adults

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ABSTRACT

Background: Heart rate variability (HRV) is a non-invasive marker of cardiac autonomic modulation and may differ according to habitual physical activity. Direct comparisons of young swimmers, runners, and sedentary adults remain limited. **Objective:** This study aimed to compare resting HRV and selected cardiovascular parameters among swimmers, runners, and sedentary adults aged 18–25 years and to explore sex-specific patterns. **Methods:** This hospital-based comparative cross-sectional study included 60 participants, comprising 20 swimmers, 20 runners, and 20 sedentary adults, with 10 males and 10 females in each group. Participants with cardiac, endocrine, or respiratory disease; substance dependence; chronic smoking or alcohol use; or medications likely to affect autonomic function were excluded. Resting heart rate, blood pressure, and 5-min lead II electrocardiogram recordings were obtained after a 15-min supine rest. Time-domain and frequency-domain HRV indices were analyzed. **Results:** Groups were similar in age and height. Sedentary participants had higher mean weight and body mass index than swimmers and runners. Resting heart rate did not differ significantly among groups. Systolic and diastolic blood pressure differed significantly across groups, with higher values in sedentary participants. Among HRV indices, low-frequency (LF) power differed significantly among the three groups ($F = 3.983$, $P = 0.03$), whereas standard deviation of normal-to-normal intervals (SDNN), root mean square of successive differences, pRR50, very-low-frequency, high-frequency (HF), and LF/HF ratio did not. Swimmers had lower SDNN and LF than sedentary participants. Sex-stratified analyses showed significant differences in LF among males and in SDNN, pRR50, and LF among females. **Conclusion:** Young adults engaged in regular swimming or running showed differences in selected resting cardiovascular and HRV measures compared with sedentary adults. Because the study was cross-sectional and based on a small sample, these findings indicate association rather than a causal effect of exercise.

Keywords: Autonomic function, Heart rate variability, Runners, Sedentary adults, Swimmers

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INTRODUCTION

Cardiovascular disease remains a major global health burden, and physical inactivity is an important modifiable risk factor. Regular physical activity is associated with favorable cardiovascular and metabolic adaptations, although the magnitude and pattern of adaptation may vary with the type, intensity, and duration of training. Swimming and running are commonly practiced endurance activities, but they differ in posture, environmental exposure, muscle recruitment, and respiratory demands. These differences may influence autonomic cardiovascular regulation.^[1,2]

The autonomic nervous system regulates heart rate, vascular tone, and cardiac contractility through interacting sympathetic and parasympathetic pathways. Heart rate variability (HRV), defined as variation in successive beat-to-beat intervals, provides a non-invasive assessment of cardiac autonomic modulation. HRV can be evaluated in the time domain and frequency domain. Common time-domain measures include standard deviation of normal-to-normal intervals (SDNN), root mean square of successive differences (RMSSD), and pRR50, whereas frequency-domain measures include very-low-frequency (VLF), low-frequency (LF), and high-frequency (HF) power. The 1996 Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology established widely used standards for HRV measurement and interpretation.^[3,4]

Exercise training has been associated with changes in resting autonomic function, including enhanced vagal modulation in many endurance-trained populations. Lower resting heart rate and altered HRV have been described in trained individuals compared with sedentary controls. However, the literature is not uniform: Training status, exercise modality, training load, age, sex, recording

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duration, and analytical methods can influence HRV. In addition, LF should not be interpreted as a pure measure of sympathetic activity, and the LF/HF ratio should not be considered a definitive measure of sympathovagal balance.

Studies comparing different endurance sports in young adults are relatively limited. Swimming may have distinctive autonomic effects because water immersion, horizontal posture, and breathing pattern alter venous return and cardiovascular loading. Running, in contrast, is performed upright and involves repetitive weight-bearing exercise. A direct comparison with sedentary young adults may therefore help characterize differences in resting cardiovascular and HRV measures.^[5-7]

The present study was designed to compare resting HRV among swimmers, runners, and sedentary adults aged 18–25 years. Secondary objectives were to compare resting heart rate, systolic and diastolic blood pressure, anthropometric variables, and sex-specific HRV patterns. The study was hypothesis-generating and cross-sectional; therefore, differences between groups were interpreted as associations rather than evidence that exercise caused the observed changes.^[8]

MATERIALS AND METHODS

Study Design and Setting

This hospital-based comparative cross-sectional study was conducted over 18 months, from June 2022 to December 2023, at Government Medical College, Nagpur, a tertiary care hospital in Central India. The study included young adults aged 18–25 years belonging to one of three predefined activity groups: swimmers, runners, and sedentary adults.

Participants and Sample Size

A total of 60 participants were enrolled, with 20 participants in each group. Each group contained 10 males and 10 females. The sample size was based on estimates from a previous study using an assumed standard deviation of approximately 5–6 units, a mean difference of 7 units, 80% power, and a two-sided alpha error of 10%, resulting in a total sample of 60 participants. Participants were recruited using the sampling approach described in the original study protocol.^[9–11]

Group Definitions and Eligibility

Swimmers were young adults who had been swimming regularly for at least 2 months during the preceding year. Runners met an analogous criterion for regular running. Sedentary participants were young adults who had not participated in regular exercise, organized sports, or meditation during the preceding year. All participants were volunteers aged 18–25 years.

Participants were excluded if they had a history of drug addiction, cardiac disease, thyroid disease, asthma, or other endocrine disease; chronic smoking or alcohol use; or use of hormone replacement therapy or medications known to influence autonomic function. These criteria were intended to minimize major clinical and pharmacological confounding of HRV.^[12]

Ethical Considerations

The study was approved by the institutional ethics committee. Written informed consent was obtained from all participants after explanation of the study procedures, risks, and voluntary nature of participation.

Clinical and Anthropometric Assessment

A structured history and clinical examination were performed. Weight was measured in light clothing without shoes using a calibrated electronic weighing scale and recorded to the nearest 0.1 kg. Height was measured without shoes and recorded to the nearest 0.5 cm. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Resting heart

rate and blood pressure were recorded under standardized resting conditions.^[13–15]

HRV Recording

Participants rested supine for 15 min before HRV recording. A 5-min lead II electrocardiogram was obtained using a computerized 16-channel biopotential recording system (PHYSIOPAC PP-4, Medicaid Systems, Chandigarh, India). Electrode gel was used to reduce movement artifact and maintain adequate skin-electrode contact. HRV was assessed using time-domain and frequency-domain measures derived from the RR interval series.

Time-domain variables included SDNN, RMSSD, and pRR50. Frequency-domain variables included VLF, LF (0.04–0.15 Hz), and HF (0.15–0.40 Hz). LF and HF were interpreted as spectral components rather than as isolated measures of sympathetic or parasympathetic activity, because both components may be influenced by multiple physiological mechanisms.^[16]

Statistical Analysis

Data were entered into Microsoft Excel 2019 and analyzed using the Statistical Package for the Social Sciences version 24.0. Continuous variables were summarized as mean $\pm$ standard deviation. One-way analysis of variance (ANOVA) was used for comparison of the three groups. Pairwise comparisons reported in the original analysis used the unpaired Student's *t*-test. $P < 0.05$ was considered statistically significant. Because this was a secondary, exploratory analysis with multiple pairwise comparisons and a small sample, *P*-values were interpreted cautiously, and effect patterns were emphasized over isolated statistical significance.^[17–20]

RESULTS

Participant Characteristics

The study included 60 participants: 20 swimmers, 20 runners, and 20 sedentary adults. Mean age did not differ significantly between groups. Mean height was also similar. Sedentary participants had higher mean weight and BMI than swimmers and runners.

Resting Cardiovascular Parameters

Resting heart rate did not differ significantly among the three groups ($F = 0.579$, $P = 0.56$). Systolic blood pressure differed significantly ($F = 11.226$, $P < 0.001$), with the sedentary group having the highest mean value. Diastolic blood pressure also differed significantly ($F = 5.822$, $P = 0.005$), again with the highest mean value among sedentary participants [Tables 1–3].

HRV

Among the HRV measures, only LF power showed a statistically significant overall difference between groups ($F = 3.983$, $P = 0.03$). Mean LF was lowest in swimmers and highest in sedentary adults. SDNN, RMSSD, pRR50, VLF, HF, and LF/HF ratio did not differ significantly in the overall three-group comparison [Table 4].

Sex-Stratified Findings

Sex-stratified analyses were exploratory because each subgroup contained only 10 participants. Among males, LF differed significantly across the three groups ($F = 7.921, P = 0.001$), and the LF/HF ratio also differed ($F = 5.028, P = 0.01$). The principal pairwise difference in males was the lower LF in swimmers compared with runners ($P = 0.01$). Other male HRV measures did not show significant differences.

Among females, SDNN ($F = 3.906, P = 0.03$), pRR50 ($F = 3.853, P = 0.03$), and LF ($F = 6.604, P = 0.003$) differed across the three groups. Swimmers had lower SDNN and LF than sedentary females. In direct comparison of male and female participants within groups, most HRV measures were not significantly different; LF was higher in females than males in the sedentary group ($P = 0.03$), and pRR50 differed between male and female swimmers ($P = 0.01$). These subgroup findings should be considered hypothesis-generating.^[21-24]

DISCUSSION

This comparative cross-sectional study examined resting cardiovascular and HRV measures in 60 young adults divided equally into swimming, running, and sedentary groups. The groups were broadly similar in age and height, whereas sedentary participants had higher weight and BMI. Resting heart rate was not significantly different among groups, whereas both systolic and diastolic blood pressure were higher in sedentary participants. For HRV, the principal overall finding was a difference in LF power, whereas most other time- and frequency-domain measures did not differ significantly.^[25-27]

The anthropometric findings are compatible with observations from studies comparing trained and sedentary young

adults. Regular physical activity is associated with greater energy expenditure and may contribute to healthier body composition. However, the cross-sectional design cannot establish that exercise caused the lower body weight or BMI in the swimmer and runner groups. Differences in diet, occupational activity, socioeconomic factors, and unmeasured training characteristics could also contribute.

The lack of a statistically significant difference in resting heart rate is notable. Endurance-trained individuals often demonstrate resting bradycardia, which is commonly attributed in part to enhanced vagal modulation. In the present sample, runners had the lowest mean resting heart rate, followed by swimmers, but the differences were small relative to within-group variability. The relatively short minimum training duration of 2 months and the broad variation in actual training volume may partly explain the absence of a statistically significant difference.^[28,29]

Both systolic and diastolic blood pressure were higher in sedentary adults. Similar observations have been reported in studies comparing physically active and sedentary populations. Regular exercise can influence vascular function, endothelial responsiveness, and autonomic regulation. Nevertheless, blood pressure is affected by numerous factors, and a single cross-sectional measurement cannot establish a sustained treatment effect. The findings should therefore be interpreted as an association between activity status and resting blood pressure.

The central HRV finding was a significant difference in LF power across the three groups. Mean LF was lowest among swimmers, intermediate among runners, and highest among sedentary adults. A similar pattern was seen in the swimmer-versus-sedentary comparison. Some previous studies have reported differences in LF between trained and sedentary individuals, although the direction and magnitude of the effect have varied. These differences may reflect training status, recording protocol, respiration, age, sex, fitness level, and other methodological factors.

Interpretation of LF requires particular caution. Although LF has historically been described as a marker of sympathetic activity, contemporary HRV interpretation recognizes that LF reflects mixed autonomic and physiological influences and cannot be used as a pure index of sympathetic tone. Similarly, the LF/HF ratio should not be treated as a direct or definitive measure of sympathovagal balance. The present study therefore supports an association with altered spectral HRV characteristics rather than a conclusion of isolated sympathetic activation or suppression.

SDNN was significantly lower in swimmers than sedentary adults in the reported pairwise analysis, although the overall three-group ANOVA was not significant. Because SDNN reflects overall variability and is strongly dependent on recording duration and physiological conditions, this isolated pairwise finding should not be interpreted independently of the overall analysis. The

Table 1: Baseline demographic and anthropometric characteristics

Variable	Swimmers (n=20)	Runners (n=20)	Sedentary (n=20)	ANOVA P
Age, years	21.0±1.75	21.8±1.64	21.65±1.63	0.28
Weight, kg	59.1±7.14	61.55±7.67	66.55±6.17	0.005
Height, cm	166.2±6.23	166.3±10.42	168.1±7.88	0.72
BMI, kg/m ²	21.37±2.07	22.22±1.52	23.71±3.31	0.01

Values are mean±SD. BMI: Body mass index

Table 2: Resting cardiovascular parameters

Variable	Swimmers	Runners	Sedentary	ANOVA P
Heart rate, beats/min	73.4±11.90	71.4±10.39	75.1±10.28	0.56
Systolic BP, mmHg	114.9±5.89	114.6±6.43	123.3±7.37	<0.001
Diastolic BP, mmHg	77.2±5.21	79.8±7.33	84.0±6.36	0.005

Values are mean±SD. BP: Blood pressure, ANOVA: Analysis of variance

Table 3: Resting HRV parameters across the three groups

HRV variable	Swimmers	Runners	Sedentary	ANOVA P
SDNN, ms	149.8±16.56	156.65±21.66	163.5±21.41	0.11
RMSSD, ms	32.1±6.28	33.6±8.87	29.3±8.92	0.24
pRR50, %	23.9±6.37	25.0±6.25	24.85±7.68	0.86
VLF, ms ²	700.65±83.36	701.8±104.16	713.35±110.67	0.91
LF, ms ²	1392±162.96	1498±216.49	1553±165.69	0.03
HF, ms ²	1061.6±180.49	1009.5±287.30	1052.2±222.6	0.76
LF/HF ratio	1.34±0.27	1.56±0.47	1.52±0.32	0.13

Values are mean±SD. HRV: Heart rate variability, LF/HF: Low-frequency/High-frequency, VLF: Very-low-frequency, SDNN: Standard deviation of normal-to-normal intervals, RMSSD: Root mean square of successive differences, ANOVA: Analysis of variance

Table 4. Selected pairwise comparisons were exploratory and were not adjusted for multiple testing.

Comparison	Parameter	Group 1 mean±SD	Group 2 mean±SD	P
Swimmers vs sedentary	SDNN, ms	149.8±16.56	163.5±21.41	0.02
Swimmers vs sedentary	LF, ms ²	1392±162.96	1553±165.69	0.004
Swimmers vs runners	LF, ms ²	1392±162.96	1498±216.49	0.08
Runners vs sedentary	LF, ms ²	1498±216.49	1553±165.69	0.37

difference may represent sample variability or an unmeasured characteristic of the groups.

RMSSD, pRR50, VLF, and HF did not show significant overall differences. RMSSD and HF are commonly used to characterize short-term vagally mediated HRV, although they are influenced by respiratory pattern and other conditions. The absence of significant differences in these measures suggests that the observed between-group variation was not consistent across all domains of autonomic modulation.

Swimming and running showed broadly similar HRV profiles. No significant differences were observed between swimmers and runners for most measures, including SDNN, RMSSD, pRR50, VLF, HF, and LF/HF ratio. The mean LF difference between swimmers and runners did not reach conventional statistical significance. This similarity is biologically plausible because both activities are predominantly aerobic endurance exercises, despite differences in exercise environment and biomechanics.

The sex-stratified analyses generated additional observations but must be interpreted cautiously. Among males, LF and LF/HF ratio differed across groups. Among females, SDNN, pRR50, and LF differed. The sample size of 10 participants per sex within each activity group is small, and multiple comparisons increase the possibility of chance findings. These results should therefore be regarded as hypothesis-generating rather than definitive evidence of sex-specific training effects.

The present findings are broadly consistent with prior work showing that HRV may differ between physically active and sedentary adults. Hegde *et al.* reported differences in selected HRV parameters between trained athletes and sedentary individuals. Sawane and Gupta demonstrated changes in resting HRV following exercise-related interventions, whereas other studies have shown that training load and prolonged exercise may modify HRV in complex ways. Research in elite swimmers has also demonstrated that reductions in training volume can be accompanied by changes in resting HRV, with recovery after resumption of training.

The current study differs from longitudinal exercise interventions because participants were classified according to existing activity status rather than assigned to an exercise program. This distinction is important. An intervention study can provide stronger evidence that exercise changes HRV, whereas the present study can only demonstrate differences between naturally occurring groups. Reverse causation and residual confounding cannot be excluded.

Several methodological considerations are important. First, HRV was assessed during a short 5-min recording rather than with 24-h Holter monitoring. Short-term HRV is appropriate for standardized resting assessment but does not capture circadian variation or responses to daily activity. Second, the study did not quantify exact weekly exercise duration, intensity, training load,

competitive level, or time since the last training session. Third, respiration was not reported as a controlled variable, which is relevant to HF and other spectral measures. Fourth, the sample was restricted to healthy adults aged 18–25 years, limiting generalizability.

The study also used several pairwise t-tests after a three-group ANOVA without correction for multiple comparisons. Because multiple statistical tests were performed, some nominally significant results may represent type I error. This is particularly relevant to the sex-specific analyses. A future adequately powered study should prespecify primary HRV outcomes, use appropriate *post hoc* procedures, quantify training exposure, and consider multivariable adjustment for sex, BMI, blood pressure, and other potential confounders.

Despite these limitations, the study provides a useful comparison of three common activity states in young adults using standardized resting HRV recording. The combination of anthropometric, blood pressure, and HRV measurements provides a broader picture than any single HRV parameter. The results support further prospective research using larger samples and standardized training exposure to determine whether specific exercise modalities produce distinct autonomic adaptations.^[30,31]

Limitations

- Small overall sample size and only 10 males and 10 females in each group
- Cross-sectional design, which prevents inference of causality or temporal change
- Narrow age range of 18–25 years, limiting generalizability to other age groups
- Exercise exposure was defined by minimum duration rather than detailed quantified training load
- Five-minute resting HRV was used instead of 24-h ambulatory monitoring
- Respiratory rate and other acute influences on HRV were not formally quantified
- Multiple pairwise and sex-specific comparisons were exploratory and were not corrected for multiple testing.

CONCLUSION

In this hospital-based comparative cross-sectional study of young adults, swimmers, runners, and sedentary participants showed similar age and height but differed in weight, BMI, and resting blood pressure. Resting heart rate did not differ significantly. Among HRV measures, LF power differed across the three activity groups, whereas most other time- and frequency-domain indices did not. Swimmers had lower LF and SDNN than sedentary participants in the reported pairwise analyses. Sex-stratified findings suggested additional differences in selected HRV measures but were limited by small subgroup sizes. Overall, the findings indicate an association between habitual activity status and selected resting cardiovascular and HRV characteristics; prospective studies with larger samples, quantified training exposure, and standardized HRV protocols are required to establish temporal and causal relationships.

ETHICS APPROVAL AND CONSENT

The study was approved by the institutional ethics committee. Written informed consent was obtained from all participants.

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