INFLUENCE OF WORK-INTERVAL INTENSITY AND DURATION ON TIME SPENT AT A HIGH PERCENTAGE OF VO$_2$\textsubscript{max} DURING INTERMITTENT SUPRAMAXIMAL EXERCISE

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ABSTRACT
Wakefield, BR and Glaister, M. Influence of work-interval intensity and duration on time spent at a high percentage of VO$_2$\textsubscript{max} during intermittent supramaximal exercise. J Strength Cond Res 23(9): 2548–2554, 2009—The purpose of this study was to examine the effect of work-interval duration (WID) and intensity on the time spent at, or above, 95% VO$_2$\textsubscript{max} (T95 VO$_2$\textsubscript{max}) during intermittent bouts of supramaximal exercise. Over a 5-week period, 7 physically active men with a mean (± SD) age, height, body mass, and VO$_2$\textsubscript{max} of 22 ± 5 years, 181.5 ± 5.6 cm, 86.4 ± 11.4 kg, and 51.5 ± 1.5 ml kg$^{-1}$ min$^{-1}$, respectively, attended 7 testing sessions. After completing a submaximal incremental test on a treadmill to identify individual oxygen uptake/running velocity relationships, subjects completed a maximal incremental test to exhaustion to establish VO$_2$\textsubscript{max} and subsequently (from the aforementioned relationship) the minimum velocity required to elicit VO$_2$\textsubscript{max} (vVO$_2$\textsubscript{max}). In a random order, subjects then carried out 3 intermittent runs to exhaustion at both 105% and 115% vVO$_2$\textsubscript{max}. Each test used a different WID (20 s, 25 s, or 30 s) interspersed with 20-second passive recovery periods. Results revealed no significant difference in T95 vVO$_2$\textsubscript{max} for intermittent runs at 105% versus 115% vVO$_2$\textsubscript{max} (p = 0.142). There was, however, a significant effect (p < 0.001) of WID on T95 VO$_2$\textsubscript{max}, with WIDs of 30 seconds enabling more time relative to WIDs of 20 seconds (p = 0.018) and 25 seconds (p = 0.009). Moreover, there was an interaction between intensity and duration such that the effect of WID was magnified at the lower exercise intensity (p = 0.046). In conclusion, despite a number of limitations, the results of this investigation suggest that exercise intensities of approximately 105% vVO$_2$\textsubscript{max} combined with WIDs greater than 25 seconds provide the best way of optimizing T95 VO$_2$\textsubscript{max} when using fixed 20-second stationary rest periods.

KEY WORDS maximal aerobic capacity, endurance running performance, interval training

INTRODUCTION

Maximal oxygen uptake (VO$_2$\textsubscript{max}) is one of the most important physiologic determinants of endurance performance (9,28). Consequently, the enhancement of VO$_2$\textsubscript{max} to its maximum trainable limit is an objective for many athletes (12,28). Numerous researchers agree that for improvements in VO$_2$\textsubscript{max} to take place, exercise protocols must allow individuals to work at, or very close to (≥95%), the velocity that elicits maximal oxygen uptake (vVO$_2$\textsubscript{max}) (3,15,32) as well as enabling athletes to maintain that intensity for a prolonged period of time (34). For many years, it was believed that continuous bouts of submaximal exercise (at a constant velocity) were the most effective way of achieving this improvement (11,18,19). However, in distance runners competing at a relatively high level, the cardiorespiratory adaptations likely to be elicited by submaximal running have probably already occurred (21). Consequently, if well-trained individuals are to gain further improvements in aerobic capacity, it is recommended that they undertake some form of high-intensity interval training (HIT) (22).

Support for the premise that HIT (repeated bouts of exercise performed at an intensity greater than the anaerobic threshold) is effective at improving time spent at VO$_2$\textsubscript{max} comes from a number of studies (7,13,16). For instance, Demarie et al. (11) demonstrated that time at VO$_2$\textsubscript{max} was significantly shorter for a continuous run to exhaustion (tlim) (run at 50% of the difference between the velocity that elicits lactate threshold and vVO$_2$\textsubscript{max}; v50%Δ) than for an intermittent run to exhaustion (run at v50%Δ for 1/2 of tlim with recovery periods run at 1/2 of v50%Δ for 1/4 of tlim). Similarly, Billat et al. (8) showed that repeated bouts of intermittent running (30 s at 100% vVO$_2$\textsubscript{max} with 30-s active...
recovery at 50% $V\text{O}_{2}\text{max}$) enabled runners to maintain $V\text{O}_{2}\text{max}$ for approximately 10 minutes. This was nearly 3 times longer than $V\text{O}_{2}\text{max}$ was sustained during a single bout at $V\text{O}_{2}\text{max}$. However, despite substantial support for the improvement in time spent at $V\text{O}_{2}\text{max}$ with HIT, there appears to be little evidence as to which training protocol is most effective at enhancing time spent at $V\text{O}_{2}\text{max}$ (27). For example, Dupont et al. (15) reported that, relative to intermittent runs at 110%, 130%, and 140% $V\text{O}_{2}\text{max}$, intermittent runs at 120% $V\text{O}_{2}\text{max}$ allowed subjects to spend the longest amount of time at 100% $V\text{O}_{2}\text{max}$, whereas Millet and colleagues (30) confirmed that time spent at, or above, 90% $V\text{O}_{2}\text{max}$ was significantly greater for intermittent runs at 105% $V\text{O}_{2}\text{max}$ than for runs at 100% $V\text{O}_{2}\text{max}$. These findings suggest that work-interval intensities somewhere between 105% and 120% $V\text{O}_{2}\text{max}$ are most effective at allowing an individual to spend time at, or close to, $V\text{O}_{2}\text{max}$. However, the duration of the work interval has also been shown to have a substantial influence on time spent at $V\text{O}_{2}\text{max}$ (24). For instance, several researchers have demonstrated that, for intermittent runs completed at, or above, 100% $V\text{O}_{2}\text{max}$, short-duration work intervals (15–60 s) are effective at allowing individuals to spend time at, or above, 90% $V\text{O}_{2}\text{max}$ (7,8,12,15). Nevertheless, Rozenek et al. (33) demonstrated that intermittent runs at 100% $V\text{O}_{2}\text{max}$ with work-interval durations greater than 30 seconds resulted in higher levels of blood lactate relative to intermittent runs with work-interval durations of 15 seconds. Because the accumulation of lactate has been associated with the onset of peripheral fatigue (17), these findings would suggest that work-interval durations between 15 and 30 seconds would enable individuals to optimize time at, or very close to, $V\text{O}_{2}\text{max}$.

Although researchers continue to address many of the methodologic inconsistencies that exist between studies (differences in work and recovery interval durations and intensities, the characteristics of the warm-up period, the number of work intervals per set, the number of sets completed, and the considerable variability in the way that $V\text{O}_{2}\text{max}$, $V\text{O}_{2}\text{max}$ and time at $V\text{O}_{2}\text{max}$ is calculated), it remains unclear which combination of work-interval duration and intensity, if any, is most effective at allowing an individual to spend time at $V\text{O}_{2}\text{max}$. Therefore, the purpose of this study was to examine the effect of manipulations of work-interval intensity (105% $V\text{O}_{2}\text{max}$ and 115% $V\text{O}_{2}\text{max}$) and duration (20 s, 25 s, and 30 s) used during intermittent bouts of supramaximal exercise on time spent at, or above, 95% $V\text{O}_{2}\text{max}$.

**METHODS**

**Experimental Approach to the Problem**

All subjects were required to attend 7 separate testing sessions over the course of a 5-week period. Subjects first performed a submaximal incremental test (7 × 3 min stages, with increments of 1 km·h$^{-1}$) to establish an oxygen uptake/running velocity relationship. After a 5-minute passive recovery period, subjects completed a maximal incremental exercise test to determine $V\text{O}_{2}\text{max}$. With use of this value, the submaximal oxygen uptake/running velocity relationship was extrapolated to calculate 105% $V\text{O}_{2}\text{max}$ and 115% $V\text{O}_{2}\text{max}$. This technique has been used effectively to estimate supramaximal work intensities in tests determining maximal accumulated oxygen deficit (23). In a random order, participants then carried out 3 supramaximal intermittent runs to exhaustion at both 105% $V\text{O}_{2}\text{max}$ and 115% $V\text{O}_{2}\text{max}$. Each of the 3 tests was conducted using a different work-interval duration (20 s, 25 s, and 30 s), interspersed with 20-second recovery periods.

**Subjects**

Seven healthy and physically active male sport science students volunteered to participate in this investigation, which was approved by St. Mary’s University College Ethics Committee. After completion of a pre-activity readiness questionnaire, subjects were provided with written and verbal information outlining the demands of the study before providing written informed consent. Subjects were asked to maintain their normal diet throughout the testing period, to abstain from consuming food or beverages (other than water) 2 hours before testing, and to abstain from alcohol consumption and vigorous exercise in the 24 hours before testing. Means (±SD) for age, height, body mass, and $V\text{O}_{2}\text{max}$ were 22 ± 5 years, 181.5 ± 5.6 cm, 86.4 ± 11.4 kg, and 51.5 ± 5.1 ml·kg$^{-1}$·min$^{-1}$, respectively.

**Procedures**

All testing was conducted on a motorized treadmill (h/p/cosmos, pulsar 4.0; Nussdorf-Traustein, Germany) set at a 1% incline to replicate outdoor running on a flat surface (20). During all tests, respiratory gas exchange was measured at the mouth using a breath-by-breath online gas analysis system (Vacu-Med, model 17570; Ventura, CA, USA). Before each test, the gas analyzer was calibrated using ambient air, which was assumed to contain 20.93% O$_2$ and 0.03% CO$_2$, and with gas of a known O$_2$ and CO$_2$ concentration (BOC Gases, Surrey, UK). Heart rate (HR) was recorded continuously throughout every test using a telemetric system (Polar Electro, Oy, Finland), which was interfaced with the gas analyzer to provide synchronous oxygen uptake ($V\text{O}_{2}$) and HR data. Capillary blood samples were taken from the subject’s earlobe immediately before and after each test and subsequently analyzed for blood lactate using an automated analyzer (Biosen C-Line; EFK Diagnostic, Ebendorfer Chaussee 3, Germany). This analyzer has been reported to provide an accurate and reliable measure of blood lactate (10).

**Maximal Incremental Exercise Test.** Because of the slow running pace required for the initial stages of the test, and because of the effects of the previous submaximal incremental protocol, subjects were not required to complete a warm-up before the start of the test. The test began at a suitable submaximal
intensity determined from the submaximal incremental test. The treadmill speed was increased by 1 km·h⁻¹ each minute until the subject reached volitional exhaustion. Blood lactate levels were measured immediately postexercise to provide an indication of maximal effort. A subject was judged to have reached $\dot{V}_\text{O}_{2\max}$ when 3 or more of the following criteria were met: a) a plateau in oxygen uptake despite an increase in running speed, b) a final respiratory exchange ratio greater than 1.15, c) an inability to maintain the required running speed, d) a postexercise blood lactate concentration higher than 8 mmol·L⁻¹, e) a HR within 10 beats per minute of age-predicted maximum (1).

**Supramaximal Intermittent Running Test.** Only 1 supramaximal intermittent run was carried out on any given day, and each test was separated by at least 48 hours to ensure adequate recovery. Before each test, subjects completed a 5-minute warm-up at 50% $\dot{V}_\text{O}_{2\max}$. To begin each test, the treadmill speed was increased to match the velocity for the supramaximal run. The subject was then required to (repeatedly) maneuver themselves onto the moving belt from a straddled position. Strong verbal encouragement was given throughout the test to induce a maximal effort. After the completion of the test, subjects performed a 5-minute cool-down at 50% $\dot{V}_\text{O}_{2\max}$. Time to exhaustion (which included the duration of the recovery periods) and the number of work intervals completed were recorded for each supramaximal run. The time spent at, or above, $95\%$ $\dot{V}_\text{O}_{2\max}$ was calculated through the accumulation of $\dot{V}_\text{O}_2$ values superior, or equal, to $95\%$ of the $\dot{V}_\text{O}_{2\max}$ score obtained from the maximal incremental test. This method of calculating time spent at, or near to, $\dot{V}_\text{O}_{2\max}$ has been supported by previous researchers (14,18,19) and has been shown to have good test-retest reliability (intra-class correlation coefficient = 0.80) (25).

**Statistical Analyses**
All data analysis was conducted using the Statistical Package for Social Sciences (SPSS for Windows, Version 15.0, Chicago, IL, USA). A two-way (intensity × work-interval duration) repeated measures analysis of variance (ANOVA) was used to compare time spent at, or above, $95\%$ $\dot{V}_\text{O}_{2\max}$, peak HR, the number of work intervals completed, and time to exhaustion between the 2 supramaximal intensities (105% $\dot{V}_\text{O}_{2\max}$ and 115% $\dot{V}_\text{O}_{2\max}$). A three-way ANOVA was used to compare pre- and postexercise lactate concentrations between the 2 supramaximal intensities (105% $\dot{V}_\text{O}_{2\max}$ and 115% $\dot{V}_\text{O}_{2\max}$). Significant effects were followed up using Bonferroni-adjusted post hoc analyses. $\alpha$ was set at 0.05 for all analyses.

**RESULTS**

**Time Spent At, or Above, 95% $\dot{V}_\text{O}_{2\max}$**
A summary of the effects of the experiment on time spent at, or above, 95% $\dot{V}_\text{O}_{2\max}$ is presented in Figure 1. Relative to intermittent runs at 105% $\dot{V}_\text{O}_{2\max}$ time spent at, or above, 95% $\dot{V}_\text{O}_{2\max}$ was not significantly different from that at 115% $\dot{V}_\text{O}_{2\max}$ ($F(1,6) = 2.850, p = 0.142$). There was, however, a significant effect of work-interval duration on time spent at, or above, 95% $\dot{V}_\text{O}_{2\max}$ ($F(2,12) = 17.110, p < 0.001$), with post hoc analyses revealing that work-interval durations of 30 seconds allowed subjects to spend significantly longer at, or above, 95% $\dot{V}_\text{O}_{2\max}$ than work intervals of 20 seconds (mean difference = 89 s; 95% likely range: 19–160 s) and 25 seconds (mean difference = 75 s; 95% likely range: 24–126 s) (no significant difference [$p = 0.625$] in time spent at, or above, 95% $\dot{V}_\text{O}_{2\max}$ between 20-s and 25-s work intervals). Moreover, there was an interaction between exercise intensity and work-interval duration such that the effect of work-interval duration was magnified at the lower exercise intensity ($F(2,12) = 4.040, p = 0.046$). An example of a typical oxygen uptake response to one of the intermittent protocols is presented in Figure 2.

**Blood Lactate**
The influence of work-interval intensity and duration on blood lactate is illustrated in Figure 3. As anticipated, postexercise blood lactate was significantly higher than pre-exercise, irrespective of the condition ($F(1,6) = 12.758, p = 0.012$). Relative to 105% $\dot{V}_\text{O}_{2\max}$, intermittent runs at $115\%$ $\dot{V}_\text{O}_{2\max}$
115% \( \text{vV}O_2\text{max} \) resulted in significantly \((F(1,6) = 22.099, p = 0.003)\) higher concentrations of blood lactate (mean difference = 1.00 mmol-L\(^{-1}\); 95% likely range: 0.48–1.51 mmol-L\(^{-1}\)). There was also an effect of work-interval duration \((F(2,12) = 15.421, p < 0.001)\), with significantly higher blood lactate concentrations observed between work-interval durations of 30 seconds versus 25 seconds (mean difference = 0.57 mmol-L\(^{-1}\); 95% likely range: 0.15–0.99 mmol-L\(^{-1}\)) and 30 seconds versus 20 seconds (mean difference = 0.73 mmol-L\(^{-1}\); 95% likely range: 0.24–1.22 mmol-L\(^{-1}\)). However, there was no significant interaction between work-interval intensity and duration on blood lactate \((F(2,12) = 0.412, p = 0.672)\).

**Mean Heart Rate**

There was no significant effect of exercise intensity \((F(1,6) = 0.363, p = 0.569)\) or work-interval duration \((F(2,12) = 1.655, p = 0.232)\) on mean HR during the intermittent runs (Table 1). There was also no significant interaction between exercise intensity and work-interval duration on mean HR \((F(2,12) = 1.871, p = 0.196)\).

**Number of Work Intervals Completed**

Intermittent runs at 115% \( \text{vV}O_2\text{max} \) resulted in a significantly greater number of work intervals being completed than intermittent runs at 115% \( \text{vV}O_2\text{max} \) \((F(1,6) = 80.766, p < 0.001)\) (Table 1). There was also a significant effect of work-interval duration on the number of work intervals completed \((F(2,12) = 46.029, p < 0.001)\). Pair-wise comparisons revealed that work intervals of 20 seconds allowed subjects to complete a significantly greater number of intervals than those of 25 seconds \((p = 0.014)\) and 30 seconds \((p = 0.001)\). Moreover, the number of work intervals completed during intermittent runs with 25-second work intervals was significantly greater than for work intervals of 30 seconds \((p < 0.001)\). There was no significant interaction between exercise intensity and work-interval duration for the number of work intervals completed \((F(2,12) = 1.019, p = 0.390)\).

**Time to Exhaustion**

Time to exhaustion was significantly longer for intermittent runs at 115% \( \text{vV}O_2\text{max} \) than for intermittent runs at 115% \( \text{vV}O_2\text{max} \) \((F(1,6) = 81.962, p < 0.001)\). Furthermore, there was a significant effect of work-interval duration on time to exhaustion \((F(2,12) = 22.373, p < 0.001)\). Although there was no significant difference in time to exhaustion between
20-second and 25-second work intervals ($p = 0.156$), pairwise comparisons revealed that 20-second and 25-second work intervals resulted in significantly longer ($p = 0.007$ and $p = 0.002$, respectively) times to exhaustion than 30-second work intervals. There was, however, no significant interaction between exercise intensity and work-interval duration on time to exhaustion ($F(2,12) = 1.774, p = 0.211$).

**DISCUSSION**

The purpose of this study was to examine the effect of manipulations of work-interval intensity (105% $V_{O_2}$max and 115% $V_{O_2}$max) and duration (20 s, 25 s, and 30 s) used during intermittent bouts of supramaximal exercise on time spent at, or above, 95% $V_{O_2}$max. The results of the study revealed that time spent at, or above, 95% $V_{O_2}$max was not significantly different for intermittent runs at 105% $V_{O_2}$max than for intermittent runs at 115% $V_{O_2}$max. This finding was surprising given that there was a significant interaction between work-interval intensity and work-interval duration on time spent at, or very close to, $V_{O_2}$max. On the basis of previous recommendations (24), it was hypothesized that time spent at, or above, 95% $V_{O_2}$max would be significantly greater for supramaximal intermittent runs at 105% $V_{O_2}$max than for identical runs conducted at 115% $V_{O_2}$max. It was anticipated that supramaximal intensities above 105% $V_{O_2}$max would not be maintained for long enough because of the substantial increase in anaerobic metabolism (as evidenced by the increased accumulation of lactate) and the corresponding increase in fatigue (33). Although there was no significant difference in time spent at, or close to, $V_{O_2}$max between the 2 supramaximal exercise intensities, there was a trend toward an effect (Figure 1), with 105% $V_{O_2}$max showing a longer mean time at, or above, 95% $V_{O_2}$max at each of the 3 work-interval durations. Such an observation is consistent with some previous studies that have reported that running velocities closer to 100% $V_{O_2}$max allow more time to be spent at $V_{O_2}$max than much higher (i.e., 110–140% $V_{O_2}$max) running velocities (7,15). Within these studies, exercise intensities greater than 105% $V_{O_2}$max were considered to be too intense to be maintained for very long (generally not $> 12$ min). In the present study, the significantly higher blood lactate concentrations for intermittent runs at 115% $V_{O_2}$max, coupled with the shorter times to exhaustion and fewer work intervals completed, would certainly support this idea.

The lack of a significant difference in time spent at, or close to, $V_{O_2}$max between the 2 supramaximal exercise intensities in this investigation is most likely to be caused by the large between-subject variability in the data. This makes the time spent at, or above, 95% $V_{O_2}$max for each supramaximal run appear more similar than they really were. Although a number of factors may have contributed to this large variability (i.e., criteria for determining $V_{O_2}$max, subject fitness level, criteria for accepting oxygen uptake data points as being close to $V_{O_2}$max), the largest source of error in determining time spent at $V_{O_2}$max appears to lie in the initial measurement of $V_{O_2}$max (24). This is because variations in $V_{O_2}$max can greatly influence any factors dependent upon it. An underestimation of an individual’s $V_{O_2}$max in the present study, for example, is also likely to result in underestimated calculations of $V_{O_2}$max, 105% $V_{O_2}$max, and 115% $V_{O_2}$max. If this occurs, the (subject’s) oxygen uptake response during the supramaximal run is not likely to give a true reflection of the relevant exercise intensity. Consequently, the validity of the findings regarding the influence of exercise intensity on time at $V_{O_2}$max is an issue that requires further investigation.

The other major finding from the present study was the significant effect of work-interval duration on time spent at, or close to, $V_{O_2}$max, with longer work intervals of 30 s allowing more time to be spent at, or above, 95% $V_{O_2}$max relative to work-interval durations of 25 seconds or 20 seconds. This pattern of results is similar to that observed in previous research. For example, Rozenek et al. (33) confirmed that intermittent runs at 100% $V_{O_2}$max with longer work-interval durations of 60 seconds allowed subjects to spend the longest time at, or above, 90% $V_{O_2}$max relative to intermittent runs with work-interval durations of 30 s and 15 s. Similarly, Millet et al. (29) demonstrated that intermittent runs at 100% $V_{O_2}$max with longer work-interval durations (60 s) resulted in significantly greater time spent at, or above,

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**TABLE 1.** Summary of 3 of dependent variables measured during intermittent treadmill running at 105% $V_{O_2}$max and 115% $V_{O_2}$max with work-interval durations of 20, 25, and 30 seconds (20-s passive recovery periods).

<table>
<thead>
<tr>
<th>Intensity</th>
<th>105% $V_{O_2}$max</th>
<th>115% $V_{O_2}$max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work intervals (s)</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Mean heart rate (b·min⁻¹)</td>
<td>163 ± 7</td>
<td>167 ± 6</td>
</tr>
<tr>
<td>Intervals completed</td>
<td>82 ± 11</td>
<td>73 ± 7</td>
</tr>
<tr>
<td>Time to exhaustion (min)</td>
<td>54.9 ± 7.1</td>
<td>54.1 ± 5.0</td>
</tr>
</tbody>
</table>

*Values are means ± SD.
Practical Applications

The present study revealed that longer duration work intervals allow subjects to spend the greatest amount of time at, or close to, \( \dot{V}_O_{2\text{max}} \). Moreover, the results suggest that the magnitude of the effect of work-interval duration is magnified at lower exercise intensities. Overall, despite a number of limitations, the results of this investigation suggest that exercise intensities of approximately 105% \( \dot{V}_O_{2\text{max}} \) combined with work-interval durations greater than 25 seconds provide the optimal means of spending time at, or above, 95% \( \dot{V}_O_{2\text{max}} \) when using fixed 20-second stationary rest periods.

References


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