

Conference Abstract

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Time Spent Above 90% and 95% of $\dot{V}O_{2max}$ During Three High-Intensity Interval Cycling ProtocolsGörkem A. Balci ^{1*}, Burak A. Ünsal ¹, Hakan Arslan ¹, Ramazan Aydınoğlu ¹ and Bent R. Rønnestad ²

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¹ Coaching Education Department,
Faculty of Sports Sciences, Ege
University, İzmir, Türkiye² Section for Health and Exercise
Physiology, University of Inland
Norway, Lillehammer, Norway

Correspondence

Görkem A. Balci

Coaching Education Department,
Faculty of Sports Sciences, Ege
University, İzmir, Türkiyegorkem.aybars.balci@ege.edu.tr

Abstract

Maximising time spent at high fractions of maximal oxygen uptake ($\dot{V}O_{2max}$) is considered an important target of high-intensity interval training (HIIT). This study compared the accumulated time spent at $\geq 90\%$ and $\geq 95\%$ of $\dot{V}O_{2max}$ during three work- and effort-matched cycling HIIT protocols. Twelve level 3–4 male cyclists completed Short HIIT (15×43.5 s work/43.5 s recovery), Long HIIT (4×3 min work/3 min recovery), and decreasing power output HIIT (6×114.5 s work/114.5 s recovery) in a randomised crossover design. Pulmonary gas exchange was measured breath-by-breath, and the accumulated time above 90% and 95% of $\dot{V}O_{2max}$ was calculated for each session. Significant differences were observed between protocols for both outcomes. Long HIIT produced greater time above 90% of $\dot{V}O_{2max}$ (580 ± 61.8 s) than decreasing power output HIIT (512 ± 77 s) and short HIIT (422 ± 90 s). A similar pattern was observed above 95% of $\dot{V}O_{2max}$, with long HIIT (404 ± 126 s) exceeding decreasing power output HIIT (308 ± 131 s) and short HIIT (193 ± 69 s). Peak blood lactate concentrations did not differ between protocols. These findings suggest that, under matched 1:1 work-to-recovery conditions, longer intervals may provide a greater acute near-maximal aerobic stimulus than shorter intervals.

Keywords

high-intensity interval training; maximal oxygen uptake; work-to-recovery ratio; interval duration; cycling performance

1 Introduction

Maximal oxygen uptake ($\text{VO}_{2\text{max}}$), together with the fractional utilisation of $\text{VO}_{2\text{max}}$ and efficiency, are among the primary determinants of cycling endurance performance (Joyner & Coyle, 2008). Maximising the accumulated time spent above 90% or 95% of $\text{VO}_{2\text{max}}$ appears to be particularly important when the objective is to enhance $\text{VO}_{2\text{max}}$ (Midgley & McNaughton, 2006; Rønnestad et al., 2022; Turnes et al., 2016). Additionally, exercising at intensities near $\text{VO}_{2\text{max}}$ is thought to impose substantial stress on the body's oxygen transport and utilisation systems. Therefore, time spent at a high percentage of $\text{VO}_{2\text{max}}$ is a key determinant of the adaptive response to interval training. It has long been recognised that training programs aimed at increasing $\text{VO}_{2\text{max}}$ and the time spent at near $\text{VO}_{2\text{max}}$ intensities should include high-intensity interval training (HIIT) (Almquist et al., 2020; Støren et al., 2012). Acute physiological responses to HIIT depend on several programming variables, particularly the intensity and duration of work and recovery intervals, exercise modality, and the overall interval structure. However, the optimal composition and precise nature of HIIT remain disputed and continue to evolve. This study examines the effects of Short HIIT (S-HIIT), Long HIIT (L-HIIT), and Decreasing Power Output HIIT (DPO-HIIT) protocols on time spent at $\geq 90\%$ of $\text{VO}_{2\text{max}}$ ($t_{90\%} \text{VO}_{2\text{max}}$) and time spent at $\geq 95\%$ of $\text{VO}_{2\text{max}}$ ($t_{95\%} \text{VO}_{2\text{max}}$).

2 Material and Methods

2.1 Participants

Level 3-4 male cyclists (De Pauw et al., 2013) ($n = 12$), age: 29.7 ± 5.3 years; body mass: 69.8 ± 6.0 kg; $\text{VO}_{2\text{max}}$: 57.8 ± 4.1 mL·kg⁻¹ volunteered for this study.

The study was conducted in accordance with the Declaration of Helsinki and received institutional ethics committee approval (Decision No: 24-11.1T/41; Date: 28 November 2024).

2.2 Design

A randomised repeated-measures design was used in this study.

Participants completed 6 - 9 separate laboratory visits for the determination of gas exchange threshold (GET), peak work rate (WR_{peak}), maximal oxygen uptake ($\text{VO}_{2\text{max}}$), critical power (CP), W' , and highest intensity permitting $\text{VO}_{2\text{max}}$ attainment (I_{HIGH}).

Participants completed three HIIT exercise sessions: S-HIIT (1 series of 15×43.5 sec work - 43.5 sec recovery; $\text{WR} \sim 110\%$ of WR_{peak} ; recovery $\text{WR} [\text{Rec}] \sim 10\%$ of WR_{peak}), L-HIIT (4×3 min work - 3 min recovery; $\text{WR} \sim 88\%$ of WR_{peak} ; $\text{Rec} \sim 25\%$ of WR_{peak}), and DPO-HIIT (6×114.5 sec work - 114.5 sec recovery; WR starting at I_{HIGH} and decreased by 4 equal steps to the $\text{CP} + 10\%$; $\text{Rec} \sim 25\%$ of WR_{peak}). All HIIT sessions were work-matched (similar total work completed) and effort-matched (rate of perceived exertion: $\text{RPE} \geq 19$).

2.3 Methodology

During all baseline tests and HIIT sessions, breath-by-breath pulmonary gas exchange (Innocor, COSMED, Italy), heart rate (HR) (Polar H10, Kempele, Finland), and RPE (Borg scale 6-20) were recorded. Blood lactate [bLa^-] was collected at the end of the sessions (Biosen C-Line Lactate analyser, EKF Diagnostics, Barleben, Germany). Across all work periods, VO_2 values were calculated as 5-sec averages, and subsequently, $t_{90\%} \text{VO}_{2\text{max}}$ and $t_{95\%} \text{VO}_{2\text{max}}$ were quantified for each session. All tests were performed on an electronically braked ergometer (Lode Excalibur Sport).

2.4 Statistical Analysis

Variables were analysed using a one-way repeated-measures ANOVA with partial eta squared (η^2) reported as a measure of the main effect size ($\eta^2 \geq 0.01$ small, ≥ 0.06 medium, and ≥ 0.14 large) (Richardson, 2011). For pairwise comparisons, Bonferroni post-hoc analysis was applied, and effect sizes were calculated using Cohen’s d ($d \geq 0.20$ small, ≥ 0.50 medium, and ≥ 0.80 large) (Cohen, 1988). Statistical analyses were performed using JASP (Version 0.98.1; JASP Team, 2026).

3 Results

A one-way repeated-measures ANOVA revealed significant differences in accumulated $t90\% \text{VO}_{2\text{max}}$ across the protocols ($F=14.75$, $p<0.001$, $\eta^2=0.573$). L-HIIT elicited significantly greater $t90\% \text{VO}_{2\text{max}}$ (580 ± 62 s) compared to DPO-HIIT (512 ± 77 s, $p=0.025$, $d=0.891$) and S-HIIT (422 ± 90 s, $p<0.001$, $d=2.058$). There was no significant difference between DPO-HIIT and S-HIIT ($p=0.070$, $d=1.167$). Similarly, $t95\% \text{VO}_{2\text{max}}$ varied significantly across protocols also varied across protocols ($F=12.36$; $p<0.001$, $\eta^2=0.529$), with L-HIIT producing higher $t95\% \text{VO}_{2\text{max}}$ (404 ± 126 s) than DPO-HIIT (308 ± 131 s; $p=0.05$; $d=0.854$) and S-HIIT (193 ± 69 s; $p=0.002$; $d=1.881$), while DPO-HIIT did not differ strictly from S-HIIT ($p=0.098$; $d=1.026$) (Table 1). There was no significant difference in peak [bLa] concentrations across HIIT modalities ($p>0.05$).

Table 1. Time spent above 90% and 95% of $\text{VO}_{2\text{max}}$ during the different HIIT protocols

Protocol	$t90\% \text{VO}_{2\text{max}}$	$t95\% \text{VO}_{2\text{max}}$
S-HIIT	422±90	193±69
L-HIIT	580±62	404±126
DPO-HIIT	512±77	308±131

$t90\% \text{VO}_{2\text{max}}$: Time spent at $\geq 90\%$ of $\text{VO}_{2\text{max}}$; $t95\% \text{VO}_{2\text{max}}$: Time spent at $\geq 95\%$ of $\text{VO}_{2\text{max}}$

4 Discussion

The L-HIIT protocol produced the greatest near-maximal oxygen uptake response,

demonstrating the highest accumulated $t90\% \text{VO}_{2\text{max}}$ and $t95\% \text{VO}_{2\text{max}}$ across the three HIIT sessions. This pattern indicates that, within the intervals performed with a 1:1 work-to-rest ratio, longer continuous work bouts provide the most potent acute stimulus for sustaining high fractions of $\text{VO}_{2\text{max}}$. Accordingly, during the present conditions L-HIIT appears to be the most effective strategy for maximize time at near-maximal oxygen uptake. Previous studies comparing short- and long-interval HIIT have generally reported a greater time spent at high fractions of $\text{VO}_{2\text{max}}$ during short intervals. Rønnestad and Hansen (2016) compared work intervals of 30 s, around 3 minutes and around 5 minutes performed at the power output associated with $\text{VO}_{2\text{max}}$, with recovery duration set at half of the preceding work interval, resulting in a 2:1 work-to-recovery ratio. The 30-s protocol resulted in a longer time $\geq 90\%$ of $\text{VO}_{2\text{max}}$ than the longer-interval protocols (Rønnestad & Hansen, 2016). Similarly, Almquist et al. (2020) compared effort- and work-duration-matched short intervals (3 sets of 13×30 s/15 s) with long intervals (4×5 min / 2.5 min), again using a 2:1 work-to-recovery ratio. Short intervals allowed a $\sim 14\%$ higher mean power output and resulted in a longer time above 90% of $\text{VO}_{2\text{max}}$ than long intervals (Almquist et al., 2020). In contrast, the present study used a 1:1 work-to-recovery ratio across all protocols, with total duration, work performed, and effort matched between conditions, and L-HIIT produced the greatest accumulated time above both 90% and 95% of $\text{VO}_{2\text{max}}$. A shorter recovery relative to work, as used in the previous 2:1 protocols, may particularly favour short intervals by limiting the decline in VO_2 between repetitions. Conversely, when recovery duration is equal to work duration, as in the present study, this advantage may be reduced, while longer work intervals may provide sufficient uninterrupted time for VO_2 to rise and remain at a high fraction

of $\text{VO}_{2\text{max}}$. Thus, although the work-to-recovery ratio cannot be isolated as the sole explanation, the present findings suggest that long intervals may be more effective than short intervals when a 1:1 work-to-recovery ratio is used.

5 Practical Applications

When the primary training goal is to accumulate time at high fractions of $\text{VO}_{2\text{max}}$, longer work intervals may represent a useful option under 1:1 work-to-recovery conditions. In the present study, L-HIIT provided the greatest accumulated time above both 90% and 95% of $\text{VO}_{2\text{max}}$, suggesting that coaches may consider longer intervals when designing sessions with a 1:1 work:recovery design that specifically aims at maximising the near-maximal aerobic stimulus. However, the choice of HIIT format should not be based solely on interval duration. The athlete's physiological profile, training goal, recovery characteristics, current training phase, and sport-specific demands should also be considered when selecting the most appropriate interval structure. Accordingly, HIIT prescription should remain individualised rather than assuming that either short- or long-interval formats are universally superior.

6 Conclusions

Under work- and effort-matched conditions with a 1:1 work-to-recovery ratio, L-HIIT elicited the greatest accumulated time above both 90% and 95% of $\text{VO}_{2\text{max}}$. These findings suggest that longer intervals may provide a stronger acute near-maximal aerobic stimulus than shorter intervals when equal work and recovery durations are utilised.

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Conflicts of Interest: The authors declare no conflict of interest.

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