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ORIGINAL RESEARCH

# Different work rate distributions elicit similar time spent near $\dot{V}O_2max$ during short-duration interval sessions

Tiago Turnes[1]✉, Daiane Wommer[1], Thiago P. Ventura[1], Jean C. Pauleti[1], Lucas D. V. Lanzarini[1], Bruno Spiess[1], Fernando K. Borszcz[1,2,3,4], and Luiz G. A. Guglielmo[1]

*[1]Physical Effort Laboratory, Sports Center, Federal University of Santa Catarina, Florianópolis, Brazil; [2]Human Performance Research Group, Center for Health and Sports Sciences, Santa Catarina State University, Florianópolis, Brazil; [3]Department of Animal and Food Production, Agroveterinary Sciences Center, Santa Catarina State University, Lages, Brazil; and [4]Secretariats of State for Education of Santa Catarina, Lages, Brazil*

**Abstract**

**Background:** Time spent near $\dot{V}O_2max$ has been suggested as an optimal stimulus for the promotion of greater $\dot{V}O_2max$ improvements. Thus, this study aimed to compare time spent above 90% (t90$\dot{V}O_2max$) and 95% of $\dot{V}O_2max$ (t95$\dot{V}O_2max$) during three cycling interval training protocols with decreasing, increasing, or constant work rate distributions within each exercise interval. **Methods:** After an incremental test to determine $\dot{V}O_2max$ and peak power output ($P_{peak}$), ten physically active male individuals (age 28 ± 5 years, $\dot{V}O_2max$ 48.4 ± 8.1 mL·kg$^{-1}$·min$^{-1}$) performed in a random order three work-matched cycling interval training sessions comprising 8 × 60 s efforts with 60 s passive recovery. The power output was held constant (100%$P_{peak}$; $IT_{CON}$), decreasing (from 110 to 90%$P_{peak}$; $IT_{DEC}$), or increasing (from 90 to 110%$P_{peak}$; $IT_{INC}$) throughout each work interval. Time sustained above 90% and 95% of $\dot{V}O_2max$, above 90% and 95% of maximal heart rate (t90HRmax; t95HRmax), blood lactate concentrations (BLC), and rating of perceived exertion (RPE) were measured. **Results:** There was no difference in t90$\dot{V}O_2max$ among sessions ($IT_{CON}$ 152 ± 72 s, $IT_{DEC}$ 157 ± 81 s, $IT_{INC}$ 161 ± 81 s, $p$ = .857), t95$\dot{V}O_2max$ ($IT_{CON}$ 84 ± 65 s, $IT_{DEC}$ 86 ± 87 s, $IT_{INC}$ 99 ± 73 s, $p$ = .585), t90HRmax ($p$ = .204), t95HRmax ($p$ = .119), BLC ($p$ = .694), or RPE ($p$ = .482). **Conclusions:** Short-duration cycling interval training around $P_{peak}$ induces similar time spent near $\dot{V}O_2max$, regardless of the work rate distribution.

**Keywords:** oxygen consumption, high-intensity interval training, exercise physiology, cycling performance

## Introduction

Endurance training typically involves either continuous exercise at submaximal work rates and/or interval exercise in which relatively high-intensity exercise bouts are alternated with relatively low-intensity recovery periods (MacInnis & Gibala, 2017). Although both methods are effective in improving cardiorespiratory fitness and health-related outcomes, there appears to be a consensus for the benefit of interval training not only in athletes, but also in non-athletic, sedentary individuals (M. Weston et al., 2014), and in the patient population (K. S. Weston et al., 2014). Additionally, exercise intensity is a key component determining changes in maximal oxygen uptake ($\dot{V}O_2max$) in young healthy individuals (Inglis et al., 2024), and it appears that interval training elicits improvements in $\dot{V}O_2max$ slightly greater than is typically reported with continuous training in healthy, active adults (Bacon et al., 2013).

Interval training is an effective method for improving cardiorespiratory and metabolic function in both athletic and non-athletic populations (Buchheit & Laursen, 2013). There is growing evidence that the more time spent near $\dot{V}O_2max$ during interval training, the greater the improvements in $\dot{V}O_2max$ (Mølmen & Rønnestad, 2024; Odden et al., 2024; Turnes et al., 2016). As a result, time spent near $\dot{V}O_2max$ has become a key marker for evaluating the effects of manipulating exercise prescription variables during interval training. Consequently, investigating strategies that maximize time spent near $\dot{V}O_2max$ during training sessions could provide valuable insights not only for athletes but also in the general population.

Among the myriad of factors that can be manipulated during interval training sessions, as intensity, duration, and number of work and recovery intervals performed, the manipulation of work rate during exercise intervals can be forgotten. Still, it can impact acute physiological responses (Zadow et al., 2015). This practice is consistent not only with the training principle of specificity, since many endurance sports display intensity variations during the event (Mølmen & Rønnestad, 2024), but is also supported from a physiological view. Decreasing work rate (i.e., from intensities above to below maximal intensity achieved during an incremental test) prolonged the time spent at high

✉ **Corresponding author:** Tiago Turnes, e-mail tiago.turnes@ufsc.br, ORCID® record https://orcid.org/0000-0001-8797-0437

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percentages of $\dot{V}O_2$max in active (de Aguiar et al., 2013; Lisbôa et al., 2015) and trained individuals (Lisbôa et al., 2019), which could be attributed to accelerated $\dot{V}O_2$ kinetics, resulting in longer time spent near $\dot{V}O_2$max (Jones et al., 2008). However, interval training sessions were not matched in terms of total work accomplished and were conducted until exhaustion (de Aguiar et al., 2013; Lisbôa et al., 2015, 2019), which could be infeasible in a real practice setting for a non-athletic population.

In well-trained athletes, Rønnestad et al. (2020) reported that a decreasing work rate from 100% to 85% of maximal aerobic speed during the first 1.5 min of each 5-min work intervals, interspersed with a 3-min recovery, induced similar time spent above 90% of $\dot{V}O_2$max (t90$\dot{V}O_2$max; 11.95 ± 4.08 min) compared to a constant work rate approach (90% maximal aerobic speed). However, when the time to decrease work rate was prolonged for 2 min, there was an increase in t90$\dot{V}O_2$max in comparison with a constant protocol (Rønnestad et al., 2022). Recently, Wommer et al. (2022) compared a decreasing or increasing work rate from 10% above or below maximal aerobic power, respectively, within each of 8 × 1-min intervals interspaced with a 1 min of active recovery, with a constant work rate protocol in active individuals. Even though the decreasing and increasing intervals induced a faster $\dot{V}O_2$ response in comparison with the constant protocol, the t90$\dot{V}O_2$max was similar in comparison with a constant work rate protocol. However, the adoption of active recovery may have contributed to a lesser reduction in $\dot{V}O_2$ between intervals despite a faster increase in $\dot{V}O_2$ response, resulting in similar t$\dot{V}O_2$max. Thus, the utilization of passive recovery could be useful to verify the influence of a decreasing or increasing work rate manipulation per se on time spent near $\dot{V}O_2$max during work-matched protocols not performed until exhaustion.

While it has been speculated that a decreasing work rate would increase time spent near $\dot{V}O_2$max due to an accelerated $\dot{V}O_2$ kinetics (Jones et al., 2008), the literature is sparse for the increasing intensity approach. Despite that, the high intensities per se during increasing work rate strategy might prolong time spent near $\dot{V}O_2$max because a faster $\dot{V}O_2$ increase could be a response to a high intensity per se. Therefore, the hypothesis of the current study was that higher intensities associated with interval training applying decreasing or increasing work rates would induce longer time spent near $\dot{V}O_2$max compared to a constant work rate approach. Thus, this study aimed to compare time spent near $\dot{V}O_2$max during three work-matched cycling interval training protocols comprising 8 × 60-s exercise efforts with decreasing (from 110% to 90% of incremental peak power output; $P_{peak}$), increasing (from 90% to 110% $P_{peak}$), or constant (100% $P_{peak}$) work rate distribution within each 60-s exercise interval, interspaced by a 60-s passive recovery. Considering the increasing interest in short-duration interval training protocols (Inglis et al., 2024; M. Weston et al., 2014), the current 8 × 60 s protocol was adopted to induce a total training session lasting less than 30 min (including warm-up and cool-down). Furthermore, in addition to continuous moderate training, this interval training protocol can represent a relevant time-saving option for non-athlete individuals intending to improve $\dot{V}O_2$max.

## Methods

### Design and procedures

In this experimental cross-sectional study, physically active individuals visited the laboratory four times, with at least 72 hr separating each visit, and all tests were completed within 3 weeks. On the first day, participants performed an anthropometric assessment and a submaximal step incremental test (four to six stages) to determine their lactate threshold (LT), followed by (15-min passive recovery) by a maximal ramp incremental test for the measurement of $\dot{V}O_2$max and $P_{peak}$. During their second, third, and fourth visits, participants performed, in random order, three interval training sessions in which the power output during work intervals was either held constant throughout ($IT_{CON}$) or controlled to result in either decreasing ($IT_{DEC}$) or increasing ($IT_{INC}$) work rate manipulation. The cycle ergometer was chosen for its capacity to provide a highly controlled and reproducible external workload, thus enabling precise manipulation of work rates within protocols that incorporate such variations. Each participant was always tested at the same time of day (±2 hr) in a temperature-controlled laboratory, 18 °C to 22° C. The volunteers were required to rest the day before the test and to eat their last light meal 2 hr before the test.

### Participants

Ten healthy male participants (age 28 ± 5 years, body mass 80 ± 14 kg, height 179 ± 6 cm, body fat 12.2 ± 6.1%, body mass index 25.1 ± 3.2 $kg \cdot m^{-2}$) volunteered and gave written informed consent to participate in this study. Subjects were regarded as recreationally trained ($n$ = 8), trained ($n$ = 1), or well-trained cyclists ($n$ = 1) based on the classification by De Pauw et al. (2013). The study was approved by the institutional ethics committee for research on humans (reference number 1.097.372) and performed in accordance with the Declaration of Helsinki.

### Materials

All protocols were performed on an electromagnetically braked cycle ergometer (Excalibur Sport, Lode BV). The individually preferred pedal cadence between 70 and 90 rpm was maintained and replicated for all protocols. The pulmonary gas exchange was measured breath-by-breath using a previously calibrated automated open-circuit gas analysis system (Quark CPET, Cosmed). Heart rate (HR) was monitored (Polar H9, Polar). Capillary blood samples (25 µl) were obtained from the earlobe of each participant, and blood lactate concentration (BLC) was measured using an electrochemical analyzer (YSI 2700 STAT, YSI Inc.). For anthropometric assessment, body mass was measured to the nearest 0.05 kg on a digital scale (2096 PP, Toledo do Brazil). Standing height was measured with a stadiometer with a resolution of 1 mm (Sanny ES2020, Sanny). For skinfold measurements, a scientific skinfold caliper with a resolution of 1 mm was utilized (TopTec 2, Cescorf).

### Anthropometric assessment

Body density was first quantified to determine the percentage of body fat using the male-specific equation proposed by Jackson and Pollock (1978). This calculation utilized seven skinfold measurements: pectoral, midaxillary, triceps, subscapular, abdominal, suprailiac, and thigh, along with two circumferences: abdominal and forearm. Subsequently, body density was used to estimate body fat using the Siri equation (1961).

### Incremental test

Each participant performed a submaximal step incremental test to determine the LT. The test started at 60 W and was increased by 20 W every 3 min for 4 to 6 stages. At the end of each stage, capillary blood samples were collected. The power output before the intensity at which the blood lactate begins to rise above baseline levels was defined as LT (Yoshida et al., 1987). Fifteen minutes after the test, the participants performed a maximal ramp incremental test for the measurement of $\dot{V}O_2$max and $P_{peak}$. The test started at 90% LT during the first 4 min and was thereafter continuously increased by a rate of 25 W·min$^{-1}$ until volitional exhaustion.

Breath-by-breath $\dot{V}O_2$ and HR data were reduced to 15- and 5-s averages, respectively. The $\dot{V}O_2$max was taken as the highest 15-s mean value achieved (Robergs et al., 2010), and maximal heart rate (HRmax) as the highest 5-s mean value attained. The highest power output attained for 3 s in the ramp incremental test was considered $P_{peak}$ (Iannetta et al., 2020).

### Interval training sessions

Over the next three visits, participants performed three cycling interval training protocols. One session was performed per day in a randomized order. Prior to each session, participants performed a standardized 5-min warm-up (100% LT) followed by a 5-min rest. Following a 3-min cycling baseline at 20 W, the session started. The three work-matched sessions were designed with a work-to-rest ratio of 1:1 and were performed as follows (Figure 1):

1. $IT_{CON}$: Interval training with constant intensity comprising 8 × 60 s in which the power output was held constant at 100% $P_{peak}$.
2. $IT_{DEC}$: Interval training with decreasing intensity comprising 8 × 60 s in which the power output decreased from 110% to 90% $P_{peak}$ throughout each work interval. The power output decreased individually and linearly during each bout. For example, the $P_{peak}$ of participant 1 was 300 W. Thus, the initial power output of each effort was 330 W (110% $P_{peak}$) and decreased linearly until reaching 270 W (90% $P_{peak}$) at 60 s.
3. $IT_{INC}$: Interval training with increasing intensity comprising 8 × 60 s in which the power output increased from 90% to 110% $P_{peak}$ throughout each work interval. The power output increased individually and linearly during each bout. For example, the $P_{peak}$ of participant 1 was 300 W. Thus, the initial power output was 270 W (90% $P_{peak}$) and increased linearly until reaching 330 W (110% $P_{peak}$) at 60 s.

The rate at which the power output decreased/increased linearly was individual and depended on the participant's $P_{peak}$. In the example of participant 1 ($P_{peak}$ = 300 W), the work rate was decreased/increased by 1 W per second. For all three protocols, each work interval was interspersed with 60 s of passive recovery. The $\dot{V}O_2$ and HR were recorded throughout the training sessions. The blood samples for BLC analyses were collected before the protocol and after the fifth and final repetitions. Rating of perceived effort (RPE) was measured at the end of each repetition using Borg's 0 to 10 scale (Borg, 1982).

### Data analyses

Breath-by-breath $\dot{V}O_2$ data during interval training sessions were first filtered manually to remove any outlying breaths (±3 *SD* from the adjacent 5 breaths) and then reduced to a 5-s stationary mean (Thevenet et al., 2007). The times sustained above 90% (≥ 90% $\dot{V}O_2$max, t90$\dot{V}O_2$max) and 95% of $\dot{V}O_2$max (≥ 95% $\dot{V}O_2$max, t95$\dot{V}O_2$max) and above 90% (≥ 90% HRmax, t90HRmax) and 95% of HRmax (≥ 95% HRmax, t95HRmax) during exercise and passive recovery intervals were quantified. The peak $\dot{V}O_2$ and HR for the entire session (including all work and rest intervals) were determined. The peak and nadir (i.e., the lowest value) $\dot{V}O_2$ and HR (5-s period) during work and rest intervals of each protocol were recorded.

### Statistical analysis

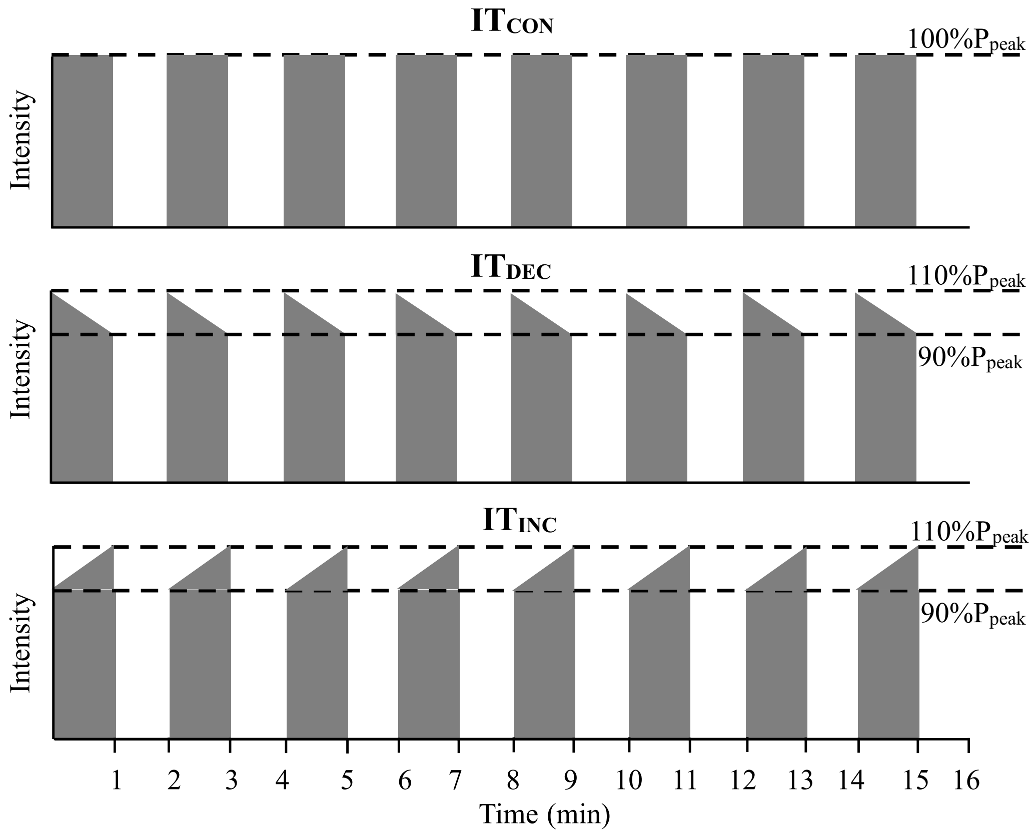
Descriptive data are presented as mean ± standard deviation. One-way and two-way analysis of variance (ANOVA) with repeated measures completed with the post-hoc Tukey test were used to compare variables between protocols or within protocols, respectively. Normality of the ANOVA residuals was assessed using the Shapiro-Wilk test. When the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied. Eta squared ($\eta^2$) effect sizes were calculated for ANOVA and interpreted as: .01 to .06 *small*, .06 to .14 *medium*, and > .14 *large* (Cohen, 2013). Multiple comparisons were presented as mean differences with 95% confidence intervals (CI). All analyses were carried out using the software GraphPad Prism (Version 8.1.2; GraphPad Software). The level of significance was set at $p < .05$.

Due to our limited sample size of only 10 participants, we performed a sensitivity analysis using G*Power software (Version 3.1.9.7; https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower) with the following parameters for a one-way ANOVA on the t90$\dot{V}O_2$max (the main study variable): number of groups = 1, number of measurements = 3, statistical power = 80%, $\alpha$ = .05, sample size = 10, correlation among repeated measures = .90, and nonsphericity correction = 1. A critical $F$ = 3.55 was required to achieve adequate statistical power.

## Results

During the incremental test, participants achieved a $P_{peak}$ of 327 ± 39 W and presented a $\dot{V}O_2$max of 3.83 ± 0.53

Figure 1 Schematic illustration of training protocols with constant ($IT_{CON}$), decreasing ($IT_{DEC}$), or increasing ($IT_{INC}$) work rate




L·min$^{-1}$ (48.4 ± 8.1 mL·kg$^{-1}$·min$^{-1}$). The power at LT was 110 ± 30 W and represented 33 ± 6% of $P_{peak}$. The HRmax and peak BLC for all the participants were 186 ± 10 bpm and 10.0 ± 2.2 mmol·L$^{-1}$, respectively.

The peak $\dot{V}O_2$, as well as t90$\dot{V}O_2$max and t95$\dot{V}O_2$max, presented small effect sizes and were not significantly different ($p \geq .585$) between sessions (Table 1). Large to moderate effects, but no significant differences were observed in peak HR, t90HRmax, and t95HRmax ($p \geq .119$). The RPE and blood lactate concentrations during rest and exercise did not differ significantly between sessions ($p \geq .143$). The ANOVA main effect did not reach the critical value of $F = 3.55$; nevertheless, these values were not significant.

During exercise bouts, there were no significant effects for $\dot{V}O_2$ among sessions ($F(2, 18) = 0.497$; $p = .617$; $\eta^2 = .05$, small effect) or interaction between interval training and the work interval ($F(14, 126) = 1.071$; $p = .390$; $\eta^2 = .11$, medium effect). Figure 2 presents mean $\dot{V}O_2$ values during work and recovery intervals of the training sessions. A large main effect was observed within the work interval ($F(7, 63) = 82.53$, $p < .001$, $\eta^2 = .90$), revealing that $\dot{V}O_2$ during the first and second bouts differed significantly from all the others, with no differences from the fifth to the last bout within each session.

Regarding $\dot{V}O_2$ response during recovery intervals, large and significant main effects were observed for both the IT session type ($F(2, 18) = 3.771$, $p = .043$, $\eta^2 = .30$) and the rest interval number ($F(6, 54) = 20.12$, $p < .001$, $\eta^2 = .69$). However, the interaction between IT session and recovery interval was considered large. Still, it did not reach statistical significance ($F(12, 108) = 1.659$, $p = .086$, $\eta^2 = .16$). Post-hoc comparisons revealed that $\dot{V}O_2$ decreased significantly during the first two intervals, followed by a stabilization from the fifth to the seventh intervals (Figure 2). The mean $\dot{V}O_2$ during recovery intervals was higher during the $IT_{INC}$ compared to the $IT_{CON}$ (mean difference [95% CI] 108.3 [7.0, 209.5] mL·min$^{-1}$, $p = .035$). No significant differences were found between $IT_{DEC}$ and either $IT_{INC}$ (–64.9 [–166.2, 36.4] mL·min$^{-1}$, $p = .257$) or $IT_{CON}$ (43.3 [–57.9, 144.6] mL·min$^{-1}$, $p = .531$), see Figure 2.

## Discussion

The present study hypothesized that work-matched cycling interval training sessions with decreasing or increasing work rate distribution would increase t$\dot{V}O_2$max in comparison with a constant intensity session. However, this hypothesis was rejected because t$\dot{V}O_2$max was not different irrespective of work rate manipulation. These findings support others in well-trained athletes (Rønnestad et al., 2020) and active individuals (Wommer et al., 2022), indicating that varying exercise intensity during short-duration work-matched interval training near $P_{peak}$ and not performed until exhaustion did not impact t$\dot{V}O_2$max in active individuals. Thus, during short-duration interval training, the work rate manipulation within each exercise effort did not impact time spent near $\dot{V}O_2$max in healthy male participants.

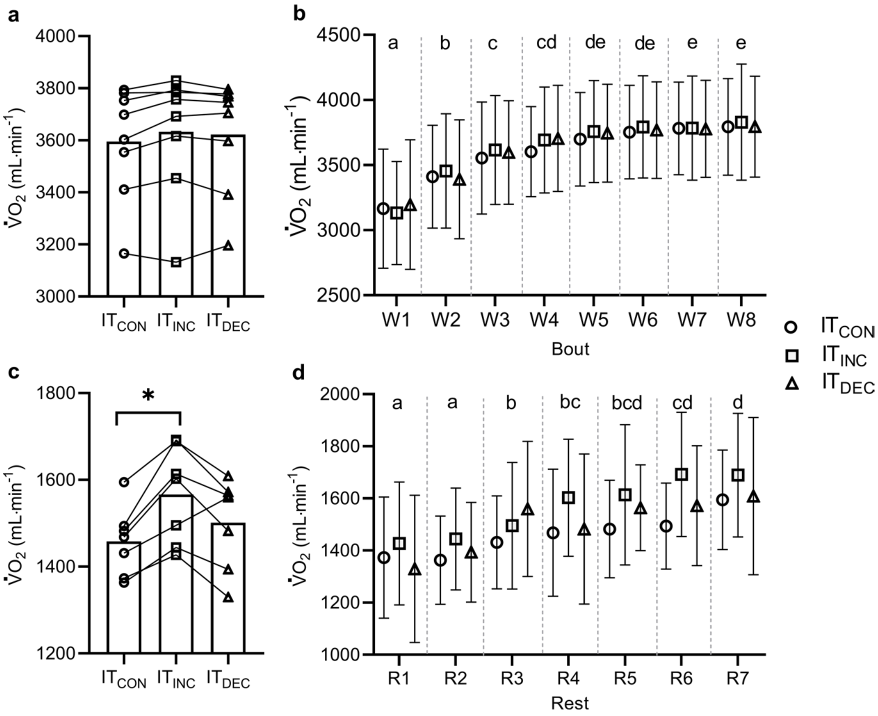
Table 1 Physiological responses during interval training sessions

| Parameter | Mean ± *SD* | | | Analysis of variance | Mean difference [95% confidence interval] | | |
|---|---|---|---|---|---|---|---|
| | $IT_{CON}$ | $IT_{DEC}$ | $IT_{INC}$ | | $IT_{CON} - IT_{INC}$ | $IT_{CON} - IT_{DEC}$ | $IT_{INC} - IT_{DEC}$ |
| $\dot{V}O_2$ responses | | | | | | | |
| $t90\dot{V}O_2max$ (s) | 152 ± 72 | 157 ± 81 | 161 ± 81 | $F(2, 15) = 0.11$; $p = .857$; $\eta^2 = .01$, small effect | −9.1 [−48.4, 30.1] | −5.3 [−65.0, 54.4] | 3.8 [−55.9, 63.5] |
| $t95\dot{V}O_2max$ (s) | 84 ± 65 | 86 ± 87 | 99 ± 73 | $F(1, 12) = 0.42$; $p = .585$; $\eta^2 = .04$, small effect | −15.0 [−41.4, 11.4] | −2.1 [−58.1, 53.9] | 12.9 [−46.9, 72.7] |
| Peak $\dot{V}O_2$ (L·min$^{-1}$) | 3.82 ± 0.38 | 3.81 ± 0.39 | 3.85 ± 0.42 | $F(2, 17) = 1.17$; $p = .332$; $\eta^2 = .12$, medium effect | −0.030 [−0.129, 0.069] | 0.017 [−0.063, 0.098] | 0.048 [−0.037, 0.132] |
| Peak $\dot{V}O_2$ (%$\dot{V}O_2max$) | 99 ± 4 | 98 ± 5 | 99 ± 5 | $F(2, 17) = 1.14$; $p = .340$; $\eta^2 = .11$, medium effect | −0.6 [−3.0, 1.8] | 0.6 [−1.5, 2.7] | 1.2 [−0.9, 3.3] |
| HR responses | | | | | | | |
| t90HRmax (s) | 244 ± 194 | 159 ± 93 | 205 ± 98 | $F(2, 14) = 1.81$; $p = .204$; $\eta^2 = .17$, large effect | 39.5 [−102.1, 181.1] | 85.2 [−58.0, 228.4] | 45.7 [−35.4, 126.8] |
| t95HRmax (s) | 77 ± 107 | 24 ± 38 | 43 ± 45 | $F(1, 12) = 2.75$; $p = .119$; $\eta^2 = .23$, large effect | 33.7 [−38.6, 106.0] | 52.5 [−23.5, 128.5] | 18.8 [−13.3, 50.9] |
| Peak HR (%HRmax) | 95 ± 4 | 94 ± 3 | 95 ± 3 | $F(1, 13) = 1.26$; $p = .302$; $\eta^2 = .12$, medium effect | 0.7 [−2.9, 4.4] | 1.7 [−1.4, 4.8] | 1.0 [−1.0, 3.0] |
| Blood lactate concentration (mmol·L$^{-1}$) | | | | | | | |
| Rest | 1.0 ± 0.2 | 0.9 ± 0.2 | 1.1 ± 0.3 | $F(2, 16) = 2.22$; $p = .143$; $\eta^2 = .20$, large effect | −0.1 [−0.4, 0.3] | 0.2 [−0.1, 0.4] | 0.2 [−0.1, 0.5] |
| Interval 5 | 9.8 ± 1.4 | 9.9 ± 1.6 | 9.6 ± 1.6 | $F(2, 17) = 0.31$; $p = .723$; $\eta^2 = .03$, small effect | 0.3 [−1.2, 1.8] | −0.1 [−1.6, 1.4] | −0.4 [−1.6, 0.8] |
| Final | 13.6 ± 2.4 | 13.7 ± 2.6 | 13.2 ± 2.1 | $F(2, 16) = 0.34$; $p = .694$; $\eta^2 = .04$, small effect | 0.3 [−1.0, 1.6] | −0.1 [−1.9, 1.7] | −0.5 [−2.0, 1.1] |
| Rating of Perceived Exertion (a.u.) | | | | | | | |
| Mean | 7 ± 1 | 7 ± 1 | 7 ± 0 | $F(2, 16) = 0.73$; $p = .482$; $\eta^2 = .08$, medium effect | −0.2 [−0.6, 0.2] | −0.1 [−0.6, 0.4] | 0.1 [−0.4, 0.6] |
| Final | 10 ± 0 | 10 ± 0 | 10 ± 0 | NA[a] | 0 | 0 | 0 |

*Note.* $IT_{CON}$ = interval training with constant intensity (8 × 60 s at 100% peak power output); $IT_{DEC}$ = interval training with decreasing intensity (8 × 60 s with power output decreasing linearly from 110% to 90% peak power output); $IT_{INC}$ = interval training with increasing intensity (8 × 60 s with power output increasing linearly from 90% to 110% peak power output); $\dot{V}O_2$ = oxygen uptake; $\dot{V}O_2max$ = maximal oxygen uptake; $t90\dot{V}O_2max$ = time spent at or above 90% of $\dot{V}O_2max$; $t95\dot{V}O_2max$ = time spent at or above 95% of $\dot{V}O_2max$; HR = heart rate, HRmax: maximal HR; t90HRmax = time spent at or above 90% of HRmax; t95HRmax = time spent at or above 95% of HRmax; a.u. = arbitrary units. [a]All participants reported a Rating of Perceived Exertion of 10, so no statistical comparison was performed.

Contrary to the current findings, previous studies manipulating a decreasing work rate during interval training verified superior $t\dot{V}O_2max$ (de Aguiar et al., 2013; Lisbôa et al., 2015, 2019), suggesting that initiating exercise at intensities above $P_{peak}$ during interval training can be beneficial to maximize cardiovascular stimuli at the beginning of the training session. However, some methodological aspects, such as exercise duration and total training volume,

Figure 2 Individual values (and the means – bars) of the average $\dot{V}O_2$ of each session during work (a) and recovery interval (c) during training sessions (i.e., main effect of IT session), and the (mean [circle/square/triangle] with *SD* [whiskers]) $\dot{V}O_2$ of each work (b) and recovery (d) interval (i.e., bouts (W1–8) and rest (R1–7) time comparisons)




*Note.* $\dot{V}O_2$ = oxygen uptake; IT = interval training. $IT_{CON}$ = IT with constant intensity (8 × 60 s at 100% peak power output); $IT_{DEC}$ = IT with decreasing intensity (8 × 60 s with power output decreasing linearly from 110% to 90% peak power output); $IT_{INC}$ = IT with increasing intensity (8 × 60 s with power output increasing linearly from 90% to 110% peak power output). *Significantly different from $IT_{CON}$ ($p < .05$). As there was no analysis of variance interaction between time and IT session, in panels b and d, different letters indicate significant differences between the means of the three IT sessions at each bout and rest intervals ($p < .05$). Different letters indicate significant differences in $\dot{V}O_2$ between bouts ($p < .05$). For example, in panel b, $\dot{V}O_2$ at W1 and W2 are labeled with the letters "a" and "b", respectively, indicating that they were significantly different. Similarly, in panel d, $\dot{V}O_2$ at R3, R4, and R5 were not significantly different, as they all share the letter "b".

can help to explain such divergences. Studies in which training session was performed until voluntary exhaustion have reported longer $t\dot{V}O_2max$ during interval training with decreasing work rate in comparison with a constant intensity (de Aguiar et al., 2013; Lisbôa et al., 2015, 2019). These investigations reinforce the benefits of such manipulation to prolong total exercise time, which could consequently result in longer $t\dot{V}O_2max$. Thus, when comparing sessions matched in terms of total work per bout not performed until exhaustion, exercise duration exposed to work rate manipulation seems to be an important parameter to optimize $t\dot{V}O_2max$.

When a decreasing strategy maintaining exercise intensity at or above $P_{peak}$ lasting for 0.5, 1.0 or 1.5 min was applied, $t\dot{V}O_2max$ remained unchanged during 8 × 1 min:1 min in active individuals (5.2 ± 1.7 vs 4.6 ± 2.2 min; Wommer et al., 2022), 3 × 4 min:3 min in trained cyclists (3.0 ± 1.1 vs 3.1 ± 1.4 min; Miller et al., 2023) or 5 × 5 min:3 min in well-trained cross-country skiers (12.0 ± 4.1 vs 10.8 ± 5.7 min; Rønnestad et al., 2020) respectively. However, prolonging the same decreasing work rate strategy from 1.5 min (Rønnestad et al., 2020) to 2 min during a 5 × 5 min:3 min, increased significantly $t\dot{V}O_2max$ (14.6 ± 4.2 min) in comparison with a constant (13.2 ± 4.1 min) interval training session in elite cross-country skiers (Rønnestad et al., 2022). Thus, the 0.5 min sustained above $P_{peak}$ during each exercise interval was probably too short to increase $t\dot{V}O_2max$ in comparison with the constant work rate manipulation applied in the current study. Taken collectively, these results suggest that prolonging the decreasing work rate manipulation is relevant to induce a larger $\dot{V}O_2$ response when the fast start lasts more than 2 min, in comparison with a constant intensity. These likely differences can be attributed to a quicker rise in $\dot{V}O_2$ and, consequently, optimizing $t\dot{V}O_2max$. This aspect is particularly relevant for active individuals, such as those in the present study, who possess slower $\dot{V}O_2$ kinetics compared to well-trained athletes (Caputo & Denadai, 2004).

Buchheit and Laursen (2013) suggested that 10 min of $t\dot{V}O_2max$ per session is reasonable to maximize cardiopulmonary adaptations in trained individuals. In order to improve $t\dot{V}O_2max$, in addition to decreasing work rate duration, another relevant parameter to be considered is the mode of recovery intensity. As mentioned above, $t\dot{V}O_2max$ increased approximately from ~10–12 min (Rønnestad et al., 2020) to ~13–15 min (Rønnestad et al., 2022) during 5 × 5 min:3 min not only by prolonging fast start, but it is likely that increasing the duration of active recovery from 1.0 min to 1.5 min may have impacted in the increase from 43–48% to ~53–58% of $t\dot{V}O_2max$ relative to the total exercise period. In the current study, $t90\dot{V}O_2max$ was substantially lower than this value, lasting less than 2.5 min, or ~1.5 min above 95% of $\dot{V}O_2max$. Considering that the duration of exercise effort was ~10 min, and "lack of time" is an important barrier of regular participation in exercise (Gillen & Gibala, 2014), this could represent a relevant stimulus to improve $\dot{V}O_2max$ of active individuals, as increasing time spent above 95% of $\dot{V}O_2max$ from ~1.0 min to ~2.0 min per session was accompanied by superior benefits in $\dot{V}O_2max$ after 4 weeks of training in recreationally-trained individuals (Turnes et al., 2016). Thus, the utilization of some strategies during interval training, such as prolonging the duration of work rate manipulation, increasing the number of intervals, and adjusting the intensity of recovery intervals, could be useful to maximize $t\dot{V}O_2max$. These findings provide valuable additional information for training prescriptions in active individuals. This information, when combined with traditional continuous moderate training, allows individuals to implement diverse interval training protocols to maximize cardiorespiratory improvements.

During interval training comprising 1-min efforts near $P_{peak}$, the HR lag at exercise onset, with a much slower response of HR compared with $\dot{V}O_2$, and the HR inertia at exercise cessation could overestimate the actual physiological strain of the training session (Midgley et al., 2007). Accordingly, the time sustained above 90% HRmax was similar among protocols, which supports previous findings with similar $t\dot{V}O_2max$ in well-trained skiers (Rønnestad et al., 2020), active individuals (Wommer et al., 2022), or even reporting a similar t90HRmax despite different $t\dot{V}O_2max$ (Rønnestad et al., 2022). The current findings reinforce this interpretation, as a large effect size was observed for time spent above 90% and 95% of HRmax across the different protocols. These results suggest that while time spent near $\dot{V}O_2max$ remained virtually identical among protocols, the duration spent at specific high percentages of maximal heart rate might still differ. Besides HR, considering that the relationship of $\dot{V}O_2$ with other physiological variables, such as BLC, is not linear, manipulation of work rate did not impact BLC. This has been previously reported when decreasing (Lisbôa et al., 2019; Rønnestad et al., 2020, 2022) or variable (Billat et al., 2013) intensity protocols were applied, irrespective of the time spent near $\dot{V}O_2max$. Finally, the similarities in acute physiological responses were accompanied by similar RPE among the protocols, which could be a result of the equalization of work and the similar physiological responses reported among training sessions.

The small sample size of the current study represents a limitation because of the risk of type II error. In addition, the current study included only young adult males and could not be generalized to other populations, such as females or highly trained athletes. Besides, the similarities in $t\dot{V}O_2max$ irrespective of work rate manipulation could also be explained by the individual variability in $t\dot{V}O_2max$ (Coyle et al., 1988) or in fractional utilization of $\dot{V}O_2max$ at the lactate threshold (Billat & Koralsztein, 1996). In addition, the limited number of 8 repetitions lasting 60-s efforts, along with the training level of individuals, when compared with previous findings in athletes using longer intervals with 3 min (Zadow et al., 2015) or 5 min (Rønnestad et al., 2020), would result in a lower margin for accelerated $\dot{V}O_2$ kinetics and improve $t\dot{V}O_2max$ in the entire session. Thus, for active individuals, work rate manipulation does not appear to be a critical factor for maximizing time spent above 90% and 95% of $\dot{V}O_2max$ during interval training with 1-min bouts. Future studies aiming to increase time near $\dot{V}O_2max$ could investigate the influence of longer exposure to work rate manipulation during longer work intervals (> 60 s) and with a higher total exercise volume. Additionally, it would be relevant to investigate whether these findings hold for protocols combining a decreasing work rate with shorter recovery intervals or a greater number of repetitions. The applicability of these results to individuals with different training levels should also be explored.

From a practical point of view, the $P_{peak}$ is an easy-to-use and accessible index integrating $\dot{V}O_2max$ and the energetic cost of movement (Billat & Koralsztein, 1996), useful for interval training planning (Buchheit & Laursen, 2013) which elicit $t\dot{V}O_2max$ and elevated metabolic demand in active individuals during a short-duration interval training session with a limited number of repetitions, which approximates a real practice scenario. However, it is important to note that $P_{peak}$ is protocol dependent, and potential differences should be considered in accordance with its determination. Finally, an increasing work rate manipulation is sometimes required in some sports events, but has received less attention (Sandford et al., 2019). This strategy elicited a higher mean $\dot{V}O_2$ during recovery periods, which could be insightful to designing interval training sessions combining this "delayed" $\dot{V}O_2$ response during the recovery period with work rate manipulations, which would maintain an elevated $\dot{V}O_2$ and consequently improve $t\dot{V}O_2max$.

## Conclusions

In conclusion, decreasing intensity from 110 to 90% $P_{peak}$ or increasing intensity from 90 to 110% $P_{peak}$ during work-matched cycling interval training with passive recovery did not impact time sustained above 90% of $\dot{V}O_2max$ and maximal heart rate, blood lactate concentrations, and rating of perceived exertion in comparison with a constant work rate at 100% $P_{peak}$ in active individuals. These findings indicate that coaches have flexibility when designing interval training protocols for active individuals aiming to optimize cardiorespiratory fitness. Specifically, varying work rates around $P_{peak}$ can be implemented to elicit similar physiological adaptations and potentially enhance training adherence and motivation. Future research should investigate the influence of prolonging the duration of these intervals in both active and trained populations to further explore these findings.

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## Conflict of interest

The authors report no conflict of interest.

## References

Bacon, A. P., Carter, R. E., Ogle, E. A., & Joyner, M. J. (2013). VO2max trainability and high intensity interval training in humans: A meta-analysis. *PLOS ONE*, *8*(9), Article e73182. https://doi.org/10.1371/journal.pone.0073182

Billat, L. V., & Koralsztein, J. P. (1996). Significance of the velocity at $VO_{2max}$ and time to exhaustion at this velocity. *Sports Medicine*, *22*(2), 90–108. https://doi.org/10.2165/00007256-199622020-00004

Billat, V., Petot, H., Karp, J. R., Sarre, G., Morton, R. H., & Mille-Hamard, L. (2013). The sustainability of VO2max: Effect of decreasing the workload. *European Journal of Applied Physiology*, *113*(2), 385–394. https://doi.org/10.1007/s00421-012-2424-7

Borg, G. A. V. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise*, *14*(5), 377–381. https://journals.lww.com/acsm-msse/abstract/1982/05000/psychophysical_bases_of_perceived_exertion.12.aspx

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle: Part I: Cardiopulmonary emphasis. *Sports Medicine*, *43*(5), 313–338. https://doi.org/10.1007/s40279-013-0029-x

Caputo, F., & Denadai, B. S. (2004). Effects of aerobic endurance training status and specificity on oxygen uptake kinetics during maximal exercise. *European Journal of Applied Physiology*, *93*(1–2), 87–95. https://doi.org/10.1007/s00421-004-1169-3

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences* (2nd ed.). Routledge. https://doi.org/10.4324/9780203771587

Coyle, E. F., Coggan, A. R., Hopper, M. K., & Walters, T. J. (1988). Determinants of endurance in well-trained cyclists. *Journal of Applied Physiology*, *64*(6), 2622–2630. https://doi.org/10.1152/jappl.1988.64.6.2622

de Aguiar, R. A., Turnes, T., de Oliveira Cruz, R. S., & Caputo, F. (2013). Fast-start strategy increases the time spent above 95 $\%VO_{2max}$ during severe-intensity intermittent running exercise. *European Journal of Applied Physiology*, *113*(4), 941–949. https://doi.org/10.1007/s00421-012-2508-4

De Pauw, K. D., Roelands, B., Cheung, S. S., de Geus, B., Rietjens, G., & Meeusen, R. (2013). Guidelines to classify subject groups in sport-science research. *International Journal of Sports Physiology and Performance*, *8*(2), 111–122. https://doi.org/10.1123/ijspp.8.2.111

Gillen, J. B., & Gibala, M. J. (2014). Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness? *Applied Physiology, Nutrition, and Metabolism*, *39*(3), 409–412. https://doi.org/10.1139/apnm-2013-0187

Iannetta, D., de Almeida Azevedo, R., Ingram, C. P., Keir, D. A., & Murias, J. M. (2020). Evaluating the suitability of supra-$PO_{peak}$ verification trials after ramp-incremental exercise to confirm the attainment of maximum $O_2$ uptake. *American Journal of Physiology – Regulatory, Integrative and Comparative Physiology*, *319*(3), R315–R322. https://doi.org/10.1152/ajpregu.00126.2020

Inglis, E. C., Iannetta, D., Rasica, L., Mackie, M. Z., Keir, D. A., Macinnis, M. J., & Murias, J. M. (2024). Heavy-, severe-, and extreme-, but not moderate-intensity exercise increase $\dot{V}o_{2max}$ and thresholds after 6 wk of training. *Medicine & Science in Sports & Exercise*, *56*(7), 1307. https://doi.org/10.1249/MSS.0000000000003406

Jackson, A. S., & Pollock, M. L. (1978). Generalized equations for predicting body density of men. *British Journal of Nutrition*, *40*(3), 497–504. https://doi.org/10.1079/BJN19780152

Jones, A. M., Wilkerson, D. P., Vanhatalo, A., & Burnley, M. (2008). Influence of pacing strategy on $O_2$ uptake and exercise tolerance. *Scandinavian Journal of Medicine & Science in Sports*, *18*(5), 615–626. https://doi.org/10.1111/j.1600-0838.2007.00725.x

Lisbôa, F. D., Raimundo, J. A. G., Salvador, A. F., Pereira, K. L., Turnes, T., Diefenthaeler, F., de Oliveira, M. F. M., & Caputo, F. (2019). Acute cardiopulmonary, metabolic, and neuromuscular responses to severe-intensity intermittent exercises. *Journal of Strength and Conditioning Research*, *33*(2), 408–416. https://doi.org/10.1519/jsc.0000000000002130

Lisbôa, F. D., Salvador, A. F., Raimundo, J. A. G., Pereira, K. L., de Aguiar, R. A., & Caputo, F. (2015). Decreasing power output increases aerobic contribution during low-volume severe-intensity intermittent exercise. *Journal of Strength and Conditioning Research*, *29*(9), 2434–2440. https://doi.org/10.1519/jsc.0000000000000914

MacInnis, M. J., & Gibala, M. J. (2017). Physiological adaptations to interval training and the role of exercise intensity. *Journal of Physiology*, *595*(9), 2915–2930. https://doi.org/10.1113/JP273196

Midgley, A. W., McNaughton, L. R., Polman, R., & Marchant, D. (2007). Criteria for determination of maximal oxygen uptake: A brief critique and recommendations for future research. *Sports Medicine*, *37*(12), 1019–1028. https://doi.org/10.2165/00007256-200737120-00002

Miller, P., Perez, N., & Farrell, J. W. (2023). Acute oxygen consumption response to fast start high-intensity intermittent exercise. *Sports*, *11*(12), Article 238. https://doi.org/10.3390/sports11120238

Mølmen, K. S., & Rønnestad, B. R. (2024). A narrative review exploring advances in interval training for endurance athletes. *Applied Physiology, Nutrition, and Metabolism*, *49*(7), 1008–1013. https://doi.org/10.1139/apnm-2023-0603

Odden, I., Nymoen, L., Urianstad, T., Kristoffersen, M., Hammarström, D., Hansen, J., Mølmen, K. S., & Rønnestad, B. R. (2024). The higher the fraction of maximal oxygen uptake is during interval training, the greater is the cycling performance gain. *European Journal of Sport Science*, *24*(11), 1583–1596. https://doi.org/10.1002/ejsc.12202

Robergs, R. A., Dwyer, D., & Astorino, T. (2010). Recommendations for improved data processing from expired gas analysis indirect calorimetry. *Sports Medicine*, *40*(2), 95–111. https://doi.org/10.2165/11319670-000000000-00000

Rønnestad, B. R., Bakken, T. A., Thyli, V., Hansen, J., Ellefsen, S., & Hammarstrøm, D. (2022). Increasing oxygen uptake in cross-country skiers by speed variation in work intervals. *International Journal of Sports Physiology and Performance*, *17*(3), 384–390. https://doi.org/10.1123/ijspp.2021-0226

Rønnestad, B. R., Rømer, T., & Hansen, J. (2020). Increasing oxygen uptake in well-trained cross-country skiers during work intervals with a fast start. *International Journal of Sports Physiology and Performance*, *15*(3), 383–389. https://doi.org/10.1123/ijspp.2018-0360

Sandford, G. N., Day, B. T., & Rogers, S. A. (2019). Racing fast and slow: Defining the tactical behavior that differentiates medalists in elite men's 1,500 m championship racing. *Frontiers in Sports and Active Living*, *1*, Article 43. https://doi.org/10.3389/fspor.2019.00043

Siri, W. E. (1961). Body composition from fluid spaces and density: Analysis of methods. In J. Brožek & A. Henschel (Eds.), *Techniques for measuring body composition* (pp. 223–244). National Academy of Sciences. https://www.nationalacademies.org/read/21603/chapter/5#223

Thevenet, D., Tardieu, M., Zouhal, H., Jacob, C., Abderrahman, B. A., & Prioux, J. (2007). Influence of exercise intensity on time spent at high percentage of maximal oxygen uptake during an intermittent session in young endurance-trained athletes. *European Journal of Applied Physiology*, *102*(1), 19–26. https://doi.org/10.1007/s00421-007-0540-6

Turnes, T., De Aguiar, R. A., Cruz, R. S. D. O., & Caputo, F. (2016). Interval training in the boundaries of severe domain: Effects on aerobic parameters. *European Journal of Applied Physiology*, *116*(1), 161–169. https://doi.org/10.1007/s00421-015-3263-0

Weston, K. S., Wisløff, U., & Coombes, J. S. (2014). High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *48*(16), 1227–1234. https://doi.org/10.1136/bjsports-2013-092576

Weston, M., Taylor, K. L., Batterham, A. M., & Hopkins, W. G. (2014). Effects of low-volume high-intensity interval training (HIT) on fitness in adults: A meta-analysis of controlled and non-controlled trials. *Sports Medicine*, *44*(7), 1005–1017. https://doi.org/10.1007/s40279-014-0180-z

Wommer, D., Turnes, T., Souza, K., & Guglielmo, L. G. A. (2022). Similar time near $VO_2$max regardless of work rate manipulation in cycling interval training. *International Journal of Sports Medicine*, *43*(4), 350–356. https://doi.org/10.1055/a-1550-9977

Yoshida, T., Chida, M., Ichioka, M., & Suda, Y. (1987). Blood lactate parameters related to aerobic capacity and endurance performance. *European Journal of Applied Physiology and Occupational Physiology*, *56*(1), 7–11. https://doi.org/10.1007/bf00696368

Zadow, E., Gordon, N., Abbiss, C., & Peiffer, J. (2015). Pacing, the missing piece of the puzzle to high-intensity interval training. *International Journal of Sports Medicine*, *36*(3), 215–219. https://doi.org/10.1055/s-0034-1389973