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

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Catalogue Data

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Mots-clés: demande aérobie, cadence, cyclistes, tolérance à l’exercice, fréquence de pédalage

Abstract/Résumé
The aim of this study was to evaluate the effect of a 15% increase in preferred pedal rate (PPR) on both time to exhaustion and pulmonary O₂ uptake (VO₂) response during heavy exercise. Seven competitive cyclists underwent two constant-power tests (CPT) at a power output that theoretically requires 50% of the difference in VO₂ between the second ventilatory threshold and VO₂max (PΔ50). Each cyclist cycled a CPT at PPR (CPTₚₚᵣ) and a CPT at +15% of PPR (CPT₊₁₅%) in a randomized order. The average PPR value was 94 ± 4 rpm, and time to exhaustion was significantly longer in CPTₚₚᵣ compared with CPT₊₁₅% (465 ± 139 vs. 303 ± 42 s, respectively; p = 0.01). A significant decrease in VO₂ values in the first minutes of exercise and a significant increase in VO₂ slow component was reported in CPT₊₁₅% compared with CPTₚₚᵣ. These data indicate that the increase of 15% PPR was associated with a decrease in exercise tolerance and a specific VO₂ response, presumably due to an increase of negative muscular work, internal work, and an altering of motor unit recruitment patterns.

L’objet de cette étude est d’évaluer l’effet d’une augmentation de 15% de la fréquence de pédalage préférée (FPP) sur le temps d’épuisement et la réponse de la consommation d’oxygène (VO₂) lors d’un exercice intense. Sept cyclistes compétiteurs accomplissent deux
tests à puissance constante (CPT) sollicitant théoriquement une $\dot{V}O_2$ correspondant à 50% de la différence entre le second seuil ventilatoire et $\dot{V}O_{2\text{max}}$ ($P\Delta 50$). Chaque cycliste réalise un CPT à FPP (CPT$_{FPP}$) et un CPT à +15% de FPP (CPT$_{+15\%}$) dans un ordre aléatoire. La FPP moyenne était de 94 ± 4 rpm et le temps d’épuisement était significativement plus long lors du CPT$_{FPP}$ comparé au CPT$_{+15\%}$ (465 ± 139 vs. 303 ± 42 s, respectivement; $p = 0,01$). Comparativement au CPT$_{FPP}$, les valeurs de $\dot{V}O_2$ dans les premières minutes d’exercice sont significativement inférieures et la composante lente de $\dot{V}O_2$ significativement supérieure dans le CPT$_{+15\%}$. Ces données indiquent qu’une augmentation de 15% de la FPP provoque une diminution de la tolérance à l’exercice et un ajustement spécifique de la réponse de $\dot{V}O_2$, ce qui peut être occasionné par une augmentation du travail musculaire négatif, du travail interne, et à une modification du pattern de recrutement des unités motrices.

Introduction

In cycling, a great diversity in the choice of preferred pedal rate (PPR) has been reported according to the population being studied. Experienced cyclists routinely use a high pedal rate from 90 to 100 rpm in laboratory tests while inexperienced subjects usually use 50 to 60 rpm (Hagberg et al., 1981). The reasons why trained cyclists select higher pedal rates during training and racing have not been clearly elucidated (Marsh and Martin, 1997; Marsh et al., 2000; Takaishi et al., 1996). Moreover, in road racing conditions, cyclists must to be able to adopt and maintain a pedal rate greater than 100 rpm in order to ride over 55 km·h$^{-1}$ because of the use of limited gear ratio (Lucia et al., 2001). During training sessions, therefore, cyclists often intentionally increase their pedal rate to become more comfortable while pedaling at cadences close to 110 rpm. Some studies have analyzed the effect of pedal rate on the power/time relationship in cycling (Carnevale and Gaesser, 1991; Hill et al., 1995; McNaughton and Thomas, 1996). These researchers demonstrated that cycling at low pedal rates of 50 to 60 rpm allows inexperienced cyclists to achieve better performance in heavy constant-power tests; they concluded that increasing pedal rate leads to a decrease in exercise tolerance and time to exhaustion. Nevertheless, this point has never been verified in experienced and competitive cyclists.

Likewise, previous studies have shown that this range of low pedal rate (50–60 rpm) makes it possible to minimize the energy expenditure for any given power output (Coast and Welch, 1985; Gaesser and Brooks, 1975). The curvilinear relationship between pedal rate and pulmonary O$2$ uptake ($\dot{V}O_2$) suggests that higher pedal rate produces higher aerobic demand (Marsh and Martin, 1993). Previously, Nickleberry and Brooks (1996) reported a greater $\dot{V}O_2$ in cyclists undertaking an exercise at 80 rpm vs. 50 rpm. Recently, Pringle et al. (2003) have studied the effect of pedal rate on the $\dot{V}O_2$ kinetics during heavy constant-load exercise. In the heavy intensity domain above the anaerobic threshold, $\dot{V}O_2$ response is complicated by the development of a $\dot{V}O_2$ slow component that causes $\dot{V}O_2$ to increase to values higher than would be expected for the external power output. Pringle et al. (2003) tested an extreme range of pedal rates (35 to 115 rpm) in the same metabolic rate and demonstrated that higher pedal rates were associated with a greater amplitude of the $\dot{V}O_2$ slow component, presumably by altering motor unit recruitment patterns.
Most of the studies on the effect of cadence on time to exhaustion and/or cardiorespiratory responses used imposed pedal rates and did not allow the subjects to choose their PPR as they normally would during everyday training and competition (McNaughton and Thomas, 1996; Nickleberry and Brooks, 1996; Pringle et al., 2003). To date, only Billat et al. (1999) analyzed a variation in PPR in triathletes on both exercise tolerance and VO₂ response. They reported that a decrease of 10% PPR affected neither the time to exhaustion nor the VO₂ slow component in heavy exercise. Based on all this, it seems necessary to verify whether an increase of PPR in cyclists is linked to a decrease in endurance time and a variation of the VO₂ response.

Thus the purpose of this study was to assess the effect of a 15% increase in PPR on time to exhaustion and VO₂ response during a heavy constant-power test in well-trained cyclists. It was hypothesized, first, that an increase of 15% PPR would induce a decrease in performance, and second, that this decrease in endurance time would be associated with a greater amplitude of the VO₂ slow component.

**Methods**

**SUBJECTS AND TESTING PROCEDURE**

Seven competitive male cyclists (mean ± SD: age 27.4 ± 4.2 yrs; height 1.77 ± 0.03 m; body mass 72.3 ± 3.6 kg; weekly training = 12.1 ± 2.6 hrs·wk⁻¹) volunteered to take part in this study. All subjects gave informed written consent to participate and underwent a complete medical examination prior to being included in the study. All measurements were carried out under medical supervision in a climate-controlled laboratory (21 to 22 °C).

The subjects were familiar with all procedures. They performed a maximal graded test for the measurement of maximal oxygen uptake (VO₂max), to determine maximal aerobic power (MAP) and ventilatory thresholds (VT₁ and VT₂). Two subsequent constant-power tests (CPT) were completed at a power output that theoretically requires 50% of the difference in VO₂ between VT₂ and VO₂max (PΔ50). After the determination of PPR in a preliminary exercise at PΔ50, cyclists cycled a CPT at PPR (CPTₚₚₑₑ) and a CPT at +15% of PPR (CPTₚₚₑₑ+₁₅%) in a randomized order. They were instructed to arrive at the laboratory fully hydrated and to avoid strenuous exercise in the 48 hours preceding a test session. Each session took place at the same time of day (±1 hr) in order to minimize possible effects of diurnal biological variations on the results.

**MATERIAL**

Subjects cycled on their own bicycles, which were attached to a Spintrainer ergometer (Technogym, Gambettola, Italy). This device simulates an actual time-trial situation since the subjects can choose the gear ratio and pedal rate depending on the power output required. In order to keep power output constant during the graded test and the two CPT, cyclists cycled with visual power output and pedal rate feedbacks. The ergometer was calibrated for each subject before each test. Calibration of the Spintrainer ergometer consisted of a “run-down” test. The cyclist had to cycle up to a speed of 34 km·h⁻¹ and then stop pedaling immediately when the
Spintrainer displayed the message “STOP.” The cyclist then had to remain motionless on his cycle during the calibration.

The speed-decay curve was drawn from 34 km·h⁻¹ to 5 km·h⁻¹. The ergometer’s built-in computer generated a reference decay curve specific to the subject’s body mass which was entered prior to the calibration test. If the acquired decay curve closely fitted the reference decay curve, the calibration was accepted. If not, the rolling resistance was adjusted automatically by adjusting the electromagnetic resistance system, and a second calibration test was performed. The test was repeated with adjustments to rolling resistance until the Spintrainer display accepted the calibration as correct, which usually took two to three attempts. Calibration of the ergometer was followed by 10 min of rest during which cyclists were equipped with the portable gas analyzer and instructed about the following test.

Measurements of oxygen uptake (\(\dot{V}_\text{O}_2\)), carbon dioxide output (\(\dot{V}_\text{CO}_2\)), minute ventilation (\(V_E\)), and respiratory frequency (\(f\)) were conducted throughout each test using a breath-by-breath portable gas analyzer (Cosmed K4b², Rome, Italy) which has been shown to be valid for measuring \(\dot{V}_\text{O}_2\) (McLaughlin et al., 2001). The Cosmed K4b² oxygen analyzer and carbon dioxide analyzer were calibrated immediately prior to each testing session in accordance with manufacturer guidelines. The turbine flow-meter of the K4b² was calibrated with a 3-L syringe (Quinton Instruments, Seattle, WA). A 10-lead ECG (Quinton Instruments, Q-710) was recorded continuously during tests to determine heart rate (HR). Mean respiratory exchange ratio (RER) and ventilatory equivalents in \(\dot{V}_\text{O}_2\) (\(\dot{V}_E/\dot{V}_\text{O}_2\)) and \(\dot{V}_\text{CO}_2\) (\(\dot{V}_E/\dot{V}_\text{CO}_2\)) values were calculated from the recorded measurements.

At each test, measurements of blood lactate concentrations ([La]) were obtained from capillary blood samples 3 minutes postexercise (Margaria et al., 1971). The fingertip was cleaned with an alcohol swab, dried, and then punctured with an automated lancet to sample blood in capillary tubes. Blood samples were analyzed using Dr. Lange’s® photometric method (Berlin, Germany).

**DETERMINATION OF \(\dot{V}_\text{O}_2\)\text{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 every minute until volitional exhaustion, which was at 13 ± 2 min. The \(\dot{V}_\text{O}_2\), RER, \(V_E\), and HR values were averaged each 30 sec and maximal values attained during the test were reported (\(\dot{V}_\text{O}_2\)\text{max}, \(\text{RER}_\text{max}\), \(V_{E\text{max}}\), and \(HR_{\text{max}}\), respectively). According to Duncan et al. (1997), the primary criterion used for defining \(\dot{V}_\text{O}_2\)\text{max} was a plateau in \(\dot{V}_\text{O}_2\) (change < 1.5 ml·kg⁻¹·min⁻¹). The secondary criteria were an RER > 1.1 and [La] > 8 mmol·L⁻¹.

When no plateau of \(\dot{V}_\text{O}_2\) was achieved, MAP was identified as the peak power output, i.e., the maximal exercise intensity maintained during the complete last stage. When a plateau of \(\dot{V}_\text{O}_2\) was achieved, MAP was defined as the minimal exercise intensity that could elicit \(\dot{V}_\text{O}_2\)\text{max}. The single indices used individually in order to determine VT₁ and VT₂ for each subject were \(V_E\), \(\dot{V}_\text{CO}_2\), \(\dot{V}_E/\dot{V}_\text{O}_2\), and \(\dot{V}_E/\dot{V}_\text{CO}_2\).

The following criteria were employed in selecting the thresholds: According to Wasserman et al. (1973), VT₁ was defined as the minimal load at which \(\dot{V}_E/\dot{V}_\text{O}_2\) exhibited a systematic increase without a concomitant increase in \(\dot{V}_E/\dot{V}_\text{CO}_2\). VT₂
corresponded to the minimal work rate at which the increase in $\dot{V_e}/\dot{V}O_2$ was accompanied by an increase of $\dot{V_e}/\dot{V}CO_2$. Beaver et al. (1986) defined $VT_1$ and $VT_2$ as the work rates associated with a first and a second nonlinear increase of $\dot{V_e}$ and $\dot{V}CO_2$. According to the criteria outlined above, three independent researchers blindly reviewed the plots of each index and made individual determinations of $VT_1$ and $VT_2$. Extrapolation of the linear relationship between $\dot{V}O_2$ and power output for exercise at sub-$VT_2$ intensities was used to estimate the power output at $\Delta 50$ ($P\Delta 50$).

DETERMINATION OF PPR, TIME TO EXHAUSTION, AND $\dot{V}O_2$ RESPONSE

In order to randomize the order of CPT, each subject chose his own gear ratio and pedal rate (PPR) allowing him to develop $P\Delta 50$ during an initial exercise of 3 min realized one hour after the end of the maximal graded test. Marsh and Martin (1997) reported that there is some day-to-day variation in PPR but that in general this measurement is quite stable.

Each 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 sec. Subjects were instructed to cycle for as long as possible and were encouraged to maintain the specific pedal rate ($\pm 1$ rpm) without changing gear ratio. Exhaustion was defined as the point at which the subject could not maintain the correct pedal rate (PPR or $+15\%$ PPR). No indication was given as to the time elapsed; the time to exhaustion was recorded to the nearest second for each subject.

A single transition test methodology used in the present study did not permit modeling of the $\dot{V}O_2$ responses due to the low signal-to-noise ratio. Breath-by-breath $\dot{V}O_2$ values were averaged every 15 sec and expressed in ml·min$^{-1}$ and $%\dot{V}O_2_{max}$. The $\dot{V}O_2$ response was described from the $\dot{V}O_2$ values reported at 0, 60, 120, and 180 sec after the onset of CPT and at the end of exercise ($\dot{V}O_2$ baseline, 60-$\dot{V}O_2$, 120-$\dot{V}O_2$, 180-$\dot{V}O_2$, and end-$\dot{V}O_2$, respectively). The $\dot{V}O_2$ value at 265 sec after the onset of CPT ($265-\dot{V}O_2$, i.e., shorter time to exhaustion observed in this study) was also reported in order to compute an amplitude of $\dot{V}O_2$ slow component over the same exercise duration for all cyclists under each pedal rate condition. A recent study has demonstrated that $\dot{V}O_2$ slow component becomes evident at about 110–140 sec after the onset of heavy exercise cycled at a high pedal rate (Pringle et al., 2003). Thus the increase in $\dot{V}O_2$ beyond the 2nd minute is used to quantify the $\dot{V}O_2$ slow component in the present study ($\dot{V}O_{2SC}$; the difference between $265-\dot{V}O_2$ and 120-$\dot{V}O_2$). The $\dot{V}O_{2SC}$ was expressed relative to the increase in $\dot{V}O_2$ above $\dot{V}O_2$ baseline at 265-$\dot{V}O_2$ ($\Delta \dot{V}O_2$).

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. A paired $t$-test and, where appropriate, a Wilcoxon matched pairs test were used to compare the differences between the two pedal rate conditions. Statistical significance was set at $p = 0.05$ level for all analysis. All calculations were made with Statistica (Version 6.0, StatSoft, Tulsa, OK).
Results

GRADED TEST

The mean MAP value was 354 ± 53 W and the mean \( \dot{V}O_2 \)max value was 4419 ± 693 ml·min\(^{-1}\), corresponding to 61.2 ± 9.2 ml·kg\(^{-1}\)·min\(^{-1}\). Mean RER max, [La], \( \dot{V}E \)max, and HRmax values were 1.18 ± 0.03; 13.7 ± 3.4 mmol·L\(^{-1}\); 190 ± 20 L·min\(^{-1}\); and 186 ± 10 beats·min\(^{-1}\), respectively. The VT\(_1\) and VT\(_2\) represented 52.7 ± 6.3 and 86.0 ± 4.7% \( \dot{V}O_2 \)max, respectively.

CONSTANT-POWER TESTS

The 6-min warm-up was set at a power output corresponding to VT\(_1\). The \( \dot{V}O_2 \) baseline reported at the onset of each CPT was around 53% \( \dot{V}O_2 \)max (Table 1) and not significantly different from VT\(_1\) (both \( p > 0.87 \)). The power output, corresponding to PA50 as determined from the graded test, averaged 328 ± 45 W (93.2 ± 3.7% MAP), and the average value of PPR was 94 ± 4 rpm. Time to exhaustion was significantly longer in CPT\(_{PPR}\) compared with CPT\(_{+15\%}\) (465 ± 139 vs. 303 ± 42 sec, respectively; \( p = 0.01 \)), and [La] did not differ significantly between the two pedal rate conditions (12.9 ± 5.2 vs. 13.2 ± 3.6 mmol·L\(^{-1}\), respectively, \( p = 0.47 \)).

The \( \dot{V}O_2 \) response to heavy CPT at each pedal rate condition in a typical cyclist is shown in Figure 1. Table 1 shows the results of the \( \dot{V}O_2 \) response in CPT cycled under both pedal rate conditions. There was no significant difference in the \( \dot{V}O_2 \) baseline reported at the onset of each CPT. The increase of 15% PPR induced a significant decrease in \( \dot{V}O_2 \) values in the first minutes of CPT (i.e., 60-\( \dot{V}O_2 \) and

Table 1  \( \dot{V}O_2 \) Responses (\( M \pm SEM \)) to Exhaustive Heavy CPT Cycled at PPR and +15% PPR in Competitive Cyclists

<table>
<thead>
<tr>
<th>Pedal rate</th>
<th>PPR</th>
<th>+ 15% PPR</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \dot{V}O_2 ) baseline (% ( \dot{V}O_2 )max)</td>
<td>53.2 ± 2.6</td>
<td>52.3 ± 2.1</td>
<td>0.76</td>
</tr>
<tr>
<td>60-( \dot{V}O_2 ) (% ( \dot{V}O_2 )max)</td>
<td>81.0 ± 1.0</td>
<td>77.5 ± 0.7</td>
<td>0.02</td>
</tr>
<tr>
<td>120-( \dot{V}O_2 ) (% ( \dot{V}O_2 )max)</td>
<td>88.2 ± 0.8</td>
<td>85.7 ± 1.1</td>
<td>0.04</td>
</tr>
<tr>
<td>180-( \dot{V}O_2 ) (% ( \dot{V}O_2 )max)</td>
<td>91.6 ± 1.0</td>
<td>90.6 ± 0.9</td>
<td>0.22</td>
</tr>
<tr>
<td>265-( \dot{V}O_2 ) (% ( \dot{V}O_2 )max)</td>
<td>92.8 ± 1.2</td>
<td>95.4 ± 0.9</td>
<td>0.07</td>
</tr>
<tr>
<td>end-( \dot{V}O_2 ) (% ( \dot{V}O_2 )max)</td>
<td>97.7 ± 1.3</td>
<td>97.6 ± 1.1</td>
<td>0.95</td>
</tr>
<tr>
<td>( \Delta \dot{V}O_2 ) (ml·min(^{-1}))</td>
<td>1767 ± 183</td>
<td>1924 ± 201</td>
<td>0.12</td>
</tr>
<tr>
<td>( \dot{V}O_2)SC (% ( \Delta \dot{V}O_2 ))</td>
<td>11.5 ± 1.7</td>
<td>22.3 ± 2.5</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Note: \( \dot{V}O_2 \) baseline, 60-, 120-, 180-, 265-, and end-\( \dot{V}O_2 \): average values reported at 0, 60, 120, 180, and 265 sec after the onset of CPT and at the end of exercise, respectively. \( \dot{V}O_2\)SC: \( \dot{V}O_2 \) slow component computed from the difference between 265- and 120-\( \dot{V}O_2 \). \( \Delta \dot{V}O_2 \): increasing in \( \dot{V}O_2 \) above \( \dot{V}O_2 \) baseline at 265-\( \dot{V}O_2 \).
120-V·O\textsubscript{2}) and a significant increase in V·O\textsubscript{2SC} (201 ± 80 vs. 436 ± 193 ml·min\textsuperscript{−1}; p = 0.01). At exhaustion, no significant difference was reported in maximal value of V·O\textsubscript{2} (i.e., end-V·O\textsubscript{2}) between the two pedal rate conditions.

**Discussion**

The most relevant finding of the present study was that an increase of +15\% PPR during heavy CPT induced a significant decrease in time to exhaustion in competitive cyclists. Also, a specific V\textsubscript{O2} response, corresponding to a decrease in V\textsubscript{O2} values in the first minutes of exercise and a greater V\textsubscript{O2} slow component, was reported in CPT+15\%.

In road races, successful performance requires that cyclists tolerate a level of exercise intensity above VT\textsubscript{2} over long periods of time (Lucia et al., 1999). Therefore, the present study tested the effect of an increase of 15\% PPR on exercise tolerance in competitive cyclists during heavy CPT. In CPT cycled at PPR, cyclists were able to maintain PΔ50 (93.2 ± 3.7\% MAP) over 7 min 45 s ± 2 min 19 s. In triathletes, Billat et al. (1998; 1999) reported time to exhaustion equating to 13 min 32 s ± 4 min 52 s during CPT cycled at 86\% MAP, and 10 min 37 s ± 4 min 11 s during CPT cycled at 90\% MAP. Thus, considering the hyperbolic relationship between relative power output and time to exhaustion (Péronnet and Thibault, 1989), the average time to exhaustion value reported was in agreement with Billat et al.'s results.
The present study reported a significant decrease in time to exhaustion of heavy CPT with an increase of 15% PPR (94 ± 4 vs. 108 ± 5 rpm). However, all cyclists sustained an intense and exhaustive effort, as shown by the same elevated [La] in the two CPT. Many researchers have demonstrated that an increase in pedal rate leads to a decrease in exercise tolerance (Carnevale and Geasser, 1991; Hill et al., 1995; McNaughton and Thomas, 1996). Nevertheless, McNaughton and Thomas (1996) reported no significant difference in exercise tolerance between 90 and 110 rpm, which was somewhat inconsistent with the present results. In these previous studies, subjects were neither experienced cyclists nor were they aerobically trained, so pedal rate values above 90 rpm certainly represented a considerable increase in PPR that could similarly influence the estimation of parameters in the power/time relationship.

In cyclists performing CPT at 75% \( \dot{V}O_2 \text{max} \), Nickleberry and Brooks (1996) reported that time to exhaustion was significantly greater at 80 rpm than at 50 rpm, which suggests that high pedal rate makes it possible to reduce peripheral fatigue of leg musculature. Indeed, cycling training influences the PPR selection up to high pedal rates (Takaishi et al., 1998), and a pedal rate ranging between 80 and 90 rpm delays the onset of local neuromuscular fatigue in cyclists (Takaishi et al., 1996). Additionally, a study by Billat et al. (1999) reported that a variation of −10% PPR in triathletes had no significant effect on the exercise tolerance in heavy CPT. Hence it seems reasonable to suggest that, in a range of pedal rates usually adopted by experienced cyclists, only an increase in PPR reduced time to exhaustion in a supra-anaerobic threshold exercise.

The primary factors responsible for the decrease in time to exhaustion were certainly biomechanical. Since the power generated by a cyclist is a linear combination of crank torque and angular velocity, the increase in pedal rate theoretically induces a decrease in pedal force to provide a given power. However, Neptune and Van den Bogert (1998) demonstrated that cocontraction and negative muscle work appear to be inevitable at a high pedal rate because of the activation dynamics and the greater need for movement control. For power outputs of 100 and 200 W, Patterson and Moreno (1990) reported that the minimum value of resultant pedal force was reached at 90 and 100 rpm, respectively. Even in competitive cyclists, the lack of muscular coordination and ability to maintain pedal rate values higher than 100 rpm induced a significant increase in negative muscular work and resultant pedal forces (Neptune and Herzog, 1999).

In the present study, the +15% PPR corresponded to 108 ± 5 rpm, and thus substantial negative muscular work may be generated in CPT_{+15%}. The latter could explain a lower time to exhaustion in CPT_{+15%} compared with CPT_{PPR}. Moreover, the muscular work required to accelerate the limb segments (i.e., internal work) significantly increases the relative exercise intensity especially when pedal rates are high (Francescato et al., 1995; Wells et al., 1986). Thus it can be suggested that the additional energy cost for internal work when the pedal rate was set at +15% PPR had an important effect on the exercise tolerance between the two pedal rate conditions. Additionally, it is widely accepted that recruitment of type II muscle fibers is enhanced with an increase in pedal rate for the same external power output. At fast movement speeds, these fibers are thought to be preferentially recruited since their optimum contraction velocity is closer to the movement speed than is
that of type I fibers (Beelen and Sargeant, 1993; Sargeant, 1994). Thus, in accordance with the study by Takaishi et al. (1996), the increase of 15% PPR may intensify the neuromuscular fatigue in working muscles due to a relatively greater contribution of fatigue-sensitive fibers, an increase of firing rate, and/or progressive recruitment of additional motor units.

An interesting finding in the present study was the change in \( \text{V} \cdot \text{O}_2 \) response with the increase in PPR in heavy CPT. The \( \text{V} \cdot \text{O}_2 \) values reported at 60 and 120 sec after the onset of exercise, 60-\( \text{V} \cdot \text{O}_2 \) and 120-\( \text{V} \cdot \text{O}_2 \), respectively, were significantly lower in CPT\(_{+15\%}\) than in CPT\(_{PPR}\). Moreover, the \( \text{V} \cdot \text{O}_2 \) slow component (difference between 265-\( \text{V} \cdot \text{O}_2 \) and 120-\( \text{V} \cdot \text{O}_2 \)) was significantly higher in CPT\(_{+15\%}\). The results of the present study are in accordance with a recent work by Pringle et al. (2003), who reported a reduction in the gain of the \( \text{V} \cdot \text{O}_2 \) primary component and a greater amplitude of the \( \text{V} \cdot \text{O}_2 \) slow component with higher pedal rates at the same relative intensity. Additionally, the average 265-\( \text{V} \cdot \text{O}_2 \) value was higher in CPT\(_{+15\%}\) than in CPT\(_{PPR}\), but was not significantly different \((p = 0.07; \text{Table 1})\), perhaps because of the low number of cyclists. Thus, an increase in PPR tended to decrease cycling efficiency, which was in accordance with previous studies (Coast and Welch, 1985; Marsh and Martin, 1993).

A possible reason for these specific \( \text{V} \cdot \text{O}_2 \) responses with an increase of 15% PPR may be a greater contribution of type II fibers with time to exercise. Previous studies reported that type II fibers are recruited in addition to type I fibers in response to increased exercise intensity (Vollestad and Blom, 1985), and that increasing the pedal rate involves a greater contribution of type II fibers (Beelen and Sargeant, 1993; Sargeant, 1994). This type of muscle fiber is presumed to provide lower efficiency because of more oxygen being consumed for the same rate of tension generation and ATP turnover than with type I fibers (Willis and Jackman, 1994). However, the increase in pedal rate brings type II fibers close to their optimal velocity of shortening for mechanical efficiency (Sargeant, 1994). Therefore, the prediction of cycling efficiency with an increase in pedal rate is not evident due to the concomitant variation in motor unit recruitment patterns and muscle fiber efficiency. In the present study, the difference between the two CPT in terms of pedal value was only 14 rpm, which may not have a significant effect on the mechanical efficiency of muscle fibers. Nevertheless, internal work is not included in our measurement of cycling power, which increases the relative intensity in CPT\(_{+15\%}\). Thus it can be speculated that combined effects of +15% PPR on the increase in shortening velocity and relative exercise intensity induce a greater contribution of type II fibers over time in CPT\(_{+15\%}\). Assuming that type II fibers have a larger gain and slower kinetics than type I fibers (Barstow et al., 1996), then the \( \text{V} \cdot \text{O}_2 \) response reported at CPT\(_{+15\%}\) is in agreement with a greater contribution of type II fibers with time to exercise.

In conclusion, for heavy CPT at the same power output, an increase of 15% PPR induced a significant decrease in time to exhaustion in competitive cyclists. Also, the \( \text{V} \cdot \text{O}_2 \) response in CPT\(_{+15\%}\) was characterized by lower \( \text{V} \cdot \text{O}_2 \) values in the first minutes of exercise and a greater amplitude of \( \text{V} \cdot \text{O}_2 \) slow component compared with \( \text{V} \cdot \text{O}_2 \) response in CPT\(_{PPR}\). In the present study, it can be suggested that the decrease in time to exhaustion with the increase in PPR was essentially due to a substantial negative and internal work in CPT\(_{+15\%}\). Additionally, the possible
greater contribution of type II fibers may intensify the neuromuscular fatigue in working muscles, decreasing the exercise tolerance and affecting the VO₂ response in CPT +15%. Thus, in response to road race conditions such as attacks and “breakaways” from the main group, sprints, or during hill descents of low inclination, cyclists need gear ratios high enough in order to use their PPR as often as possible. Moreover, because supra-PPR affect the exercise tolerance and VO₂ response, further studies should be conducted to determine whether specific periods of training using high pedal rates (115–120 rpm) can lead to useful changes in mechanical, muscular, and/or metabolic parameters and improve cycling performance.

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