Physiological and Metabolic Responses of Triathletes to a Simulated 30-min Time-Trial in Cycling at Self-Selected Intensity

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Abstract

The aim of this study was to investigate the metabolic and physiological responses to a laboratory-based simulated 30-min individual time-trial (ITT_{30}) in cycling at a self-selected intensity. Twelve experienced triathletes (n = 4 women) performed a progressive incremental exercise test on a cycle ergometer to determine $\dot{V}O_2max$ (52 ± 5 ml × min^{-1} × kg^{-1}), maximum power output (300 ± 12 W), and the second ventilatory threshold. Then, the subjects completed an ITT_{30} at self-selected work intensity on a stationary ergometer equipped with the SRM Training System. In all subjects, during the ITT_{30}, heart rate and minute ventilation increased ($p < 0.05$) progressively whereas oxygen consumption and power output remained unchanged. Triathletes rode at consistent pacing corresponding to their highest steady state of blood lactate concentration that increased by no more than 1.0 mmol × l^{-1} during the final 20-min of ITT_{30}. The self-selected intensity of triathletes during ITT_{30} represented 88 ± 5 % (mean ± SD) of $\dot{V}O_2max$ and was not significantly different to the energy demand corresponding to the second ventilatory threshold (84 ± 5 % of $\dot{V}O_2max$). Our data suggest that ITT_{30} at a self-selected intensity is a good predictor of individual endurance capacity and may be used to estimate racing pace for training purposes. This performance test for the identification of the exercise intensity that demarcate “steady state” is less troublesome than some of the traditional methods, limiting testing to a single session.

Key words
Blood lactate · heart rate · perceived exertion · pulmonary gas exchange

Introduction

One of the most common methods of performance testing in the laboratory is to ask athletes to exercise at a constant and enforced submaximal workload [4,11,18]. External pacing is usually needed to satisfy the methodological demands associated with conducting well-controlled studies of exercise under specifiable and repeatable conditions. However, the conventional incremental exercise is not how humans ordinary perform exercise. Most typically, cyclists or runners are trying to minimise the time to achieve a fixed amount of work to cover a set distance in the shortest possible time. But more frequently, the physiological responses to constant-load exercise relative to predetermined “threshold” values have been investigated [4,11,13,14,18]. While much is known about many physiological variables responses under laboratory exercise conditions, the literature does not provide as comprehensive an understanding of how athletes routinely manage their exercise without external pacing. Studies of running and walking conducted under more ecologically valid conditions (i. e. self-pacing) found that subjects tend to maintain a steady work intensity [9,21].

Therefore, in training, if the aim is to elicit the maximal oxygen uptake ($\dot{V}O_2max$), it may be useful to determine the workload for which oxygen consumption and blood lactate responses can reach a critical “steady state” [11,18]. A simple method based on a self-selected intensity of exercise for determining the highest sustainable intensity can be regarded as a functional determination of endurance capacity more convenient for cyclists when blood lactate assay is undesirable or unfeasible. This simple

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method would allow the adjustment of the exercise intensity close to a fairly constant energy expenditure according to the feeling of the athlete. Actually the present research lends weight to the view that laboratory testing to establish the "anaerobic threshold", ventilatory threshold, critical power, etc., is largely redundant [7,17,22,24]. If the purpose of this sort of testing is to establish a "race-pace" (or, if one prefers, an individual's highest sustainable work intensity), then a 1-day 30-min individual time-trial at self-selected work intensity (ITT_{30}) will clearly suffice. Therefore, the purpose of this study was to investigate the physiological and metabolic responses to a single-session 30-min individual time-trial at self-selected work intensity in cycling. Specific objectives of this study were to describe changes in energy expenditure over the course of ITT_{30}, and to determine whether the ability to sustain the highest sustainable work intensity was associated to a high blood lactate concentration. The present study allowed subjects to choose their own pace, as cycling on the field, and consequently required no interaction with the investigators.

Materials and Methods

Subjects

Twelve triathletes were recruited for the investigation comprising of 1) 8 men, of mean (± SD) age, 25 ± 8 yr, height, 174 ± 6 cm, and weight 67 ± 6 kg, and 2) 4 women, of mean age, 24 ± 6, height, 168 ± 4 cm, and weight 61 ± 5 kg. There were no significant differences in height, body weight and body mass index between men ($22.0 \pm 1.2\ kg \times m^{-2}$) and women ($21.6 \pm 0.6\ kg \times m^{-2}$). All were involved in regular physical training and Olympic distance triathlon race. After approval from the Institute's Ethics Committee, written informed consent was obtained from each subject prior to all testing and its possible risks and benefits were explained. The study complies with the Helsinki Declaration for Human Experimentation. Subjects were requested to perform the same type of training during the duration of the study and to refrain from heavy physical exercise on the day before the ITT_{30}. Each subject was familiarised with the testing protocol (blood sampling and expired gas measurement) and equipment. All subjects were equally proficient in the ITT event and had similar ITT history and experience in our laboratory but were not elite triathletes. Even if we did not evaluate specifically the reliability of our time-trial, high reproducibility has been reported of cycle TT of short and long duration [16].

Each subject visited the laboratory on two occasions at the beginning of the pre-competitive period (April). Tests were administered in a random order. All the tests were performed in a climate-controlled laboratory (20 to 23 °C, 45 to 55 % relative humidity). Subjects were cooled with an electric fan in order to reproduce the field conditions. They rode on a mechanically braked Monark ergometer (818E, Varberg, Sweden) equipped with the SRM Training System (Schoberer Rad Mebtechnik, Julich, Germany, scientific model, cranks of 172.5 mm). The ergometer had been modified with an adjustable height of both the saddle and handlebars (Ergostem, Look, Nevers, France), and the cyclists' own pedals.

Incremental exercise test

$\dot{V}O_2max$ was measured during an incremental cycling test. Starting at 120 W for men and 80 W for women, the workload was increased by 2 0 W every 2 min and pedalling rate was kept constant at $80\ rev \times min^{-1}$. To maintain this cadence the subject referred to the unit screen display of the SRM clamped on the handlebars. Attaining two of three of the following criteria were used to determine the acceptability of a $\dot{V}O_2max$ test: a drop in pedalling rate below $70\ rev \times min^{-1}$, a respiratory exchange ratio value (RER) exceeding 1.15, and a plateau in $\dot{V}O_2$ with increased workload. $\dot{V}O_2max$ and associated maximal power output were recorded as the highest mean $\dot{V}O_2$ over 30 s during the last step of the incremental test.

Gas exchange data were collected continuously using an automated breath-by-breath metabolic cart (CPX, Medical Graphics, St Paul, Minnesota, USA) to measure the following variables: $\dot{V}O_2$ ($l \times min^{-1}$), carbon dioxide production ($\dot{V}CO_2$, $l \times min^{-1}$), minute ventilation ($\dot{V}_E$, $l \times min^{-1}$), tidal volume (V_T, ml), breathing frequency (Bf, breaths $\times\ min^{-1}$), ventilatory equivalents for oxygen ($\dot{V}_E \times \dot{V}O_2^{-1}$) and carbon dioxide ($\dot{V}_E \times \dot{V}CO_2^{-1}$). This cart was calibrated before each test using gases of known O_2 and CO_2 concentration and a 3-l syringe. Calibration was verified after every test. The second ventilatory threshold (VT_2) and PO corresponding to VT_2 were also identified. VT_2 corresponded to an increase in both $\dot{V}_E \times \dot{V}O_2^{-1}$ and $\dot{V}_E \times \dot{V}CO_2^{-1}$ after observation of an isocapnic buffering region [8]. Heart rate (HR) was measured and stored continuously by using a Polar heart rate monitor (XTrainer plus, Polar Electro, Kempele, Finland) coupled with a receiver connected to the SRM data acquisition system.

Individual time-trial

At least two days after the incremental exercise test, the subjects performed a ITT_{30}. The protocol consisted of a continuous test during which each subject were instructed to cycle as fast as possible within the 30-min period at a self-selected work intensity (performance test). The data (PO and HR) on the unit display were masked excepted the pedalling rate, which was self-selected. Each subject was allowed to warm up as they normally would before a race. Thereafter, subjects began to exercise by adjusting their own PO by fine-tuning. The transition from rest to exercise took 5 – 10 s. Subjects were allowed to freely adjust the work intensity at their convenience throughout the ITT_{30}. Subjects were verbally encouraged to perform to the best of their ability throughout each test. Before testing, the SRM was calibrated according to the manufacturer's recommended procedure. Jones and Passfield [19] have previously described the calibration procedure and technical aspects of the SRM power meter. Pedalling rate, HR, and PO were monitored and stored at 1-s intervals from the SRM Training System. The data stored in the SRM power control (unit display) were thereafter transmitted to a PC via an interface. Gas exchange data and HR were monitored as in the incremental test. The values of physiological and mechanical variables at specific times (5, 10, 15, 20, 25, and 30 min) were averaged during the preceding 30 s.

Blood samples were collected from the antecubital vein during resting period, every five minutes (5, 10, 15, 20, 25, and 30 min) during the ITT_{30} without cycling interruptions and 10 min after the end of the exercise. Within 1 h of collection, all blood sam-

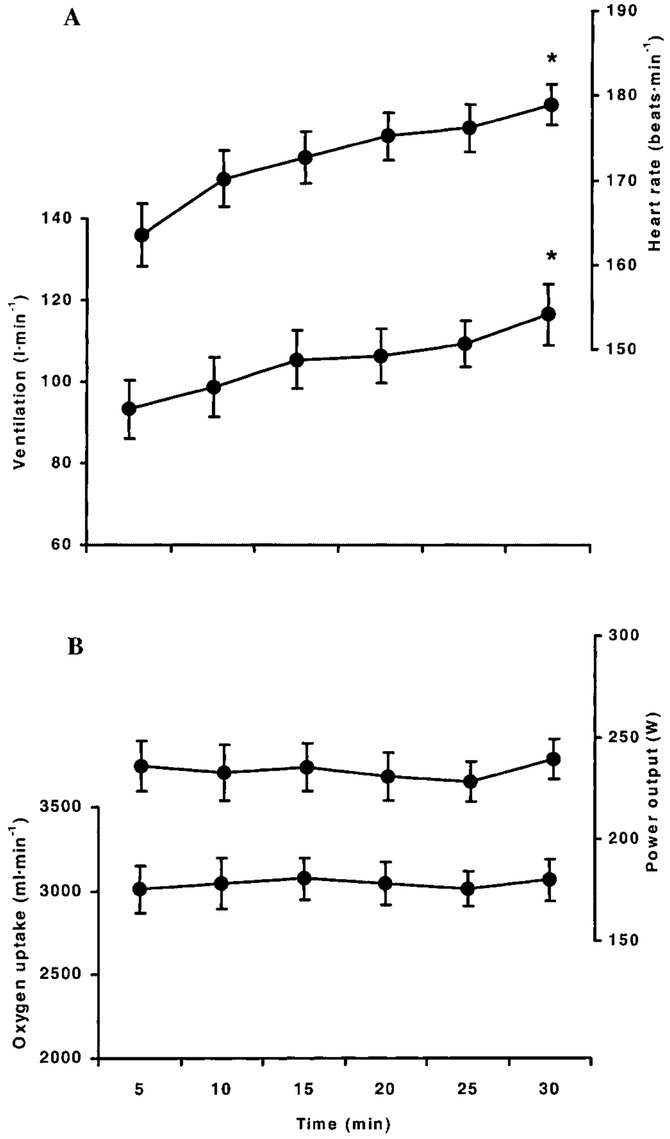

Fig. 1 Group mean response (± SEM, n = 12) during the 30-min time-trial at self-selected intensity. **A**, top: minute ventilation and heart rate. **B**, bottom: power output and oxygen uptake. There were no significant differences over time for both the power output and oxygen uptake responses. *Significantly different from min 5 at $p < 0.05$.

ples were analysed at 37 °C for pH estimation using an automated blood gas analyser (Ciba Corning 178, Medfield, MA, USA) and for determination of plasma lactate concentration by enzymatic method.

At the beginning of both tests, subjects were provided with a typewritten set of standardised directions for the use of the rating of perceived exertion (RPE 6–20 point scale) of Borg [5]. Perceptual scale anchors were established according to the recommendations of Borg [4]. Subjects were instructed to give an overall RPE immediately at the end the incremental exercise and ITT_{30} tests.

Statistical analysis

During the ITT_{30}, a one-way repeated-measures analysis of variance was performed to examine changes as a function of time in metabolic, physiological, and mechanical variables. If a significant F ratio was obtained, a Fisher's *post hoc* test was performed to analyse the differences between the variables. Where relevant, regression analysis was carried out for first- and second-degree polynomials using the method of least squares. Data are reported as mean ± SEM unless otherwise indicated. The level of statistical significance was set at $p < 0.05$.

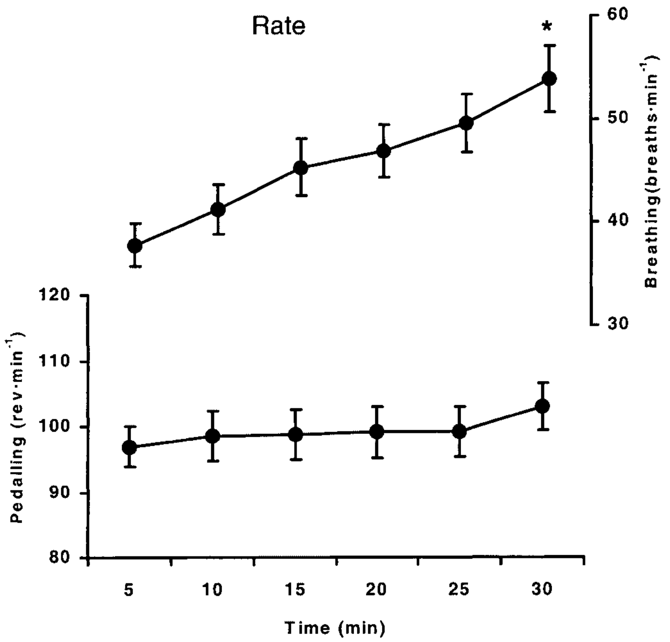

Fig. 2 Group mean response (± SEM, n = 12) for the rate of pedalling and breathing during the 30-min time-trial at self-selected intensity. *Significantly different from min 5 at $p < 0.05$.

Results

Mean $\dot{V}O_2max$, maximal power output, and maximal heart rate (HR_{max}) were 52 ± 5 ml × min^{-1} × kg^{-1}, 300 ± 12 W, and 187 ± 3 beats × min^{-1}, respectively. All subjects demonstrated the criteria for attaining $\dot{V}O_2max$ identified earlier, and reached a mean RPE value of 16.

The average self-chosen work intensity during the ITT_{30} corresponded to 88 % of the subjects' $\dot{V}O_2max$ (234 ± 11 W) and was not statistically different from the energy demand eliciting VT_2 (~84 % $\dot{V}O_2max$ and 233 ± 10 W). In addition, a significant correlation was found between the two test methods ($r^2 = 0.73$, $p < 0.05$). Timing for comfortable adjustment of PO required less than 2 min for all subjects and slight adjustments to resistance were made thereafter. All subjects completed the ITT_{30} at a mean pedalling rate of ~99 rev × min^{-1}. No significant difference in reached RPE on the Borg (6–20) scale was found between the progressive test and ITT_{30} (15.7 ± 0.5 vs. 16.6 ± 0.4; $p = 0.15$), indicating a heavy effort during both tests. Figs. **1** and **2** show the overall responses of the different metabolic, physiological and mechanical variables during the ITT_{30} test. Significant increases were recorded in the following variables from the fifth minute to the end of exercise: HR ($p < 0.05$), $\dot{V}_E$ ($p < 0.05$), Bf ($p < 0.05$), $\dot{V}_E \times \dot{V}O_2^{-1}$ ($p < 0.05$) and $\dot{V}_E \times \dot{V}CO_2^{-1}$ ($p < 0.05$). No significant change was found in V_T, RER, pH, $\dot{V}O_2$, PO, pedalling rate, and blood lactate throughout the ITT_{30}. Blood lactate concentrations

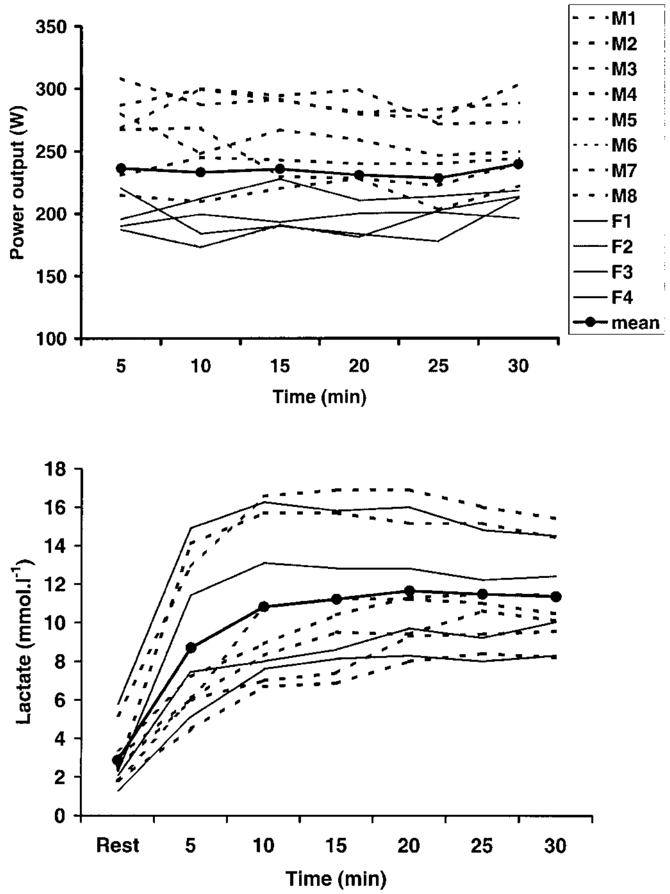

Fig. 3 A plot of the individual power output and blood lactate concentration values for each subject during the 30-min time-trial at self-selected intensity. For each time point, the figure depicts the mean response (bold line with closed circles), the individual responses for female subjects (F, thin lines), and the individual responses for male subjects (M, dotted lines).

were considerably high, but, nonetheless, metabolic steady state was maintained. This was reflected in plasma lactate concentration over the last 20 min of exercise for 9 out of 12 subjects (variation less than $1.0\,\text{mmol} \times l^{-1}$). Average blood lactate concentration for minutes 5, 10, 15, 20, 25, and 30 for individual subjects ranged between 6.1 and $15.9\,\text{mmol} \times l^{-1}$ (mean value of $10.6 \pm 1.0\,\text{mmol} \times l^{-1}$, Fig. **3B**). For each individual, average blood lactate for minutes 5 – 30 against performance (average PO during the same period) was not significantly correlated. In contrast average blood pH for minutes 5 – 30 did correlate negatively with absolute (average PO in watts) and relative (average PO in watts per kilograms) performance ($r = -0.71$ and $r = -0.64$, respectively at $p < 0.05$). A 2nd order polynomial regression described significantly the relationship between Bf and the pedalling rate throughout ITT_{30} ($r = 0.39$, $p < 0.01$, $n = 72$). Finally, significant correlation existed between changes in $\dot{V}O_2$ and PO during perceptive ITT_{30} ($r = 0.94$, $p < 0.001$, $n = 72$, Fig. **4**).

Discussion

The present data show that when exercise intensity is self-selected, no significant change in $\dot{V}O_2$ and blood lactate was found over the course of ITT_{30}, indicating that the triathletes did adjust their racing paces enough to prevent these changes. Moreover, results show that it is possible to sustain a high intensity of exercise despite considerable blood lactate accumulation. Within a group of 12 triathletes of similar training status the highest sustainable physiological demand during a ITT_{30} in laboratory at a self-selected intensity, was not different to the physiological demand corresponding to the second ventilatory threshold determined during a conventional incremental test.

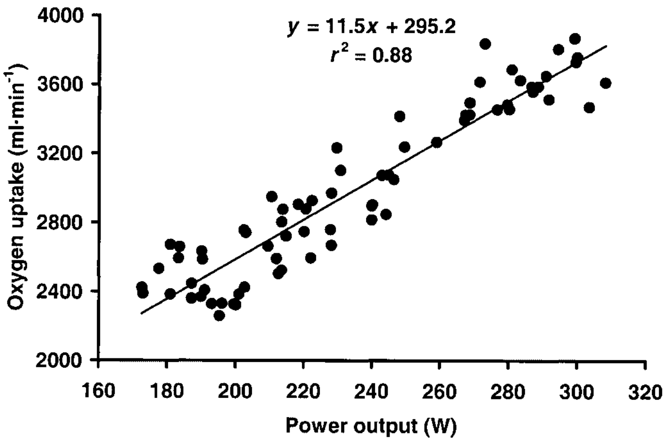

Fig. 4 The relation between the power output and the oxygen consumption over all time collection (5, 10, 15, 20, 25, and 30 min) during the perceptive 30-min time-trial.

Maintaining a steady physiological effort has been thought to be the most efficient race strategy for the performance during an individual time-trial [26]. Our findings showed clearly that subjects tended to adjust their energy expenditure and workload as needed to maintain their relative effort within a relatively narrow range (Figs. **1** and **4**). Trained athletes working at their highest sustainable intensity inevitably achieve “maximal lactate steady state”. Based on a definition of lactate steady state as less than $1.0\,\text{mmol} \times l^{-1}$ during the final 20-min of a high-intensity exercise [3], the observed values of this study signified reaching of a “maximal lactate steady state” for at least 9 subjects (Fig. **3**). So, the application of the simple method used in this study where effort management is a critical issue may offer a useful tool for athletes and coaches interested in a detailed analysis of the costs and benefits of various pacing strategies. Note that absolute and relative performance in this study reflected by average work intensity during ITT_{30} was negatively correlated with average blood pH during the same period ($p < 0.05$), but not with mean blood lactate concentration due to a highly individual response (Fig. **3**). A review of pacing strategy and performance [10] suggested that athletes learn to sense low muscle pH in order to adjust their pace.

No change across time in $\dot{V}O_2$ associated to a steady profile response in blood lactate during ITT_{30} at racing pace indicated that the triathletes maintained a fairly consistent metabolic demand throughout the test. The absence of a slow component in $\dot{V}O_2$ (i.e. continuous increase in $\dot{V}O_2$) during ITT_{30} with respect to previous findings indicate the ability of our subjects to sustain high workloads (about 88% $\dot{V}O_2max$) over long time [4,18]. This hypothesis seems to be confirmed if we consider our data together with the findings of a study of Billat et al. [4], who detected no or a low slow component in well trained triathletes cycling at about 90% $\dot{V}O_2$max. The exercise intensity associated with the onset of the $\dot{V}O_2$ slow component is of great significance to both clinical and athletic populations since it defines functional aerobic exercise capacity [11]. The present result supports also favourably the findings of previous studies that trained cyclists are able to sustain continuous exercise at approximately 90% of the maximal values of $\dot{V}O_2$ observed during incremental exercise [24]. Cyclists who perform successfully are most importantly able to sustain high workloads (at VT_2) for long period of time.

Although the metabolic demand remained constant throughout the ITT_{30}, further results of this study indicated that ventilatory and cardiac responses increased significantly from the min 5 to the end of the ITT_{30}. There was a gradual increase in HR for the duration of the trial (from 163 to 178 beats × min^{-1}, Fig. **1 A**). During continuous exercise, the HR drift has been often associated with exercise-induced dehydration resulting in a lower stroke volume [25]. However, Hamilton et al. [14] observed that hydration and thermoregulation might not be the only causes of the higher HR during continuous exercise. Increases in HR could also partially reflect an increased central command subsequent to a decrease in muscle efficiency with fatigue [20]. Since the workload during the ITT_{30} was constant, the unaltered $\dot{V}O_2$ and blood lactate indicated that the mechanical efficiency was likely the same. In contrast with most laboratory conditions, ITT_{30} in the field shows a steady profile responses in HR [24]. The latter observation and our present findings allow us to hypothesise that thermoregulation could be probably the crucial factor leading to a cardiovascular drift in laboratory setting. During road ITT events ≤30 min, HR could be a more valuable metabolic index to determine appropriate training and competition pace compared to laboratory conditions. Considering % HR_{max} as a valuable index of exercise intensity [12], the present results indicated that the ITT_{30} was performed at quite high exercise intensity levels (range of 87 – 96% HR_{max}). In athletes, these intensity levels are usually observed in major competitions where the result is absolutely decisive for subject. In the present study, the 15.7 ± 0.5 and the 16.6 ± 0.4 RPE values observed during the incremental test and ITT_{30} respectively, correspond to a heavy and hard exercise usually supported by athletes at the end of minor competition, intense training or during time-trial test [15].

The continuous increase in $\dot{V}_E$ measured over the ITT_{30} (+ 23 l × min^{-1}) is somewhat higher with other observations reported during cycling bouts at "maximal lactate steady state" but with lower percentage of sustained $\dot{V}O_2$max compared with the present study. MacLellan and Cheung [23] measured a 20 l × min^{-1} increase in $\dot{V}_E$ over 30 min while exercising from 71 to 76% $\dot{V}O_2$max and recently, Lajoie et al. [20] reported an increase of 15 l × min^{-1} over 60 min (from 71 to 79% $\dot{V}O_2$max). In our study the continuous increase in $\dot{V}_E$ was due mainly to a significant increase in Bf ($r = 0.717$, $p < 0.01$). Variation in V_T was correlated to that of $\dot{V}_E$ ($r = 0.494$, $p < 0.05$) but showed no significant change over time during ITT_{30}. Despite a ~ 24% increase in $\dot{V}_E$, we did not observe an increase in energy expenditure as reflected by the constant $\dot{V}O_2$. Thus the increased energy cost of pulmonary ventilation (estimated to be less than 50 ml O_2 by using the O_2 cost of hyperpnea proposed by Aaron et al., 1992) was not directly tied to the energy expenditure. Since $\dot{V}O_2$ was constant, the ventilatory equivalent ($\dot{V}_E \times \dot{V}O_2^{-1}$), which reflects a measure of the ventilatory efficiency, increased also significantly over time during the ITT_{30}. The changes in these different ventilatory variables involves a breathing strategy for the athletes in order to optimise the highest sustainable work intensity and the exercise-induced acidosis. According to our findings, HR and $\dot{V}_E$ may be not valid physiological variables of the cyclist work intensity at racing pace in laboratory experimental conditions. This leads to the possible need for the rider to adopt a more subjectively based strategy to ride at his optimum workload. Hagberg et al. [13] have noted that the most efficient pedalling frequency was 91 rev × min^{-1} in a group of trained road cyclists (at 80% $\dot{V}O_2$max). In the present study, triathletes chose a mean pedalling rate of 99 rev × min^{-1} (range between 78 to 114 rev × min^{-1}) during ITT_{30} likely as most comfortable for maximum efficiency during cycling but above a point where an increase in cardiac stress occurred. These high pedalling rates reduce the force used per pedal stroke [22], thereby lowering muscle fatigue (especially in type II fibers). Hagberg et al. [13] also speculated that enhanced blood flow could account for an apparent washout of lactic acid at increased pedalling rate. In the present study, the pedalling rate and Bf were related by a parabolic function. This relationship indicates an optimal pedalling rate during ITT_{30} close to 97 rev × min^{-1} associated with an optimal Bf close to 41 breaths × min^{-1}. Interestingly, the average self-selected pedalling rate throughout the ITT_{30} was 99 ± 12 rev × min^{-1}. In this study, after 5 min riding time, there was a steady state in PO associated with an optimal pedalling rhythm selection. When training or racing are performed close to the highest sustainable work intensity, a breathing/pedalling combination may be found by the athlete in order to optimisthe energy cost. Several combinations might have been used (i.e. one breath to each 2, 3, or 4 pedal strokes) but such relationship requires spectral frequency analysis [2].

In summary, the cycling ITT_{30} was characterised by a fairly self-selected constant energy expenditure (reflected by $\dot{V}O_2$ and blood lactate responses) equivalent to the energy demand associated to the second ventilatory threshold. In ITT events lasting 30 min, self-selected pace could be a valuable metabolic index to determinate appropriate training and competition race. The primary advantage of the ITT_{30} test at self-selected intensity is the ease and objectivity with which endurance capacity can be determined.

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