ORIGINAL RESEARCH ARTICLE | SIMULATION-BASED STUDY

Effects of High-Intensity Interval Training on Cardiovascular Fitness and Recovery in Young Adults

Andrei Popescu[1] · Elena Dumitrescu[2]

[1] Department of Physical Education and Sport, Romania | [2] Department of Exercise and Health Sciences, Romania

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Abstract

Background: High-intensity interval training (HIIT) is frequently examined as a time-efficient approach to improving cardiorespiratory fitness. Objective: This simulation-based study compared an eight-week HIIT prescription with moderate-intensity continuous training (MICT) in young adults. Methods: A synthetic longitudinal dataset representing 80 participants (HIIT, n = 40; MICT, n = 40) was generated with correlated baseline and follow-up measures. The primary outcome was estimated maximal oxygen uptake (VO_2max); secondary outcomes were resting heart rate, one-minute heart-rate recovery, and perceived recovery. Results: Mean VO_2max increased from 39.8 to 44.2 mL·kg^{-1}·min^{-1} in HIIT and from 40.1 to 42.2 in MICT. The simulated between-group difference in change was 2.3 mL·kg^{-1}·min^{-1} (95% CI 1.1–3.5). One-minute heart-rate recovery improved by 6.1 and 3.4 beats·min^{-1}, respectively. Conclusion: Within the specified simulation, HIIT produced larger estimated improvements in cardiorespiratory fitness and post-exercise heart-rate recovery. These numerical results are generated examples and do not constitute evidence from recruited participants.

Keywords: high-intensity interval training; cardiorespiratory fitness; VO_2max; heart-rate recovery; exercise intervention; simulation

How to Cite This Article

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1. Introduction

High-intensity interval training combines repeated vigorous efforts with structured recovery periods. Its appeal is not limited to time efficiency: the alternation of metabolic demand and recovery offers a framework for examining cardiovascular adaptation alongside short-term perceptions of exertion. Interpretation requires attention to training intensity, total work, adherence, and the baseline activity profile of participants.

A distinction between change within a group and evidence of a between-group effect is central to the analysis. Improvement following an intervention does not by itself establish superiority over comparison conditions. Accordingly, the present analysis reports group-by-time contrasts, interval estimates, and standardized effects in addition to descriptive changes.

Recovery is multidimensional. Heart-rate recovery describes autonomic adjustment after exercise, whereas perceived recovery reflects the participant's integrated experience of fatigue, soreness, sleep, and readiness. These outcomes may follow different trajectories and should not be treated as interchangeable indicators of physiological adaptation.

The simulated cohort was constructed to reproduce plausible variability rather than to reproduce observations from a specific laboratory. Correlations among baseline fitness, follow-up fitness, and recovery variables were imposed to permit an internally coherent demonstration of longitudinal analysis. The resulting estimates illustrate statistical interpretation, not effects established in a human sample.

The intervention schedule combined progressive exposure with sufficient recovery between demanding sessions. The comparison condition represented steady moderate-intensity activity. Matching all aspects of exercise dose was not the aim of the demonstration; rather, the two conditions represent different training prescriptions that commonly appear in exercise-science discussions.

Individual differences complicate the interpretation of mean responses. A favorable average change may coexist with modest responses or no improvement among particular participants. For this reason, dispersion, confidence intervals, and participant-level distributions provide information that a single mean cannot capture.

Research objective

The primary objective was to compare simulated eight-week changes in estimated VO_2max under HIIT and MICT prescriptions. Secondary objectives addressed resting heart rate, heart-rate recovery, and perceived recovery. The prespecified directional hypothesis was that the HIIT condition would show a larger mean improvement in VO_2max.

1. Introduction (continued)

Physiological rationale

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The interpretation of cardiovascular outcomes benefits from considering both absolute and relative change. Relative gains may appear large when baseline capacity is low, while absolute gains retain practical relevance for comparing performance across populations. Reporting both forms avoids overemphasis on one scale.

Analytical decisions were fixed before generating the final simulated outcomes. The principal comparison concerned the difference in change in estimated maximal oxygen uptake. Secondary comparisons concerned resting heart rate, one-minute heart-rate recovery, and perceived recovery. The analysis illustrates an intention-to-treat framework without asserting that a clinical trial occurred.

2. Materials and Methods

Study design and synthetic population

The analytical design was a two-arm, repeated-measures simulation. Eighty synthetic participant records were allocated equally to HIIT and MICT. Age was centered near 23 years, with balanced baseline fitness distributions and correlated pre–post measurements. These records do not represent identifiable people or an actual recruitment process.

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Outcomes

The primary variable was estimated VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$). Secondary variables were resting heart rate ($beats \cdot min^{-1}$), one-minute heart-rate recovery ($beats \cdot min^{-1}$), and perceived recovery (0–10 scale).

2. Materials and Methods (continued)

Training prescriptions

Condition	Session structure	Frequency	Duration
HIIT	4 × 4 min vigorous intervals; 3-min active recovery	3 sessions/week	8 weeks
MICT	Continuous moderate-intensity aerobic activity	3 sessions/week	8 weeks

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Simulated adherence

Attendance was represented by a synthetic variable with a mean of 22.1 of 24 sessions in HIIT and 22.4 in MICT. No participant attended an actual session.

2. Materials and Methods (continued)

Statistical analysis

Continuous variables are summarized as mean ± standard deviation. Change scores were defined as follow-up minus baseline, except heart-rate recovery, for which positive change represents improved recovery. The primary contrast was the between-group difference in change, reported with a 95% confidence interval. Standardized mean differences were used as descriptive effect indicators. A two-sided alpha of .05 was used for the numerical demonstration.

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A structured account of adherence is necessary because exposure to exercise is part of the causal pathway between a training prescription and an outcome. In the present demonstration, adherence was represented as a simulated attendance variable and used in sensitivity analyses. This illustrates the distinction between assignment and completed training dose.

Measurement error can affect apparent change, especially when testing is repeated over short intervals. Consistent timing, familiarization, calibration, and standardized protocols reduce avoidable variation. The simulated dataset incorporates random error but cannot establish the reliability of any physical testing apparatus.

The study framework highlights how an intervention report can connect physiological rationale, transparent procedures, and quantitative interpretation. Its purpose is to provide a complete example of manuscript organization while keeping the evidentiary status of generated observations explicit.

High-intensity interval training combines repeated vigorous efforts with structured recovery periods. Its appeal is not limited to time efficiency: the alternation of metabolic demand and recovery offers a framework for examining cardiovascular adaptation alongside short-term perceptions of exertion. Interpretation requires attention to training intensity, total work, adherence, and the baseline activity profile of participants.

3. Results

Baseline characteristics

Characteristic	HIIT (n = 40)	MICT (n = 40)
Age, years	23.2 ± 2.6	23.4 ± 2.8
Female, n (%)	20 (50%)	21 (52.5%)
Estimated VO_2max	39.8 ± 5.5	40.1 ± 5.7
Resting HR, beats/min	72.6 ± 7.8	72.1 ± 7.5
1-min HR recovery, beats/min	24.7 ± 5.8	24.9 ± 5.5

Table 1. Simulated baseline characteristics. Values are generated descriptive statistics.

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3. Results (continued)

Primary outcome: cardiorespiratory fitness

Measure	HIIT	MICT
Baseline VO_2max	39.8 ± 5.5	40.1 ± 5.7
Week 8 VO_2max	44.2 ± 5.7	42.2 ± 5.8
Mean change	+4.4	+2.1
Relative change	+11.1%	+5.2%

The simulated difference in mean change was 2.3 $mL \cdot kg^{-1} \cdot min^{-1}$ (95% CI 1.1–3.5; illustrative $p < .001$). The corresponding standardized contrast was approximately 0.84. The point estimate and uncertainty interval arise from the specified synthetic dataset.

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3. Results (continued)

Secondary outcomes

Outcome	HIIT change	MICT change	Difference in change
Resting heart rate	−5.8 beats/min	−3.1 beats/min	−2.7 beats/min
1-min heart-rate recovery	+6.1 beats/min	+3.4 beats/min	+2.7 beats/min
Perceived recovery (0–10)	+1.2	+0.8	+0.4

Heart-rate recovery showed a larger mean improvement in the simulated HIIT arm. Perceived recovery increased in both conditions, with a smaller separation between groups. These variables were treated as secondary and exploratory rather than confirmatory endpoints.

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3. Results (continued)

Sensitivity and heterogeneity

A complete-case sensitivity analysis using 36 synthetic records per arm yielded a between-group VO_2max change contrast of 2.2 $mL \cdot kg^{-1} \cdot min^{-1}$. Restricting the analysis to simulated attendance of at least 20 sessions yielded a contrast of 2.4 $mL \cdot kg^{-1} \cdot min^{-1}$. These results were deliberately generated to illustrate stability checks rather than to document intervention adherence.

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4. Discussion

Principal interpretation

The central pattern in the synthetic results is a greater increase in estimated cardiorespiratory fitness under the HIIT prescription. The magnitude of the simulated difference is consistent with the physiological rationale that vigorous interval work can impose a substantial cardiovascular stimulus. This interpretation concerns the internal logic of the generated example, not a causal finding established by observation.

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Recovery and practical interpretation

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Methodological considerations

An advantage of the simulation format is complete transparency about the assumed data-generating process. Its limitation is equally important: numerical plausibility cannot substitute for independent measurement, randomization, monitoring, or real-world adherence.

4. Discussion (continued)

Strengths and limitations

The simulated cohort was constructed to reproduce plausible variability rather than to reproduce observations from a specific laboratory. Correlations among baseline fitness, follow-up fitness, and recovery variables were imposed to permit an internally coherent demonstration of longitudinal analysis. The resulting estimates illustrate statistical interpretation, not effects established in a human sample.

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The design cannot estimate the frequency of adverse events, establish treatment safety, characterize actual dropout, or support population-level generalization. No ethics approval was sought because the dataset contains no human observations. Synthetic distributions and correlations were chosen for demonstration and may not reproduce the complexity of exercise responses in practice.

Implications

The manuscript illustrates a reproducible reporting structure: specify a primary endpoint, distinguish secondary outcomes, report effect estimates with uncertainty, and discuss measurement context alongside statistical output.

5. Conclusion

In this simulation-based comparison, the HIIT condition exhibited larger estimated gains in VO_2max and one-minute heart-rate recovery than the MICT condition over eight weeks. The findings demonstrate how an exercise intervention manuscript can integrate design, numerical analysis, and cautious interpretation. They do not describe outcomes obtained from human participants.

Declarations

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