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Effects of Work and Recovery Duration and Their Ratio on Cardiorespiratory and Metabolic Responses During Aerobic Interval Exercise

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Abstract

Myrkos, A, Smilios, I, Zafeiridis, A, Iliopoulos, S, Kokkinou, EM, Douda, H, and Tokmakidis, SP. Effects of work and recovery duration and their ratio on cardiorespiratory and metabolic responses during aerobic interval exercise. *J Strength Cond Res* XX(X): 000–000, 2020—This study examined the effect of work and recovery durations and of work-to-rest ratio (WRR) on total exercise time and oxygen consumption ($\dot{V}O_2max$), on exercise time above 80, 90, and 95% of $\dot{V}O_2max$ and HRmax, and on blood lactate concentrations during aerobic interval exercise. Twelve men (22.1 ± 1 year) executed, until exhaustion, 4 interval protocols at an intensity corresponding to 100% of maximal aerobic velocity. Two protocols were performed with work bout duration of 120 seconds and recovery durations of 120 (WRR: 1:1) or 60 seconds (WRR: 2:1), and 2 protocols with work bout duration of 60 seconds and recovery durations of 60 (WRR: 1:1) or 30 seconds (WRR: 2:1). When compared at equal exercise time, total $\dot{V}O_2$ and exercise time at $\dot{V}O_2$ above 80, 90, and 95% of $\dot{V}O_2max$ were longer ($p < 0.05$) in 120:120, 120:60 and 60:30 vs. the 60:60 protocol. When analyzed for total exercise time (until exhaustion), total $\dot{V}O_2$ was higher ($p < 0.01$) in the 60:60 compared with all other protocols, and in the 120:120 compared with 120:60. Exercise time >95% of $\dot{V}O_2max$ and HRmax was higher ($p < 0.05$) in the 120:120 vs. the 60:60 protocol; there were no differences among protocols for exercise time >90% of $\dot{V}O_2max$ and HRmax. Blood lactate was lower ($p < 0.05$) in the 60:60 compared with all other protocols and in the 60:30 vs. the 120:60. In conclusion, when interval exercise protocols are executed at similar effort (until exhaustion), work and recovery durations do not, in general, affect exercise time at high oxygen consumption and HR rates. However, as work duration decreases, a higher work-to-recovery ratio (e.g., 2:1) should be used to achieve and maintain high (>95% of maximum) cardiorespiratory stimulus. Longer work bouts and higher work-to-recovery ratio seem to activate anaerobic glycolysis to a greater extent, as suggested by greater blood lactate concentrations.

Key Words: work-to-rest ratio, repetition duration, oxygen consumption, heart rate, lactate, rest duration

Introduction

Aerobic interval training is an effective method to enhance endurance capacity in athletic and diseased populations. The efficacy of an interval training session may depend on the total stress placed on the oxygen transport (central) and consumption (peripheral) systems (1,27). Exercising with high rates of oxygen consumption ($\dot{V}O_2$) may place both the central and the peripheral components under stress, sufficient to optimize physiological adaptations. Therefore, total exercise duration at high percentage of maximal oxygen consumption (i.e., >90% of $\dot{V}O_2max$) may be important for the improvement of aerobic capacity (10,23).

Previous studies have shown that the exercise intensity during an interval training session should be between 90 and 105% of maximal aerobic velocity (MAV) to accumulate enough exercise time spent with oxygen consumption above 90% of $\dot{V}O_2max$ (22,24,28–30). Regarding the effects of work bout duration, when interval training is executed for a predetermined number of repetitions (total exercise time), long work bouts (≥60 seconds) allow more exercise time spent above 90% of $\dot{V}O_2max$ compared with short work bouts (<60 seconds) (11,13,17). When, however, the interval sessions are executed near to exhaustion, short work bouts allow the attainment of similar (30) or longer (16) exercise times spent at high percentages of $\dot{V}O_2max$ compared with longer work bouts. Based on the limited number of studies and their contradictory results, it is unclear whether increasing the duration of long work bouts would also increase exercise time at high $\dot{V}O_2$ rates and thus, the stimulus for aerobic adaptations. For example, 60- and 120-second work bouts are commonly used for the development of aerobic fitness in healthy and athletic populations (2,8,9,12,14,15,18), but is unknown if they elicit different cardiorespiratory and metabolic responses when a high-intensity interval session is performed either for equal exercise time or near to exhaustion.

Recovery duration and work to recovery ratio are also important parameters to consider when designing an aerobic interval training session. Modifications of these parameters may alter the contribution of the energy systems to total energy production and the overall physiological stress. A shorter recovery interval may accelerate fatigue development and reduce total exercise time and $\dot{V}O_2$ and thus, diminish the exercise time spent at high rates of oxygen consumption and the extent of aerobic system activation. In addition, the effect of recovery duration or more importantly of work-to-recovery ratio could interact with work bout duration and affect the extent of cardiorespiratory and metabolic responses. For example, a work-to-recovery duration ratio of 2:1 may be more

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appropriate for interval protocols with shorter work durations while a smaller work-to-recovery ratio (e.g., 1:1) with longer work durations. Two previous studies found no effects of recovery duration on exercise time spent at high $\dot{V}O_2$ and heart rate (HR) when performing very long, 4 minutes work bouts, either at self-paced (19) or at fixed velocity (20). The effects of recovery duration and the work-to-recovery duration ratios and their interaction on the extent of aerobic system activation and fatigue during long (60 and 120 seconds) work bouts have not been explored. Such knowledge will provide further insights into the physiological responses during aerobic interval exercise and give valuable information for the efficacy of different work durations and work-to-recovery ratio protocols to induce long-term adaptations.

The purpose of this study was to examine the effects of exercise and recovery duration (60 vs. 120 seconds) and of work-to-recovery ratio (1:1 vs. 2:1) on total exercise time, total oxygen consumption, time spent above 80, 90 and 95% of $\dot{V}O_2$max and HRmax, blood lactate concentrations and rate of perceived exertion (RPE) during the execution of aerobic interval exercise protocols performed for equal exercise time or until exhaustion.

Methods

Experimental Approach to the Problem

This study applied a randomized crossover design. The subjects performed 4 aerobic interval protocols on a treadmill ergometer with 2 different work and recovery durations (60 and 120 seconds) and work-to-recovery ratios (1:1 and 2:1). More specifically, the 4 aerobic exercise protocols were:

- 60:60: 60 seconds bouts of running with intensity 100% of MAV separated by 60 seconds of passive recovery, until exhaustion (work-to-recovery ratio 1:1)
- 60:30: 60 seconds bouts of running with intensity 100% of MAV separated by 30 seconds of passive recovery, until exhaustion (work-to-recovery ratio 2:1)
- 120:120: 120 seconds bouts of running with intensity 100% of MAV separated by 120 seconds of passive recovery, until exhaustion (work-to-recovery ratio 1:1)
- 120:60: 120 seconds bouts of running with intensity 100% of MAV separated by 60 seconds of passive recovery, until exhaustion (work-to-recovery ratio either 2:1).

Each exercise session started with a standardized warm-up that included: (a) running on a treadmill for 7-minute at an intensity corresponding to 60% of MAV, then for 30 seconds at 90% of MAV and after that for 30 seconds at 100% of MAV, (b) static stretching of the lower limbs for 5 minutes. After the warm-up, the subjects executed one of the 4 interval protocols. By design, the 4 interval protocols were performed with similar overall effort and strain (as indicated by RPE and HRpeak values) (26). Heart rate and RPE scores are being consistently used as measures of physiological strain and internal training load (4,6,7,21).

Total exercise time, total oxygen consumption, exercise time spent at $\dot{V}O_2$ and HR above 80, 90 and 95% of maximum were measured during the 4 exercise protocols. Blood lactate concentration and RPE were assessed at 6 and 12 minutes of exercise (recovery periods were not included in the analyses) and at exhaustion. All tests were performed at the same time of the day (±1 hour) in similar environmental conditions (temperature of 22–23° C and relative humidity of 35–40%), at least 4 days apart and completed within 3 weeks. Subjects were asked to follow their normal training weekly routine, but to abstain from any form of exercise at least 48 hours before each experimental session and rest sufficiently the night before testing.

Subjects

Twelve males (mean ± *SD*; age: 22.1 61 years, range: 20–23 years, height: 175 67 cm, body mass: 70.5 ± 6.2 kg, $\dot{V}O_2$max: 59.1 ± 4.9 ml·kg^{-1}·min^{-1}, HRmax: 198.5 ± 7.7 b·min^{-1} and MAV: 16.7 ± 0.8 km·h^{-1}) volunteered to participate in this study after being informed for the experimental procedures and signing an informed consent form. All subjects were healthy and performed continuous endurance exercise 2–4 times per week for the last 1–3 years. None of the subjects has been previously engaged in high-intensity interval training. Before the start of the study, the institutional review board committee of Democritus University of Thrace approved the experimental protocol in accordance to the Helsinki declaration.

Procedures

Maximal Incremental Test. Before the execution of the protocols, a maximal incremental test was performed on a treadmill (h/p/cosmos pulsar 3p, Nussdorf-Traunstin, Germany) for the measurement of $\dot{V}O_2$max and MAV. The maximal incremental protocol started at 9 km·h^{-1} and was increased by 1 km·h^{-1} every 2 minutes until volitional exhaustion. Treadmill grade was set at 1% throughout the protocol. $\dot{V}O_2$ and HR were continuously measured during testing. For the determination of $\dot{V}O_2$max, the oxygen consumption data were averaged over 30 seconds intervals and the highest 30 seconds value was considered as maximal. The test was considered as maximal when 2 of the following criteria were achieved: (a) a plateau in oxygen consumption (<2 ml·kg^{-1}·min^{-1} despite an increase in running velocity), (b) maximal HR higher than 95% of the predicted maximum (220-age) and (c) maximum respiratory exchange ratio >1.1. Maximal aerobic velocity was the velocity of the last completed stage. If the subject completed half of the stage, MAV was considered the velocity of the last completed state increased by 0.5 km·h^{-1}.

$\dot{V}O_2$ and Heart Rate Data Calculation. Gas exchange was measured breath by breath (K4b^2; Cosmed, Rome, Italy) and HR telemetrically (Polar RS400; Polar Electro, Finland) during the 4 experimental sessions. Data were averaged in 5 seconds intervals and the exercise time in seconds (not including the recovery phases) with oxygen consumption and HR equal to or higher than 80, 90 and 95% of $\dot{V}O_2$max and HRmax were calculated. Exercise time spent at $\dot{V}O_2$max and HRmax above 80, 90 and 95% of maximum was calculated using 2 approaches. One for the whole duration of each exercise protocol (until exhaustion) and one equalizing the exercise time for all protocols. The exercise time was matched between protocols based on the protocol that lasted less for each subject. To calculate total $\dot{V}O_2$, each 5 seconds absolute $\dot{V}O_2$ value was divided by 12 and then all values measured during the exercise sessions were summated.

Blood Lactate Concentrations. For the measurement of blood lactate concentrations, approximately 0.3 μL of whole blood were collected from the fingertip and immediately analyzed with a portable analyzer (Lactate Pro 2; Arkray Factory, Inc., Japan) using an enzymatic—amperometric method.

Statistical Analyses

A priori analysis showed that at least 11 subjects were required to detect large differences among means for the study design performed, with alpha and power levels set at 0.05 and 0.80, respectively. A one-way analysis of variance (ANOVA) with repeated measures was used to examine the differences among the exercise protocols (60:60, 60:30, 120:120, 120:60) in total exercise time and oxygen consumption, and in time spent above 80, 90 and 95% of $\dot{V}O_2$max and HRmax. A two-way ANOVA with repeated measures on both factors was used to examine the interaction between exercise protocol (60:60, 60:30, 120:120, 120:60) and time point of measurement (6th minute, 12th minute, exhaustion) on blood lactate concentrations and RPE values. The Newman-Keuls post-hoc test was used to locate significant differences among means. The level of significance was set at a p value of 0.05.

Results

Time to Exhaustion

Exercise time to exhaustion was longer ($p = 0.001$) in the 60:60 protocol (30.39 ± 8.04 minutes) compared with 120:120 (19.95 ± 5.19 minutes), 60:30 (17.75 ± 5.53 minutes) and 120:60 (14.06 ± 1.99 minutes) protocols, and in the 120:120 compared with 120:60 protocol ($p = 0.01$). In 9 of 12 subjects the shortest protocol was the 120:60 protocol and for the remaining 3 subjects, the 60:30 protocol. Therefore, the analyses of the oxygen consumption and HR data, when equalizing the protocols for exercise time, were based on the exercise time completed in these protocols and was 13.81 ± 2.10 minutes.

Total Oxygen Consumption

When the data were analyzed for each protocol using the total exercise time (run until exhaustion), total oxygen consumption was higher ($p = 0.001$) in the 60:60 protocol (97.57 ± 31.37 L) compared with 120:120 (69.51 ± 17.37 L), 60:30 (61.28 ± 15.85 L), and 120:60 (50.93 ± 6.96 L) protocols, and in the 120:120 compared with 120:60 protocol ($p = 0.03$). When the protocols were equalized for exercise time, total oxygen consumption was lower in the 60:60 protocol (44.64 ± 7.42 L) compared with 120:120 (49.30 ± 9.11 L, $p = 0.002$), 60:30 (47.52 ± 8.56 L, $p = 0.02$), and 120:60 (49.10 ± 6.89 L, $p = 0.002$) protocols.

$\dot{V}O_2$ Responses

The data for exercise time spent above 80, 90, and 95% of $\dot{V}O_2$max are presented in Table 1. When the data were analyzed for each protocol using the total exercise time (run until exhaustion), the duration of exercise at $\dot{V}O_2$ higher than 80% of $\dot{V}O_2$max was shorter ($p = 0.02$–0.05) in the 120:60 protocol compared with all other protocols. Exercise time with $\dot{V}O_2$ higher than 95% of $\dot{V}O_2$max was longer ($p = 0.05$) in the 120:120 vs. only to the 60:60 protocol. No significant differences ($p = 0.40$–0.99) were observed among protocols on exercise time with oxygen consumption higher than 90% of $\dot{V}O_2$max.

When the protocols were equalized for exercise time, the duration of exercise at $\dot{V}O_2$ higher than 80, 90, and 95% of $\dot{V}O_2$max was longer ($p < 0.05$) in the 120:120, 120:60, and the 60:30 protocols compared with the 60:60 protocol.

Heart Rate Responses

The data for exercise time spent at HR above 80, 90, and 95% of HRmax are presented in Table 2. When the data were analyzed for each protocol using the total exercise time (run until exhaustion), exercise time with HR higher than 80% of HRmax was shorter ($p = 0.001$–0.05) in the 120:60 protocol compared with all other protocols and in the 120:120 ($p = 0.03$) and the 60:30 ($p = 0.01$) protocols vs. the 60:60 protocol. Exercise time with HR higher than 95% of HRmax was longer in the 120:120 ($p = 0.003$) and 120:60 ($p = 0.03$) protocols vs. the 60:60 protocol and the 120:120 protocol vs. the 60:30 protocol ($p = 0.04$). No significant differences ($p = 0.12$–0.85) were observed among protocols on exercise time with HR higher than 90% of HRmax.

When the protocols were equalized for exercise time, the duration of exercise with HR higher than 80 and 90 of HRmax was longer ($p < 0.05$) in the 120:120, 120:60 and the 60:30 protocols compared with the 60:60 protocol. In addition, exercise time higher than 90% of HRmax was longer ($p < 0.05$) in the 120:60 than the 60:30 protocol. Exercise time with HR higher than 95% of HRmax was longer ($p < 0.05$) in the 120:60 compared with all other protocols, and in the 120:120 than in the 60:60 and 60:30 protocols.

Blood Lactate

Blood lactate concentrations (Figure 1) were significantly lower ($p = 0.001$) in the 60:60 compared with all other protocols and in the 60:30 vs. the 120:60 protocol ($p = 0.03$) across all time points. Blood lactate concentrations were similar ($p = 0.08$–0.23) at the sixth minute, 12th minute, and at exhaustion during the 60:60 protocol. During the 60:30 and 120:60

Table 1

Exercise time (seconds; $\bar{x} \pm SD$) spent with high oxygen consumption ($\dot{V}O_2$) with the execution, until exhaustion or for equal exercise time, of interval protocols with 60-s work duration and rest duration either 30- (60:30) or 60- (60:60) second or 120-second work duration and rest duration either 60 (120:60) or 120 (120:120) seconds.

	60:60	60:30	120:120	120:60
Until exhaustion				
>80% $\dot{V}O_2$max	850.00 ± 295.46†	802.92 ± 365.04†	763.75 ± 212.26†	603.33 ± 88.20
>90% $\dot{V}O_2$max	324.17 ± 227.82	392.08 ± 318.74	461.25 ± 315.78	405.00 ± 141.90
>95% $\dot{V}O_2$max	101.25 ± 90.61	210.83 ± 281.98	300.83 ± 272.09*	225.83 ± 160.28
Equal exercise time				
>80% $\dot{V}O_2$max	413.83 ± 96.96	631.25 ± 201.81*	555.92 ± 135.57*	588.58 ± 82.09*
>90% $\dot{V}O_2$max	162.50 ± 106.38	309.17 ± 202.38*	346.67 ± 232.52*	396.83 ± 131.46*
>95% $\dot{V}O_2$max	58.33 ± 65.31	162.92 ± 182.65*	233.17 ± 203.37*	218.58 ± 146.46*

*$p < 0.05$ from 60:60.
†$p < 0.05$ from 120:60.

Table 2

Exercise time (seconds; x̄ ± *SD*) spent with high heart rates (HR) with the execution, until exhaustion or for equal exercise time, of interval protocols with 60-second work duration and rest duration either 30- (60:30) or 60- (60:60) second or 120-second work duration and rest duration either 60 (120:60) or 120 (120:120) seconds.

	60:60	60:30	120:120	120:60
Until exhaustion				
>80% HRmax	1,283.50 ± 284.95	933.00 ± 288.31*†	1,020.00 ± 301.64*†	726.50 ± 98.21*
>90% HRmax	430.50 ± 310.25	521.00 ± 329.47	658.00 ± 249.46	449.50 ± 134.96
>95% HRmax	38.50 ± 60.05	114.50 ± 150.17	250.50 ± 199.80*‡	181.50 ± 103.28*
Equal exercise time				
>80% HRmax	514.50 ± 158.68	701.20 ± 243.23*	664.00 ± 141.73*	716.50 ± 110.35*
>90% HRmax	117.50 ± 140.08	328.60 ± 210.47*	389.30 ± 123.52*	446.00 ± 143.15*‡
>95% HRmax	3.00 ± 6.75	26.70 ± 35.89	103.30 ± 93.92*‡	179.00 ± 106.53*‡§

*$p < 0.05$ from 60:60.
†$p < 0.05$ from 120:60.
‡$p < 0.05$ from 60:30.
§$p = 0.06$ from 120:120.

protocols, blood lactate significantly increased being higher ($p = 0.001$) at the 12th minute and at exhaustion compared with the value at the sixth min of exercise. During the 120:120 protocol, blood lactate significantly increased ($p = 0.001$) at exhaustion compared with the value at the sixth min of exercise.

Rate of Perceived Exertion

No differences were observed among protocols at RPE values at the completion of the protocols ($p = 0.85–0.94$). When the perceived effort was examined at predetermined time-points (6th and 12th minute) before the completion of interval protocols, the RPE value at the 6th minute of exercise was higher ($p = 0.01$) in the 120:60 protocol vs. the 60:30 and 60:60 protocols and in the 120:120 protocol vs. the 60:60 protocol (Figure 2). Rate of perceived exertion at the 12th minute of exercise was higher ($p = 0.01$) in the 120:60, 120:120 and 60:30 protocols vs. the 60:60 protocol and in the 120:60 protocol vs. the 120:120 protocol ($p = 0.01$).

Discussion

This study compared the effects of work bout and recovery duration, and the work-to-recovery ratio during aerobic interval exercise sessions performed for equal exercise time or until exhaustion, on cardiorespiratory and metabolic responses. The major findings of this study are that when high-intensity interval exercise protocols are executed for equal exercise time: (a) work-to-rest ratio (WRR) (2:1 or 1:1) does not affect cardiorespiratory responses when a 120-second work bout duration is used; however, when shorter (60 seconds) work bouts are used, a higher WRR (2:1) do elicit greater cardiorespiratory responses and (b) a longer work bout duration (120 seconds) causes greater cardiorespiratory stress than a shorter work bout duration (60 seconds) only when a small WRR (1:1) is used. When exercise time is extended and an interval session is executed until exhaustion: (a) WRR (1:1 or 2:1) does not affect exercise time at high values (>90%) of $\dot{V}O_2$max and HRmax; however, as work bout duration decreases, from 120 to 60 seconds, a greater WRR should be used to achieve and maintain near maximal (>95% of max) the

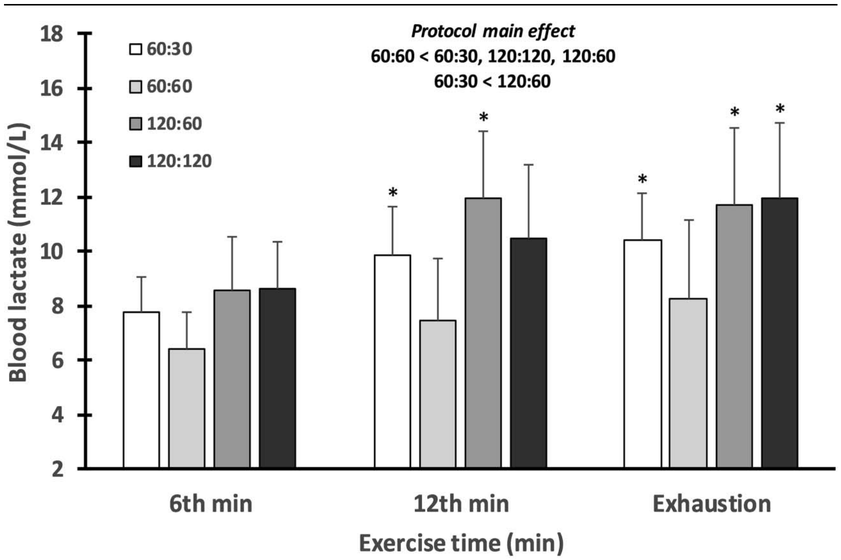

Figure 1. Blood lactate (x̄ ± *SD*) during the execution of interval protocols with 60-second work duration and rest duration either 30 (60:30) or 60 (60:60)-second or 120-second work duration and rest duration either 60 (120:60) or 120 (120:120) seconds until exhaustion. *$p < 0.05$ from sixth minute of exercise.

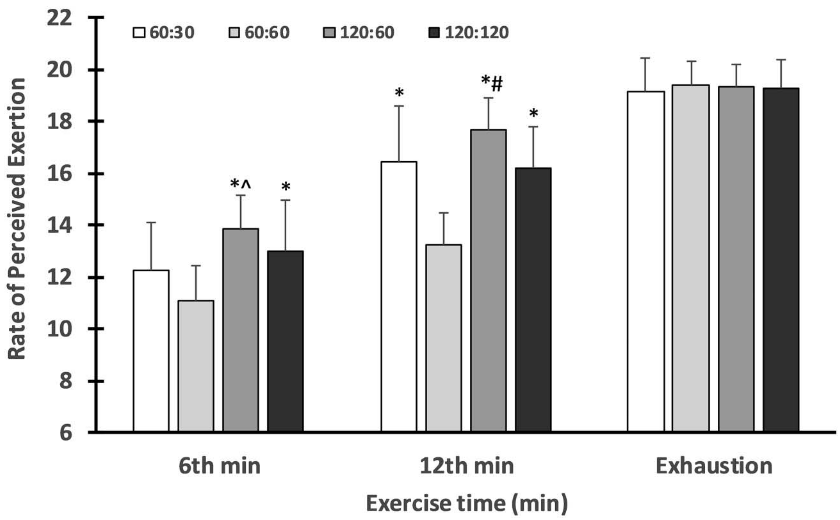

Figure 2. Rate of perceived exertion ($\bar{x} \pm SD$) during the execution of interval protocols with 60 seconds work duration and rest duration either 30 (60:30) or 60- (60:60) second or 120-second work duration and rest duration either 60 (120:60) or 120 (120:120) seconds until exhaustion. *$p < 0.05$ from 60:60, #$p < 0.05$ from 120:120, ^$p < 0.05$ from 60:30.

cardiorespiratory stimulus and (b) interval protocols with longer work bouts, 60 vs. 120 seconds, result to more blood lactate accumulation irrespective of the work-to-recovery ratio, suggesting higher activation of anaerobic glycolysis.

The results of the present study enrich the existing literature regarding the effects of 2 long duration work bouts (≥60 seconds) and recovery duration, on cardiorespiratory and metabolic responses during aerobic interval exercise sessions executed for equal exercise time or until exhaustion. Previous studies have shown longer exercise time at high $\dot{V}O_2$ rates (>90% $\dot{V}O_2$max) with work bout durations of 120 seconds vs. 30 seconds (10) or 120 seconds vs. 60 seconds (12) when the protocols were performed for equal exercise times and with 1:1 WRR. The results of the present study support these findings, because exercise times above 80, 90, and 95% of $\dot{V}O_2$max and HRmax were longer with the 120:120 protocol compared with the 60:60 protocol when performed for equal exercise time. The longer exercise time at high $\dot{V}O_2$ rates may indicate a greater contribution of oxidative metabolism to energy production during the 120-second work bouts (25). Probably, during each 60-second work bout, the exercise time remaining until the next recovery, after the 90% of $\dot{V}O_2$max is reached, is too short to further increase or sustain high $\dot{V}O_2$ values. Indeed, Davies et al. (3) have shown that as work duration increases, adenosine triphosphate production relies more on anaerobic glycolysis and oxidative phosphorylation, whereas when it becomes shorter on PCr breakdown. The greater contribution of anaerobic glycolysis for energy production during the 120:120 protocol compared with the 60:60 protocol is suggested by the higher blood lactate values measured during this protocol (5). It should be noted that this occurred despite the longer recovery interval (120 vs. 60 seconds), which should have facilitated lactate removal. Other researchers have also found higher blood lactate values with longer work bout protocols (17,24,30). It seems that for similar total exercise time and a 1:1 WRR, prolonging the work bouts increases the time spent with high $\dot{V}O_2$ and HRs and activates more anaerobic glycolysis.

A new finding in the present study is that if 2 high-intensity interval protocols are performed with similar level of fatigue (until exhaustion in the present study) and work-to-recovery ratio, relatively similar exercise times at high oxygen consumption rates (>80 and 90% $\dot{V}O_2$max) are achieved with either 60- or 120-second work durations with a 1:1 work-to-recovery ratio. This is most likely the result of the significantly longer total exercise time achieved when the 60:60 protocol is performed until exhaustion. Therefore, an extension of exercise time because of a lower accumulation of fatigue leads to an increase of exercise time at high $\dot{V}O_2$ and HR values. Still, exercise time at maximal $\dot{V}O_2$ rates (>95% $\dot{V}O_2$max) was significantly higher in the 120:120 protocol than in the 60:60 protocol. Using 60-second work durations, substantially more exercise time is required to achieve approximately similar exercise times at high $\dot{V}O_2$ and HR that are achieved with longer (120 seconds) work duration. Thus, under isoeffort conditions, a 120-second work bout with a 1:1 work-to-recovery ratio induces similar cardiorespiratory and greater metabolic perturbation with less total exercise time compared with shorter work duration. Therefore, the 120-second exercise bouts could be preferred for the long-term enhancement of aerobic performance over the use of 60 seconds work bouts during high-intensity interval training when work-to-recovery ratio is set to 1:1.

The differences between 120-second and 60-second work bouts can be diminished by reducing the recovery time between 60-second work bouts. Millet et al. (10) found similar exercise times at $\dot{V}O_2$ above 90% of $\dot{V}O_2$max with a 60:30 protocol compared with work and recovery duration equal to half time to exhaustion at MAV (1.5–2.5 minutes). In agreement, we found similar cardiorespiratory responses between the 120:120 and the 60:30 protocols. This may be because of the similar total exercise durations of the 2 protocols. Therefore, a decrease of recovery duration in a 60-second work bout counteracts the short work bout duration and the 60-second work bout protocols may lead to exercise times at high rates of $\dot{V}O_2$ and HR as the 120-second work bout protocols.

Another novel finding of the present study is that when the work-to-recovery ratio is 2:1, no differences are observed between the 120-second (120:60 protocol) and the 60-second (60:30 protocol) work bouts on exercise time at high oxygen consumption rates regardless if the protocols are performed for equal exercise time or to exhaustion. This is because the total exercise time (until exhaustion) is approximately similar in the 2 protocols. Probably, in the 60:30 protocol, oxygen consumption did not decrease to low levels during the short 30-second recovery. Consequently, each 60-second repetition was starting with oxygen consumption at a higher level allowing the attainment of high oxygen consumption rates for a longer period. It should be noted, although, that exercise time at high HR was longer with the 120:60 protocol. This may indicate a higher cardiovascular stress and may have implications both for athletic and diseased populations. Although, more indices of cardiovascular function should be measured to draw firm conclusions. In addition, blood lactate increased more during the 120:60 protocol. Therefore, an increase in work duration (from 60 to 120 seconds) induces a greater activation of the lactate system whether the work-to-recovery duration is 1:1 or 2:1.

The maintenance of high oxygen consumption levels during recovery in the 60:30 protocol may also explain the similarity in exercise time at high oxygen consumption rates that was observed in the 60:60 protocol, despite a 40% less total exercise time. Thus, with short work durations (60 seconds in the present study), the duration of recovery seems to determine cardiorespiratory responses and the short recovery periods may be preferred, because they induce similar stress in less time. This notion is even more supported when the 2 protocols are equalized for exercise time; the cardiorespiratory and metabolic responses were significantly higher with the 60:30 compared with the 60:60 protocol. Recovery duration, however, did not seem to affect oxygen consumption when work duration was 120 seconds (120:120 vs. 120:60 protocol). Maybe after the first minute of recovery, oxygen consumption does not decline much further and the next repetition is started with approximately similar oxygen consumption. So, when recovery duration is longer than 60 seconds, work duration may be a more important factor to accumulate sufficient exercise time at high oxygen consumption rates. This is in content with previous studies reporting that exercise time at high rates of oxygen consumption was not affected by the recovery duration using an interval protocol with 4-minute work bouts either at self-paced (19) or at fixed velocity (20). Blood lactate levels, however, were higher in the 60:30 protocol compared with the 60:60 protocol, whereas they did not differ between the 120:60 and the 120:120 protocol (Figure 1). It seems that with short work bouts (1 minute in the present study), the recovery duration (30 vs. 60 seconds) may regulate the extent of anaerobic glycolysis; whereas, with longer work bouts (2 minutes in the present study), the work duration becomes the determining factor for the contribution of anaerobic glycolysis to energy production, at least when the differences in recovery duration are not large (60 vs. 120 seconds in the present study).

In conclusion, during an aerobic interval training session at an intensity equal to MAV, the effect of work duration on cardiorespiratory responses depends on the work to recovery ratio as well. Similarly, the effect of recovery duration on the extent of cardiorespiratory stimulus depends on work duration. When considering time-efficiency, a short recovery should be used with 60-second work duration (2:1 work-to-recovery ratio), whereas as work duration increases to 120 seconds, the recovery duration does not affect the time-efficiency of interval training session. In any case, an increase in work duration leads to higher blood lactate levels suggesting greater involvement of anaerobic glycolysis in energy production.

Practical Applications

Coaches may use either 60- or 120-second work durations during an interval training session to cause similar cardiorespiratory stimulus when the work-to-recovery ratio is 2:1. However, when using a work-to-recovery ratio of 1:1, a much shorter total exercise time is required to obtain a similar cardiorespiratory stimulus using 120 seconds of work duration compared with 60 seconds, making this protocol more time-efficient. Still, 60-second protocols with a 1:1 WRR poses a lower cardiorespiratory and metabolic stress and could be used in conditions and populations when lower stress is desired. If coaches and fitness practitioners aim to greater involvement of anaerobic glycolysis during the interval exercise protocol, 120-second work bouts are preferable or 60-second work bouts with 30-second recovery, because they lead to greater blood lactate concentrations. It seems, several combinations of work and recovery durations may lead to similar cardiorespiratory responses giving the opportunity to coaches to modify the aerobic interval training sessions and decrease the monotony of training.

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