CARDIO-RESPIRATORY RESPONSES TO HIIT: EVIDENCE OF PERSISTENT PHYSIOLOGICAL STRESS DURING RECOVERY

A. C. Pricop[1*], Elena-Irina Ciobanu[2], St. Ciobanu[1]
1. Alexandru Ioan Cuza University of Iași, Romania
2. Independent Researcher, Iași, Romania
[*]Corresponding author. E-mail address: the.coach.alin@gmail.com

CARDIO-RESPIRATORY RESPONSES TO HIIT: EVIDENCE OF PERSISTENT PHYSIOLOGICAL STRESS DURING RECOVERY (Abstract): High-Intensity Interval Training (HIIT) represents one of the most effective and widely used exercise strategies for improving cardio-respiratory fitness and inducing metabolic adaptations. The **aim** of the present study was to analyze the acute cardio-respiratory and ventilatory responses induced by a circuit-based HIIT protocol in physically active women. **Materials and methods:** The study included 24 female participants (age: 24.37 ± 6.63 years; height: 167.25 ± 5.34 cm; weight: 66.08 ± 12.17 kg; sports experience: 4.8 ± 2.4 years). The experimental protocol consisted of a circuit-based HIIT training session involving repeated intervals of high-intensity exercise alternated with short recovery periods. Cardio-respiratory parameters were assessed before exercise, during exercise, and after a 10-minute recovery period using the Spirobank II Smart spirometer. The analyzed variables included heart rate (HR), peripheral oxygen saturation (SpO_2), Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV1), Maximum Voluntary Ventilation (MVV), and rating of perceived exertion (Borg scale). **Results:** revealed significant physiological alterations following the HIIT protocol. Significant reductions were observed in ventilatory parameters, including FVC, FEV1, MVV, and MVV%, while heart rate increased significantly during exercise and remained elevated following recovery. SpO_2 values decreased significantly during effort and remained below baseline values after the recovery period. In addition, high Borg scale scores confirmed the substantial physiological demand induced by the exercise protocol. The findings suggest that circuit-based HIIT induces substantial acute cardio-respiratory and ventilatory stress, with persistent physiological alterations observed even after the recovery period. These responses may be associated with mechanisms such as ventilatory fatigue, excess post-exercise oxygen consumption (EPOC), oxygen desaturation, and delayed autonomic recovery. **Conclusions:** The study highlights the importance of monitoring cardio-respiratory parameters during HIIT protocols and supports the role of HIIT as an effective strategy for inducing cardio-metabolic and ventilatory adaptations in physically active women. **Keywords***:* HIGH-INTENSITY INTERVAL TRAINING (HIIT), CARDIO-RESPIRATORY RESPONSE, VENTILATORY FATIGUE, SPIROMETRY, OXYGEN DESATURATION, HEART RATE RECOVERY, RESPIRATORY MUSCLES, EPOC, EXERCISE PHYSIOLOGY, WOMEN, CARDIOVASCULAR STRESS, RECOVERY KINETICS.

INTRODUCTION

In recent years, High-Intensity Interval Training (HIIT) has attracted considerable scientific interest due to its ability to in-

duce significant cardiovascular, metabolic, and ventilatory adaptations while requiring substantially lower exercise volume and training time compared to traditional endurance-based training methods (1). The growing popularity of HIIT is largely attributed to its remarkable efficiency in improving cardiorespiratory fitness and exercise-related physiological responses, making it an attractive strategy for both health promotion and sports performance optimization (1). One of the major advantages of HIIT is its time efficiency, as it can induce substantial physiological adaptations and health benefits within a considerably shorter period compared to traditional continuous training methods (2).

The increasing prevalence of sedentary behavior and the global decline in physical activity levels have highlighted the need for efficient and accessible exercise strategies capable of producing significant physiological benefits within a limited amount of time (3). According to current international guidelines, adults should perform between 150-300 minutes of moderate physical activity or 75-150 minutes of vigorous physical activity per week in order to maintain cardiovascular and metabolic health (4). However, global estimates indicate that approximately 81% of adolescents aged 11 to 17 years are insufficiently physically active (3), which has increased interest in time-efficient exercise methods such as HIIT.

HIIT is a form of exercise characterized by alternating short intervals of high-intensity effort with periods of active or passive recovery (5). The primary premise underlying this training method is the performance of a greater amount of work at high intensities during a single exercise session compared to moderate-intensity continuous training (6). Although interval training concepts have been used since the beginning of the twentieth century and were later popularized for improving the performance of Olympic athletes, recent research has demonstrated that the benefits of HIIT extend beyond sports performance, having important implications for cardiometabolic and ventilatory health as well (6).

Numerous studies and meta-analyses have demonstrated that HIIT can produce physiological adaptations similar or even superior to those induced by moderate-intensity continuous training, despite a substantially lower total exercise volume (5, 7). HIIT has been shown to improve endurance performance and aerobic capacity to a greater extent than continuous training, with significant increases in VO_2max and cardiorespiratory fitness being consistently reported (8, 9). Furthermore, recent evidence suggests that the physiological benefits induced by HIIT extend beyond improvements in aerobic capacity, influencing vascular function, metabolic regulation, oxidative stress, and post-exercise recovery mechanisms (10).

The clinical and physiological importance of improving cardiorespiratory fitness is further supported by recent epidemiological data indicating that the risk of all-cause mortality decreases by approximately 11% for every 1 MET increase in cardiorespiratory fitness (5). In this context, HIIT has been identified as a highly effective strategy for optimizing cardiometabolic and cardiovascular responses, even when interventions involve brief exercise sessions performed only a few times per week (5). Previous studies have demonstrated that HIIT protocols performed two to three times per week for periods ranging

from 2 to 12 weeks can produce significant improvements in cardiovascular, ventilatory, and metabolic function (1).

Due to its high-intensity nature, HIIT generates substantial cardiovascular and ventilatory demands, producing significant acute physiological responses both during exercise and throughout the post-exercise recovery period (2, 10). Post-exercise recovery represents an essential component of exercise physiology, as the dynamics of cardiovascular and respiratory recovery may reflect the magnitude of physiological stress induced by exercise and the efficiency of the autonomic and ventilatory mechanisms involved in recovery (11). According to Buchheit and Laursen (12), the evaluation of acute physiological responses associated with HIIT should include the simultaneous monitoring of multiple cardiopulmonary and cardiovascular variables in order to obtain a comprehensive understanding of the physiological stress induced by exercise.

In this context, monitoring cardiovascular and ventilatory parameters such as heart rate, peripheral oxygen saturation, and spirometric indices may provide valuable information regarding exercise tolerance and post-exercise recovery capacity (13). Heart rate is frequently used as an indicator of cardiovascular stress and exercise intensity during high-intensity exercise protocols (14), while peripheral oxygen saturation (SpO_2) provides important information regarding the efficiency of oxygen transport and utilization during and after exercise. Regarding ventilatory function, spirometry represents one of the most widely used physiological tests for assessing the ability to inhale and exhale air over time, providing important insights into respiratory responses associated with physical exercise. The main spirometric parameters include Forced Vital Capacity (FVC), Forced Expiratory Volume in the first second (FEV1), and the FEV1/FVC ratio, while Maximum Voluntary Ventilation (MVV) reflects ventilatory capacity and respiratory muscle endurance during intense exercise (15, 16).

Although the chronic effects of HIIT on performance and body composition have been extensively investigated, there is still a limited number of studies simultaneously analyzing the acute cardiovascular and ventilatory responses induced by high-intensity exercise. Previous studies have predominantly focused on long-term adaptations, such as improvements in VO_2max, optimization of body composition, or enhancement of aerobic performance (17, 18, 19), whereas acute physiological mechanisms and post-exercise recovery dynamics remain insufficiently investigated. This limitation is important because acute physiological responses may provide essential information regarding individual exercise tolerance, the level of cardio-respiratory stress, and the efficiency of recovery processes.

Interest in investigating acute physiological responses induced by HIIT is further supported by the fact that women continue to be underrepresented in exercise science and sports medicine research (18, 19). The direct application of findings obtained from predominantly male cohorts may be misleading due to the anthropometric, hormonal, and physiological differences between sexes (19). At the same time, recent research has demonstrated that HIIT can induce significant improvements in VO_2max, body composition, and physical performance in women, even following relatively short interventions (17, 18).

Considering the growing popularity of HIIT protocols in both health and sports performance settings, investigating acute cardio-respiratory responses and post-exercise recovery represents a relevant research direction in exercise physiology. Simultaneous monitoring of cardiovascular and ventilatory parameters may contribute to a better understanding of the physiological mechanisms involved in exercise tolerance and post-exercise recovery, with important implications for both performance optimization and the individualization of recovery and exercise monitoring strategies. In this context, the aim of the present study was to evaluate the acute impact of a HIIT protocol on cardio-respiratory responses and post-exercise recovery dynamics in female participants using multiple cardiovascular and ventilatory parameters.

MATERIALS AND METHODS

Participants

Initially, 34 physically active women participated in the study and were divided into two HIIT training groups (17 participants per group). During the course of the research, 10 participants did not complete the post-exercise testing and were therefore excluded from the final statistical analysis. Consequently, the final analyzed sample consisted of 24 participants (12 participants in each group).

The participants had between 3 and 10 years of sports experience and engaged in regular physical activity at least three times per week. The mean age of the participants was 40.5 ± 12.7 years. Anthropometric measurements indicated a mean height of 166.0 ± 6.7 cm and a mean body weight of 63.5 ± 10.6 kg (tab. I). Of the participants included in the final analysis, only three reported active smoking status; however, they did not present extreme physiological values compared to the rest of the sample and were therefore retained in the final dataset.

All participants were informed about the aim and procedures of the study and signed an informed consent form prior to testing. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki for research involving human subjects.

TABLE I.

Anthropometric and general characteristics of the participants included in the HIIT protocol

Variable	Mean ± SD
Age (years)	40.5 ± 12.7
Height (cm)	166.0 ± 6.7
Body weight (kg)	63.5 ± 10.6
Sports experience (years)	4.8 ± 2.4

Research Design

The study employed a pre-test-post-test experimental design aimed at evaluating the acute cardio-respiratory responses induced by a High-Intensity Interval Training (HIIT) session. All participants performed the same training session under identical testing conditions and using the same exercise protocol.

Physiological assessments were performed at three distinct time points:

- before exercise;
- during exercise;
- after a 10-minute post-exercise recovery period.

Spirometric parameters were assessed before exercise and after the post-exercise recovery period, while heart rate and SpO_2 values were monitored at all three experimental time points.

In order to minimize the influence of external factors on the results, all testing sessions were conducted:

- in the same fitness facility;
- at the same time of day for both groups;
- under similar ambient temperature conditions;
- without caffeine consumption prior to testing;
- without participation in other physical activities on the day of the experiment.

The post-exercise recovery period was passive, with participants remaining seated following completion of the HIIT protocol and stretching exercises.

HIIT Protocol

The HIIT protocol used in the present study had a total duration of approximately 45-50 minutes and included:

- 7-10 minutes of warm-up;
- 28-30 minutes of HIIT training;
- 7-10 minutes of stretching and cool-down.

The structure of the protocol was developed based on the principles of HIIT and the Tabata model, while being adapted for physically active individuals and heterogeneous groups in terms of age and fitness level.

The main phase of the training session included four distinct sets of functional exercises, with each set repeated three times. Each exercise was performed continuously for 30 seconds, resulting in a total work duration of 2 minutes for each circuit. A 20-second rest interval was introduced between repetitions of the same set, while very short transition periods were used between exercises to allow partial reoxygenation.

The protocol included exercises such as: squats; jumping jacks; mountain climbers; burpees; lunges; push-ups performed using stepper support; high-knee running in place; dumbbell and barbell exercises; plank exercises.

The structure of the protocol aimed to alternate the muscle groups involved in order to reduce premature peripheral fatigue and maintain a constant cardio-respiratory demand throughout the entire training session. From a physiological perspective, the protocol was designed to generate substantial metabolic and ventilatory stress characteristic of high-intensity exercise through the rapid alternation between short periods of intense effort and brief recovery intervals.

Assessment of Cardio-Respiratory Parameters

The following physiological parameters were analyzed during the study:

- heart rate (HR);
- peripheral oxygen saturation (SpO_2);
- Forced Vital Capacity (FVC);
- Forced Expiratory Volume in the first second (FEV1);
- FEV1/FVC ratio;
- Maximum Voluntary Ventilation (MVV).

Assessments were performed using the Spirobank II Smart spirometer, which was utilized both for spirometric analysis and for monitoring heart rate and SpO_2 values through the integrated digital sensor.

Heart rate and SpO_2 values were measured:

- before exercise;
- during the peak phase of effort throughout the HIIT protocol;
- after a 10-minute post-exercise recovery period.

All measurements were performed with participants in a seated position by placing the finger into the device sensor.

For spirometric assessment, participants performed between two and three attempts depending on the correctness of the execution technique, with the highest recorded value being retained for each analyzed parameter.

The subjective perception of exercise intensity was assessed using the Borg Rating of Perceived Exertion scale, applied during maximal effort and immediately after exercise completion. For each participant, the mean value of the Borg scores recorded at the two assessment moments was calculated.

Equipment and Materials

The following materials and equipment were used for the implementation of the HIIT protocol:

- dumbbells weighing between 2-4 kg;
- barbells weighing between 3-6 kg;
- weight plates ranging from 2-5 kg;
- stepper platform;
- exercise mats;
- audio system used for exercise coordination and maintenance of execution rhythm.

Cardio-respiratory and spirometric assessments were performed using the Spirobank II Smart spirometer.

Statistical Analysis. Statistical data processing was performed using IBM SPSS Statistics software. Data distribution was assessed using the Shapiro-Wilk test.

For variables with normal distribution, the following statistical tests were applied: Paired Samples t-test; Repeated Measures ANOVA.

For variables with non-normal distribution, the following tests were used: Wilcoxon Signed-Rank Test; Friedman Test.

For repeated measures ANOVA analyses, Bonferroni pairwise comparisons were applied in order to identify differences between assessment time points.

Relationships between variables were analyzed using the Spearman rho correlation coefficient. Effect size was assessed using: Cohen's d; correlation coefficient r; Kendall's W; Partial Eta Squared (η^2p). The level of statistical significance was set at $p < .05$.

RESULTS

Statistical analyses revealed that the HIIT session induced significant acute changes in the analyzed cardio-respiratory parameters, including ventilatory function, cardiovascular response, peripheral oxygenation, and maximal ventilatory capacity (tab. II).

Normality testing using the Shapiro-Wilk test revealed normal distributions for FVC, FEV1, and FEV1%, and therefore the Paired Samples t-test was applied. Non-normal distributions were identified for FVC%, FEV1/FVC, and FEV1/FVC%, for which the Wilcoxon Signed-Rank Test was used.

Statistical analysis revealed significant reductions in FVC, FVC%, FEV1, and FEV1% following the HIIT session ($p < .05$). Mean FVC values decreased from 3.54 ± 0.65 L before exercise to 3.08 ± 0.58 L after the 10-minute recovery period. Similarly, FEV1 and FEV1% values showed statistically significant reductions following exercise.

In contrast, the FEV1/FVC ratio and its percentage-predicted variant did not show statistically significant changes ($p > .05$).

TABLE II.
Comparison of spirometric parameters before and after the HIIT session

Variable	Pre-HIIT (Mean ± SD)	Post-HIIT / Recovery 10 min (Mean ± SD)	Statistical Test	Value	p
FVC (L)	3.54 ± 0.65	3.08 ± 0.58	Paired Samples t-test	t(23) = 4.880	.001
FVC (%)	101.91± 16.22	88.51 ± 14.37	Wilcoxon Signed-Rank Test	Z = -4.043	.001
FEV1 (L)	2.86 ± 0.61	2.63 ± 0.50	Paired Samples t-test	t(23) = 2.462	.022
FEV1 (%)	99.59 ± 20.24	90.72 ± 16.58	Paired Samples t-test	t(23) = 2.265	.033
FEV1/FVC (%)	82.81 ± 14.39	84.79 ± 11.09	Wilcoxon Signed-Rank Test	Z = 0.608	.543
FEV1/FVC % predicted	100.53 ± 17.26	101.76 ± 12.90	Wilcoxon Signed-Rank Test	Z = 0.608	.543

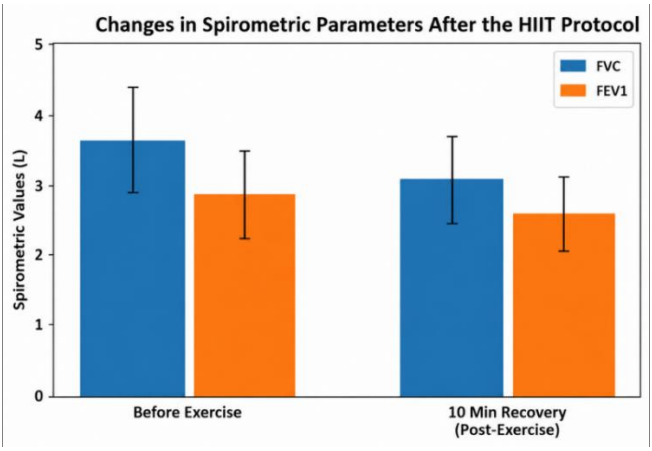

Fig. 1. Changes in the spirometric parameters FVC and FEV1 before exercise and after the 10-minute post-HIIT recovery period. Values are expressed as mean ± SD.

The Shapiro-Wilk test revealed non-normal distributions for some of the assessment time points of MVV and MVV%, and therefore the Friedman test for repeated measures was applied (tab. III).

The Friedman analysis revealed statistically significant differences between the three assessment time points for both MVV and MVV% ($p < .001$). Post-hoc analyses performed using the Wilcoxon Signed-Rank Test showed that MVV values decreased significantly both during exercise and after the recovery period compared to baseline values. In contrast, no statistically significant differences were identified between MVV values recorded during exercise and those measured after the 10-minute recovery period (fig. 2).

For MVV%, significant differences were identified between baseline values and those measured following the post-exercise recovery period (tab. IV).

TABLE III.

Evolution of MVV and MVV% values before, during, and after the HIIT session

Variable	Before Exercise (Mean Rank)	During Exercise (Mean Rank)	Post-Exercise - 10 min Recovery (Mean Rank)	Statistical Test	Value	P
MVV	2.71	1.71	1.58	Friedman Test	$\chi^2(2) = 18.250$	..001
MVV%	2.69	1.75	1.56	Friedman Test	$\chi^2(2) = 17.809$	<.001

TABLE IV.

Post-hoc comparisons for MVV and MVV%

Comparison	Z	p
MVV before exercise *vs* MVV during exercise	2.200	.028
MVV before exercise *vs* MVV after exercise	3.857	< .001
MVV during exercise *vs* MVV after exercise	0.000	1.000
MVV% before exercise *vs* MVV% during exercise	1.157	.247
MVV% before exercise *vs* MVV% after exercise	4.258	< .001
MVV% during exercise *vs* MVV% after exercise	1.143	.253

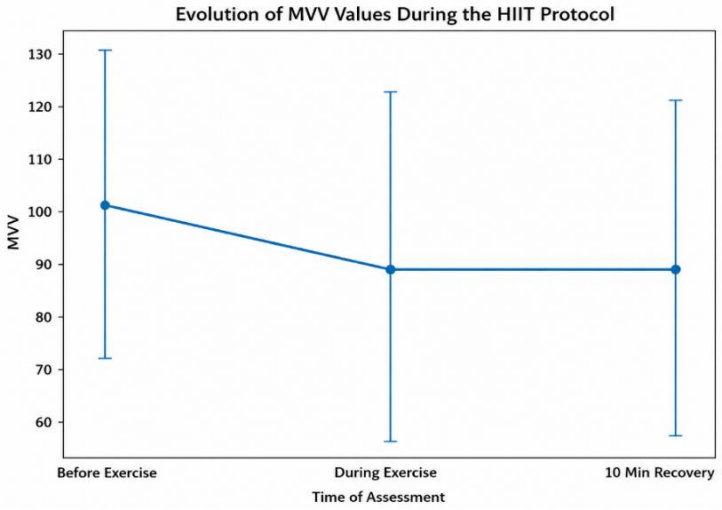

Fig. 2. Changes in MVV values across the three assessment time points of the HIIT protocol: before exercise, during exercise, and after the 10-minute recovery period. Data are presented as mean ± SD.

The distribution of heart rate values was normal across all three assessment time points; therefore, Repeated Measures ANOVA was applied (tab. V).

TABLE V.
Evolution of heart rate before, during, and after the HIIT session

Variable	Statistical Test	Value	p	Partial Eta Squared
Heart rate (HR)	Repeated Measures ANOVA	F(2,42) = 118.623	< .001	.850

Statistical analysis revealed a significant effect of time on heart rate values, $F(2,42) = 118.623$, $p < .001$, $\eta^2p = .850$. The high Partial Eta Squared coefficient indicates a very large effect of the HIIT session on the cardiovascular response of the participants.

Table VI presents the pairwise comparisons performed using the Bonferroni correction, which revealed statistically significant differences between all three analyzed time points. Heart rate increased significantly during exercise compared to baseline values and remained significantly elevated after the 10-minute recovery period (fig. 3).

TABLE VI.
Bonferroni pairwise comparisons for heart rate

Comparison	Mean Difference	p
HR before exercise *vs* HR during exercise	-46.464	< .001
HR before exercise *vs* HR after exercise	-20.414	< .001
HR during exercise *vs* HR after exercise	26.050	< .001

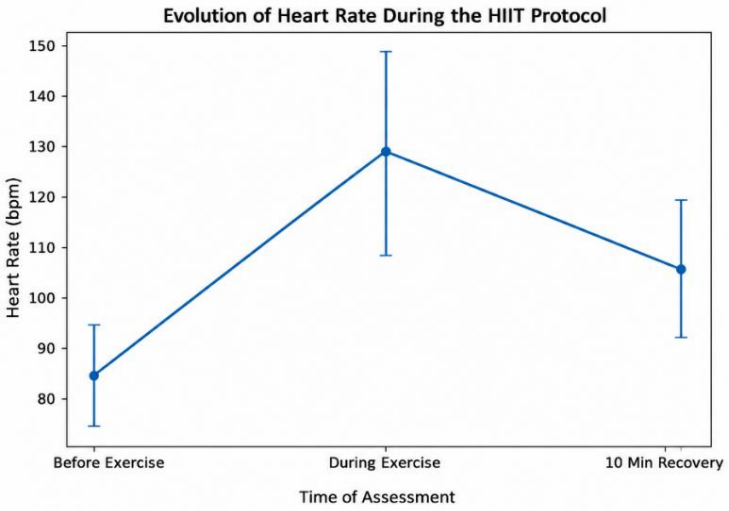

Fig. 3. Evolution of heart rate values before exercise, during effort, and after 10 minutes of recovery following the HIIT protocol. Data are presented as mean ± SD.

The Shapiro-Wilk test revealed non-normal distributions for all three assessment time points of SpO_2; therefore, the Friedman test for repeated measures was

applied (tab. VII).

The Friedman analysis revealed statistically significant differences between SpO_2 values measured before exercise, during exercise, and after the post-exercise recovery period, $\chi^2(2) = 20.916$, $p < .001$. Post-hoc analyses revealed significant reductions in peripheral oxygen saturation both during exercise and after recovery compared to baseline values (tab. VIII).

TABLE VII.
Evolution of SpO_2 values before, during, and after the HIIT session

Variable	Before Exercise (Mean Rank)	During Exercise (Mean Rank)	Post-Exercise - 10 min Recovery (Mean Rank)	Statistical Test	Value	p
SpO_2	2.77	1.64	1.59	Friedman Test	$\chi^2(2) = 20.916$	< .001

TABLE VIII.
Post-hoc comparisons for SpO_2

Comparison	Z	p
SpO_2 before exercise *vs* SpO_2 during exercise	-4.485	< .001
SpO_2 before exercise *vs* SpO_2 after exercise	-2.920	003
SpO_2 during exercise *vs* SpO_2 after exercise	0.870	.384

In contrast, no statistically significant differences were identified between SpO_2 values measured during exercise and those recorded after the recovery period (fig. 4).

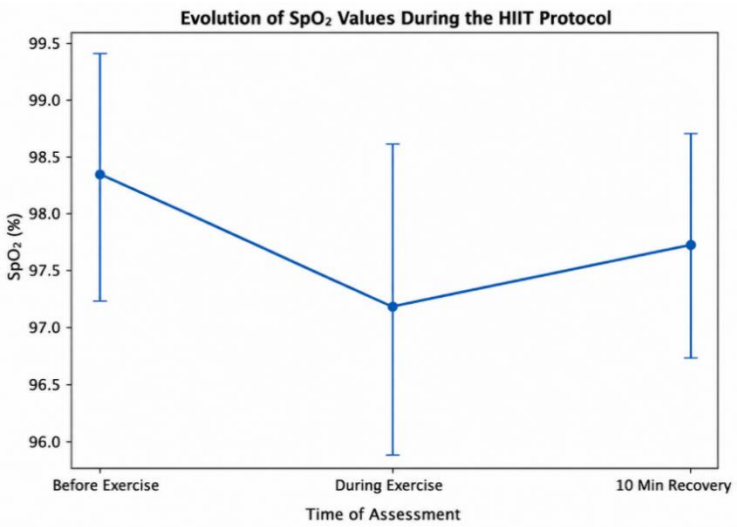

Fig. 4. Evolution of SpO_2 values before exercise, during effort, and after 10 minutes of recovery following the HIIT protocol. Data are presented as mean ± SD.

Borg Scale

The Borg scale values indicated a high perceived intensity of effort during the HIIT session (Mean = 8.17 ± 0.64), with recorded values ranging between 7 and 9 points. The results suggest that the participants perceived the HIIT protocol as highly intense and physiologically demanding.

Correlation analysis performed using the Spearman rho coefficient revealed significant relationships between the analyzed cardio-respiratory parameters (tab. IX). The strongest association identified was between heart rate measured during exercise and heart rate recorded after the post-exercise recovery period ($\rho = .641$, $p = .001$).

In addition, heart rate during exercise showed significant positive correlations with MVV and MVV% values. Likewise, SpO_2 values measured during exercise showed a significant positive correlation with baseline SpO_2 values.

Effect size was calculated using Cohen's d for paired t-tests, correlation coefficient r for Wilcoxon analyses, Kendall's W for Friedman tests, and Partial η^2 for Repeated Measures ANOVA (tab. X).

TABLE IX.

Most relevant correlations between the analyzed cardio-respiratory parameters

Analyzed variables	Spearman rho	p	Interpretation
HR during exercise ↔ HR after exercise	.641	.001	Strong positive correlation
HR during exercise ↔ MVV% before exercise	.561	.004	Moderate positive correlation
SpO_2 during exercise ↔ SpO_2 before exercise	.554	.001	Moderate positive correlation
HR during exercise ↔ MVV after exercise	.490	.015	Moderate positive correlation
HR during exercise ↔ MVV before exercise	.483	.017	Moderate positive correlation
HR during exercise ↔ MVV% after exercise	.471	.020	Moderate positive correlation
MVV during exercise ↔ HR after exercise	.444	.038	Moderate positive correlation

TABLE X.

Effect size for the main statistical analyses

Parameter	Statistical Test	Effect size	Interpretation
FVC	Paired Samples t-test	Cohen's d = 1.00	Large effect
FEV1	Paired Samples t-test	Cohen's d = 0.50	Moderate effect
FEV1%	Paired Samples t-test	Cohen's d = 0.46	Moderate effect
FVC%	Wilcoxon	r = 0.83	Very large effect
FEV1/FVC	Wilcoxon	r = 0.12	Small effect
SpO_2 before exercise *vs.* during exercise	Wilcoxon	r = 0.77	Very large effect
SpO_2 before exercise *vs.* recovery	Wilcoxon	r = 0.62	Large effect
MVV	Friedman	Kendall's W = 0.38	Moderate-to-large effect
MVV%	Friedman	Kendall's W = 0.37	Moderate-to-large effect
SpO_2	Friedman	Kendall's W = 0.48	Large effect
Heart rate	Repeated Measures ANOVA	Partial η^2 = .850	Very large effect

The obtained values revealed moderate to very large effects for most of the analyzed cardio-respiratory parameters. The largest effect sizes were identified for FVC%, SpO_2, and heart rate, suggesting a substantial physiological impact of the HIIT session on the ventilatory and cardiovascular responses of the participants.

DISCUSSION

The results obtained in the present study demonstrate that the applied HIIT protocol induced significant acute cardio-respiratory, ventilatory, and metabolic alterations both during exercise and throughout the post-exercise recovery period. Statistical analyses revealed significant reductions in spirometric parameters (FVC, FVC%, FEV1, and FEV1%), decreases in MVV and MVV% values, reductions in peripheral oxygen saturation (SpO_2), as well as substantial increases in heart rate and subjective perception of effort.

Regarding ventilatory function, the present study identified statistically significant reductions in FVC and FEV1 values following the HIIT protocol, with FVC values decreasing from 3.54 ± 0.65 L before exercise to 3.08 ± 0.58 L after the recovery period, $t(23) = 4.880$, $p < .001$, Cohen's $d = 1.00$. Similarly, FEV1 and FEV1% values showed statistically significant post-exercise reductions, suggesting the persistence of acute ventilatory stress and incomplete respiratory recovery following exercise. These findings are supported by recent literature demonstrating that high-intensity exercise substantially increases the metabolic stress imposed on respiratory muscles and may induce temporary ventilatory fatigue. Welch *et al*. (20) reported that respiratory muscles may consume approximately 10-16% of VO_2max during maximal exercise, highlighting the major role of the respiratory system in limiting high-intensity physical performance. The large effect size observed for FVC (Cohen's $d = 1.00$) further indicates that the ventilatory alterations induced by the HIIT protocol were not only statistically significant but also physiologically meaningful.

The Friedman analysis revealed statistically significant differences in MVV and MVV% values across the three assessment moments, $\chi^2(2) = 18.250$, $p < .001$ for MVV and $\chi^2(2) = 17.809$, $p < .001$ for MVV%. The absence of significant differences between MVV values recorded during exercise and those measured after the 10-minute recovery period suggests persistent ventilatory fatigue and incomplete respiratory recovery following the HIIT session. These findings are supported by Kowalski *et al*. (21), who reported that exercise performed at intensities above 85% VO_2max imposes substantial stress on respiratory musculature, promoting ventilatory fatigue and reduced post-exercise respiratory performance. The authors further emphasized that respiratory muscles may consume up to 15-20% of total body oxygen uptake during intense exercise, leading to metabolic competition between respiratory and locomotor muscles.

The persistence of reduced ventilatory values even after the recovery period may also be explained by the "respiratory metaboreflex" mechanism, described in the literature as a redistribution of blood flow toward respiratory muscles under conditions of pronounced ventilatory fatigue. This mechanism may contribute both to exercise intolerance and to the development of peripheral muscular fatigue follow-

ing high-intensity exercise. Furthermore, recent evidence suggests that HIIT significantly increases ventilatory workload and oxygen consumption due to dynamic hyperinflation and elevated respiratory cost during exercise, physiological mechanisms that may explain the ventilatory alterations observed in the present study.

With regard to peripheral oxygenation, the results revealed statistically significant reductions in SpO_2 values both during exercise and after the recovery period, $\chi^2(2) = 20.916$, $p < .001$, Kendall's $W = 0.48$. The absence of significant differences between SpO_2 values measured during exercise and those recorded following recovery suggests persistent respiratory stress and incomplete post-exercise recovery of peripheral oxygenation. Yang *et al*. (22) reported that intense exercise may induce temporary ventilation-perfusion imbalances (V/Q mismatch), contributing to exercise-induced desaturation and transient reductions in peripheral oxygenation. Similarly, Andrianopoulos *et al*. (23), within the ECLIPSE study, emphasized that exercise-induced desaturation is closely associated with ventilatory limitations and impaired pulmonary diffusion mechanisms under conditions of elevated cardio-respiratory stress. The high Kendall's W coefficient identified for SpO_2 further suggests the presence of a consistent alteration in peripheral oxygenation across the three assessment moments, indicating a pronounced respiratory response to high-intensity exercise.

Analysis of the cardiovascular response demonstrated a very large effect of the HIIT protocol on heart rate, with repeated measures ANOVA indicating statistically significant values, $F(2,42) = 118.623$, $p < .001$, Partial $\eta^2 = .850$. Heart rate increased significantly during exercise and remained elevated even after the 10-minute recovery period, suggesting persistent sympathetic activation and incomplete cardiovascular recovery following exercise. These findings are supported by the research conducted by Alansare *et al*. (24), who demonstrated that HIIT protocols induce superior autonomic and cardiovascular responses compared to moderate continuous exercise. The authors reported higher heart rate values and greater perceived exertion in HIIT groups, suggesting that exercise intensity represents the primary mechanism underlying the cardiovascular adaptations induced by this training modality. The very large effect size identified for heart rate (Partial $\eta^2 = .850$) further confirms that the applied HIIT protocol generated extremely high cardiovascular stress, supporting the intense nature of the intervention used in the present study.

The present findings are also supported by the study conducted by Lamberts *et al*. (25), who observed that HIIT may improve post-exercise cardiac recovery and physical performance even in the absence of substantial VO_2max changes. The authors reported a strong association between improved cardiac recovery and athletic performance, suggesting that autonomic recovery may represent a sensitive marker of physiological adaptations induced by HIIT. Similarly, Stöggl and Björklund (26) demonstrated that training protocols involving substantial HIIT volumes produce improvements in acute cardiac recovery, anaerobic performance, and neuromuscular characteristics even without major changes in lactate threshold values. The authors suggested that HIIT-induced adaptations involve complex physiological mechanisms extending beyond simple metabolic adapta-

tion, which may explain the magnitude of the cardio-respiratory changes observed in the present study.

The persistence of cardio-respiratory alterations during the recovery period is further supported by the findings of Ahlert *et al.* (27) regarding excess post-exercise oxygen consumption (EPOC). The authors reported that post-exercise oxygen consumption values were higher following HIIT protocols (0.61 ± 0.62 l O_2/kg/min^{-1}) compared to resting values (0.40 ± 0.29 lO_2/kg/min^{-1}), suggesting persistent metabolic activation and cardio-respiratory stress after exercise cessation. These physiological mechanisms may explain the persistence of ventilatory and cardiovascular alterations observed in the present study after the 10-minute recovery period.

The results of the present study are also supported by the research of Schleppenbach *et al.* (28), who implemented a circuit-based HIIT protocol involving 30-second work intervals alternated with 30-second active recovery periods. Participants achieved elevated heart rate values and high ratings of perceived exertion, suggesting substantial cardio-respiratory and metabolic stress extending into the post-exercise period. These findings are consistent with the results obtained in the present study, where the applied HIIT protocol induced marked increases in heart rate and persistent ventilatory alterations following recovery.

Recent literature further supports the idea that HIIT protocols induce substantial metabolic and ventilatory alterations both during exercise and throughout post-exercise recovery. Dupuit *et al.* (17), in a meta-analysis involving 959 female participants, demonstrated that HIIT performed at intensities of approximately 80-100% of maximal heart rate increases post-exercise fat oxidation and induces significant metabolic stress. The authors emphasized that HIIT represents an effective strategy for inducing cardio-metabolic adaptations and increasing post-exercise energy expenditure, mechanisms that may explain the persistence of ventilatory and cardio-respiratory alterations observed in the present study. Patten *et al.* (29) further demonstrated that HIIT induces superior cardio-metabolic improvements compared to moderate-intensity continuous exercise, observing significantly greater increases in aerobic capacity and insulin sensitivity. The authors highlighted that HIIT-induced physiological adaptations may occur even in the absence of substantial body weight changes, suggesting that the benefits of this training modality are closely associated with the elevated metabolic and cardio-respiratory stress specific to high-intensity exercise.

An important aspect of the present study is that all participants were female. Skelly *et al.* (30) emphasized that physiological responses to HIIT may differ between women and men, with women sometimes exhibiting distinct ventilatory and metabolic adaptations influenced by sex-specific physiological and hormonal characteristics. Furthermore, recent evidence suggests that the respiratory system may represent a more important limiting factor in women compared to men due to smaller lung dimensions, narrower airways, and increased ventilatory cost during intense exercise. These physiological mechanisms may explain the magnitude of the ventilatory alterations observed following the HIIT protocol applied in the present study.

Overall, the results of the present study support the idea that HIIT induces substantial acute cardio-respiratory responses

characterized by reductions in ventilatory parameters and peripheral oxygenation, accompanied by significant increases in cardiovascular stress and persistent physiological alterations during the post-exercise recovery period. The findings suggest that the applied HIIT protocol represents a highly intense physiological stimulus capable of inducing significant cardio-respiratory and metabolic adaptations, while also generating considerable short-term ventilatory and cardiovascular stress.

Study limitations

The present study presents several limitations that should be considered when interpreting the findings. The relatively small sample size and the inclusion of exclusively female participants limit the generalizability of the results to other populations. In addition, the research investigated only the acute effects of the HIIT protocol without evaluating long-term physiological adaptations. The absence of a control group and the lack of assessment of variables such as blood lactate concentration or VO_2max through ergospirometry represent additional important limitations of the study.

Practical applications

The findings of the present study suggest that circuit-based HIIT protocols represent effective strategies for stimulating the cardio-respiratory and metabolic systems. Monitoring parameters such as heart rate, SpO_2, and spirometric values may contribute to the individualization of exercise intensity and the prevention of excessive physiological stress. Furthermore, the persistence of ventilatory and cardiovascular alterations following the recovery period highlights the importance of including adequate recovery intervals within HIIT training sessions.

CONCLUSIONS

The findings of the present study demonstrate that the applied HIIT protocol induced significant acute cardio-respiratory and ventilatory alterations both during exercise and throughout the post-exercise recovery period. Reductions in spirometric parameters (FVC, FEV1, and MVV), decreases in SpO_2 values, and significant increases in heart rate and subjective perception of effort suggest the presence of substantial physiological stress induced by high-intensity exercise.

The persistence of ventilatory and cardiovascular alterations even after the 10-minute recovery period highlights that the effects of HIIT are not limited to the active phase of exercise but continue throughout the post-exercise period as well. These responses may be associated with physiological mechanisms such as excess post-exercise oxygen consumption (EPOC), respiratory muscle fatigue, and delayed autonomic recovery

The obtained results support the idea that circuit-based HIIT protocols represent effective strategies for stimulating the cardio-respiratory and metabolic systems, with important potential for improving functional capacity and exercise-induced physiological adaptations. At the same time, monitoring cardio-respiratory parameters and post-exercise recovery may represent a valuable tool for the individualization and optimization of HIIT training programs.

AUTHOR CONTRIBUTIONS

Alin Constantin Pricop, Elena-Irina Ciobanu, and Ștefan Ciobanu contributed to the design and implementation of the research, data collection, statistical analysis, interpretation of the results, and manuscript writing. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST AND FUNDING

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REFERENCES

1. Martin-Smith R, Cox A, Buchan DS, Baker JS, Grace F, Sculthorpe N. High Intensity Interval Training (HIIT) Improves Cardiorespiratory Fitness (CRF) in Healthy, Overweight and Obese Adolescents: A Systematic Review and Meta-Analysis of Controlled Studies. *International Journal of Environmental Research and Public Health* 2020; 17(8): 2955 / doi: 10.3390/ijerph17082955.
2. Batacan RB Jr, Duncan MJ, Dalbo VJ, Tucker PS, Fenning AS. Effects of high-intensity interval training on cardiometabolic health: A systematic review and meta-analysis of intervention studies. *British Journal of Sports Medicine* 2017; 51(6): 494-503 / doi: 10.1136 /bjsports-2015-095841.
3. Guthold R, Stevens, GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. The Lancet. *Child adolescent health* 2020; 4(1): 23-35 / doi: 10.1016/ S2352-4642(19)30323-2.
4. Bull FC, Al-Ansari SS, Biddle S *et al*. World Health Organization 2020 guidelines on physical activity and sedentary behavior. *British Journal of Sports Medicine* 2020; 54(24): 1451-1462 / doi: 10.1136/ bjsports-2020-102955.
5. Coates AM, Joyner MJ, Little JP, Jones AM, Gibala MJ. A Perspective on High-Intensity Interval Training for Performance and Health. *Sports medicine (Auckland, N.Z.)* 2023; 53(Suppl 1); 85-96 / doi: 10.1007/s40279-023-01938-6.
6. Ross LM, Porter RR, Durstine JL. High-intensity interval training (HIIT) for patients with chronic diseases. *Journal of sport and health science* 2016; 5(2): 139-144 / doi: 10.1016 /j.jshs.2016.04.005.
7. Gibala MJ, Little JP, MacDonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. *The Journal of Physiology* 2012; 590: 1077-1084 / doi: 10.1113/jphysiol.2011.224725.
8. Weston KS, Wisløff U, Coombes JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis. *British journal of sports medicine* 2014; 48(16): 1227-1234 / doi: 10.1136/bjsports-2013-092576.
9. Rosenblat MA, Perrott AS. Thoma SG. Effect of High-Intensity Interval Training Versus Sprint Interval Training on Time-Trial Performance: A Systematic Review and Meta-analysis. *Sports Med* 2020; 50: 1145-1161 / doi: 10.1007/s40279-020-01264-1.
10. Ramos JS, Dalleck LC, Tjonna AE, *et al*. The Impact of High-Intensity Interval Training Versus Moderate-Intensity Continuous Training on Vascular Function: a Systematic Review and Meta-Analysis. *Sports Med* 2015; 45: 679-692 / doi: 10.1007/s40279-015-0321-z.
11. Joyner MJ, Green DJ. Exercise protects the cardiovascular system: effects beyond traditional risk factors. *The Journal of Physiology* 2009; 587: 5551-5558 / doi: 10.1113/ jphysiol.2009.179432.
12. Buchhei M, Laursen PB. High-Intensity Interval Training, Solutions to the Programming Puzzle. *Sports Med* 2013; 43: 313-338 / doi: 10.1007/s40279-013-0029-x.
13. Gibala MJ, McGee SL. Metabolic adaptations to short-term high-intensity interval training: A little pain for a lot of gain? *Exercise and Sport Sciences Reviews* 2008; 36(2): 58-63 / doi: 10.1097/ JES.0b013e318168ec1f.
14. Gonçalves C, Raimundo A, Abreu A, Bravo J. Exercise Intensity in Patients with Cardiovascular Diseases: Systematic Review with Meta-Analysis. *International Journal of Environmental Research and Public Health* 2021; 18(7): 3574 / doi: 10.3390/ijerph18073 574.
15. Elsevier. (n.d.). Maximal voluntary ventilation. ScienceDirect Topics. https://www.sciencedirect.com/topics/immunology-and-microbiology/maximal-voluntary-ventilation

16. Ponce MC, Sankari A, Sharma S. Pulmonary function tests. Physical activity guidelines. *StatPearls Publishing* 2023 / https://www.ncbi.nlm.nih.gov/sites/books/NBK482339.
17. Dupuit M, Maillard F, Pereira B, Marquezi ML, Lancha AH, Boisseau N. Effect of high intensity interval training on body composition in women before and after menopause: a meta-analysis. *Experimental Physiology* 2020; 105: 1470-1490 / doi: 10.1113/EP088654.
18. Lindner R, Raj IS, Yang AWH, Zaman S, Larsen B, Denham J. Moderate to vigorous-intensity continuous training versus high-intensity interval training for improving VO2max in women: A systematic review and meta-analysis. *International Journal of Sports Medicine*, 2023; 44(7): 484-495 / doi: 10.1055/a-2044-8952.
19. Stankovic M, Djordjevic D, Trajkovic N, Milanovic Z. Effects of high-intensity interval training (HIIT) on physical performance in female team sports: A systematic review. *Sports Medicine - Open* 2023; 9: 78 / doi: 10.1186/s40798-023-00623-2.
20. Welch Joseph Frank, Shalaya Kipp, Andrew William Sheel, Respiratory muscles during exercise: mechanics, energetics, and fatigue, *Current Opinion in Physiology* 2019; 10: 102-109 / doi: 10.1016/j.cophys.2019.04.023.
21. Kowalski T, Granda D, Klusiewicz A. Practical application of respiratory muscle training in endurance sports. *Strength Conditioning Journal* 2024; 46(6): 686-695 / doi: 10.1519/SSC.0000000000000842.
22. Yang L, Shi M, Situ X, He J, Qumu S, Yang T. Prediction of exercise-induced desaturation in COPD patients without resting hypoxemia: a retrospective study. *BMC pulmonary medicine* 2022; 22(1): 405 / doi: 10.1186/s12890-022-02174-w.
23. Andrianopoulos V, Celli BR, Franssen FME, *et al*. Determinants of exercise-induced oxygen desaturation including pulmonary emphysema in COPD: Results from the ECLIPSE study. *Respiratory Medicine* 2016; 119: 87-95 / doi: 10.1016/j.rmed.2016.08.023.
24. Alansare A, Alford K, Lee S, Church T, Jung HC. The Effects of High-Intensity Interval Training *vs*. Moderate-Intensity Continuous Training on Heart Rate Variability in Physically Inactive Adults. *International Journal of Environmental Research and Public Health* 2018; 15(7): 1508 / doi: 10.3390/ijerph15071508.
25. Lamberts, R.P, Swart, J, Noakes, T.D. *et al*. Changes in heart rate recovery after high-intensity training in well-trained cyclists. *Eur J Appl Physiol* 2009; 105: 705-713 / doi: 10.1007/s00421-008-0952-y.
26. Stöggl TL, Björklund G. High Intensity Interval Training Leads to Greater Improvements in Acute Heart Rate Recovery and Anaerobic Power as High Volume Low Intensity Training. *Front Physiol* 2017; 8: 562 / doi: 10.3389/fphys.2017.00562.
27. Ahlert M, Matzenbacher F, Albarello JCDS, Halmenschlager GH. Comparison of epoc and recovery energy expenditure between hiit and continuous aerobic exercise training. *Revista Brasileira de Medicina do Esporte* 2019; 25: 20-23 / doi: 10.1590/1517-8692201925011 81346.
28. Schleppenbach LN, Ezer AB, Gronemus SA. Speed- and Circuit-Based High-Intensity Interval Training on Recovery Oxygen Consumption. *International journal of exercise science* 2017; 10(7): 942-953 / doi: 10.70252/CAZV3381.
29. Patten RK, McIlvenna LC, Levinger I, *et al*. High-intensity training elicits greater improvements in cardio-metabolic and reproductive outcomes than moderate-intensity training in women with polycystic ovary syndrome: a randomized clinical trial, *Human Reproduction* 2022; 37(5): 1018-1029 / doi: 10.1093/humrep/deac047.
30. Skelly LE, Bailleul C, Gillen JB. Physiological Responses to Low-Volume Interval Training in Women. *Sports Med - Open* 2021; 7: 99 / doi: 10.1186/s40798-021-00390-y.