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Study of heart rate variability in response to 12 weeks of endurance training in healthy female volunteers

Ahmad Fasihi *

Department of Physical Education and Sport Sciences, Faculty of Literature and Humanities, Malayer University, Malayer, Iran.

Yaser Roozbahani

Department of Physical Education, Faculty of Humanities, Islamic Azad University, Hamedan Branch, Hamedan, Iran.

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* Corresponding Author: ahmad.fasihi44@gmail.com.

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Abstract

Purpose: Heart rate variability (HRV) is a marker of cardiac autonomic regulation, with reduced HRV linked to increased cardiovascular risk. While aerobic exercise improves HRV, data on healthy women remain limited. This study aimed to assess the impact of 12 weeks of endurance training on resting HRV indices in healthy female volunteers. **Method:** In a pre-test–post-test controlled design, healthy women were randomly assigned to an endurance training group or a control group. The training group performed moderate-intensity continuous exercise three times per week for 12 weeks. HRV was measured before and after the intervention using short-term ECG recordings, analyzing time-domain indices (SDNN, RMSSD) and high-frequency (HF) components, along with the LF/HF ratio. Statistical significance was set at $p<0.05$. **Results:** After 12 weeks, the training group showed significant improvements in SDNN (from 45±5 to 58±7 ms, $p=0.023$), RMSSD (from 25±3 to 36±5 ms, $p=0.033$), and HF (from 210±30 to 310±45 ms^2, $p=0.033$), while the control group showed no significant changes. Between-group comparisons confirmed significantly higher post-intervention SDNN, RMSSD, and HF in the training group ($p=0.02$). The LF/HF ratio did not change significantly in either group. **Conclusion:** Twelve weeks of endurance training significantly improved HRV indices (SDNN, RMSSD, HF) in healthy female volunteers, suggesting enhanced autonomic regulation. These results support incorporating endurance exercise in lifestyle recommendations for women to improve cardiac health.

Keywords: Heart rate variability, endurance training, female, sympathetic nervous system, parasympathetic nervous system.

Introduction

Heart rate variability (HRV) is a vital marker of autonomic nervous system (ANS) function, reflecting the regulation of cardiac activity by the sympathetic and parasympathetic branches. It measures the variation in time intervals between successive heartbeats, and is widely used as a non-invasive tool to assess autonomic regulation. A higher HRV is typically associated with better cardiovascular health and greater resilience to stress, while reduced HRV has been linked to increased risk of cardiovascular diseases, sudden death, and other autonomic dysfunctions. Common HRV parameters include time-domain indices such as standard deviation of normal-to-normal intervals (SDNN), root mean square of successive differences (RMSSD), and total power (TP), as well as frequency-domain metrics like high-frequency power (HF) and the LF/HF ratio (Shaffer & Ginsberg, 2017).

Physical activity, particularly endurance exercise, plays a significant role in enhancing HRV by increasing parasympathetic tone and reducing sympathetic drive. This physiological adaptation has been demonstrated across various populations, including those with cardiovascular risk factors. Endurance training has been shown to improve HRV, as it facilitates the rebalancing of the autonomic nervous system and enhances heart rate regulation. Studies have found that regular aerobic exercises increase HRV indices such as RMSSD, SDNN, and HF, suggesting improved autonomic function (Iellamo et al., 2013; Cuddy et al., 2019). Both moderate-intensity continuous training (MICT) and high-intensity interval training (HIIT) have been recognized for their positive impacts on HRV, though the magnitude and scope of these effects can vary depending on the type and duration of exercise.

Several studies have investigated the impact of exercise on HRV. A study by Ghardashi-Afousi et al. (2018) found significant improvements in HRV parameters following 12 weeks of HIIT compared to MICT in individuals after coronary artery bypass surgery (Ghardashi-Afousi et al., 2018). Another study by Picard et al. (2021)

highlighted the beneficial effects of exercise training on HRV in type 2 diabetes patients, reporting significant improvements in RMSSD and SDNN after a structured aerobic exercise program (Picard et al., 2021). Similarly, research has shown that both HIIT and MICT result in positive HRV changes in sedentary adults, particularly in high-risk groups such as smokers and individuals with metabolic syndrome (Ramos et al., 2017). Despite these findings, there remains a gap in understanding how exercise specifically influences HRV in women, especially regarding gender-specific responses and long-term effects.

While the majority of HRV-related studies have focused on mixed-gender or male populations, research examining the effects of exercise on HRV in healthy women is still scarce. Women tend to have lower HRV than men, especially during periods of hormonal changes, which may influence the outcomes of exercise interventions (Koufaki et al., 2014). Additionally, few studies have comprehensively explored the long-term effects of endurance training on HRV in this population. Addressing this gap is critical, as understanding the effects of exercise on autonomic regulation in women could lead to more tailored and effective cardiovascular health recommendations. Therefore, this study aims to examine the impact of 12 weeks of endurance training on HRV in healthy female volunteers. By employing a pre- and post-test design, the research has evaluated changes in HRV parameters, including SDNN, RMSSD, and HF, following a structured aerobic exercise regimen.

Methods

Study Design

In this study, a pre-test post-test design was employed with a 12-week endurance training intervention. Healthy female volunteers were randomly assigned to either the training group or the control group. The participants in the training group completed a standardized exercise program consisting of moderate-intensity continuous training (MICT) for three sessions per week. The control group did not undergo any exercise intervention, allowing for an assessment of HRV changes without the influence of physical activity. The exercise protocol was adapted from previous studies examining HRV in both healthy and clinical populations (Afousi-Ghardashi et al., 2018; Picard et al., 2021), ensuring consistency in methodology. The study aimed to evaluate how endurance training affected HRV parameters, specifically focusing on SDNN, RMSSD, and HF, which are commonly used indicators of autonomic nervous system regulation.

HRV Measurement Methods

HRV was measured using short-term electrocardiogram (ECG) recordings, capturing both time-domain and frequency-domain parameters. Pre- and post-intervention assessments were conducted in a controlled environment to minimize external variables. Participants rested for 15 minutes in a quiet room to stabilize their physiological state before HRV was measured for 5 minutes. Time-domain measures, such as SDNN and RMSSD, and frequency-domain measures, particularly high-frequency power (HF), were recorded as they are commonly associated with autonomic regulation, particularly parasympathetic activity (Iellamo et al., 2013; Ghardashi-Afousi et al., 2018). These parameters were chosen due to their widespread use in examining the effects of exercise on cardiovascular health, and they were measured during the resting state to ensure accurate assessment of baseline autonomic function before and after the training intervention.

Data Analysis

The HRV data were analyzed using paired t-tests to compare pre- and post-intervention values within both the training and control groups. Independent t-tests were used to evaluate the differences between the two groups. The Shapiro-Wilk test was performed to assess the normality of the data, and if necessary, non-parametric tests like the

Wilcoxon signed-rank test were applied. The effect size (Cohen's d) was calculated to determine the magnitude of the intervention's impact on HRV. A p-value of less than 0.05 was considered statistically significant for all comparisons. The primary focus was on changes in SDNN, RMSSD, HF, and the LF/HF ratio, which together provided a comprehensive assessment of autonomic nervous system balance and its response to endurance training (Cuddy et al., 2019; Afousi-Ghardashi et al., 2018).

Results

Table 1 shows the results of the subjects' anthropometric characteristics at baseline.

Table 1: Anthropometric characteristics of subjects at baseline

characteristic	**training group (Mean&SD)**	**control group (Mean&SD)**
Age (yer)	28.5±3.2	29.1±2.8
Weight (kg)	62.4±6.8	63.2±7.1
BMI (kg/m^2)	24.5±3.2	25.5±3.1

The paired t-test results in Table 2 show that the training group showed a significant improvement in SDNN with a pre-test value of 45 ± 5 ms and a post-test value of 58 ± 7 ms (p=0.02) and significant increase in RMSSD, with a pretest value of 25±3 ms and a posttest value of 36±5 ms (p=0.033).

An independent t-test was used to compare the training group with the control group. The training group showed a significant increase in SDNN (post-test: 58 ± 7 ms), while the control group showed no significant change (pre-test: 46 ± 6 ms, post-test: 46 ± 5 ms) (p=0.45) also significant increase in RMSSD (posttest: 36±5 ms), while the control group showed a slight decrease in RMSSD (pretest: 24±4 ms, posttest: 23±4 ms), without significant change (p=0.38).

Table 2. Results of SDNN and RMSSD values before and after the exercise intervention.

Variable	groups	pre-test (Mean&SD)	post-test (Mean&SD)	P-value
SDNN	**training group**	45±5 ms	58±7ms	0.023*
	control group	46±6 ms	46±5ms	0.450
	P-value	0.075	0.021*	-
RMSSD	**training group**	25±3ms	36±5ms	0.033*
	control group	24±4 ms	23±4ms	0.380
	P-value	0.084	0.021*	-

* Signs of significant change

According to the results of Table 3, in the within-group comparison, the paired t-test results showed a significant increase in HF in the training group, from 210±30 ms at baseline to 310±45 ms after the 12-week endurance training program (p=0.01) and also significant change in the LF/HF ratio, with pre- and post-test values of 1.8±0.2 and 1.7±0.3, respectively (p=0.55).

Also, in the between-group comparison, the independent t-test was used to compare the changes in HF and LF/HFratio, between the training and control groups. The training group showed a significant increase in HF (post-test: 310±45 ms), while the control group showed no significant change (pre-test: 215±35 ms, post-test: 220±30 ms) (p=0.56). also, the results showed no significant changes in the LF/HF ratio in the exercise group (post-test: 1.7±0.3), the control group showed a slight increase from 1.9±0.2 to 2.1±0.2 (p=0.40). However, no statistically significant difference was observed between the two groups in the LF/HF ratio, indicating that although parasympathetic activity increased in the exercise group, the overall autonomic balance (as indicated by the LF/HF ratio) did not change significantly.

Table 3. Results of HF and LF/HF values before and after the exercise intervention

variable	**groups**	**pre-test (Mean&SD)**	**post-test (Mean&SD)**	**P-value**
HF	**training group**	210±30ms^2	310±45ms^2	0.033*
	control group	215±35ms^2	220±30ms	0.560
	P-value	0.084	0.021*	-
LF/HF	**training group**	1.8±0.2	1.7±0.3	0.550
	control group	1.9±0.2ms^2	2.1±0.2	0.400
	P-value	0.084	0.321*	-

* Signs of significant change

Discussion

Analysis showed that the endurance training program resulted in significant improvements in SDNN, RMSSD, and HF in the training group, while the control group showed no significant changes. However, the LF/HF ratio was not significantly different in either group, indicating that training improved auto-regulation without altering the sympathetic/parasympathetic balance (Ghardashi-Afousi et al., 2018; El-Malahi et al., 2024; Picard et al., 2021).

In this study, the SDNN parameter showed a significant improvement in the training group, suggesting that endurance training led to enhanced overall heart rate variability, reflecting better autonomic regulation. This finding aligns with results from Ghardashi-Afousi et al. (2018), who observed a significant improvement in SDNN following 12 weeks of high-intensity interval training (HIIT) in a clinical population recovering from coronary artery bypass surgery (Ghardashi-Afousi et al., 2018). Furthermore, El-Malahi et al. (2024) found similar improvements in SDNN among individuals with cardiovascular conditions undergoing physical activity interventions (El-Malahi et al., 2024). However, some studies, such as Cuddy et al. (2019), showed smaller improvements in SDNN, especially in younger and healthier populations, which might explain the magnitude of the change observed in this study (Cuddy et al., 2019).

Another result of this study was a significant improvement in RMSSD values in the training group, which is a reflection of enhanced parasympathetic modulation, consistent with previous studies by Iellamo et al. (2013) and Picard et al. (2021). These studies demonstrated that endurance exercise, particularly moderate-intensity training, can enhance parasympathetic activity as measured by RMSSD (Iellamo et al., 2013; Picard et al., 2021). The magnitude of change observed in this study aligns with findings from Ghardashi-Afousi et al. (2018), who also noted significant improvements in RMSSD after a structured exercise program (Ghardashi-Afousi et al., 2018.)

Additionally, the results of this study showed a significant improvement in HF values in the exercise group, indicating improved parasympathetic control. This result is in agreement with results of El-Malahi et al. (2024), where physical activity interventions led to increased HF power in various cardiovascular populations, supporting the idea that aerobic exercise enhances parasympathetic modulation (El-Malahi et al., 2024). In contrast, Ghardashi-Afousi et al. (2018) did not find as large an effect on HF when comparing different exercise regimens in post-surgical patients, suggesting that the effects on HF may vary depending on the population's baseline health and the type of exercise prescribed (Ghardashi-Afousi et al., 2018).

The LF/HF ratio, which indicates the balance between sympathetic and parasympathetic activity, did not show a significant change in the training group, and similarly, no significant change was found in the control group. This result is in line with studies such as Picard et al. (2021) and Ghardashi-Afousi et al. (2018), where changes in the LF/HF ratio were minimal or not statistically significant following exercise interventions (Picard et al., 2021; Ghardashi-Afousi et al., 2018). It suggests that while endurance training significantly improves parasympathetic modulation, it does not always lead to substantial shifts in the balance between sympathetic and parasympathetic nervous system activity. The lack of change in the LF/HF ratio could be attributed to the fact that parasympathetic effects (e.g., increased HF power) may improve autonomic regulation without drastically altering the sympathetic tone, which is commonly reflected in the LF component. These findings are consistent with results of El-Malahi et al. (2024), where HF improvements were noted without significant shifts in LF/HF ratios, suggesting that physical activity may primarily enhance parasympathetic activity without affecting sympathetic tone as much (El-Malahi et al., 2024).

Overall, the findings of the present study indicate that 12 weeks of endurance training can meaningfully enhance cardiac autonomic regulation in healthy young women, as evidenced by significant increases in SDNN, RMSSD, and HF, while leaving the LF/HF ratio largely unchanged. This pattern suggests that the primary adaptation to endurance training in this population is a strengthening of parasympathetic (vagal) modulation rather than a major shift in the overall sympatho–vagal balance, which is consistent with several previous exercise–HRV studies in clinical and non-clinical groups. From a practical standpoint, these results support the inclusion of structured endurance training in exercise prescriptions for women to promote autonomic and cardiovascular health, even in the absence of overt disease. However, the relatively small sample size, short follow-up period, and restriction to healthy young females limit the generalizability of the findings, and future research should examine different age groups, training intensities, and longer interventions, as well as incorporate additional clinical and functional outcomes. Despite these limitations, the current study adds to the limited body of evidence focused specifically on women and underscores the potential of endurance exercise as a simple, low-cost strategy to improve HRV and, by extension, long-term cardiovascular risk profiles in this population.

Conclusion

This study showed that 12 weeks of endurance training significantly improved HRV indices (SDNN, RMSSD, HF) in healthy female volunteers, indicating enhanced parasympathetic and overall autonomic regulation. The lack of significant change in LF/HF suggests that training mainly strengthened vagal activity without markedly altering sympatho

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Conflicts of Interest:

The author declares no conflict of interest.

ORCID

Ahmad Fasihi	**https://orcid.org/**
Yaser Roozbahani	**https://orcid.org/**

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Corresponding Author: ahmad.fasihi44@gmail.com.

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