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The Influence of Work Interval Intensity and Duration on Time Spent at a High Percentage of $\dot{V}O_{2max}$ during Intermittent Supramaximal Exercise

Brief Running Head: Work interval manipulations on time spent at $\dot{V}O_{2max}$

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ABSTRACT

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% $\dot{V}O_{2max}$ (T95$\dot{V}O_{2max}$) during intermittent bouts of supramaximal exercise. Over a five week period, seven physically active men with a mean (± *standard deviation*) age, height, body mass and VO_{2max} of 22 ± 5 yrs, 181.5 ± 5.6 cm, 86.4 ± 11.4 kg, and 51.5 ± 1.5 $ml.kg^{-1}.min^{-1}$, respectively, attended seven 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 $\dot{V}O_{2max}$, and subsequently (from the aforementioned relationship) the minimum velocity required to elicit $\dot{V}O_{2max}$ (v$\dot{V}O_{2max}$). In a random order, subjects then carried out three intermittent runs to exhaustion at both 105% and 115% v$\dot{V}O_{2max}$. Each test utilized a different WID (20 s, 25 s, or 30 s) interspersed with 20 s passive recovery periods. Results revealed no significant difference in T95$\dot{V}O_{2max}$ for intermittent runs at 105% versus 115% v$\dot{V}O_{2max}$ (p = 0.142). There was however, a significant effect (p < 0.001) of WID on T95$\dot{V}O_{2max}$; with WIDs of 30 s enabling more time relative to WIDs of 20 s (p = 0.018) and 25 s (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 around 105% v$\dot{V}O_{2max}$ combined with WIDs > 25 s provide the best way of optimizing T95$\dot{V}O_{2max}$ when using fixed 20 s stationary rest periods.

KEYWORDS*:* Maximal aerobic capacity, endurance running performance, interval training.

INTRODUCTION

Maximal oxygen uptake ($\dot{V}O_{2max}$) is one of the most important physiological determinants of endurance performance (9, 27). Consequently, the enhancement of $\dot{V}O_{2max}$ to its maximum trainable limit is an objective for many athletes (12, 27). Numerous researchers agree that for improvements in $\dot{V}O_{2max}$ to take place, exercise protocols must allow individuals to work at, or very close to ($\geq$ 95%) the velocity that elicits maximal oxygen uptake ($v\dot{V}O_{2max}$) (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 $\dot{V}O_{2max}$ comes from a number of studies (7, 13, 16). For instance, Demarie et al. (11) demonstrated that time at $\dot{V}O_{2max}$ was significantly shorter for a continuous run to exhaustion (tlim) (run at 50% of the difference between the velocity that elicits lactate threshold and $v\dot{V}O_{2max}$; v50%Δ) than for an intermittent run to exhaustion (run at v50%Δ for one half of tlim with recovery periods run at one half of v50%Δ for one quarter of tlim). Similarly, Billat et al. (8) showed that repeated bouts of intermittent running (30 s at 100% $v\dot{V}O_{2max}$ with 30 s active recovery at 50% $v\dot{V}O_{2max}$) enabled runners to maintain $\dot{V}O_{2max}$ for around 10 mins. This was nearly three times longer than $\dot{V}O_{2max}$ was sustained during a single bout at $v\dot{V}O_{2max}$. However, despite substantial support for the improvement in time spent at $\dot{V}O_{2max}$ with HIT, there appears to be little evidence as to which training protocol is most effective at enhancing time spent at $\dot{V}O_{2max}$ (27). For example, Dupont et al. (15) reported that, relative to intermittent runs at 110%, 130% and 140% $v\dot{V}O_{2max}$, intermittent runs at 120% $v\dot{V}O_{2max}$ allowed subjects to spend the longest amount of time at 100% $\dot{V}O_{2max}$, while Millet and colleagues (30) confirmed that time spent at, or above, 90% $\dot{V}O_{2max}$ was significantly greater for intermittent runs at 105% $v\dot{V}O_{2max}$, than for runs at 100% $v\dot{V}O_{2max}$. These findings suggest that work interval intensities somewhere between 105% and 120% $v\dot{V}O_{2max}$ are most effective at allowing an individual to spend time at, or close to, $\dot{V}O_{2max}$. However, the duration of the work interval has also been shown to have a substantial influence on time spent at $\dot{V}O_{2max}$ (24). For instance, several researchers have demonstrated that for intermittent runs completed at, or above 100% $v\dot{V}O_{2max}$, short duration work intervals (15-60 s) are effective at allowing individuals to spend time at, or above, 90% $\dot{V}O_{2max}$ (7, 8, 12, 15). Nevertheless, Rozenek et al. (33) demonstrated that intermittent runs at 100% $v\dot{V}O_{2max}$ with work interval durations >30 s resulted in higher levels of blood lactate relative to intermittent runs with work interval durations of 15 s. Since 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 s would enable individuals to optimize time at, or very close to, $\dot{V}O_{2max}$.

While researchers continue to address many of the methodological 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 $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$ and time at $\dot{V}O_{2max}$ 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 $\dot{V}O_{2max}$. Therefore, the purpose of this study was to examine the effect of manipulations of work interval intensity (105% $v\dot{V}O_{2max}$ and 115% $v\dot{V}O_{2max}$) and duration (20 s, 25 s, and 30 s) utilized during intermittent bouts of supramaximal exercise on time spent at, or above, 95% $\dot{V}O_{2max}$.

METHODS

Approach to the Problem

All subjects were required to attend seven separate testing sessions over the course of a five week period. Subjects first performed a submaximal incremental test (7 x 3 min stages, with increments of 1 $km.h^{-1}$) to establish an oxygen uptake/running velocity relationship. Following a 5 min passive recovery period, subjects completed a maximal incremental exercise test to determine $\dot{V}O_{2max}$. Using this value, the submaximal oxygen uptake/running velocity relationship was extrapolated to calculate 105% $v\dot{V}O_{2max}$ and 115% $v\dot{V}O_{2max}$. 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 three supramaximal intermittent runs to exhaustion at both 105% $v\dot{V}O_{2max}$ and 115% $v\dot{V}O_{2max}$. Each of the three tests was conducted using a different work interval duration (20 s, 25 s, and 30 s), interspersed with 20 s 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. Following completion of a pre-activity readiness questionnaire, subjects were provided with written and verbal information outlining the demands of the study prior to 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) two hours before testing, and to abstain from alcohol consumption and vigorous exercise in the 24 hrs before testing. Means (± standard deviation) for age, height, body mass, and VO_{2max} were: 22 ± 5 yrs, 181.5 ± 5.6 cm, 86.4 ± 11.4 kg and 51.5 ± 5.1 $ml \cdot kg^{-1} \cdot min^{-1}$ 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, California, 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 ($\dot{V}O_2$) 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 analyser has been reported to provide an accurate and reliable measure of blood lactate (10).

1) Maximal Incremental Exercise Test

Due to 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 post-exercise to provide an indication of maximal effort. A subject was judged to have reached $\dot{V}O_{2\,max}$ when three 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 (RER) greater than 1.15, (c) an inability to maintain the required running speed (d) a post-exercise blood lactate concentration higher than 8 $mmol \cdot L^{-1}$, (e) a heart rate within 10 beats per min of age-predicted maximum (1).

2) Supramaximal Intermittent Running Test

Only one supramaximal intermittent run was carried out on any given day, and each test was separated by at least 48 hrs to ensure adequate recovery. Before each test, subjects completed a 5 min warm-up at 50% $v\dot{V}O_{2max}$. 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. Following the completion of the test, subjects performed a 5 min cool-down at 50% $v\dot{V}O_{2max}$. 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% $\dot{V}O_{2\,max}$ was calculated through the accumulation of $\dot{V}O_2$ values superior, or equal, to 95% of the $\dot{V}O_{2\,max}$ score obtained from the maximal incremental test. This method of calculating time spent at, or near to, VO_{2max} has been supported by previous researchers (14, 18, 19) and has been shown to have good test-retest reliability (ICC = 0.80) (25).

Statistical Analyses

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

RESULTS

Time spent at, or above, 95% VO_{2max}

A summary of the effects of the experiment on time spent at, or above, 95% $\dot{V}O_{2\,max}$ is presented in Figure 1. Relative to intermittent runs at 105% $v\dot{V}O_{2max,}$ time spent at, or above, 95% $\dot{V}O_{2\,max}$ was not significantly different from that at 115% $v\dot{V}O_{2max}$ ($F_{(1,6)} = 2.850$, $p = 0.142$). There was however, a significant effect of work interval duration on time spent at, or above, 95% $\dot{V}O_{2\,max}$ ($F_{(2,12)} = 17.110$, $p < 0.001$); with *post hoc* analyses revealing that work interval durations of 30 s allowed subjects to spend significantly longer at, or above, 95% $\dot{V}O_{2\,max}$ than work intervals of 20 s (mean difference = 89 s; 95% likely range: 19 to 160 s) and 25 s (mean difference = 75 s; 95% likely range: 24 to 126 s) (no significant difference [$p = 0.625$] in time spent at, or above, 95% $\dot{V}O_{2\,max}$ 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.

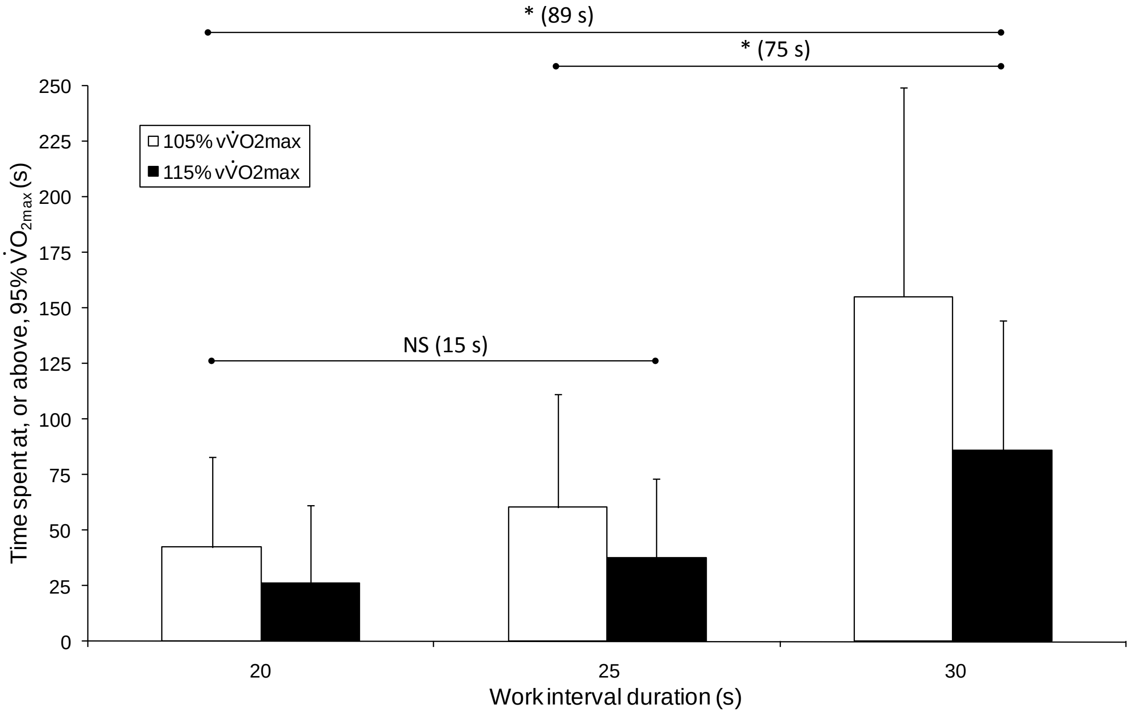

Figure 1. Time spent at, or above, 95% $\dot{V}O_{2max}$ for intermittent runs at 105% v$\dot{V}O_{2max}$ and 115% v$\dot{V}O_{2max}$ with work interval durations of 20, 25 and 30 s (20 s passive recovery periods). Values are means ± *standard deviation*. * denotes a significant difference ($p < 0.05$). NS denotes no significant difference ($p \geq 0.05$).

Blood lactate

The influence of work interval intensity and duration on blood lactate is illustrated in Figure 3. As anticipated, post exercise blood lactate was significantly higher than pre exercise, irrespective of the condition ($F_{(1,6)}$ = 12.758, p = 0.012). Relative to 105% v$\dot{V}O_{2max}$, intermittent runs at 115% v$\dot{V}O_{2max}$ 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 to 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 s versus 25 s (mean difference = 0.57 mmol·L^{-1}; 95% likely range: 0.15 to 0.99 mmol·L^{-1}), and 30 s versus 20 s (mean difference = 0.73 mmol·L^{-1}; 95% likely range: 0.24 to 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).

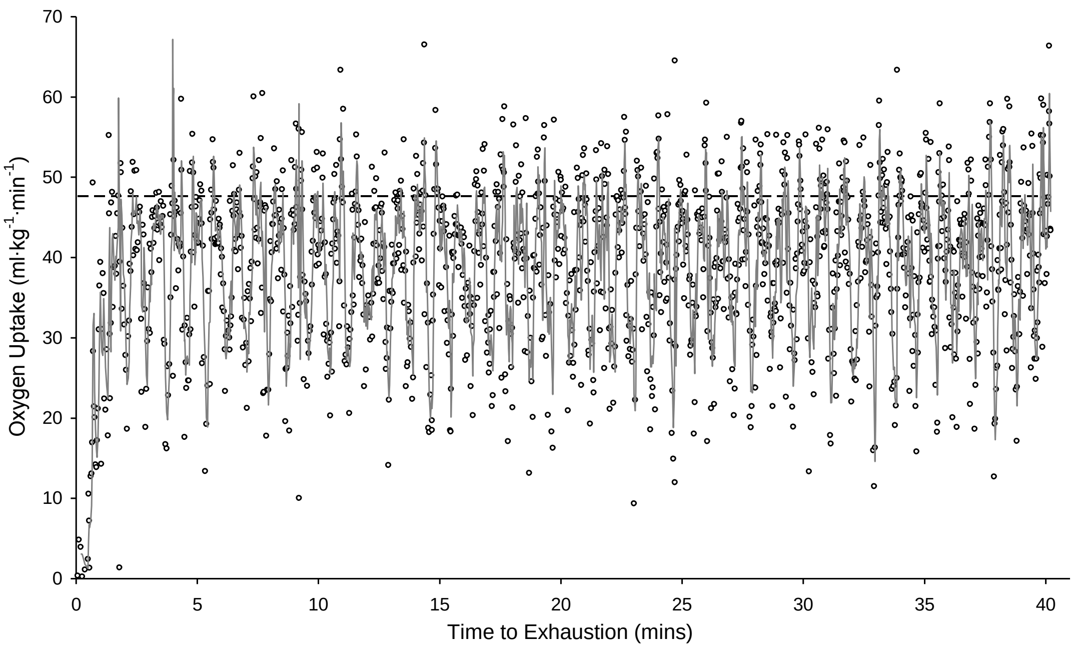

Figure 2. An example of the oxygen uptake response elicited by a subject during an intermittent run at 105% v$\dot{V}O_{2max}$ with work interval durations of 30 s. Open circles represent breath-by-breath $\dot{V}O_2$ data; the dashed horizontal line represents 95% of the subject's $\dot{V}O_{2max}$; the solid line represents a three breath moving average.

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 heart rate during the intermittent runs (Table 1). There was also no significant interaction between exercise intensity and work interval duration on mean heart rate ($F_{(2,12)}$ = 1.871, p = 0.196).

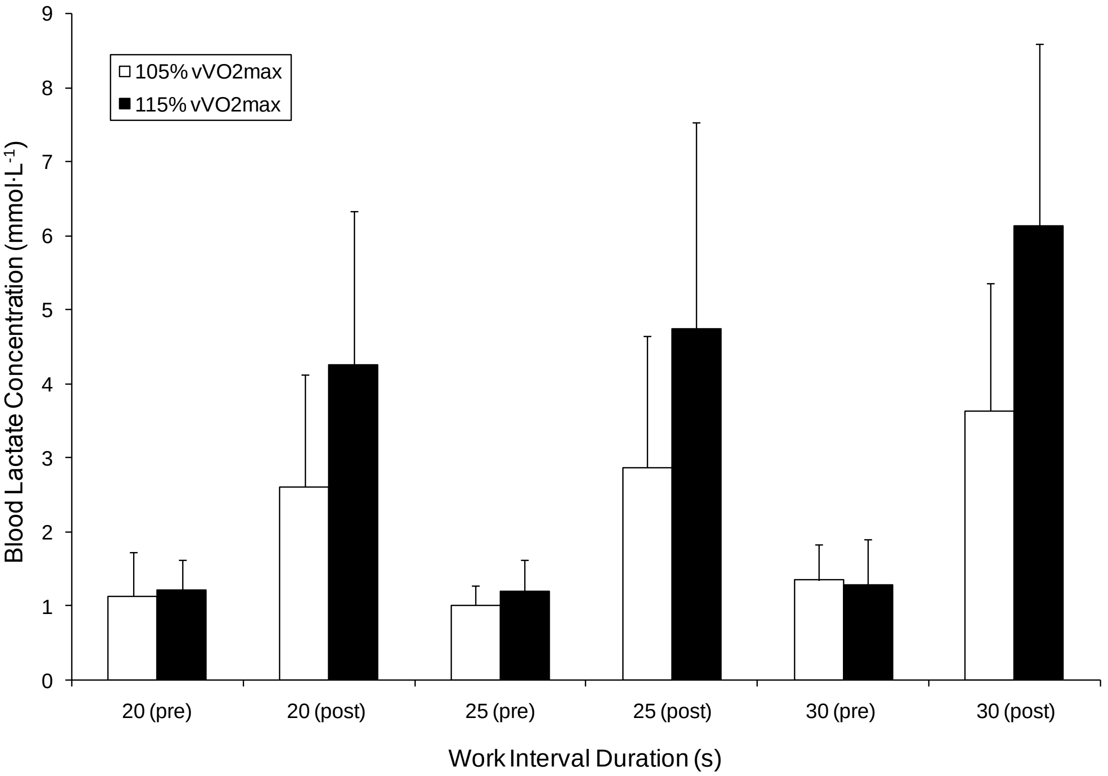

Figure 3. Pre- and post-exercise blood lactate responses to intermittent runs at 105% $v\dot{V}O_{2max}$ and 115% $v\dot{V}O_{2max}$ with contrasting work interval durations of 20, 25 and 30 s (20 s passive recovery periods). Values are means ± *standard deviation*. Note: pre = pre-exercise; post = post-exercise.

Table 1 – Summary of three of the dependent variables measured during intermittent treadmill running at 105% $v\dot{V}O_{2max}$ and 115% $v\dot{V}O_{2max}$ with work interval durations of 20, 25 and 30 s (20 s passive recovery periods). Values are means ± *standard deviation*.

Intensity	105% $v\dot{V}O_{2max}$			115% $v\dot{V}O_{2max}$		
Work intervals (s)	20	25	30	20	25	30
Mean heart rate (b·min^{-1})	163 ± 7	167 ± 6	172 ± 13	167 ± 8	165 ± 13	165 ± 11
Intervals completed	82 ± 11	73 ± 7	53 ± 12	59 ± 17	39 ± 9	24 ± 6
Time to exhaustion (mins)	54.9 ± 7.1	54.1 ± 5.0	43.7 ± 10.4	39.1 ± 11.4	29.0 ± 6.5	19.8 ± 5.4

Number of work intervals completed

Intermittent runs at 105% $v\dot{V}O_{2max}$ resulted in a significantly greater number of work intervals being completed than intermittent runs at 115% $v\dot{V}O_{2max}$ ($F_{(1,6)} = 80.766$, $p < 0.001$) (Table 1). There was also a significant effect of work interval duration on the number of work intervals completed ($F_{(2,12)} = 46.029$, $p < 0.001$). Pairwise comparisons revealed that work intervals of 20 s allowed subjects to complete a significantly greater number of intervals than those of 25 s ($p = 0.014$) and 30 s ($p = 0.001$). Moreover, the number of work intervals completed during intermittent runs with 25 s work intervals was significantly greater than for work intervals of 30 s ($p < 0.001$). 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 105% $v\dot{V}O_{2max}$ than for intermittent runs at 115% $v\dot{V}O_{2max}$ ($F_{(1,6)} = 81.962$, $p < 0.001$). 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 s and 25 s work intervals ($p = 0.156$), pairwise comparisons revealed that 20 s and 25 s work intervals resulted in significantly longer ($p = 0.007$ and $p = 0.002$ respectively) times to exhaustion than 30 s 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% $v\dot{V}O_{2max}$ and 115% $v\dot{V}O_{2max}$) and duration (20 s, 25 s, and 30 s) utilized during intermittent bouts of supramaximal exercise on time spent at, or above, 95% $\dot{V}O_{2max}$. The results of the study revealed that time spent at, or above, 95% $\dot{V}O_{2max}$ was not significantly different for intermittent runs at 105% $v\dot{V}O_{2max}$ than for intermittent runs at 115% $v\dot{V}O_{2max}$. 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, $\dot{V}O_{2max}$. Based upon previous recommendations (24), it was hypothesized that time spent at, or above, 95% $\dot{V}O_{2max}$ would be significantly greater for supramaximal intermittent runs at 105% $v\dot{V}O_{2max}$, than for identical runs conducted at 115% $v\dot{V}O_{2max}$. It was anticipated that supramaximal intensities above 105% $v\dot{V}O_{2max}$ 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 at, or close to, $\dot{V}O_{2max}$ between the two supramaximal exercise intensities, there was a trend towards an effect (see Figure 1); with 105% $v\dot{V}O_{2max}$ showing a longer mean time at, or above, 95% $\dot{V}O_{2max}$ at each of the three work interval durations. Such an observation is consistent with some previous studies which have reported that running velocities closer to 100% $v\dot{V}O_{2max}$ allow more time to be spent at $\dot{V}O_{2max}$ than much higher (i.e. 110% - 140% $v\dot{V}O_{2max}$) running velocities (7, 15). Within these studies, exercise intensities greater than 105% $v\dot{V}O_{2max}$ were considered to be too intense to be maintained for very long (generally not >12 mins). In the present study, the significantly higher blood lactate concentrations for intermittent runs at 115% $v\dot{V}O_{2max}$, 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, $\dot{V}O_{2max}$ between the two supramaximal exercise intensities in this investigation is most likely to be due to the large between-subject variability in the data. This makes the time spent at, or above, 95% $\dot{V}O_{2max}$ 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 $\dot{V}O_{2max}$, subject fitness level, criteria for accepting oxygen uptake data points as being close to $\dot{V}O_{2max}$), the largest source of error in determining time spent at $\dot{V}O_{2max}$ appears to lie in the initial measurement of $\dot{V}O_{2max}$ (24). This is because variations in $\dot{V}O_{2max}$ can greatly influence any factors dependent upon it. An underestimation of an individual's $\dot{V}O_{2max}$ in the present study, for example, is also likely to result in underestimated calculations of $v\dot{V}O_{2max}$, 105% $v\dot{V}O_{2max}$ and 115% $v\dot{V}O_{2max}$. 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 $\dot{V}O_{2max}$ 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, $\dot{V}O_{2max}$; with longer work intervals of 30 s allowing more time to be spent at, or above, 95% $\dot{V}O_{2max}$, relative to work interval durations of 25 s or 20 s. This pattern of results is similar to that observed in previous research. For example, Rozenek et al. (33) confirmed that intermittent runs at 100% $v\dot{V}O_{2max}$ with longer work interval durations of 60 s allowed subjects to spend the longest time at, or above, 90% $\dot{V}O_{2max}$ (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% $v\dot{V}O_{2max}$ with longer work interval durations (60s) resulted in significantly greater time spent at, or above, 90% $\dot{V}O_{2max}$

than those with shorter work interval durations (30 s). Although the intensity and duration of the work and recovery intervals differ from those of the present study, it appears that work period durations greater than 25 s provide the most effective means of optimizing time spent at, or above, 95% $\dot{V}O_{2max}$.

Despite the significant effect of work interval duration on time spent at, or close to, $\dot{V}O_{2max}$, the present study reported values that are considerably shorter than those reported in previous research. For example, Dupont et al. (15) demonstrated that subjects spent, on average, 383 ± 180 s at, or above, 90% $\dot{V}O_{2max}$ during intermittent runs at 110% $v\dot{V}O_{2max}$, while Thevenet et al. (35) reported values of 316 ± 360 s for mean time spent above 90% $\dot{V}O_{2max}$ during intermittent runs at 105% $v\dot{V}O_{2max}$. Aside from error during the initial measurement of $\dot{V}O_{2max}$, and the fact that the above investigations used 90% rather than 95% as their cut-off threshold, the longer times at $\dot{V}O_{2max}$ reported in previous studies can in part be explained by the different procedures used for establishing $v\dot{V}O_{2max}$. For example, Noakes (31) calculated $v\dot{V}O_{2max}$ as the highest running velocity reached and maintained for one minute during a maximal incremental treadmill test, while Billat et al. (6) defined $v\dot{V}O_{2max}$ as the minimum velocity necessary to elicit $\dot{V}O_{2max}$ in a similar protocol. A consequence of this lack of consistency in the method used to calculate $v\dot{V}O_{2max}$ was highlighted by Billat and Koralsztein (4) who reported different values (18.6-21 km.h^{-1}) of $v\dot{V}O_{2max}$ for the same athlete when using different protocols. Researchers are therefore encouraged to use caution when making comparisons between studies that have used different procedures for establishing $v\dot{V}O_{2max}$. Alternatively, the shorter times sustained at, or near to, $\dot{V}O_{2max}$ in the present study may be explained by the training status of the subjects (24). Several investigations have employed endurance-trained runners (7, 8, 11) or triathletes (29) as subjects, while the present study utilized recreationally-active Sport Science students. Since oxygen uptake kinetics become more rapid in response to endurance training (2), the relatively shorter times at, or close to, $\dot{V}O_{2max}$ may be due, in part, to slower oxygen uptake kinetics at the onset of each work interval.

Another plausible explanation for the differences in time at $\dot{V}O_{2max}$ between the present study and previous work could be the criteria for accepting oxygen uptake data as being at, or close to, $\dot{V}O_{2max}$. Numerous investigations have focused on time spent above 90% $\dot{V}O_{2max}$ (12, 15, 30, 38) while others have used 95% $\dot{V}O_{2max}$ (18, 25) or $\dot{V}O_{2max}$ minus 2.1 $ml.kg^{-1}.min^{-1}$ (5). The lack of uniformity in the way that time at $\dot{V}O_{2max}$ has been calculated makes interpretation of results and comparisons between studies extremely difficult (28). Since researchers are unlikely to agree to standardized test procedures, these methodological inconsistencies are likely to hinder the design and interpretation of future studies that attempt to characterize intermittent running protocols that allow the longest time at $\dot{V}O_{2max}$ (26).

PRACTICAL APPLICATIONS

The present study revealed that longer duration work intervals allow subjects to spend the greatest amount of time at, or close to, $\dot{V}O_{2max}$. 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 around 105% $v\dot{V}O_{2max}$ combined with work interval durations greater than 25 s provide the optimal means of spending time at, or above, 95% $\dot{V}O_{2max}$ when using fixed 20 s stationary rest periods.

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