Effect of a 15% Increase in Preferred Pedal Rate on Time to Exhaustion During Heavy Exercise

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Abstract

The purpose of this study was to assess the fast and slow $\dot{V}O_2$ component and exhaustion time during a heavy constant-power test (CPT) under two different pedal conditions. The oxygen consumption kinetics was analysed through mathematical modelling of the breath-by-breath gas exchange response to heavy cycling exercise. After continuous graded test, seven well-trained cyclists performed two all-out CPT. The first CPT was cycled at spontaneously chosen pedal rate (SCPR) and the second one at + 15% SCPR. As expected, the present study reported a significant decrease of exhaustion time on CPT at + 15% SCPR (respectively, 465.1 ± 138.6 *vs* 303.0 ± 42.5 s; $P < 0.05$) without change in $\dot{V}O_2$ kinetics between the two pedal rate conditions. Moreover, the decrease of exhaustion time was inverse correlated with variation of aerobic demand computed between the two pedal rate conditions. In conclusion, it could be suggested that factors implicated in this decrease of exercise tolerance were principally neural and muscular factors. Nevertheless, the capacity to maintain the aerobic demand regardless of the increase of pedal rate could be assumed like factor associated to the performance in road race.

Key words: Cadence; Cycling; Endurance time; Mathematical modelling.

Introduction

In cycling, a great diversity in the choice of spontaneously chosen pedal rate (SCPR) has been reported according to the population studied. Experienced cyclists routinely use high pedal rate from 90 to 100 rpm in laboratory tests or competitive events while inexperienced subjects use usually 50 to 60 rpm [14]. The variations of preferred cadence could be related to training status and pedal skill [15, 23]. In road race conditions, cyclists have the use of limited gear ratio and must adopt pedal rate greater than 100 rpm in order to ride over 55 $km.h^{-1}$. Thus, during specific sessions of training, cyclists often increase consciously their spontaneously pedal rate to become more comfortable and efficient while pedalling at cadence close to 110 rpm. Some studies have analysed the effect of cadence on the power-time relationship in cycling (McNaughton and Thomas, 1996; Hill et al., 1995; Carnevale and Gaesser, 1991). McNaughton and Thomas (1996) and Carnevale and Gaesser (1991) have shown that cycling at low pedal rate (50-60 rpm) make it possible to inexperienced cyclists to achieve better performance in heavy constant-power tests. These previous studies concluded that increasing pedal rate leads a to decrease exercise tolerance and exhaustion time. Nevertheless, on the best of our knowledges, this point have never been verify in trained and experienced cyclists.

During the transition from rest or unloaded cycling to constant-load exercise of moderate intensity (below the anaerobic threshold), after the cardio-dynamic phase (phase 1), $\dot{V}O_2$ rises in an approximately mono-exponential fashion (phase 2) to attain a new steady state (phase 3) within 3-5-min in normal subjects. In contrast, $\dot{V}O_2$ response to constant-load exercise of heavy intensity (superior to anaerobic threshold) is complicated by the development of an additional component of $\dot{V}O_2$ such that attainment of a new steady state, if attained, is delayed [31]. Barstow et al. [2] have studied the effect of different imposed frequency (45, 60, 75 and 90 rpm) on the $\dot{V}O_2$ kinetics in heavy exercise and have concluded that pedal frequency has no significant effect in inexperienced subjects. Nevertheless, they did not allow the subjects to choose their own pedal rate as they normally do everyday during training and competition. Likewise, Marsh and Martin (1993; 1997) have studied the aerobic demand response to cadence manipulation and reported a curvilinear relationship with higher cadence producing higher oxygen consumption. Up to this date, only the study of Billat et al. (1999) has analysed the effect of decrease in spontaneously chosen cadence of exercise on $\dot{V}O_2$ slow component. They have reported no difference on $\dot{V}O_2$ slow component between the two cadences (freely *vs* lower of 10%). A limitation of this study was the characterization of the slow component, which involved the simple calculation of the difference between $\dot{V}O_2$ at 3-min and $\dot{V}O_2$ at the end of exercise. Indeed, the use of the model validated by Barstow and Molé [3] makes it possible to determine more accurately the components of the $\dot{V}O_2$ kinetics [5]. Moreover, Billat et al. (1999) have reported an amplitude of slow component significantly higher during cycling than in running with no difference in exhaustion time, suggesting that the relationship between the $\dot{V}O_2$ slow component and the fatigue process remains unclear. Nevertheless, Demarle et al. (2001) have shown that the decrease of oxygen deficit observed after a specific program of endurance training reflects a faster adjustment on $\dot{V}O_2$ kinetics (i.e. decreasing of τ_1) and was correlated with the improvement of exhaustion time. Based on this background, it seems necessary to verify whether the decrease of endurance time during heavy exercise is linked to adjustment and/or magnitude of $\dot{V}O_2$ response.

Thus, the purpose of this study was to assess the fast and slow component of $\dot{V}O_2$, using the mathematical modelling procedure [3], and the performance during a heavy constant-power test (CPT) in well-trained cyclists when the pedal rate was spontaneously chosen or set at + 15% SCPR. It was hypothesised, on the one hand that an increase of + 15% SCPR induce a decrease of performance with no significant change in $\dot{V}O_2$ kinetics and on the other hand, that the decrease of endurance time is correlated with an increase of the time constant of primary $\dot{V}O_2$ component and amplitude $\dot{V}O_2$ response .

Methods

Subjects

Seven competitive cyclists (mean ± SD: age 27.4 ± 4.2 yr; height 1.77 ± 0.03 m; body mass 72.3 ± 3.6 kg; weekly hourly volume of training 12.1 ± 2.6 $h.wk^{-1}$) volunteered to take part in this study, which was approved by the French National Committee for Clinical Research. All subjects gave informed written consent to participate in this study and underwent a complete medical examination prior to the experiments. All measurements were carried out under medical supervision in a climate-controlled laboratory (21 to 22°C).

Testing procedure

All the subjects were familiar with all procedures and performed:

- a maximal graded test (Tmax) where the power output was set at 100 W and increased by 25 W every minute, in order to measure the maximal oxygen uptake ($\dot{V}O_2$max), to determine the maximal aerobic power (MAP), and the ventilatory thresholds (VT_1 and VT_2)
- two constant power tests (CPT) set at a power output that theoretically requires 50% of the difference in $\dot{V}O_2$ between VT_2 and $\dot{V}O_2$ max (pΔ50). The first CPT was performed at SCPR, while the second one was performed at + 15% of SCPR of the preceding session.

Each session took place on non-consecutive days at the same time (± 1h) in order to minimise possible effects of diurnal biological variations on the results. Subjects were instructed to arrive at the laboratory in a fully hydrated state and to avoid strenuous exercise in the 48-h preceding a test session. Subjects were required to cycle on their own bicycles, which were attached to a Spintrainer ergometer (Technogym, Gambettola, Italy). This device simulates a real life time-trial situation since the subjects can choose the gear ratio and pedal rate depending on the power output required. The ergometer was calibrated for each subject immediately before each test. Calibration of the Spintrainer ergometer consists of a "run-down" test. The cyclist is required to cycle up to a speed of 34 km·h^{-1} and then to stop pedalling immediately the Spintrainer display shows the message "STOP." The cyclist must then remain motionless on his cycle while the calibration takes place. The speed-decay curve is drawn from 34 km·h^{-1} to 5 km·h^{-1}. The ergometer´s built-in computer generates a reference decay curve specific to the subject's body mass that is entered before the calibration test. If the acquired decay curve closely fits the reference decay curve, the calibration is accepted. If not, the rolling resistance is adjusted automatically by adjusting the electromagnetic resistance system, and a second calibration test is performed. The test is repeated with adjustments to rolling resistance until the Spintrainer display accepts the calibration as correct. This usually takes two to three attempts.

Determination of $\dot{V}O_2$max, MAP and VT

The maximal graded test was preceded by a 3-min warm-up period at 100 W. This initial work rate was then increased by 25 W.min^{-1}. To ensure that $\dot{V}O_2$max was reached, subjects were encouraged to continue as long as possible so that a levelling off in the $\dot{V}O_2$ course occurred. The test ended at the point of voluntary exhaustion. During the test, the subjects breathed through a facemask. Measurement of oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$) and respiratory frequency (f) were carried out throughout each test using a breath-by-breath portable gas analyser (Cosmed K4b^2, Roma, Italy). It has been shown to be a valid instrument for the measurement of $\dot{V}O_2$ (McLaughlin et al., 2000). The Cosmed K4b^2 oxygen analyser and carbon dioxide analyser were calibrated immediately before each testing session in accordance with manufacturer's guidelines. The calibration of the turbine flow-meter of the K4b^2 was performed with a 3-L syringe (Quinton Instruments, Seattle, Washington). A 10-lead ECG (Quinton Instruments, Q-710, Seattle, Washington) was recorded continuously during tests to determine heart rate (HR). The mean respiratory exchange ratio (RER), and ventilatory equivalents in O_2 ($\dot{V}_E/\ \dot{V}O_2$) and CO_2 ($\dot{V}_E/\ \dot{V}CO_2$) values were calculated from the recorded measurements. The maximal values of $\dot{V}O_2$, HR, $\dot{V}CO_2$, RER and $\dot{V}_E$ attained during the test were reported ($\dot{V}O_2$max, HRmax, $\dot{V}CO_2$max, RERmax, $\dot{V}_E$max). When no plateau of $\dot{V}O_2$ was achieved, maximal aerobic power (MAP) was identified as the peak power output, i.e. the maximal exercise intensity maintained during the last stage. When a plateau of VO_2 was achieved, MAP was defined as the minimal exercise intensity, which can elicit $\dot{V}O_2$max. A plateau of $\dot{V}O_2$ in the $\dot{V}O_2$-exercise intensity relationship was defined as an increase in oxygen uptake of less than 1.5 $ml.min^{-1}.kg^{-1}$ with the increase in exercise intensity. The single indices used individually in order to determine VT_1 and VT_2 for each subjects were VE, VCO_2, VE/ $\dot{V}O_2$ and VE/ VCO_2. The following criteria were employed in selecting the thresholds: According to Wasserman et al. (1973), VT_1 was defined as the minimal load at which VE/ $\dot{V}O_2$ exhibited a systematic increase without a concomitant increase in VE/VCO_2. VT_2 corresponded to the minimal work rate at which the increase in VE/ $\dot{V}O_2$ went with an increase of VE/ VCO_2 (Wasserman and McIlroy, 1964). Beaver et al. (1986) defined VT_1 and VT_2 as the work rates associated with a first and a second non-linear increase of VE and VCO_2. According to the criteria outlined above, three independent investigators blindly reviewed the plots of each index and made individual determinations of VT_1 and VT_2. Extrapolation of the relationship between $\dot{V}O_2$ and power output for exercise at sub-VT_2 intensities was used to estimate the power output at Δ50 (pΔ50).

Measurements of blood lactate concentrations ([La]) were obtained from capillary blood samples. The fingertip was cleaned with an alcohol swab, dried and then punctured with an automated lancet to sample blood into capillary tubes to determine [La] three minute postexercise. Blood samples were analysed using Dr Lange's® photometric method (Berlin, Germany).

Determination of SCPR, exhaustion time and $\dot{V}O_2$ kinetics

During a initial exercise of 3-min, each subject self-selected the pedal rate (SCPR) and gear ratio allowing to develop pΔ50. Marsh et Martin (1997) reported that some day-to-day variation in SCPR exists but that in general this measure in quite stable. Thus, in order to keep power output constant during each CPT, the cyclist cycled with cadence feedback and was encouraged to maintain the pedal rate spontaneously chosen in initial exercise (± 1 rpm) without change of gear ratio. The CPT began with a 6-min warm-up performed at a power output corresponding to VT_1 and the transition from the warm-up to exercise was complete within 15-s. Subjects were instructed to cycle for as long as possible and exhaustion was defined as the point at which the subject could no maintain the correct pedal rate (SCPR or + 15% SCPR). No indication was given as to the time elapsed and the exhaustion time was recorded to the nearest second for each subject.

The end-values of $\dot{V}O_2$, HR and $\dot{V}_E$ attained during each CPT were reported and termed respectively end-$\dot{V}O_2$, end-HR and end-$\dot{V}_E$. End-HR and end-$\dot{V}_E$ were computed from the average value of recorded measurements during the last 30-s of CPT. End-$\dot{V}O_2$ was calculated from the equation 1. The time course of alveolar $\dot{V}O_2$ after the onset of exercise was described in terms of an exponential function that was fit to the data with the use of non-linear regression techniques in which minimizing the sum of the mean squares of the difference between the fitted $\dot{V}O_2$ and the experimental data (Solver from Excel 9.0 Microsoft Corporation). The mathematical model of the breath-by-breath $\dot{V}O_2$ response consisted of three exponentials terms, each representing one phase of the response [3]. The first exponential term started with the onset of exercise (*time = 0*), whereas the other terms began after independent time delays

$$
\begin{aligned}
\dot{V}O_2\ (t) = \dot{V}O_2\ (w) &+ A0 \times (1 - e^{-t/\tau_0}) && \text{Phase 1 (initial component)} \\
&+ A1 \times (1 - e^{-(t-TD_1)/\tau_1}) && \text{Phase 2 (primary component)} \qquad (1) \\
&+ A2 \times (1 - e^{-(t-TD_2)/\tau_2}) && \text{Phase 3 (slow component)}
\end{aligned}
$$

where $\dot{V}O_2$ (w) is the average value over the last minute of warm-up at VT_1; A_0, A_1, A_2 are the asymptotic amplitudes for the exponential terms; τ_0, τ_1, τ_2 are the time constants; TD_1, TD_2 are the time delays. The phase 1 term was terminated at the start of phase 2 (i.e., at TD_1) and assigned the value for that time (A_0')

$$A_0' = A_0 \times (1 - e^{-TD_1/\tau_0})$$

The amplitude of phase 1 (A_0') and the amplitude of phase 2 (A_1) were added to calculate the amplitude at the end of the primary component (A_1'). The slow component at the end of exercise (A_2') was calculated and was used in preference to the asymptotic value [2]. The increase in $\dot{V}O_2$ above $\dot{V}O_2$ (w) at the end of exercise was calculated as the sum of A_1' and A_2' and termed EE$\dot{V}O_2$. The end-value of $\dot{V}O_2$ (i.e. end-$\dot{V}O_2$) was equal to the sum of $\dot{V}O_2$(w) and EE$\dot{V}O_2$.

Statistical analysis

Standard statistical methods were used for the calculation of means and standard deviations. Normal Gaussian distribution and homogeneity of variance were verified by the Shapiro-Wilk and the Levenne tests, respectively. Paired t-test, and where appropriate, Wilcoxon matched pairs test were used to compare the differences between the two pedal rate conditions. Relationship between variations of exhaustion time and $\dot{V}O_2$ kinetics parameters were evaluating using a Pearson correlation coefficient. A two-way analysis of variance with repeated measures was used to test the overall effect of time and pedal rate on the $\dot{V}_E$ and HR values averaged each 30-s. Compound symmetry, or *sphericity*, was verified by the Mauchley test [27]. When the assumption of sphericity was not met, the significance of F-ratios was adjusted according to the Greenhouse-Geisser procedure [26]. Statistical significance was set at P = 0.05 level for all analysis. All calculations were made with Statistica (Release 5.5, Statsoft, Tulsa, USA).

Results

Graded test.

Mean MAP value was 353.6 ± 52.9 W and mean $\dot{V}O_2$max value was 4419.0 ± 692.6 ml.min^{-1}; corresponding to 61.2 ± 9.2 ml.min^{-1}.kg^{-1}. The VT_1 and VT_2 represented respectively 52.7 ± 6.3 and 86.0 ± 4.7% $\dot{V}O_2$max. Mean HRmax, $\dot{V}CO_2$max, $\dot{V}_E$max and RERmax values were 186.3 ± 9.8 beats.min^{-1}, 4785.9 ± 752.1 ml.min^{-1}, 189.9 ± 20.4 l.min^{-1} and 1.18 ± 0.03, respectively. Mean blood lactate concentration value was 13.7 ± 3.4 mmol.l^{-1} and mean HRmax achieved 96.8 ± 4,8% of theoretical maximal HR.

Constant-power tests.

During constant-power tests (CPT) set at pΔ50 (equal to 328.0 ± 45.1 W), the average value of SCPR was 94.3 ± 3.8 rpm. Exhaustion time recorded at SCPR was significantly longer than at + 15% SCPR (465.1 ± 138.6 *vs* 303.0 ± 42.5 s, respectively; P < 0.05).

Despite the difference between the exercise modes in terms of pedal rate (SCPR and + 15% SCPR), no significant difference (P > 0.05) was found in end-$\dot{V}O_2$ (3911.9 ± 552.6 *vs* 4125.5 ± 702.8 ml.min^{-1}, respectively), end-HR (175.3 ± 3.7 *vs* 179.8 ± 4.8 beat.min^{-1}, respectively) and blood lactate concentration (12.9 ± 5.2 *vs* 13.2 ± 3.6 mmol.l^{-1}, respectively), except for $\dot{V}_E$ where the mean end-value of CPT at + 15% SCPR was significantly higher (136.1 ± 13.9 *vs* 165.3 ±25.6 l.min^{-1}; P < 0.01).

No difference of $\dot{V}O_2$ kinetics parameters and HR response were noticed between each pedal rate conditions (P > 0.05; Table I). The $\dot{V}O_2$ response of a typical cyclist performing under the two different pedal rate conditions is shown in Figure 1. A significant overall effect of time and pedal rate was found on the $\dot{V}_E$ response (P < 0.05); the "drift" $\dot{V}_E$ was significantly larger during CPT cycled at + 15% SCPR.

No relationship was reported between the variation of time constant of the primary $\dot{V}O_2$ component (i.e. τ_1) and the decrease of exhaustion time in CPT at + 15% SCPR (r = 0.17; P > 0.05). Finally, the decrease of exhaustion time (-31.1 ± 15.7%) was significantly related to changes of A_1' (17.0 ± 29.6%; r = -0.87; P < 0.02) and end-$\dot{V}O_2$ (16.7 ± 21.4%; r = -0.87; P < 0.02) computed during the CPT set at + 15% SCPR (Figure 2).

Discussion

The aim of this study was to assess the endurance time and parameters of oxygen consumption kinetics during heavy constant-power test under two different pedal rate conditions (spontaneously chosen pedal rate: SCPR *vs* + 15% SCPR). As hypothesised, the endurance time decreased in CPT cycled at + 15% SCPR with no change both on $\dot{V}O_2$ fast and slow components. No relationship was reported between the variation of time constant of the primary $\dot{V}O_2$ component (i.e. τ_1) and the decrease of exhaustion time in CPT at + 15% SCPR that was inconsistence with hypothesis. However, the decrease of performance in CPT at + 15% SCPR was related to changes of amplitude of fast $\dot{V}O_2$ component and global $\dot{V}O_2$ response.

To make a valid description of $\dot{V}O_2$ kinetics during heavy exercise for all subjects, a normalization of the exercise intensity with reference to both VT_2 and $\dot{V}O_2$max was chosen (i.e., we used the "Δ" concept; [29]). This approach seems to be preferable to normalize the exercise intensity by $\dot{V}O_2$max alone, because the latter can lead to differences in metabolic and perceptual stress, depending on the proximity of the exercise intensity to the VT_2 [16]. The mean $\dot{V}O_2 max$ estimated during the graded test was in accordance with the values determined in subjects who are specifically trained in cycling [6, 8, 9]. Nevertheless, the anaerobic threshold solved by ventilatory analysis (i.e. VT_2) occurred at a higher percentage of $\dot{V}O_2 max$. Thus, the power output at Δ50 represented a higher fraction of maximal aerobic power (MAP) than previously computed in cyclists [8] or in untrained subjects [2, 10]. In the present study, cyclists were able to maintain pΔ50 (corresponding to 93.2 ± 3.7% MAP) during 7 min 45 s ± 2 min 19 s at SCPR. In triathletes, Billat et al. [8, 9] reported exhaustion time equating to 10 min 37 s ± 4 min 11 s and 13 min 32 s ± 4 min 52 s during exercise cycled respectively at 90% MAP and pΔ50 (corresponding to 86.3 ± 1.9% MAP). Thus, considering the hyperbolic relationship between relative power output and exhaustion time [21], the present results are in agreement with these previous studies. Many authors (Takaishi et al.,1998; Ericson et al., 1986) have shown that cycling training have a significant effect on the pedal skill and legcoordination. Hence, experienced cyclists have been chosen in this study in order to limited the probable effect of pedal skill on the exercise tolerance in supra-SCPR condition. Moreover, Takaishi et al. (1998) suggested that pedalling skills influence the preferred cadence selection up to high pedal rate (80-90 rpm). Supported by the assumptions of Takaishi et al. (1998), the average SCPR value reported in the present study (94.1 ± 4.1 rpm) confirmed the subject's cycling experience.

Many authors (McNaughton and Thomas, 1996; Hill et al., 1995; Carnevale and Gaesser, 1991) have shown in inexperienced cyclists that high pedal rates (90, 100 and 110 rpm) compromise endurance performance compared to lower pedal rates (50 and 60 rpm). In the present study, the increase of 15% of SCPR (94.1 ± 4.1 *vs* 108.3 ± 4.7 rpm) induced a significant decrease in exhaustion time of cycling exercise performed at pΔ50 (31.1 ± 15.7%). McNaughton and Thomas [20] reported no significant difference on power asymptote of the hyperbolic power-duration relationship between the two high pedal rate conditions (90 and 110 rpm) that is not in accordance with the present results. Nevertheless, pedal rate values of 90 rpm or 110 rpm could influence similarly the power-duration relationship parameters in inexperienced cyclists who adopt generally low SCPR values. Hill et al. (1995) reported no significant difference on the parameters of power-duration relationship between the lower pedal rate (60 rpm) and preferred pedal rate (from 83 to 89 rpm) in recreational active subjects. Similarly, Billat et al. [8] reported no significant difference on exhaustion time during tests cycled at SCPR and –10% SCPR (82.5 ± 10.0 vs 73.4 ± 8.9 rpm) in triathletes. From all these data, we can concluded that pedal rate at SCPR or slightly slower make it possible to optimise the endurance time and that an increase of pedal rate over SCPR leads to a decrease of cycling exercise tolerance.

The majority of time-based parameters of the $\dot{V}O_2$ kinetics fitted from the regression is in accordance with those computed in active or trained subjects during heavy exercise (Carter et al., 2000; Barstow et al., 1996; 1993). However, it was surprising to notice that the adjustment of primary component was slow (i.e. high τ_1 value) in this group of trained cyclists. Indeed, some studies have shown a faster $\dot{V}O_2$ on-kinetic adjustment in individuals with higher $\dot{V}O_2$max values and after endurance training program (Chilibeck et al. [11] and Phillips et al. [22]). In the present study, there was no recovery between warm-up cycled at VT_1 and exercise performed at pΔ50 increasing the $\dot{V}O_2$ value at the onset of CPT (2300 ml.min^{-1}). In previous studies (Carter et al., 2000; Barstow et al., 1996; 1993), the constant-load exercise take place after a period of rest or unloaded cycling and the $\dot{V}O_2$ baseline was in a range from 400 to 1000 ml.min^{-1}. Thus, it could be put forward that a lower difference between $\dot{V}O_2$ baseline and primary $\dot{V}O_2$ steady state could induce a slow down of $\dot{V}O_2$ adjustment in the early minutes of heavy exercise.

As hypothesised, no significant difference was observed in amplitudes (i.e.; in A_0', A_1', and A_2') or in time-based parameters (i.e., TD_1, TD_2, τ_0, τ_1, τ_2) between the two pedal rate conditions. In a previous study, Barstow et al. [2] have shown that changing pedal rate, from 45 to 90 rpm, does not alter the overall characteristics of $\dot{V}O_2$ kinetic. Moreover, Billat et al. [8] have shown that decrease of 10% SCPR have no influence on the difference in $\dot{V}O_2$ between 3 and 6-min of heavy exercise. From the present results and those of previous studies, it was reasonable to conclude that a variation of ± 15% of SCPR in experienced cyclists has any significant effect on the $\dot{V}O_2$ kinetics.

No significant difference was reported in end-values of $\dot{V}O_2$, HR and blood lactate concentration, except for end-$\dot{V}_E$ that is in accordance with the results of Chavarren and Calbet (1999). The larger "drift" of $\dot{V}_E$ during supra-SCPR conditions can be related to the mechanism of respiratory control from muscular input (Duranti et al., 1991). Indeed, an increase of pedal rate corresponds to an increase in the muscle activation-relaxation rate and in the muscle shortening velocity. Takaishi et al. (1996; 1994) have shown that SCPR was closely related to the pedal rate minimizing the neuromuscular fatigue in working muscles and Beelen and Sargeant (1993) have found a 14% greater reduction in maximal peak power after a prior 6-min exercise at 120 rpm compared to 60 rpm. Thus, an increase of SCPR decreasing the exercise tolerance could be linked to neural and muscular factors such as a relatively greater contribution of fatigue-sensitive fibres, an increase of firing rate and/or progressive recruitement of additional motor units . Moreover, no relationship was reported between the variation of time constant of the primary $\dot{V}O_2$ component (i.e. τ_1) and the decrease of exhaustion time in CPT at + 15% SCPR that was inconsistence with hypothesis. From this result, it seems reasonable to suggest that the difference of exercise tolerance was not in relation to the oxygen delivery to the active muscles in the first minutes of CPT which highligths the unclear relation between the $\dot{V}O_2$ kinetics and the fatigue process.

Nevertheless, the decrease of exhaustion time was correlated with variations of amplitude both of fast $\dot{V}O_2$ component and global $\dot{V}O_2$ response. Higher the increase of amplitude of the primary $\dot{V}O_2$ component and global $\dot{V}O_2$ response, higher the decrease of exhaustion time in CPT at + 15% SCPR. These changes of $\dot{V}O_2$ amplitude between the two pedal rate conditions could explain the inter-individual variations in the decrease of exhaustion time (from 15 to 60%). According to previous study (Goldnick et al., 1974; Vollestad and Blom, 1985), the work intensity in the present study corresponds to an intensity exercise at which fast twitch (FT) fibres are recruited in addition to the slow twitch (ST) fibres. This fibre type is known to be less efficient energetically that ST fibres (Wills and Jackman, 1994). Moreover, Sargeant (1994) suggested that FT fibres may be recruited preferentially for the same external power output when contraction velocity is high. Thus, it could be speculated that cyclists who recruit a greater FT fibres in the early minutes of CPT at + 15% SCPR present a greater amplitude of the fast $\dot{V}O_2$ component and $\dot{V}O_2$ response leading to a decrease of exercise tolerance.

Conclusion

The SCPR makes it possible cyclists to continue for longer at heavy exercise, in comparison to a 15% increase of SCPR. This decrease of CPT performance observed at + 15% SCPR was not associated with change in $\dot{V}O_2$ kinetics and could be related to a greater activity of working muscles, neuromuscular fatigue and FT fibres recruitment. However, higher the increase of amplitude of the primary $\dot{V}O_2$ component and global $\dot{V}O_2$ response, higher the decrease of exhaustion time in CPT at + 15% SCPR. In practical terms, these results suggest that it is better for competitive cyclists to adopt pedal rate clote to these ones frequently used during training in order to optimise their road race performance, essentially during high intensity phases. However, using limited crank gear, cyclists were obliged to adopt pedal rate greater than 100 rpm during phases where the speed was greater to 55 $km.h^{-1}$ (back wind, descent, finish of flat stage). Thus, the capacity to maintain the aerobic demand regardless of the increase of pedal rate could be assumed like factor associated to the performance in road race.

Table and Figures

Table I. Parameters of oxygen uptake response during CPT at pΔ50 under different pedal rate conditions: spontaneously chosen pedal rate (SCPR) and + 15% SCPR. Please refer to *Eq. 1* and see the text for details. Rel. A_2' (A_2'/EE$\dot{V}O_2$) relative contribution of the slow component to a net increase in $\dot{V}O_2$ at end exercise.

Variable	SCPR	+ 15% SCPR
$\dot{V}O_2$(w) (ml.min^{-1})	2338.3 ± 181.5	2282.3 ± 194.7
A_0' (ml.min^{-1})	364.3 ± 121.0	405.1 ± 171.6
τ_0 (s)	14.8 ± 4.8	21.2 ± 8.9
TD_1 (s)	25.1 ± 7.5	18.3 ± 8.5
A_1' (ml.min^{-1})	1227.8 ± 303.5	1458.4 ± 426.1
τ_1 (s)	30.0 ± 13.5	44.6 ± 16.3
TD_2 (s)	255.8 ± 41.9	232.7 ± 26.4
A_2' (ml.min^{-1})	345.8 ± 130.9	384.8 ± 204.4
τ_2 (s)	81.6 ± 39.1	83.5 ± 41.8
Rel. A_2' (%EE$\dot{V}O_2$)	21.9 ± 11.0	20.1 ± 11.9
EE$\dot{V}O_2$ (ml.min^{-1})	1573.6 ± 291.1	1843.2 ± 549.6

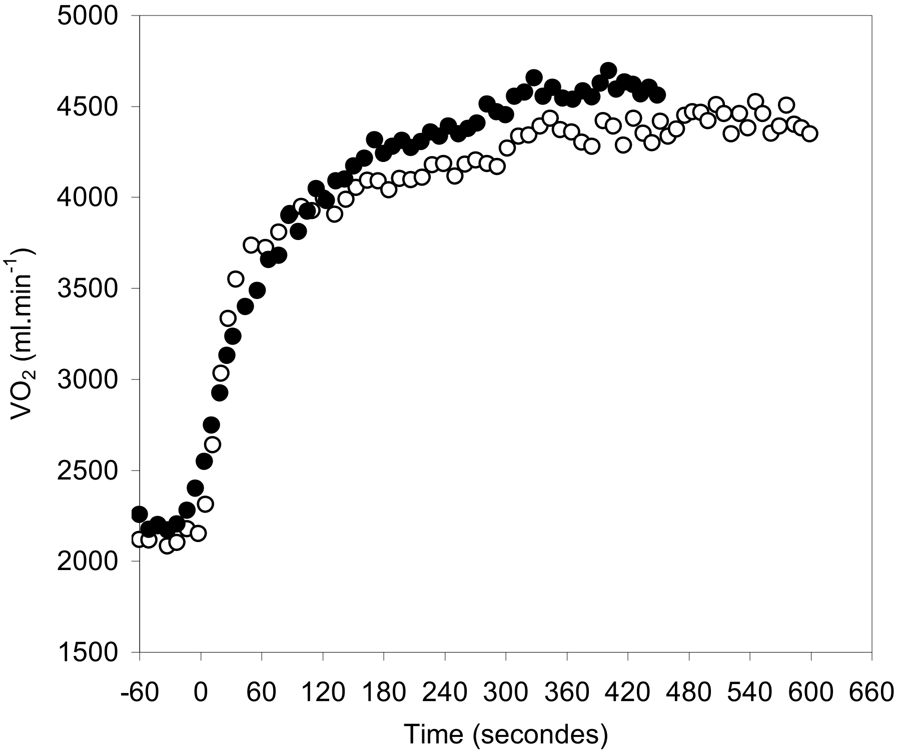

Figure 1. Example of oxygen uptake ($\dot{V}O_2$) response in 1 subject during a constant-power test (pΔ50) at spontaneously chosen pedal rate (SCPR, ○) and + 15% SCPR (●).

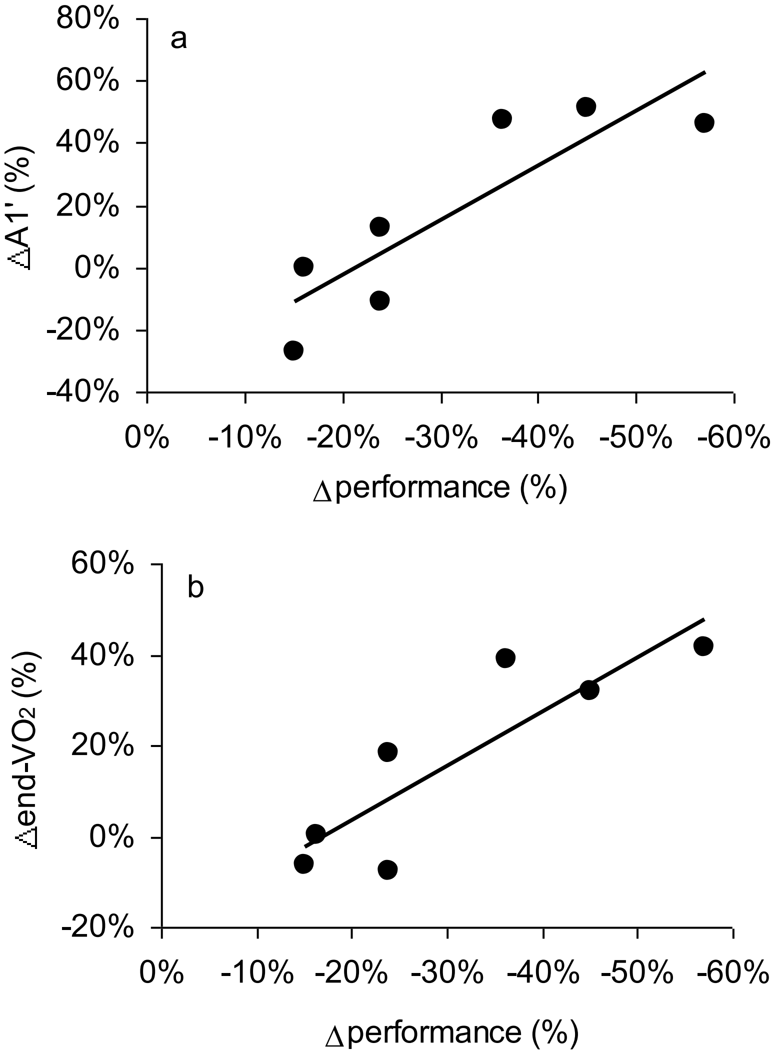

Figure 2. Relationship between the decrease of exhaustion time (i.e. Δperformance, -31.1 ± 15.7%) and a) the variation of amplitude of $\dot{V}O_2$ fast component (i.e. ΔA_1', 17.0 ± 29.6%; r = -0.87; P < 0.02) b) the variation of amplitude of the global $\dot{V}O_2$ response (i.e. Δend-$\dot{V}O_2$, 16.7 ± 21.4%; r = -0.87; P < 0.02) computed between CPT cycled at + 15% SCPR and at SCPR.