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ORIGINAL ARTICLE

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Prolonged stage duration during incremental cycle exercise: effects on the lactate threshold and onset of blood lactate accumulation

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Abstract The aim of this study was to investigate whether increasing the duration of workloads from 3 min to 8 min during incremental exercise would influence workload (W), oxygen consumption ($\dot{V}O_2$) and heart rate (HR) at the lactate threshold (LT) and the onset of blood lactate accumulation(OBLA). Two groups of six male cyclists were assigned to a well-trained (WT) and recreational (REC) group on the basis of their performance in a maximal incremental ramp test. Each subject then performed two incremental lactate tests (EXT) consisting of six workloads of either 3 min ($EXT_{3\text{-min}}$) or 8 min ($EXT_{8\text{-min}}$) duration. At the completion of each workload whole capillary blood samples were obtained for the determination of blood lactate (BLa) concentration (mM). Power output (Watts, W), HR and $\dot{V}O_2$ were averaged in the final minute of each workload as well as in the third minute of the $EXT_{8\text{-min}}$. The workload, HR and $\dot{V}O_2$ at the LT and OBLA were subsequently determined from the data of $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$. The results demonstrate that workload and $\dot{V}O_2$, but not HR, at the LT and OBLA were higher in the WT cyclists. At the same time, the workload at the LT obtained from the results of the $EXT_{3\text{-min}}$ was significantly ($P<0.05$) higher then the value obtained in the $EXT_{8\text{-min}}$ in the WT subjects but not the REC subjects. However, the workload, $\dot{V}O_2$ and HR at the OBLA, together with the $\dot{V}O_2$ and HR at the LT were not significantly different when calculated from data obtained from $EXT_{3\text{-min}}$ or $EXT_{8\text{-min}}$. The data obtained in this study suggest that incremental exercise protocols using workloads of duration longer than 3 min have the effect of increasing the workload at the LT in well-trained cyclists. However, the OBLA determined in exercise tests using stage increments of either 3 min or 8 min is similar in cyclists of different training status.

Keywords Adaptation · Athletes · Blood lactate · Incremental exercise · Oxygen consumption · Workload

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Introduction

The physiological response to incremental exercise is often conducted by measuring the plasma or whole blood lactate (BLa) concentration coupled with oxygen consumption ($\dot{V}O_2$) (Coyle 1995; Farrell et al. 1979; Weltman et al. 1990). The $\dot{V}O_2$ at a BLa concentration of 4 mM (OBLA) or the lactate threshold (LT), for example, have been used to predict distance running performance or distinguish between well-trained and elite-trained time-trial cyclists with similar maximal oxygen uptake ($\dot{V}O_2$max) (Coyle et al. 1991; Tanaka and Matsuura 1984). In addition, the response to endurance training has been quantified by measuring the $\dot{V}O_2$ at the LT (LT_{VO_2}) in previously sedentary subjects (Coyle et al. 1983). Another study has reported a strong relationship between skeletal muscle oxidative capacity and the LT_{VO2} (Ivy et al. 1980).

A potentially influential factor in all of these investigations is the type of incremental exercise protocol that is used to determine the workload or $\dot{V}O_2$ at the LT and OBLA (Bishop et al. 1998b; Coyle et al. 1983, 1991). Several research groups, for example, have used a series of 10-min exercise bouts on different test days in trained or sedentary subjects (Coyle et al. 1983; Farrell et al. 1979). Others (Coyle et al. 1991; Horowitz et al. 1994) have used 5-min staged protocols to determine the LT_{VO2} in well-trained cyclists. More recently 3-min and 4-min staged protocols have been used to determine the LT during cycle exercise in triathletes or female cyclists (Bishop et al. 1998b; Hoogeveen and Schep 1997).

During incremental exercise muscle and BLa accumulation may change at different rates relative to the exercise intensity being completed (Chwalbinska-

Moneta et al. 1989). At exercise intensities below the LT, and where a "steady state" is achievable, BLa accumulation remains minimal and may even decrease with increasing exercise duration. However, at work rates above the LT, BLa concentration increases with time despite no change in work rate (Smith et al. 1998). In addition to changes in BLa accumulation, $\dot{V}O_2$ may also rise until a steady state has been reached, usually after approximately 3 min (Whipp and Wasserman 1972). At work rates that evoke a marked increase in Bla, that is greater than the LT, $\dot{V}O_2$ does not reach a steady state but continues to rise (Jones et al. 1999). This delayed phase of $\dot{V}O_2$ kinetics has been termed "the $\dot{V}O_2$ slow component" (Whipp 1994). Therefore, the delayed increase in $\dot{V}O_2$ during higher intensity exercise beyond the LT, together with the change in BLa accumulation, may influence the workload and $\dot{V}O_2$ at the LT or OBLA when different incremental exercise protocols are used.

There have been a number of research groups who have compared lactate and ventilation responses to different incremental exercise tests with stage durations of less than 5 min (Coen et al. 2000; Prioux et al. 1997). There are few data examining stages of less than 5 min when changes in oxygen uptake kinetics and BLa accumulation may change markedly. In one study, Weltman et al. (1990) showed that 3-min or 10-min incremental step tests resulted in no significant difference in the workload or $\dot{V}O_2$ at the LT or OBLA. However, other researchers have shown that the physiological response to exercise may change depending upon the length of stages during incremental exercise used to determine the workload of the exercise (Foxdal et al. 1994, 1996). However, these investigations were conducted without an untrained control group, or they did not couple BLa and $\dot{V}O_2$ measurements in the analysis.

During cycle exercise it has been reported that well-trained subjects are able to exert more efficient force during the down phase of the pedalling cycle (Coyle et al. 1991). Thus, during prolonged submaximal exercise of the same relative exercise intensity, the recruitment patterns of slow and fast motor units and subsequent BLa production may differ between cyclists of varying ability level. Indeed it has been suggested that changes in motor recruitment patterns may influence changes in BLa during prolonged cycle exercise (Marcinik et al. 1991).

The existing literature therefore suggests that cycling efficiency, together with the length of the incremental exercise protocol, may influence coupled BLa and $\dot{V}O_2$ measurements. Therefore, the purpose of this investigation was to measure the workload and $\dot{V}O_2$ at the LT and OBLA using a 3-min or an 8-min incremental step test protocol. Furthermore, two populations of cyclists that differed in aerobic capacity were assessed to determine the effects of training status on the metabolic response during these incremental exercise tests.

Methods

Subjects

Twelve male subjects with the following physical characteristics [mean (SD)]: age 31.2 (4.9) years, body mass 76.7 (6.3) kg and $\dot{V}O_2$max 60.1 (7.5) ml·kg^{-1}·min^{-1} volunteered to participate in the study. Six subjects were assigned to a recreational (REC) group and six to a well-trained group (WT) group based on their performance in the ramp test (maximum workload in WT subjects ≥400 W). The WT group consisted of triathletes ($n=3$) who had recently competed internationally in age group multisport events, elite mountain cyclists ($n=2$) and a British Cycling Federation (BCF) category two cyclist. The REC were active in triathlon or road cycling at club level, but had not competed at an international level. The methods and possible risks were explained verbally and in writing to each subject and all signed informed consent. The protocol was approved by the local research ethics committee.

Experimental design

Each subject completed three exercise tests over a 2-week period performed on an SRM electrically braked cycle ergometer system (SRM, Schroberer Rad MeBtechnik, Weldorf, Germany). A previous report has demonstrated the reliability of power output during incremental exercise tests using the SRM system (Balmer et al. 2000).

The first test was an incremental ramp test to exhaustion to determine the maximum workload (W) (PPO) and $\dot{V}O_2$max (l·min^{-1}). The second and third tests included two separate continuous incremental lactate tests (EXT) involving six stages of either 3 min ($EXT_{3\text{-min}}$) or 8 min ($EXT_{8\text{-min}}$) duration. The ramp test was always completed first whilst the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ were performed in a randomized order. Each test was separated by at least 48 h and followed 24 h of inactivity or low-intensity/duration exercise.

Ramp test

The ramp test was preceded by a 10-min warm up that was performed at a self-selected intensity representing less than 50% of $\dot{V}O_2$max. The test commenced at a workload of 125 W and increased at 30-W·min^{-1} increments until volitional exhaustion or if the subject was not able to produce the desired work rate. Power output (W) was sampled continuously throughout the test then averaged in the final minute to maximum workload (PPO) (Balmer et al. 2000). Expired gases were also sampled continuously breath by breath throughout the test using an online mass spectrometer (EX670, Morgan Medical, England) and the data were averaged every 15 s. The system was calibrated with known gas concentrations and volumes prior to each test according to manufacturer's specifications. Heart rate (beats·min^{-1}) was sampled at 5-s intervals throughout the test by a HR monitor (Polar, Vantage, Finland). $\dot{V}O_2$max was deemed to have been achieved if the respiratory exchange ratio was greater than 1.2, HR was within 5 beats·min^{-1} of the age-predicted maximum and $\dot{V}O_2$ failed to increase with subsequent increments in power output. $\dot{V}O_2$max was deemed to be the highest $\dot{V}O_2$ measured during any averaged 15-s period.

Incremental lactate tests

Whole BLa and $\dot{V}O_2$ measurements were obtained during two EXT. The $EXT_{3\text{-min}}$ test involved six continuous stages each of 3 min duration while the $EXT_{8\text{-min}}$ test involved six stages of 8 min duration. In both EXT, the first workload represented 50–60% of $\dot{V}O_2$max depending upon the ability level of the cyclist. At the completion of the first workload each subject was required to increase the power output every 3 or 8 min depending on the test completed. The workload increments were determined so that an increase in $\dot{V}O_2$ of between 5% and 8% would occur with each subsequent stage (Coyle 1995; Pierce et al. 1999). The increments were also structured so that three stages would be completed below the LT, one stage would be completed at the LT and the final two stages completed above the LT (Coyle 1995). The subject continued the test until the six workloads were completed or until the required workload could not be maintained.

During both tests the power output was collected continuously whilst HR was sampled at 5-s intervals. Power output and HR were then averaged in the last minute of each workload during the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ as well as in the third minute of $EXT_{8\text{-min}}$. Similarly, expired gases were sampled continuously breath by breath for $\dot{V}O_2$ as described previously. The average $\dot{V}O_2$ was then determined for the final minute of each workload during the $EXT_{3\text{-min}}$ and the $EXT_{8\text{-min}}$ as well as the third minute of the $EXT_{8\text{-min}}$. Power output was also averaged for the duration of each workload during both the EXT.

Capillary whole blood samples were obtained via a small incision made in the left earlobe in the final 30 s of each workload during both EXT. The blood sample was subsequently analysed for BLa (mM) using a portable lactate analyser (LT 1710 Lactate Pro, KDK, Shiga, Japan). The reliability of this device for measuring whole BLa concentration is reported elsewhere (Pyne et al. 2000). The analyser was calibrated prior to each test using the manufacturer's recommendations.

Blood lactate, $\dot{V}O_2$ and HR values were plotted against the average power output during each stage of the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ respectively. A curvilinear line of best fit was then constructed for BLa against power output and a linear line was constructed for power output and $\dot{V}O_2$, and $\dot{V}O_2$ and HR. The power output at the LT was calculated using the procedures of Beaver et al. (1985). This method is thought to accurately detect the LT as opposed to visual inspection (Beaver et al. 1985). The workload at the OBLA was also interpolatedfrom the curvilinear line and deemed to be the point eliciting a BLa concentration of 4 mM (Sjodin and Jacobs 1981). The HR and $\dot{V}O_2$ at the LT and OBLA were interpolated from the linear line at the workload corresponding to the LT and OBLA respectively.

Statistical analysis

The physical characteristics of the two groups (age, height and body mass) as well as maximal oxygen uptake ($l{\cdot}min^{-1}$ and $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) and PPO (W) for the WT and REC groups obtained from the ramp test were compared using independent sample *t*-tests. The power output during each of the tests was expressed as a percentage of PPO. A series of single-factor (test protocol) analysis of variance (ANOVA) with repeated measures and between-subject comparisons (subject group) was used to compare the average power output during each stage of the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$. Whole BLa concentration at the completion of each workload in each EXT, together with power output and $\dot{V}O_2$ averaged in the final minute of each workload during the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ as well as the third minute of $EXT_{8\text{-min}}$ were also analysed using a series of single-factor (test protocol) ANOVA with repeated measures and between-subject comparisons (subject group). The workload, $\dot{V}O_2$ and HR at the LT and the OBLA for the WT and REC groups obtained from the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ were compared using a single-factor ANOVA with repeated measures and between-subject comparisons (subject group). Significance was set at $P < 0.05$.

Results

The differences in the physical characteristics of the two groups of subjects can be seen in Table 1. Maximal oxygen uptake and PPO obtained during the ramp test were significantly higher in the WT when compared to the REC cyclists (Table 1). Although the power output significantly ($P < 0.01$) increased during each stage of each EXT, there were no significant ($P > 0.05$) differences in the power output (relative to PPO) in the $EXT_{3\text{-min}}$ or $EXT_{8\text{-min}}$ (Table 2). Furthermore, the WT and REC cyclists exercised at a statistically similar power output relative to PPO at the three time periods during each stage of either the $EXT_{3\text{-min}}$ or $EXT_{8\text{-min}}$.

BLa concentrations were similar at the completion of each workload in each EXT in both the WT and REC subjects. However, the BLa concentration following the second workload of the $EXT_{8\text{-min}}$ was significantly lower ($P < 0.03$) in the WT as compared to the REC group (Table 3). At the same time, the BLa concentration was significantly ($P < 0.005$) elevated in both the WT and

Table 1 Physical characteristics, maximal oxygen uptake ($\dot{V}O_2$max) and maximum power output (*PPO*) obtained in the incremental ramp test of subjects in the recreational (*REC*) and well-trained (*WT*) cyclist groups

Variable	WT ($n = 6$)	REC ($n = 6$)
Age (years)	29.8 (6.1)	32.5 (3.3)
Height (cm)	185.2 (5.1)	178.8 (4.9)*
Body mass (kg)	75.7 (6.6)	77.8 (6.4)
$\dot{V}O_2$max ($l{\cdot}min^{-1}$)	4.85 (0.12)	4.29 (0.28)**
$\dot{V}O_2$max ($ml{\cdot}kg{\cdot}min^{-1}$)	64.6 (6.4)	55.6 (5.9)*
PPO (W)	422.2 (23.5)	329.2 (13.7)**

*Significantly different from WT ($P < 0.05$)
**Significantly different from WT ($P < 0.01$)

Table 2 Power output (*W*) as a percentage (%) of maximum workload (*PPO*) in the third minute of the $EXT_{8\text{-min}}$ as well as the final min of the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ ($n = 12$)

Stage	Test		
	$EXT_{3\text{-min}}$ 3rd min	$EXT_{8\text{-min}}$	
		3rd min	8th min
1	44.3 (8.8)	46.2 (4.2)	47.4 (3.7)
2	52.7 (5.0)	53.1 (4.7)	53.4 (4.3)
3	58.2 (5.1)	58.6 (4.9)	58.7 (4.3)
4	64.3 (5.2)	63.8 (4.2)	64.3 (4.5)
5	70.1 (6.3)	69.6 (4.8)	69.5 (4.5)
6	75.4 (6.1)	75.5 (4.3)	76.4 (4.6)

Table 3 Blood lactate concentration (*[BLa]*, mM) at the completion of each workload during the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ in the WT ($n = 6$) and REC ($n = 6$) cyclists

Workload	$EXT_{3\text{-min}}$		$EXT_{8\text{-min}}$	
	WT	REC	WT	REC
1	$2.0\ (1.0)_x$	$2.0\ (1.0)_x$	$1.7\ (0.5)_x$	$2.1\ (1.0)_x$
2	$2.3\ (0.8)_x$	$2.3\ (1.0)_x$	$1.4\ (0.2)_y$	$2.5\ (1.2)_x$
3	$2.5\ (0.8)_x$	$2.8\ (1.3)_x$	$1.8\ (0.3)_x$	$3.4\ (2.2)_x$
4	$2.9\ (0.7)_x$	$3.9\ (1.8)_x$	$2.9\ (0.2)_x$	$4.3\ (2.3)_x$
5	$3.9\ (0.7)_x$	$5.5\ (2.7)_x$	$4.4\ (0.6)_x$	$6.3\ (3.2)_x$
6	$5.3\ (0.8)_x$	$6.9\ (2.8)_x$	$6.7\ (1.3)_y$	$9.0\ (3.4)_y$

Subscripts indicate significant ($P < 0.03$) differences within a *row*

REC cyclists following completion of the final workload in the $EXT_{8\text{-min}}$ as compared to the $EXT_{3\text{-min}}$ (Table 3; Fig. 1).

Oxygen consumption was significantly higher ($P < 0.01$) higher in the WT subjects at each time period in each stage as compared to the REC cyclists (Table 4). However, despite the elevation of $\dot{V}O_2$ in the WT subjects, there was no significant effect of training status on the change in $\dot{V}O_2$ determined at the completion of each workload in the $EXT_{3\text{-min}}$ or in the third as well as the final minute of each individual stage of the $EXT_{8\text{-min}}$. When the results of the WT and REC were combined, $\dot{V}O_2$ was significantly ($P = 0.05$) higher in the final minute of the first workload in the $EXT_{8\text{-min}}$ as compared to the final minute of $EXT_{3\text{-min}}$ or the third minute of $EXT_{8\text{-min}}$. This finding aside, there were no significant differences in $\dot{V}O_2$ measured at each time period during each stage of the $EXT_{8\text{-min}}$ or $EXT_{3\text{-min}}$.

Whichever EXT was used for analysis, the workload corresponding to the LT (LT_W) and at OBLA ($OBLA_W$), as well as $\dot{V}O_2$ at the LT (LT_{VO2}) and at OBLA ($OBLA_{VO2}$) were all significantly higher in the WT group of cyclists (Table 5). However, the HR at the LT (LT_{HR}) and at OBLA ($OBLA_{HR}$) did not significantly differ between the WT and REC cyclists. The LT_W was significantly ($P < 0.05$) higher in the $EXT_{3\text{-min}}$ as compared to the $EXT_{8\text{-min}}$ in the WT cyclists. With the exception of the LT_W the different exercise protocols had no effect on each of these variables regardless of the cyclists' training status (Table 5, Figs. 2, 3).

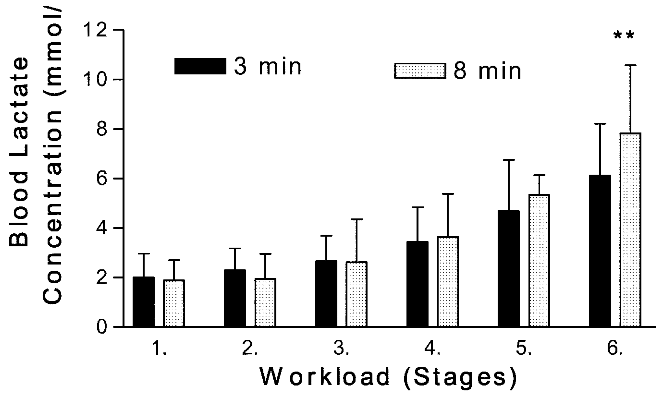

Fig. 1 Blood lactate concentration (*[BLa]*) [mean (SD)] at the completion of each workload during the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$. (*$EXT_{3\text{-min}}$* An incremental lactate test consisting of six workloads of 3 min duration, *$EXT_{8\text{-min}}$* as before but 8 min duration.) **Significantly ($P < 0.01$) different than $EXT_{3\text{-min}}$ data

Discussion

A number of different incremental exercise protocols have been designed to determine coupled workload, $\dot{V}O_2$ and BLa measurements in trained athletes (Farrell et al. 1979; Horowitz et al. 1994). The purpose of this investigation was to compare coupled whole BLa and $\dot{V}O_2$ as well as power output and BLa measurements obtained

Table 4 Oxygen consumption ($\dot{V}O_2$) ($l \cdot min^{-1}$) in the final minute of each workload during the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ as well as the third minute of the $EXT_{8\text{-min}}$ in the well trained (*WT*) ($n = 6$) and recreational (*REC*) ($n = 6$) cyclists

Workload	Test					
	$EXT_{3\text{-min}}$		$EXT_{8\text{-min}}$			
	3rd min		3rd min		8th min	
	WT	REC	WT	REC	WT	REC
1	$2.60 (0.35)_x$	$2.21 (0.12)_y$	$2.71 (0.33)_x$	$2.12 (0.21)_y$	$2.80 (0.38)_x$	$2.24 (0.15)_y$
2	$2.92 (0.32)_x$	$2.46 (0.18)_y$	$3.04 (0.39)_x$	$2.32 (0.47)_y$	$3.02 (0.40)_x$	$2.45 (0.31)_y$
3	$3.17 (0.30)_x$	$2.72 (0.17)_y$	$3.30 (0.43)_x$	$2.66 (0.19)_y$	$3.31 (0.43)_x$	$2.74 (0.18)_y$
4	$3.42 (0.34)_x$	$2.97 (0.18)_y$	$3.58 (0.39)_x$	$2.91 (0.20)_y$	$3.68 (0.44)_x$	$2.96 (0.23)_y$
5	$3.70 (0.33)_x$	$3.21 (0.20)_y$	$3.87 (0.44)_x$	$3.10 (0.23)_y$	$3.95 (0.41)_x$	$3.18 (0.18)_y$
6	$3.97 (0.29)_x$	$3.43 (0.26)_y$	$4.19 (0.49)_x$	$3.40 (0.15)_y$	$4.28 (0.42)_x$	$3.50 (0.17)_y$

Subscript indicate significant ($P < 0.01$) differences within a *row*

Table 5 Oxygen consumption ($\dot{V}O_2$) ($l \cdot min^{-1}$), heart rate (*HR*) ($beats \cdot min^{-1}$) and workload (*W*) at the lactate threshold (*LT*) and onset of blood lactate accumulation (*OBLA*) obtained during $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ for the well-trained (*WT*) ($n = 6$) and recreational (*REC*) cyclists ($n = 6$)

Variable	$EXT_{3\text{-min}}$		$EXT_{8\text{-min}}$	
	WT	REC	WT	REC
LT_{VO2}	$3.50 (0.53)_x$	$2.60 (0.14)_y$	$3.14 (0.42)_x$	$2.72 (0.15)_y$
LT_{HR}	$152.6 (12.1)_x$	$143.8 (7.3)_x$	$138.4 (18.2)_x$	$154.8 (18.5)_x$
LT_W	$264.0 (42.2)_x$	$193.2 (15.0)_y$	$225.2 (26.6)_z$	$201.8.8 (18.4)_y$
$OBLA_{VO2}$	$3.62 (0.41)_x$	$2.88 (0.29)_y$	$3.94 (0.43)_x$	$2.80 (0.52)_y$
$OBLA_{HR}$	$156.2 (12.1)_x$	$154.8 (9.7)_x$	$159.2 (12.7)_x$	$152.4 \pm(10.8)_x$
$OBLA_W$	$275.4 (38.6)_x$	$219.4 (21.0)_y$	$280.6 (21.0)_x$	$209.0 (32.0)_y$

Subscripts indicate significant ($P < 0.05$) differences within a *row*

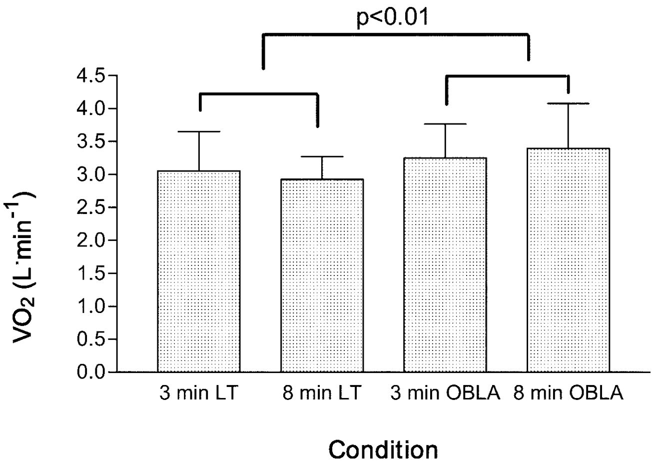

Fig. 2 Oxygen consumption at the lactate threshold (*LT*) and onset of blood lactate accumulation (*OBLA*) obtained during $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$. There were no significant ($P > 0.05$) differences between the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ data

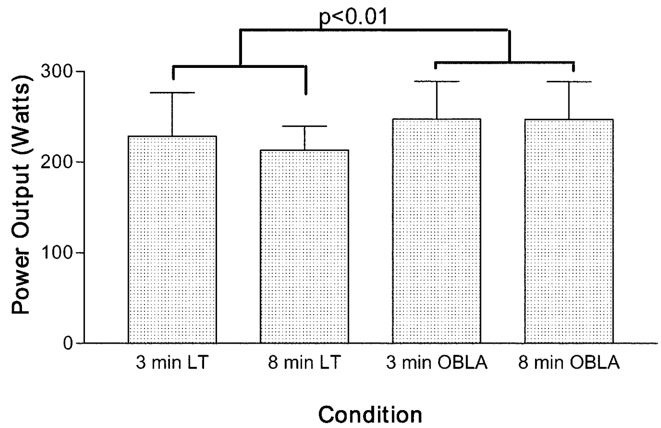

Fig. 3 Power output at the lactate threshold (*LT*) and onset of blood lactate accumulation (*OBLA*) obtained during $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$. There were no significant ($P > 0.05$) differences between the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ data

from two separate incremental exercise tests with step increments of either 3 min ($EXT_{3\text{-min}}$) or 8 min ($EXT_{8\text{-min}}$) duration. Furthermore, we compared the results of these tests in a group of well-trained as opposed to a recreational group of cyclists.

In this study we hypothesized that the prolonged duration of each workload during the $EXT_{8\text{-min}}$ combined with the different abilities of the two groups of cyclists would result in contrasting BLa and $\dot{V}O_2$ measurements at the end of each workload. This in turn would effect the coupled $\dot{V}O_2$ and BLa values at the LT and the OBLA. The results demonstrate that the LT_W of the WT subjects was significantly higher when calculated from the results of the $EXT_{3\text{-min}}$ as compared with the $EXT_{8\text{-min}}$. This finding aside, there were no significant effects of training status (WT or REC) on the $\dot{V}O_2$ or HR at the LT or OBLA obtained from either the $EXT_{3\text{-min}}$ or $EXT_{8\text{-min}}$. Furthermore, there was no significant effect of training status on the $OBLA_W$ obtained from the two different exercise protocols.

BLa is determined by both the production and elimination of lactate (MacRae et al. 1992). During low-intensity exercise lactate is shuttled from the muscle cell and may be eliminated by less metabolically active tissues (Brooks 2000). At the same time oxidative metabolism is preferential at lower work rates, which will result in less production and the possible appearance of lactate in the blood (Jeukendrup et al. 1999). However, during higher intensity exercise greater than the LT, BLa accumulation is more pronounced and continues to rise with prolonged exercise despite a constant work rate (Smith et al. 1998). The ability to reduce muscle lactate production and increase its elimination will dictate the appearance of this metabolite in the blood (Brooks 2000). The WT group of cyclists were superior to the REC group in terms of PPO and $\dot{V}O_2$max. Thus, it is likely that the WT subjects may have had a greater metabolic capacity to reduce BLa accumulation at low and high work rates (Pilegaard et al. 1994). Regardless of training status, during sustained exercise for longer than 3 min, BLa accumulation will more pronounced especially at work rates above the LT (Jones et al.1999). At the same time, it has also been recently shown that training status effects the metabolic response during prolonged exercise above the LT (Baldwin et al. 2000). We have shown that during the $EXT_{8\text{-min}}$ test, when compared to the REC group, the WT subjects had a significantly reduced BLa concentration at low work rates. At higher work rates there was a trend for the BLa concentration to be greater in the REC cyclists, especially in the $EXT_{8\text{-min}}$; however, the BLa concentration remained statistically similar when compared to the WT subjects. Thus, it is likely that the similar BLa response at higher work rates in the $EXT_{8\text{-min}}$ and $EXT_{3\text{-min}}$ in both groups may explain why the W_{OBLA} was statistically similar when calculated from the results of either EXT.

Whilst other reports have detailed changes in ventilation and BLa parameters with different exercise protocols using stages shorter than 5 min (Bishop et al. 1998a; Coen et al. 2000; McLellan 1985; Prioux et al. 1997), to our knowledge, only one previous study has directly investigated the effects on LT and fixed BLa measurements of different exercise protocols using stage durations of less than 3 min and more than 5 min (Weltman et al. 1990). These authors compared the $\dot{V}O_2$, velocity (m/min) and HR values at the LT, and 2.0, 2.5 and 4.0 mM BLa points during incremental treadmill exercise involving either continuous 3-min or discontinuous 10-min workloads. The results showed that the different testing protocols did result in significant effects on the coupled $\dot{V}O_2$ and velocity measurements at the LT or 4 mM BLa point, which is comparable to the present study in terms of the power output and $\dot{V}O_2$ at the OBLA but not the power output at the LT. However, the discontinuous (10-min stage) tests used by Weltman et al. (1990) were conducted over three separate days, which in turn may have reduced the residual effects of the previously completed workloads that may have been influential in the present study. Furthermore, these authors also used running exercise that may elicit differential metabolic responses than cycling exercise at the same relative exercise intensity (Jones and McConnell 1999). The present study was also able to compare a WT and REC group of athletes during cycle exercise that was controlled in terms of the relative exercise intensity completed during each workload in each test. With this in mind, the results of this study indicate that training status has a limited physiological effect on the OBLA results obtained from a 3-min or 8-min stage incremental exercise test. However, it is possible that the workload at the LT may be influenced by the protocol used to determine this variable in more highly trained subjects. This is especially true as there were no significant effects of the EXT protocol on the LT_W when data from the WT and REC groups were combined.

The purpose of determining the LT and OBLA should be considered when interpreting the significance of the results of this study. Both the LT and OBLA have been used as "predictors" of endurance performance (Sjodin and Svedenhag 1985). Since we did not include a performance test, we are unable to establish whether the differences in the LT or OBLA obtained from the different EXT would reduce or heighten the predictive power of such variables. However, it has been suggested that the change in results obtained from two different incremental exercise tests does not influence the predictive power of the variables assessed (Foxdal et al. 1994). The workload at the OBLA and the LT can also be used to examine the metabolic responses to exercise at these work rates. It is likely that the small but non-significant changes in the workload at the LT or OBLA with the different EXT will effect the physiological responses at these workloads during prolonged exercise. Foxdal et al. (1996) have examined the BLa concentration during 50 min of treadmill exercise at a velocity representing the OBLA calculated from the results of a 4-, 6- or 8-min stage test carried out by a group of either trained runners or firemen. These authors did not directly report the workload at the OBLA; however, the results show contrasting rates of BLa accumulation and time to fatigue during exercise at the different workloads calculated from the different length tests. In the present study no significant differences were found in the W_{OBLA} determined from the $EXT_{8\text{-min}}$ as compared to the $EXT_{3\text{-min}}$. However, it is likely that the small differences that were shown in the $OBLA_W$ may result in contrasting metabolic responses during sustained exercise bouts at these work rates.

An interesting but secondary finding of this study was that $\dot{V}O_2$ was similar in the final minute of both the $EXT_{3\text{-min}}$ and $EXT_{8\text{-min}}$ as well as in the third minute of $EXT_{8\text{-min}}$. It has been suggested that the $\dot{V}O_2$ slow component or a delayed rise in $\dot{V}O_2$ occurs as a result of metabolic acidosis during prolonged exercise (Carter et al. 2000). Indeed, it has been shown that the change in $\dot{V}O_2$ from the third to the seventh minute during six successive incremental work rates is associated with the increase in BLa above the LT (Jones et al. 1999). The results of the present study indicate that the delayed increase in $\dot{V}O_2$ during sustained exercise above the LT did not occur in the WT or REC cyclists that participated in this experiment. However, further studies are required to examine the effects of the magnitude of work rate increment during different exercise modes on the $\dot{V}O_2$ slow component during incremental exercise.

In conclusion, this study compared the workload, $\dot{V}O_2$ and HR at the LT and OBLA determined from the results of incremental exercise tests consisting of workloads of 3 min or 8 min. The results suggest that in contrast to lengthy and sometimes impractical incremental tests incorporating 8- to 10-min stage increments, a 3-min stage test can produce similar results in terms of the OBLA in well-trained or recreational cyclists. However, it is also likely that incremental exercise tests using stage increments longer than 3 min may reduce the workload at the LT in well-trained subjects.

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