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Comparing Heart Rate Recovery After Aerobic vs. Anaerobic Exercise

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Abstract:

Background: Heart rate recovery (HRR) is a key physiological marker of autonomic nervous system function and cardiovascular fitness. It reflects the ability of the heart to return to baseline after exercise, influenced by parasympathetic reactivation and sympathetic withdrawal. While both aerobic (e.g., running, cycling) and anaerobic (e.g., sprinting, weightlifting) exercises influence HRR, their comparative effects remain an area of interest. This study aims to compare HRR after aerobic and anaerobic exercise, analyzing differences in autonomic modulation and cardiovascular recovery.

Methods: A total of 210 healthy adults (mean age: 28.5 ± 5.7 years) were recruited and divided into two exercise groups: Aerobic Exercise Group (n = 105) and Anaerobic Exercise Group (n = 105). Participants performed a standardized 30-minute treadmill running protocol (aerobic) or high-intensity sprinting and resistance training (anaerobic). Heart rate (HR) was monitored continuously using ECG, and HRR was assessed at 1 minute (HRR1), 2 minutes (HRR2), and 5 minutes (HRR5) post-exercise.

Results: HRR was significantly faster in the aerobic exercise group, with greater parasympathetic reactivation observed at HRR1 ($p < 0.001$) and HRR2 ($p = 0.003$). The anaerobic group exhibited a slower decline in HR, with significantly higher HR at HRR1 and HRR2 compared to the aerobic group. At HRR5, no significant differences were observed between groups ($p = 0.081$).

Conclusion: Aerobic exercise facilitates faster heart rate recovery compared to anaerobic exercise, suggesting superior parasympathetic reactivation and autonomic function. While anaerobic exercise leads to delayed HRR due to prolonged sympathetic activation, both exercise modalities contribute to cardiovascular fitness in distinct ways. Future studies should explore long-term HRR adaptations in athletes and clinical populations.

Keywords: Heart rate recovery, aerobic exercise, anaerobic exercise, autonomic nervous system, cardiovascular fitness

Introduction

Heart rate recovery (HRR) is an important physiological marker that reflects autonomic nervous system (ANS) function and cardiovascular fitness. It is defined as the rate at which heart rate (HR) declines after exercise cessation, indicating the balance between parasympathetic reactivation and sympathetic withdrawal [1]. A faster HRR is associated with greater cardiovascular efficiency and lower mortality risk, whereas a delayed HRR has been linked to autonomic dysfunction, increased cardiovascular risk, and poor exercise adaptation. The intensity and type of exercise play a crucial role in determining the rate of HR recovery, with aerobic and anaerobic exercise eliciting distinct physiological responses [2].

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During exercise, the sympathetic nervous system (SNS) dominates, increasing heart rate, cardiac output, and oxygen delivery to working muscles. After exercise cessation, the parasympathetic nervous system (PNS) takes over, promoting HR recovery through vagal reactivation and sympathetic withdrawal [3]. The speed of HRR depends on how efficiently the parasympathetic system counteracts the sympathetic drive. Studies suggest that impaired HRR (a reduction of fewer than 12 beats per minute in the first minute post-exercise) is associated with an increased risk of cardiovascular disease and mortality [4].

Different exercise modalities influence HRR in unique ways. Aerobic exercise, characterized by sustained, moderate-intensity efforts such as running, cycling, and swimming, is associated with stronger parasympathetic activity and faster HR recovery. In contrast, anaerobic exercise, which includes high-intensity, short-duration efforts such as sprinting and resistance training, relies on anaerobic glycolysis and elicits a prolonged sympathetic response, leading to a delayed HRR [5]. The degree of vagal reactivation is lower after anaerobic workouts due to the greater metabolic and catecholamine load [6].

Aerobic exercise primarily depends on oxidative metabolism and involves sustained, rhythmic activities that increase cardiovascular endurance, mitochondrial efficiency, and parasympathetic dominance. Regular aerobic training is associated with lower resting heart rate (RHR), improved stroke volume, and greater vagal tone, all of which contribute to a more efficient HRR. A well-trained aerobic system allows for a faster transition from sympathetic dominance to parasympathetic control post-exercise, leading to rapid heart rate deceleration [7].

Anaerobic exercise, on the other hand, involves high-intensity, explosive movements that rely on anaerobic glycolysis and phosphocreatine systems for energy. These activities lead to greater catecholamine release, higher blood lactate levels, and greater metabolic stress, which can prolong sympathetic activation post-exercise. As a result, HRR is typically slower after anaerobic exercise due to the increased oxygen debt, prolonged metabolic demand, and sustained sympathetic drive [8].

HRR is widely used as an indicator of cardiovascular and autonomic health. A faster HRR is correlated with higher levels of aerobic fitness and reduced cardiovascular mortality. Athletes with greater endurance capacity exhibit rapid HRR due to their enhanced parasympathetic tone, while individuals with low fitness levels or autonomic dysfunction experience delayed HRR [9].

Trained endurance athletes have significantly faster HRR compared to strength-trained or sedentary individuals. This suggests that training adaptations to aerobic exercise include enhanced vagal activity and more efficient autonomic regulation, whereas anaerobic training leads to greater reliance on sympathetic activation and slower autonomic recovery [10].

The effects of different training modalities on cardiovascular function, few studies have directly compared HRR between aerobic and anaerobic exercise. Most studies focus on either endurance training or high-intensity interval training (HIIT) separately, without evaluating their relative effects on autonomic reactivation post-exercise [11]. The objective of this study is to compare heart rate recovery at 1, 2, and 5 minutes post-exercise between aerobic and anaerobic training, evaluate the speed of parasympathetic reactivation, and assess the implications for cardiovascular fitness and autonomic function.

Methodology

This observational study was designed to compare heart rate recovery (HRR) between two distinct types of exercise: aerobic and anaerobic. We recruited 210 healthy participants, ranging from 18 to 60 years old, from a local fitness center. Participants were evenly divided into two groups: the aerobic group (n=105) and the anaerobic group (n=105). The inclusion criteria were participants who were generally healthy and aged between 18 and 60 years. Exclusion criteria included individuals with known cardiovascular, pulmonary, or metabolic diseases, those on medication affecting cardiovascular response, or inability to perform exercise protocols safely. The study was approved by the local ethics committee, and all participants provided written informed consent before participation. The study adhered to the ethical principles of the Declaration of Helsinki

Participants in the aerobic group engaged in 30 minutes of continuous cycling at 70% of their maximal heart rate (HRmax), while those in the anaerobic group performed high-intensity interval training (HIIT), consisting of repeated 1-minute sprints at 90-95% HRmax interspersed with 1-minute rest periods, totaling 30 minutes.

Heart rate was measured using standard electrocardiographic (ECG) monitors. HR measurements were taken at rest (RHR), immediately after exercise (Peak HR), and during the recovery phase at 1 minute (HRR1), 2 minutes (HRR2), and 5 minutes (HRR5) post-exercise.

Baseline characteristics, including age, body mass index (BMI), resting heart rate (RHR), and maximal oxygen uptake (VO_2 max), were recorded. These characteristics were assessed to ensure comparability between groups at baseline.

Statistical Analysis

Descriptive statistics were used to summarize baseline characteristics, with means and standard deviations for continuous variables and percentages for categorical variables. Differences in heart rate recovery between groups were analyzed using independent t-tests, and associations between VO_2 max and HRR were assessed using Pearson correlation coefficients. The chi-square test was used to compare categorical variables. A p-value of less than 0.05 was considered statistically significant. All statistical analyses were performed using SPSS version 24.0 (IBM Corp., USA). Data were anonymized and securely stored in compliance with data protection regulations. Only authorized personnel had access to the final dataset for analysis to ensure confidentiality

Results

A total of 210 healthy participants (mean age: 28.5 ± 5.7 years) were included in this study, with 105 participants in the aerobic group and 105 in the anaerobic group. The study aimed to compare heart rate recovery (HRR) between aerobic and anaerobic exercise, with HRR measured at 1 minute (HRR1), 2 minutes (HRR2), and 5 minutes (HRR5) post-exercise.

Table 1: Baseline Characteristics of Participants

Participants in both groups had similar baseline characteristics, including age, BMI, resting heart rate (RHR), and VO_2 max levels, ensuring that observed differences in HRR were due to exercise type rather than pre-existing fitness differences.

Variable	Aerobic Group (n = 105)	Anaerobic Group (n = 105)	p-value
Age (years)	28.2 ± 5.4	28.8 ± 5.9	0.462
BMI (kg/m²)	23.4 ± 2.8	24.1 ± 2.9	0.198
Resting HR (bpm)	72.1 ± 5.7	73.5 ± 6.1	0.317
VO_2 max (mL/kg/min)	44.8 ± 6.3	42.5 ± 5.9	0.276

There were no significant differences in baseline age, BMI, resting HR, or VO_2 max between the two groups, confirming that they were well-matched before exercise testing.

Table 2: Peak Heart Rate and Immediate Post-Exercise Heart Rate

Peak heart rate (HR) was significantly higher in the anaerobic group (183.4 ± 7.6 bpm) compared to the aerobic group (176.2 ± 6.9 bpm, $p < 0.001$).

Exercise Type	Peak HR (bpm)	Post-Exercise HR (bpm, 0 min)
Aerobic	176.2 ± 6.9	171.1 ± 7.4
Anaerobic	183.4 ± 7.6	179.6 ± 6.8

The anaerobic group had a significantly higher peak HR due to the greater intensity of sprinting and resistance training, which stimulates a stronger sympathetic nervous system (SNS) response. The immediate post-exercise HR was also higher in the anaerobic group, suggesting a greater oxygen debt and metabolic demand.

Table 3: Heart Rate Recovery (HRR) at 1, 2, and 5 Minutes

Heart rate recovery was significantly faster in the aerobic group at both HRR1 and HRR2, but by HRR5, the differences were no longer statistically significant.

Time	Aerobic HRR (bpm)	Anaerobic HRR (bpm)	p-value
HRR1 (1 min post-exercise)	28.7 ± 4.3	18.5 ± 3.9	<0.001
HRR2 (2 min post-exercise)	42.1 ± 5.6	32.4 ± 4.8	0.003
HRR5 (5 min post-exercise)	58.9 ± 6.1	56.2 ± 5.9	0.081

Observations:

HRR1 (1 min post-exercise): The aerobic group showed a significantly greater decrease in HR (28.7 bpm) compared to the anaerobic group (18.5 bpm, $p < 0.001$).

HRR2 (2 min post-exercise): The aerobic group continued to exhibit a greater drop in HR (42.1 bpm) than the anaerobic group (32.4 bpm, $p = 0.003$). Although the HRR gap narrowed, HR recovery remained significantly slower in the anaerobic group, likely due to higher post-exercise catecholamine levels.

HRR5 (5 min post-exercise): By 5 minutes post-exercise, HRR values were similar between the two groups ($p = 0.081$).

Table 4: Influence of Exercise Type on HRR Percentage Reduction

The percentage reduction in heart rate from peak levels further highlights the differences in HRR dynamics between the groups.

Time	Aerobic HRR (% Reduction)	Anaerobic HRR (% Reduction)	p-value
HRR1	16.3%	10.1%	<0.001
HRR2	24.7%	17.7%	0.002
HRR5	35.6%	33.8%	0.089

At HRR1 and HRR2, the aerobic group had a significantly greater percentage reduction in HR, supporting the hypothesis that aerobic exercise facilitates faster autonomic recovery.

Table 5: Correlation Between HRR and VO_2 max

A significant positive correlation was found between VO_2 max and HRR, confirming that higher aerobic fitness is associated with faster HR recovery.

Variable	r-value	p-value
VO_2 max vs. HRR1	0.62	<0.001
VO_2 max vs. HRR2	0.51	0.002
VO_2 max vs. HRR5	0.39	0.019

These findings support previous research showing that trained endurance athletes have superior HRR due to enhanced parasympathetic tone and autonomic balance (Buchheit et al., 2013).

Table 6: Gender-Based HRR Differences

Although HRR was generally faster in females, the differences were not statistically significant after adjusting for VO_2 max and peak HR differences.

Gender	HRR1 (bpm)	HRR2 (bpm)	HRR5 (bpm)
Males	25.9 ± 4.8	39.4 ± 5.2	57.6 ± 6.1
Females	27.1 ± 4.3	40.2 ± 5.5	58.1 ± 5.8
p-value	0.182	0.219	0.345

These results suggest that gender-related differences in HRR may be primarily influenced by cardiovascular fitness levels rather than sex-specific autonomic regulation.

Discussion

The present study provides a comprehensive comparison of heart rate recovery (HRR) following aerobic and anaerobic exercise, revealing distinct differences in autonomic regulation, metabolic demand, and cardiovascular recovery. The findings indicate that aerobic exercise results in significantly faster HRR at both 1- and 2-minutes post-exercise, while anaerobic exercise leads to a prolonged sympathetic response and delayed HRR. However, by 5 minutes post-exercise, HRR differences were no longer statistically significant, suggesting that both exercise modalities eventually allow for autonomic recovery. These results align with prior studies highlighting the role of exercise intensity, metabolic demands, and autonomic reactivation in post-exercise cardiovascular function [12].

The faster HRR observed in the aerobic exercise group supports the hypothesis that endurance-based training promotes quicker parasympathetic reactivation, leading to more efficient autonomic function [13]. Aerobic exercise, characterized by sustained moderate-intensity efforts, primarily activates oxidative metabolism and vagal tone, facilitating a faster transition from sympathetic to parasympathetic dominance post-exercise [14].

Conversely, anaerobic exercise, which relies on high-intensity, short-duration activity, results in greater catecholamine release, lactate accumulation, and metabolic acidosis, prolonging sympathetic dominance and delaying vagal reactivation [15]. The significantly slower HRR at 1 and 2 minutes post-exercise in the anaerobic group suggests that high-intensity efforts require a longer recovery period for autonomic stabilization.

The importance of autonomic balance in cardiovascular health is well established. Studies have shown that impaired HRR (defined as a reduction of fewer than 12 beats per minute in the first minute post-exercise) is associated with an increased risk of cardiovascular disease and all-cause mortality [16]. The faster HRR observed in the aerobic group suggests that endurance training may have superior long-term cardiovascular benefits, promoting better heart rate variability (HRV) and reduced cardiovascular risk [4].

One of the primary reasons for the delayed HRR in anaerobic exercise is the higher oxygen debt and prolonged metabolic recovery associated with high-intensity efforts. Anaerobic workouts, such as sprinting and resistance training, rely on anaerobic glycolysis and phosphocreatine (PCr) breakdown, leading to a rapid accumulation of lactate, hydrogen ions, and catecholamines. This metabolic environment creates a greater physiological demand for post-exercise recovery, requiring more time for HR to return to baseline [17].

In contrast, aerobic exercise promotes a steady-state metabolic process, allowing for more gradual HR fluctuations and a quicker return to homeostasis. This is supported by our findings, where the HRR percentage reduction at 1 and 2 minutes was significantly greater in the aerobic group compared to the anaerobic group [18].

A possible explanation for the eventual normalization of HRR at 5 minutes post-exercise is that both aerobic and anaerobic exercise lead to full autonomic recovery over time, despite their differing immediate post-exercise metabolic demands. This aligns with previous findings were anaerobic exercise delays early HRR, the overall cardiovascular recovery process is completed within 5–10 minutes post-exercise [19].

Another critical finding in this study was the positive correlation between VO_2 max and HRR, confirming that higher aerobic fitness levels are associated with faster post-exercise autonomic recovery. This relationship is well-documented in the literature, with studies indicating that endurance-trained athletes exhibit faster HRR due to enhanced vagal tone and greater stroke volume efficiency [20].

Participants with higher VO_2 max values exhibited greater HR reductions at 1 and 2 minutes post-exercise, regardless of exercise modality. This suggests that cardiorespiratory fitness plays a crucial role in HRR dynamics, potentially mitigating the delayed autonomic recovery observed in anaerobic exercise. These findings further reinforce the importance of aerobic conditioning for overall cardiovascular health and autonomic function. While previous research has suggested potential gender differences in HRR, our study found no statistically significant

differences between male and female participants after adjusting for fitness level (VO_2 max) and peak heart rate. Gender-related differences in HRR are largely influenced by cardiovascular fitness levels rather than intrinsic autonomic regulation differences [21].

A possible explanation is that trained individuals, regardless of gender, exhibit similar HRR trends due to enhanced vagal reactivation. However, some studies have suggested that estrogen may play a role in modulating autonomic function, potentially contributing to faster parasympathetic recovery in females [22].

Limitations

While this study provides valuable insights into HRR differences between aerobic and anaerobic exercise, some limitations must be considered: Short-Term HRR Assessment, Lack of Longitudinal Data, Influence of Training Status, Hormonal and Environmental Factors:

Conclusion

Aerobic exercise leads to faster HRR, indicating superior parasympathetic reactivation compared to anaerobic exercise. While anaerobic exercise induces greater cardiac strain and delayed HRR, it remains a valuable training modality for strength and power development.

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