Optimizing Interval Training at Power Output Associated With Peak Oxygen Uptake in Well-Trained Cyclists

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Abstract

Rønnestad, BR and Hansen, J. Optimizing interval training at power output associated with peak oxygen uptake in well-trained cyclists. *J Strength Cond Res* 30(4): 999–1006, 2016—The purpose of this study was to investigate the acute physiological responses of interval protocols using the minimal power output (MAP) that elicits peak oxygen uptake ($\dot{V}O_2$peak) as exercise intensity and different durations of work intervals during intermittent cycling. In randomized order, 13 well-trained male cyclists ($\dot{V}O_2$peak = 67 ± 6 ml·kg^{-1}·min^{-1}) performed 3 different interval protocols to exhaustion. Time to exhaustion and time ≥ 90% of $\dot{V}O_2$peak were measured with MAP as exercise intensity, and work duration of the intervals equals either 80% of T_{max}, 50% of T_{max}, or 30 seconds with recovery period being 50% of the work duration at intensity equal to 50% of MAP. The major findings were that the interval protocol using 30-second work periods induced longer time ≥90% of $\dot{V}O_2$peak and longer work duration at MAP intensity than the interval protocols using work periods of 50% of T_{max} or 80% of T_{max} ($p \leq 0.05$). There was no difference between the protocols using work periods of 50% of T_{max} or 80% of T_{max}. In conclusion, the present study suggests that the 30-second work interval protocol acutely induces a larger exercise stimulus in well-trained cyclists than the protocols using work periods of 50% of T_{max} or 80% of T_{max}. The practical application of the present findings is that fixed 30-second work intervals can be used to optimize training time at MAP and time ≥90% of $\dot{V}O_2$peak in well-trained cyclists using MAP exercise intensity and a 2:1 work:recovery ratio.

Key Words intense cycling exercise, interval training prescription, endurance training

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Introduction

For a long time, it has been recognized that high-intensity interval training can improve endurance performance (e.g., Refs. 16,33). Especially, for well-trained endurance athletes to achieve optimal training stimulus on maximal oxygen uptake ($\dot{V}O_2$max), it has been recommended to perform a certain amount of training at intensities of 90–100% of $\dot{V}O_2$max (21,30,40). Moreover, it has been suggested that the training time ≥90% $\dot{V}O_2$max could serve as good criteria to judge the effectiveness of the stimulus to improve aerobic fitness (38). However, continuous work at such high intensities cannot be sustained for a long time and thus limits total training time at this intensity during a single training session. It has been concluded that, to spend a long time at or close to $\dot{V}O_2$max, the minimal exercise intensity that elicits $\dot{V}O_2$max during a graded test (minimal power output [MAP]) is an essential training intensity (3,19,21,26). Because the time that an athlete can exercise at his or her MAP (T_{max}) is highly individual (4), the fractional utilization of T_{max} has been suggested as an appropriate reference to establish the individual interval duration.

Examination of high-intensity interval training protocols in well-trained runners suggests MAP as the exercise intensity and the duration of each work interval should be between 50 and 75% of T_{max} (2,6,34,35). Furthermore, intermittent runs at MAP with short nonindividualized work intervals (often 30 seconds) have been shown effective in eliciting a long time ≥90% of $\dot{V}O_2$max (6,27,37,38). Surprisingly, this approach of MAP and T_{max} has not been extensively investigated in the exercise mode of cycling. Based on previous observations of differences in $\dot{V}O_2$ kinetics between the exercise mode of running and cycling (9,10) and a greater degree of metabolic acidosis during cycling than during running (20), it may be suggested that findings from running cannot be transferred directly to cycling. To the best of our knowledge, only the group of Laursen has focused on this approach to prescribe interval training in well-trained cyclists. They have suggested using MAP as the interval intensity and 60% of T_{max} as the interval duration for well-trained cyclists (23). However, they did not compare the effects of using different fractions other than 60% of T_{max}. Therefore, there is a need to look closer at

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Table 1. Physical characteristics of participants ($n = 13$).

Characteristics	Value*	Range
Age (y)	29 ± 2	20–39
Height (cm)	179 ± 6	166–190
Body mass (kg)	73.4 ± 5.1	65.5–84.6
$\dot{V}O_2$peak† (ml·kg^{-1}·min^{-1})	66.7 ± 6.1	56.4–75.4
Heart rate peak (b·min^{-1})	193 ± 7	176–202
BLa_{peak} (mmol·L^{-1})	14.0 ± 1.9	10.9–16.7
RPE_{peak}	19.5 ± 0.5	19–20
MAP (W)	375 ± 41	325–425
T_{max} (s)	340 ± 108	184–520

*Values are mean ± *SD*.
†$\dot{V}O_2$peak = peak oxygen uptake; BLa_{peak} = peak blood lactate concentration; RPE_{peak} = peak rate of perceived exertion; MAP = minimal power output that elicits $\dot{V}O_2$peak; T_{max} = time to exhaustion during continuously cycling to exhaustion at MAP.

the effect of different exercise durations for each work interval on time ≥90% of $\dot{V}O_2$max in the exercise mode of cycling.

The primary purpose of this study was thus to investigate the effect of interval durations of 30 seconds, 50% of T_{max}, and 80% of T_{max} on their associated time ≥90% of peak oxygen uptake ($\dot{V}O_2$peak) during intermittent cycling exercise to exhaustion with an active recovery at 50% of MAP lasting half of the work periods.

Methods

Experimental Approach to the Problem

The participants visited the test laboratory on 5 separate occasions. The first test session was used to determine MAP and $\dot{V}O_2$peak by a graded protocol to exhaustion. The second test session was used to determine T_{max}. On the subsequent 3 visits, time to exhaustion and time ≥90% of $\dot{V}O_2$peak was measured with MAP as exercise intensity, and work duration of the intervals equals either 30 seconds, 50% of T_{max}, or 80% of T_{max} with recovery period being 50% of the work duration at intensity equal to 50% of MAP. The order of interval protocols on the third, fourth, or fifth test session was randomized. All tests were performed within a period of 3 weeks, during which the participants were asked to maintain normal activity and training.

Subjects

Thirteen well-trained male cyclists volunteered for the study (Table 1 for descriptive characteristics). All participants trained for 6 hours or more per week during the 3 months before the intervention. All participants provided written informed consent to participate in the study that was approved by the institution's ethics committee, in accordance with the Declaration of Helsinki.

Procedures

The cyclists were instructed to refrain from all types of intense exercise the day preceding each of the 5 test days.

Table 2. Characteristics and responses during intermittent cycling to exhaustion with work intervals of 30 seconds, 50% of T_{max}, or 80% of T_{max} ($n = 13$).*

	30 Seconds	Range	50% of T_{max}	Range	80% of T_{max}	Range
Work period (s)	30 ± 0	30–30	170 ± 54	92–260	272 ± 86	147–416
Recovery period (s)	15 ± 0	15–15	85 ± 27	46–130	136 ± 43	74–208
TTE (s)	1385 ± 547†	567–2777	827 ± 283	396–1484	642 ± 191	281–952
$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1})	67.1 ± 5.2	58.8–77.1	67.7 ± 6.4	57.5–78.6	67.6 ± 5.9	57.6–76.9
HRpeak (b·min^{-1})	188 ± 6	179–193	189 ± 8	184–203	186 ± 6	181–193
RPE_{peak}	19.3 ± 0.9	18–20	19.6 ± 0.5	19–20	19.1 ± 0.7	18–20
BLa_{peak} (mmol·L^{-1})	13.0 ± 2.7	7.1–16.1	14.9 ± 1.0‡	13.2–15.9	14.3 ± 1.8	11.0–16.0
Time to 90% of $\dot{V}O_2$peak (s)	306 ± 140	135–615	120 ± 47‡	75–240	127 ± 39‡	75–195
Time to 90% of $\dot{V}O_2$peak (% TTE)	22 ± 8	13–40	15 ± 6	8–28	23 ± 15	8–34
Time ≥90% of $\dot{V}O_2$peak (s)	678 ± 270†	345–1260	397 ± 156	150–735	366 ± 127	180–630
Time ≥90% of $\dot{V}O_2$peak (% TTE)	55 ± 23	19–80	48 ± 11	18–57	57 ± 7	48–67
Time ≥90% of HRpeak (s)	832 ± 486†	300–1905	376 ± 144	90–555	302 ± 166	60–585
Time ≥90% of HRpeak (% TTE)	59 ± 20§	19–81	47 ± 16	12–68	48 ± 21	18–76

*TTE = time to exhaustion; $\dot{V}O_2$peak = peak oxygen uptake; HRpeak = peak heart rate; RPE_{peak} = rate of perceived exertion (measured immediately after termination of the interval protocol); BLa_{peak} = peak blood lactate concentration.
†Significant different from the other interval protocols ($p < 0.01$).
‡Significant different from the interval protocol using 30-second work intervals ($p \leq 0.05$).
§Tendency toward different from the other interval protocols ($p < 0.1$).

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They were also instructed to consume the same type of meal before each test and were not allowed to eat during the hour preceding a test or to consume coffee or other products containing caffeine during the 3 hours preceding the tests. All tests were performed under similar environmental conditions (18–21° C) with a fan ensuring circulating air around the cyclist. Strong verbal encouragement was given during all tests to ensure maximal effort. All tests for the individual participant were conducted at the same time of day (±1 hour) to avoid influence of circadian rhythm. All testing was performed on the same electromagnetically braked cycle ergometer (Lode Excalibur Sport; Lode BV, Groningen, The Netherlands), which was adjusted according to each cyclist's preference for seat height, horizontal distance between tip of seat and bottom bracket, and handlebar position. Identical seating positions were used at all tests.

Determination of $\dot{V}O_2$peak and Minimal Power Output

A 20-minute individual warm-up was performed before the start of the graded protocol to exhaustion for determination of $\dot{V}O_2$peak. This test has been described elsewhere (31). Briefly, the test was initiated with 1 minute of cycling at a power output corresponding to 3 $W \cdot kg^{-1}$ (rounded down to the nearest 50 W). Power output was subsequently increased by 25 W every minute until exhaustion. $\dot{V}O_2$peak was calculated as the average of the 2 highest 30 seconds $\dot{V}O_2$ measurements by using a computerized metabolic system with mixing chamber (Oxycon Pro; Erich Jaeger, Hoechberg, Germany). The gas analyzers were calibrated with certified calibration gases of known concentrations before every test. The flow turbine (Triple V; Erich Jaeger) was calibrated before every test with a 3 L calibration syringe (5530 series; Hans Rudolph, Kansas City, KS, USA). The same metabolic system with identical calibration routines was used on all subsequent tests. Heart rate (HR) was measured using a Polar S610i heart rate monitor (Polar, Kempele, Finland). Blood lactate concentration ($[la^-]$) at exhaustion was measured using blood samples from a fingertip and was analyzed for whole blood $[la^-]$ using a portable lactate analyzer (Lactate Pro LT-1710; Arcray, Inc., Kyoto, Japan). Heart rate ≥ 95% of the subjects reported that maximal HR, RER ≥ 1.05, and $[la^-] \geq 8.0$ $mmol \cdot L^{-1}$ were used as criteria to evaluate if $\dot{V}O_2$peak was obtained. Minimal power output was calculated according to the description of Billat and Koralsztein (3): The lowest power output that elicited $\dot{V}O_2 < 2.1$ $ml \cdot kg^{-1} \cdot min^{-1}$ of $\dot{V}O_2$peak during the graded $\dot{V}O_2$peak protocol. For training prescription, this method has been suggested to be the most appropriate as it accounts for the anaerobic contribution to metabolism necessary to elicit $\dot{V}O_2$max (26).

Determination of T_{max}

Before starting the T_{max} test, the participants performed a 15-minute individual warm-up that was concluded by 2–3 submaximal sprints lasting 20–30 seconds. Thereafter, participants cycled to fatigue at their individual MAP with a self-selected cadence; the test was stopped when cadence fell below 60 rpm (22,23). Just before the start of the T_{max} test, the participants were pedaling with a freely chosen cadence (80–105 rpm) with zero power output. The test started with an instant increase in power output (rate of 1000 $W \cdot s^{-1}$) to MAP. This procedure for warm-up, start, and termination of test was also applied when testing the effects of different durations of work intervals on time ≥90% $\dot{V}O_2$peak. The participants exhibit similar $\dot{V}O_2$peak during T_{max} testing as during MAP testing (67.2 ± 4.8 vs. 66.6 ± 5.4 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively).

Determination of Time ≥90% $\dot{V}O_2$peak During Intermittent Cycling at Minimal Power Output to Exhaustion

Participants were blinded to the time elapsed on all testing occasions. Time to exhaustion included the recovery periods and was regarded as the time between the start of the first interval and the termination of the test. Oxygen uptake and

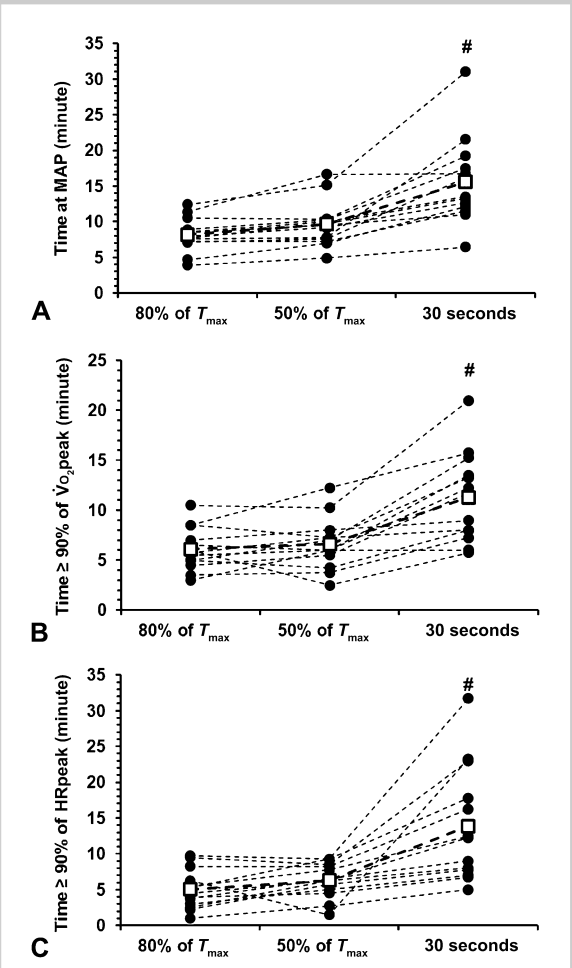


Figure 1. Individual data points for (A) time at the lowest power output that elicit peak oxygen uptake ($[\dot{V}O_2peak]$ [minimal power output]), (B) time ≥90% of $\dot{V}O_2$peak, and (C) time ≥90% of peak heart rate (HRpeak) during intermittent cycling to exhaustion with work intervals of 30 seconds, 50% of T_{max}, or 80% of T_{max}. Open squares represent the mean value of the data points. #Significantly larger than the other interval protocols ($p < 0.01$).

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HR were recorded at 15-second intervals throughout exercise. The time ≥90% of $\dot{V}O_2$peak was calculated by the accumulation of $\dot{V}O_2$ values ≥90% of the $\dot{V}O_2$peak obtained from the graded exercise test to exhaustion. Several studies have focused on time spent above 90% of $\dot{V}O_2$max in intermittent runs at MAP (e.g., Refs. 14,15,27,32). The exercise intensity during the intermittent cycling to exhaustion was set to MAP, and work duration of the intervals was either 30 seconds, 50% of T_{max}, or 80% of T_{max} with relief intervals performed for 50% of the work duration at 50% of MAP. A 2:1 work:recovery ratio has also previously been used (reviewed in 26,32).

Blood samples were taken from a fingertip while the cyclists were cycling on the cycle ergometer every fifth minute and at exhaustion and were analyzed for [la^-]. Nine of the participants exercised >10 minutes before exhaustion on all 3 interval protocols and their [la^-] data at 5 minutes, 10 minutes, and at exhaustion are presented in Figure 3. Rate of perceived exertion (RPE) was recorded at exhaustion of each interval protocol by using Borg's 6–20 scale (8).

Preliminary measurements of cardiac stroke volume (SV) were performed on 6 participants on the intervals sessions with 30 seconds and 50% of T_{max} as work periods. Stroke volume was measured beat-by-beat by a noninvasive cardiac output measurement using analysis of instant thoracic impedance variations (PhysioFlow Enduro; Manatec Biomedical, Paris, France). The theoretical basis for this device and its validity during rest and exercise testing has been previously published (11,29,39). Briefly, 2 electrodes were placed at position CB_5 for electrocardiographic measurements and 2 pairs of electrodes (1 transmitting and 1 sensing) were placed above the supraclavicular fossa at the left base of the neck and along the xiphoid. No specific skin preparation, except shaving, is needed and unlike traditional impedance method, positioning of electrodes is not critical (11). After placement of the electrodes, the participant's age, height, body mass, systolic blood pressure, and diastolic blood pressure are entered. Thereafter, the participant has to be immobile and relaxed while an autocalibration procedure takes place to provide basic curves and data necessary to measure SV variations (11). Stroke volume was averaged every 5 seconds. Peak SV (SV_{peak}) was identified as the highest averaged 30-second value during each interval session and time ≥90% of SV_{peak} was calculated by the accumulation of SV values ≥90% of SV_{peak}.

Statistical Analyses

All values presented in the text, figures, and tables are mean ± *SD*s. To analyze whether there was differences in physiological responses between intermittent exercise using either work periods of 30 seconds, 50% of T_{max}, or 80% of T_{max}, a 1-way analysis of variance (ANOVA) was used. If there was a significant difference, a Tuckey's HSD test was preselected for post hoc analysis. To test for differences in time ≥ 90% of peak SV between the interval protocol using 30-second work periods and the protocol using work periods of 50% of T_{max}, paired Student's *t*-test was used. The *t*-test was performed in Excel 2010 (Microsoft Corporation, Redmond, WA, USA) and ANOVA were performed in GraphPad (GraphPad Software, Inc., CA, USA). Test-retest reliability (intraclass correlations) for time to exhaustion protocol was 0.92 ($p < 0.01$). There was a statistical power of 80% to detect differences between groups in time ≥90% of $\dot{V}O_2$peak of 2.5 minutes, using a significance level (alpha) of 0.05. All analyses resulting in $p \leq 0.05$ were considered statistically significant. Values of p between 0.06 and 0.10 are described as tendencies.

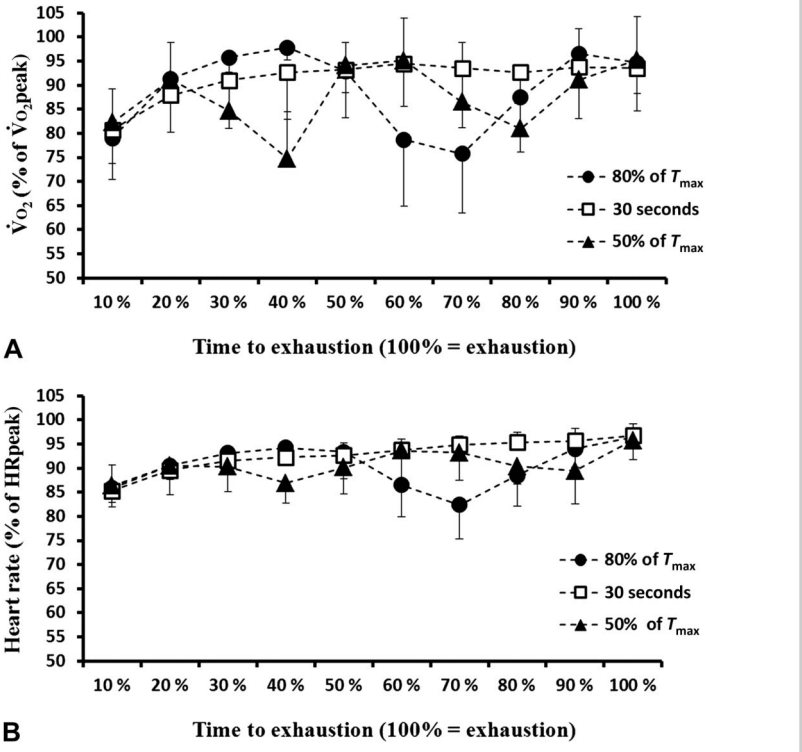


Figure 2. Oxygen uptake ($\dot{V}O_2$, panel A) and HR (panel B) during cycling to exhaustion with work intervals of 30 seconds, 50% of T_{max}, or 80% of T_{max} expressed as percentage of time to exhaustion.

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Results

Responses during intermittent cycling to exhaustion with work intervals of 30 seconds, 50% of T_{max}, or 80% of T_{max} are shown in Table 2. The interval protocol using 30-second work periods induced a longer time ≥90% of $\dot{V}O_2$peak, longer time ≥90% of HRpeak, and longer work duration at MAP intensity than the interval protocols using work periods of 50% of T_{max} or 80% of T_{max} (individual data are presented in Figure 1, all $p < 0.01$). There were no differences between interval protocols when time ≥90% of $\dot{V}O_2$peak was as expressed as percentages of time to exhaustion (Table 2). However, when time ≥90% of HRpeak was as expressed in the same way, there was tendency toward superiority of the protocol using 30-second work intervals ($p < 0.1$; Table 2). Figure 2 shows the mean $\dot{V}O_2$ and HR response during the 3 different interval protocols as percentage of time to exhaustion.

After 5 minutes of exercise, the [la^-] was lower in the interval protocol using work periods of 30 seconds than the 2 other protocols (Figure 3; $p < 0.01$). After 10 minutes, there was still a lower [la^-] in the 30-second protocol than the 50% of T_{max} protocol ($p \leq 0.05$; Figure 3) and there was a tendency toward lower [la^-] than the 80% of T_{max} protocol ($p < 0.1$; Figure 3). During the preliminary measurement of SV, there was no difference in SV_{peak} between the interval protocol using 30-second work intervals and the protocol using work periods of 50% of T_{max} (173 ± 21 ml·beat^{-1} and 179 ± 23 ml·beat^{-1}, respectively). However, the protocol using 30-second work intervals induced a longer time ≥90% of SV_{peak} than the protocol using work periods of 50% of T_{max} (787 ± 447 vs. 510 ± 336 seconds, respectively, $p \leq 0.05$).

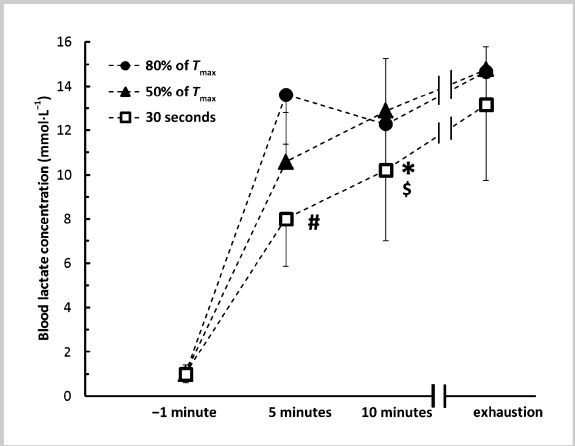


Figure 3. Blood lactate concentration before (−1 minute), after 5 minutes, after 10 minutes, and at exhaustion during cycling to exhaustion with work intervals of 30 seconds, 50% of T_{max}, or 80% of T_{max} ($n = 9$). #, Significantly lower than the other interval protocols ($p < 0.01$). *, Significantly lower than the interval protocol using 50% of T_{max} as work intervals ($p < 0.05$). $, Tendency toward different from the interval protocol using 80% of T_{max} as work intervals ($p < 0.1$).

Discussion

The primary finding of the present study was that the interval protocol using 30-second work periods induced a longer time ≥90% of $\dot{V}O_2$peak, longer time ≥90% of HRpeak, and longer work duration at MAP intensity than the interval protocols using work periods of 50% of T_{max} and 80% of T_{max}.

Although not directly comparable, the present findings diverge somewhat from the findings of Millet et al. (27). They compared, amongst others, intermittent runs at MAP with a work duration of 30 seconds and 50% of T_{max} with a 1:1 work:recovery ratio and a recovery intensity of 50% of MAP. They found that work intervals lasting 50% of T_{max} resulted in greater time ≥90% of $\dot{V}O_2$peak than work intervals of 30 seconds (~8 vs. ~2.5 minutes, respectively). However, amongst the methodological differences, the present study uses 15-second recovery intervals, whereas Millet et al. (27) used 30 seconds. It may be suggested that doubling the recovery periods from 15 to 30 seconds contributes to the fall in HR and $\dot{V}O_2$ during the recovery period, thereby delaying time to achieve ≥90% of $\dot{V}O_2$peak during the work intervals. Accordingly, reducing the recovery periods by one-half (i.e., 15 seconds) during a protocol with 30-second work intervals seems to increases running time ≥90% of $\dot{V}O_2$peak (32). Moreover, in neither of the abovementioned studies were the interval protocols performed until exhaustion (27,32). Billat et al. (6) performed intermittent running (30 seconds at MAP with 30-second recovery at 50% of MAP) to exhaustion and observed that time at or near $\dot{V}O_2$max (defined as time above $\dot{V}O_2$max − 2.1 ml·kg^{-1}·min^{-1}) was ~8 minutes. In the present study, time ≥90% of $\dot{V}O_2$peak in the protocol using 30-second work periods was ~11 minutes. When taking into account a slightly lower percentage of $\dot{V}O_2$peak and shorter recovery periods with assumingly a lower fall in $\dot{V}O_2$ and HR, the present results are in accordance with the findings of Billat et al. (6). To the contrary, Thevenet et al. (38) used the same interval running protocol as Billat et al. (6) and reported approximately one-half of the time ≥90% of $\dot{V}O_2$peak than the present study. That being said, time to exhaustion in the study of Thevenet et al. (38) was approximately the same as in the present (24 vs. 23 minutes, respectively). Therefore, 1 reason for the different time ≥90% of $\dot{V}O_2$peak is likely to be related to increased fall in HR and $\dot{V}O_2$ during the 15-second longer recovery period in the study of Thevenet et al. (38). Another reason may be that time to achieve 90% of $\dot{V}O_2$peak is likely to be shorter when the recovery periods are 15 seconds instead of 30 seconds. Accordingly, time to 90% of $\dot{V}O_2$peak was 438 seconds in the study of Thevenet et al. (38), whereas it was 306 seconds in the present study.

Time to achieve 90% of $\dot{V}O_2$peak was shorter when using protocols with 50 and 80% of T_{max} as work intervals (120 and 127 seconds, respectively) than fixed 30-second work periods. This finding is in agreement with the initial argument for using 50–80% of T_{max}: This timeframe enables athletes to reach high $\dot{V}O_2$ values (e.g., Refs. 2,6,34,35). However, despite

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this faster achievement of 90% of $\dot{V}O_2$peak in the 50 and 80% of T_{max} protocol, it was not enough to fully compensate for the lower total work period before exhaustion and the drop in $\dot{V}O_2$ during the longer recovery periods (Figure 2)–leading to lower time ≥90% of $\dot{V}O_2$peak than the protocol using 30-second work periods. The lower total time at MAP is likely to be caused by earlier fatigue because of the longer work intervals and too short duration of the recovery intervals to compensate for the developed fatigue. An indication of this is shown in Figure 3, where the 50 and 80% of T_{max} protocols had higher [la^-] after 5 minutes and a tendency to being higher also after 10 minutes of the protocols. The present findings of a slightly lower [la^-] after the protocol using 30-second work intervals are in line with the finding of a nonsignificant lower [la^-] at exhaustion after 30-second intervals than after continuous exercise (6). Metabolic acidosis may be related to muscular fatigue during intermittent supramaximal exercise (7). Taking into account the close relationship between [la^-] and H^+ ions responsible for acidosis, the present [la^-] values could contribute to explain the longer time to exhaustion and longer time at MAP in the protocol using 30-second work intervals.

Among others, the delayed [la^-] accumulation in the protocol using 30-second work intervals may be because of multiple refilling of O_2 to muscular myoglobin. Actually, already in 1960 it was suggested by Åstrand et al. (1) that the contribution to the used energy from O_2 bounded to myoglobin is larger during short intermittent exercise than during intermittent exercise with longer work intervals. During the protocol with 30-second work intervals and 15-second recovery periods, the myoglobin may function as a O_2-store in the beginning of each work interval that also recharges during the recovery period (12), thereby reducing reliance on anaerobic glycolysis. Another related advantage of the protocol using 30-second work intervals with 15-second recovery breaks may be that the frequent recovery periods allows for adequate resynthesis of phosphocreatine (17). This may lead to a larger contribution to the total energy consumption from breakdown of phosphocreatine. Furthermore, fatigue during intermittent supramaximal exercise seems to be largely related to limitations in energy supply, like reduced phosphocreatine content (7,25). The frequent resynthesis of phosphocreatine during the multiple short recovery periods is likely to be 1 important reason for the longer time to exhaustion in the protocol using 30-second work intervals.

In addition to a superior stimulus on the cardioventilatory system, the protocol using 30-second work periods also lead to a longer time at MAP than the protocols using 50 and 80% of T_{max} (~15.5, ~9.5, and ~8 minutes, respectively). It has been suggested that time spent at this high exercise intensity (i.e., MAP) might have an additive effect on muscular adaptations (13,28). Therefore, it might be hypothesized that the 30-second protocol also facilitates a greater stimulus on the neuromuscular system. Furthermore, the strength of stimuli that elicit adaptation in well-trained athletes (e.g., increased maximal SV, capillarization, myoglobin concentration, and oxidative capacity of type II skeletal muscle fibers) seems to be exercise intensity dependent (40). Interestingly, the preliminary measurement of time ≥90% of SV_{peak} in 6 participants in the protocols using work intervals of 30 seconds and 50% of T_{max} revealed superiority of the 30-second protocol (~13 vs. ~8.5 minutes, respectively). An increase in SV until ~90% of $\dot{V}O_2$peak in endurance-trained athletes has frequently been observed (e.g., Refs. 5,18,24). Although the latter is not a uniform finding (36), the present observation of largest time ≥90% of SV_{peak} in the protocol eliciting largest time ≥90% of $\dot{V}O_2$peak seems logical and supports the present findings of a superior acute exercise stimulus by the protocol using 30-second work intervals.

It may be speculated that another work:recovery ratio would lead to different findings. A longer recovery period between the protocols using 50 and 80% of T_{max} is likely to increase time to exhaustion. However, it might also increase the time to achieve ≥90% of $\dot{V}O_2$peak in each work interval and induce a larger drop in $\dot{V}O_2$ and HR during the recovery period. The finding of no differences between the interval protocols using work duration of 50 and 80% of T_{max} may be related to the fact that both work durations are within the frequently recommended percentages of T_{max}. That being said, these percentages of T_{max} are from the upper and lower limits of the recommended 50–75% of T_{max} (e.g., Refs. 2,6,35). The use of a certain percentage of T_{max} was suggested to be a method of individualizing training prescription and thereby achieving superior training adaptations than the usual fixed duration training. Indeed, intervention studies in long-distance runners have shown significant improvements in performance determinants by interval protocols using 50–75% of T_{max} (e.g., Refs. 2,13,35). To the best of our knowledge, the only training study using MAP as the exercise intensity and a percentage of T_{max} (60%) as the duration in trained cyclists reported performance improvements (23). This research group suggests that 60–70% of T_{max} is the appropriate exercise duration for well-trained cyclists to maximize time near or at $\dot{V}O_2$peak during intermittent exercise at MAP (22). The present findings indicate that work intervals with both 50 and 80% of T_{max} give a substantial time ≥90% of $\dot{V}O_2$peak. However, when using 2:1 work:recovery ratio, a protocol using fixed 30-second work intervals may lead to larger exercise stimulus than work intervals of 50 or 80% of T_{max}. Whether this actually induces superior training adaptations remains to be investigated.

In conclusion, the present study suggests that interval protocol using 30-second work periods induces a larger exercise stimulus in well-trained cyclists than interval protocols using work periods of 50 and 80% of T_{max} when MAP is the exercise intensity and the work:recovery ratio is 2:1.

Practical Applications

The present findings indicate that work intervals with both 50 and 80% of T_{max} give a substantial time ≥90% of $\dot{V}O_2$peak. However, when using 2:1 work:recovery ratio,

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a protocol using fixed 30-second work intervals seems to induce a longer time ≥90% of $\dot{V}O_2$peak and longer time at MAP intensity than work period of 50 or 80% of T_{max}. Therefore, when coaches aim to optimize time ≥90% of $\dot{V}O_2$peak, they are recommended to use the 30-second work interval protocol. To reduce the monotony of a training programme, coaches may wish to use a mixture of shorter and more prolonged interval training sessions when designing their athletes' training programmes, but superior results may be obtained using short interval durations at the MAP intensity. It is likely that the acute larger time at high $\dot{V}O_2$ in the 30-second work interval protocol can induce larger training adaptations.

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