

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

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15

16 **Abstract**

17 The purpose of this study was to assess the fast and slow  $\dot{V}O_2$  component and exhaustion time  
18 during a heavy constant-power test (CPT) under two different pedal conditions. The oxygen  
19 consumption kinetics was analysed through mathematical modelling of the breath-by-breath  
20 gas exchange response to heavy cycling exercise. After continuous graded test, seven well-  
21 trained cyclists performed two all-out CPT. The first CPT was cycled at spontaneously chosen  
22 pedal rate (SCPR) and the second one at + 15% SCPR. As expected, the present study  
23 reported a significant decrease of exhaustion time on CPT at + 15% SCPR (respectively,  
24  $465.1 \pm 138.6$  vs  $303.0 \pm 42.5$  s;  $P < 0.05$ ) without change in  $\dot{V}O_2$  kinetics between the two  
25 pedal rate conditions. Moreover, the decrease of exhaustion time was inverse correlated with  
26 variation of aerobic demand computed between the two pedal rate conditions. In conclusion, it  
27 could be suggested that factors implicated in this decrease of exercise tolerance were  
28 principally neural and muscular factors. Nevertheless, the capacity to maintain the aerobic  
29 demand regardless of the increase of pedal rate could be assumed like factor associated to the  
30 performance in road race.

31

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

33

## 34 **Introduction**

35 In cycling, a great diversity in the choice of spontaneously chosen pedal rate (SCPR) has been  
36 reported according to the population studied. Experienced cyclists routinely use high pedal  
37 rate from 90 to 100 rpm in laboratory tests or competitive events while inexperienced subjects  
38 use usually 50 to 60 rpm [14]. The variations of preferred cadence could be related to training  
39 status and pedal skill [15, 23]. In road race conditions, cyclists have the use of limited gear  
40 ratio and must adopt pedal rate greater than 100 rpm in order to ride over 55 km.h<sup>-1</sup>. Thus,  
41 during specific sessions of training, cyclists often increase consciously their spontaneously  
42 pedal rate to become more comfortable and efficient while pedalling at cadence close to 110  
43 rpm. Some studies have analysed the effect of cadence on the power-time relationship in  
44 cycling (McNaughton and Thomas, 1996; Hill et al., 1995; Carnevale and Gaesser, 1991).  
45 McNaughton and Thomas (1996) and Carnevale and Gaesser (1991) have shown that cycling  
46 at low pedal rate (50-60 rpm) make it possible to inexperienced cyclists to achieve better  
47 performance in heavy constant-power tests. These previous studies concluded that increasing  
48 pedal rate leads a to decrease exercise tolerance and exhaustion time. Nevertheless, on the  
49 best of our knowledges, this point have never been verify in trained and experienced cyclists.  
50 During the transition from rest or unloaded cycling to constant-load exercise of moderate  
51 intensity (below the anaerobic threshold), after the cardio-dynamic phase (phase 1),  $\dot{V}O_2$  rises  
52 in an approximately mono-exponential fashion (phase 2) to attain a new steady state (phase 3)  
53 within 3-5-min in normal subjects. In contrast,  $\dot{V}O_2$  response to constant-load exercise of  
54 heavy intensity (superior to anaerobic threshold) is complicated by the development of an  
55 additional component of  $\dot{V}O_2$  such that attainment of a new steady state, if attained, is  
56 delayed [31]. Barstow et al. [2] have studied the effect of different imposed frequency (45, 60,  
57 75 and 90 rpm) on the  $\dot{V}O_2$  kinetics in heavy exercise and have concluded that pedal  
58 frequency has no significant effect in inexperienced subjects. Nevertheless, they did not allow

59 the subjects to choose their own pedal rate as they normally do everyday during training and  
60 competition. Likewise, Marsh and Martin (1993; 1997) have studied the aerobic demand  
61 response to cadence manipulation and reported a curvilinear relationship with higher cadence  
62 producing higher oxygen consumption. Up to this date, only the study of Billat et al. (1999)  
63 has analysed the effect of decrease in spontaneously chosen cadence of exercise on  $\dot{V}O_2$   
64 slow component. They have reported no difference on  $\dot{V}O_2$  slow component between the  
65 two cadences (freely vs lower of 10%). A limitation of this study was the characterization of  
66 the slow component, which involved the simple calculation of the difference between  $\dot{V}O_2$   
67 at 3-min and  $\dot{V}O_2$  at the end of exercise. Indeed, the use of the model validated by Barstow  
68 and Molé [3] makes it possible to determine more accurately the components of the  $\dot{V}O_2$   
69 kinetics [5]. Moreover, Billat et al. (1999) have reported an amplitude of slow component  
70 significantly higher during cycling than in running with no difference in exhaustion time,  
71 suggesting that the relationship between the  $\dot{V}O_2$  slow component and the fatigue process  
72 remains unclear. Nevertheless, Demarle et al. (2001) have shown that the decrease of oxygen  
73 deficit observed after a specific program of endurance training reflects a faster adjustment on  
74  $\dot{V}O_2$  kinetics (i.e. decreasing of  $\tau_1$ ) and was correlated with the improvement of exhaustion  
75 time. Based on this background, it seems necessary to verify whether the decrease of  
76 endurance time during heavy exercise is linked to adjustment and/or magnitude of  $\dot{V}O_2$   
77 response.

78 Thus, the purpose of this study was to assess the fast and slow component of  $\dot{V}O_2$ , using the  
79 mathematical modelling procedure [3], and the performance during a heavy constant-power  
80 test (CPT) in well-trained cyclists when the pedal rate was spontaneously chosen or set at +  
81 15% SCPR. It was hypothesised, on the one hand that an increase of + 15% SCPR induce a  
82 decrease of performance with no significant change in  $\dot{V}O_2$  kinetics and on the other hand,

83 that the decrease of endurance time is correlated with an increase of the time constant of  
84 primary  $\dot{V}O_2$  component and amplitude  $\dot{V}O_2$  response .

## 85 **Methods**

### 86 *Subjects*

87 Seven competitive cyclists (mean  $\pm$  SD: age  $27.4 \pm 4.2$  yr; height  $1.77 \pm 0.03$  m; body mass  
88  $72.3 \pm 3.6$  kg; weekly hourly volume of training  $12.1 \pm 2.6$  h.wk<sup>-1</sup>) volunteered to take part in  
89 this study, which was approved by the French National Committee for Clinical Research. All  
90 subjects gave informed written consent to participate in this study and underwent a complete  
91 medical examination prior to the experiments. All measurements were carried out under  
92 medical supervision in a climate-controlled laboratory (21 to 22°C).

### 93 *Testing procedure*

94 All the subjects were familiar with all procedures and performed:

- 95 • a maximal graded test (Tmax) where the power output was set at 100 W and increased by  
96 25 W every minute, in order to measure the maximal oxygen uptake ( $\dot{V}O_{2\max}$ ), to determine  
97 the maximal aerobic power (MAP), and the ventilatory thresholds (VT<sub>1</sub> and VT<sub>2</sub>)
- 98 • two constant power tests (CPT) set at a power output that theoretically requires 50% of the  
99 difference in  $\dot{V}O_2$  between VT<sub>2</sub> and  $\dot{V}O_2\max$  (p $\Delta$ 50). The first CPT was performed at SCPR,  
100 while the second one was performed at + 15% of SCPR of the preceding session.

101 Each session took place on non-consecutive days at the same time ( $\pm$  1h) in order to minimise  
102 possible effects of diurnal biological variations on the results. Subjects were instructed to  
103 arrive at the laboratory in a fully hydrated state and to avoid strenuous exercise in the 48-h  
104 preceding a test session. Subjects were required to cycle on their own bicycles, which were  
105 attached to a Spinrainer ergometer (Technogym, Gambettola, Italy). This device simulates a  
106 real life time-trial situation since the subjects can choose the gear ratio and pedal rate  
107 depending on the power output required. The ergometer was calibrated for each subject

108 immediately before each test. Calibration of the Spintrainer ergometer consists of a "run-  
109 down" test. The cyclist is required to cycle up to a speed of 34 km·h<sup>-1</sup> and then to stop  
110 pedalling immediately the Spintrainer display shows the message "STOP." The cyclist must  
111 then remain motionless on his cycle while the calibration takes place. The speed-decay curve  
112 is drawn from 34 km·h<sup>-1</sup> to 5 km·h<sup>-1</sup>. The ergometer's built-in computer generates a reference  
113 decay curve specific to the subject's body mass that is entered before the calibration test. If  
114 the acquired decay curve closely fits the reference decay curve, the calibration is accepted. If  
115 not, the rolling resistance is adjusted automatically by adjusting the electromagnetic resistance  
116 system, and a second calibration test is performed. The test is repeated with adjustments to  
117 rolling resistance until the Spintrainer display accepts the calibration as correct. This usually  
118 takes two to three attempts.

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

120 The maximal graded test was preceded by a 3-min warm-up period at 100 W. This initial  
121 work rate was then increased by 25 W·min<sup>-1</sup>. To ensure that  $\dot{V}O_2$  max was reached, subjects  
122 were encouraged to continue as long as possible so that a levelling off in the  $\dot{V}O_2$  course  
123 occurred. The test ended at the point of voluntary exhaustion. During the test, the subjects  
124 breathed through a facemask. Measurement of oxygen uptake ( $\dot{V}O_2$ ), carbon dioxide output  
125 ( $\dot{V}CO_2$ ), minute ventilation ( $\dot{V}_E$ ) and respiratory frequency (f) were carried out throughout  
126 each test using a breath-by-breath portable gas analyser (Cosmed K4b<sup>2</sup>, Roma, Italy). It has  
127 been shown to be a valid instrument for the measurement of  $\dot{V}O_2$  (McLaughlin et al., 2000).  
128 The Cosmed K4b<sup>2</sup> oxygen analyser and carbon dioxide analyser were calibrated immediately  
129 before each testing session in accordance with manufacturer's guidelines. The calibration of  
130 the turbine flow-meter of the K4b<sup>2</sup> was performed with a 3-L syringe (Quinton Instruments,  
131 Seattle, Washington). A 10-lead ECG (Quinton Instruments, Q-710, Seattle, Washington) was

132 recorded continuously during tests to determine heart rate (HR). The mean respiratory  
133 exchange ratio (RER), and ventilatory equivalents in O<sub>2</sub> ( $\dot{V}_E / \dot{V}O_2$ ) and CO<sub>2</sub> ( $\dot{V}_E / \dot{V}CO_2$ )  
134 values were calculated from the recorded measurements. The maximal values of  $\dot{V}O_2$ , HR,  
135  $\dot{V}CO_2$ , RER and  $\dot{V}_E$  attained during the test were reported ( $\dot{V}O_{2max}$ , HRmax,  $\dot{V}CO_{2max}$ ,  
136 RERmax,  $\dot{V}_E max$  ). When no plateau of  $\dot{V}O_2$  was achieved, maximal aerobic power (MAP)  
137 was identified as the peak power output, i.e. the maximal exercise intensity maintained during  
138 the last stage. When a plateau of  $\dot{V}O_2$  was achieved, MAP was defined as the minimal  
139 exercise intensity, which can elicit  $\dot{V}O_{2max}$ . A plateau of  $\dot{V}O_2$  in the  $\dot{V}O_2$ -exercise intensity  
140 relationship was defined as an increase in oxygen uptake of less than 1.5 ml.min<sup>-1</sup>.kg<sup>-1</sup> with  
141 the increase in exercise intensity. The single indices used individually in order to determine  
142 VT<sub>1</sub> and VT<sub>2</sub> for each subjects were VE, VCO<sub>2</sub>, VE/  $\dot{V}O_2$  and VE/ VCO<sub>2</sub>. The following  
143 criteria were employed in selecting the thresholds: According to Wasserman et al. (1973),  
144 VT<sub>1</sub> was defined as the minimal load at which VE/  $\dot{V}O_2$  exhibited a systematic increase  
145 without a concomitant increase in VE/VCO<sub>2</sub>. VT<sub>2</sub> corresponded to the minimal work rate at  
146 which the increase in VE/  $\dot{V}O_2$  went with an increase of VE/ VCO<sub>2</sub> (Wasserman and McIlroy,  
147 1964). Beaver et al. (1986) defined VT<sub>1</sub> and VT<sub>2</sub> as the work rates associated with a first and  
148 a second non-linear increase of VE and VCO<sub>2</sub>. According to the criteria outlined above, three  
149 independent investigators blindly reviewed the plots of each index and made individual  
150 determinations of VT<sub>1</sub> and VT<sub>2</sub>. Extrapolation of the relationship between  $\dot{V}O_2$  and power  
151 output for exercise at sub-VT<sub>2</sub> intensities was used to estimate the power output at  $\Delta 50$   
152 (p $\Delta 50$ ).

153 Measurements of blood lactate concentrations ([La]) were obtained from capillary blood  
154 samples. The fingertip was cleaned with an alcohol swab, dried and then punctured with an  
155 automated lancet to sample blood into capillary tubes to determine [La] three minute post-



156 exercise. Blood samples were analysed using Dr Lange's<sup>®</sup> photometric method (Berlin,  
157 Germany).

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

159 During a initial exercise of 3-min, each subject self-selected the pedal rate (SCPR) and gear  
160 ratio allowing to develop p $\Delta$ 50. Marsh et Martin (1997) reported that some day-to-day  
161 variation in SCPR exists but that in general this measure is quite stable. Thus, in order to keep  
162 power output constant during each CPT, the cyclist cycled with cadence feedback and was  
163 encouraged to maintain the pedal rate spontaneously chosen in initial exercise ( $\pm 1$  rpm)  
164 without change of gear ratio. The CPT began with a 6-min warm-up performed at a power  
165 output corresponding to VT<sub>1</sub> and the transition from the warm-up to exercise was complete  
166 within 15-s. Subjects were instructed to cycle for as long as possible and exhaustion was  
167 defined as the point at which the subject could no longer maintain the correct pedal rate (SCPR or +  
168 15% SCPR). No indication was given as to the time elapsed and the exhaustion time was  
169 recorded to the nearest second for each subject.

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

179 exponential term started with the onset of exercise (*time = 0*), whereas the other terms began  
 180 after independent time delays

$$\begin{aligned}
 181 \quad \dot{V}O_2(t) &= \dot{V}O_2(w) + A_0 \times (1 - e^{-t/\tau_0}) && \text{Phase 1 (initial component)} \\
 182 & && \\
 183 \quad &+ A_1 \times (1 - e^{-(t-TD_1)/\tau_1}) && \text{Phase 2 (primary component)} \\
 184 & && (1) \\
 185 \quad &+ A_2 \times (1 - e^{-(t-TD_2)/\tau_2}) && \text{Phase 3 (slow component)} \\
 186 & &&
 \end{aligned}$$

187 where  $\dot{V}O_2(w)$  is the average value over the last minute of warm-up at VT<sub>1</sub>; A<sub>0</sub>, A<sub>1</sub>, A<sub>2</sub> are  
 188 the asymptotic amplitudes for the exponential terms;  $\tau_0$ ,  $\tau_1$ ,  $\tau_2$  are the time constants; TD<sub>1</sub>,  
 189 TD<sub>2</sub> are the time delays. The phase 1 term was terminated at the start of phase 2 (i.e., at TD<sub>1</sub>)  
 190 and assigned the value for that time (A<sub>0</sub>' )

$$191 \quad A_0' = A_0 \times (1 - e^{-TD_1/\tau_0})$$

192 The amplitude of phase 1 (A<sub>0</sub>' ) and the amplitude of phase 2 (A<sub>1</sub>) were added to calculate the  
 193 amplitude at the end of the primary component (A<sub>1</sub>' ). The slow component at the end of  
 194 exercise (A<sub>2</sub>' ) was calculated and was used in preference to the asymptotic value [2]. The  
 195 increase in  $\dot{V}O_2$  above  $\dot{V}O_2(w)$  at the end of exercise was calculated as the sum of A<sub>1</sub>' and  
 196 A<sub>2</sub>' 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  
 197  $\dot{V}O_2(w)$  and EE $\dot{V}O_2$ .

### 198 ***Statistical analysis***

199 Standard statistical methods were used for the calculation of means and standard deviations.  
 200 Normal Gaussian distribution and homogeneity of variance were verified by the Shapiro-Wilk  
 201 and the Levene tests, respectively. Paired t-test, and where appropriate, Wilcoxon matched  
 202 pairs test were used to compare the differences between the two pedal rate conditions.  
 203 Relationship between variations of exhaustion time and  $\dot{V}O_2$  kinetics parameters were  
 204 evaluating using a Pearson correlation coefficient. A two-way analysis of variance with

205 repeated measures was used to test the overall effect of time and pedal rate on the  $\dot{V}_E$  and HR  
206 values averaged each 30-s. Compound symmetry, or *sphericity*, was verified by the Mauchley  
207 test [27]. When the assumption of sphericity was not met, the significance of F-ratios was  
208 adjusted according to the Greenhouse-Geisser procedure [26]. Statistical significance was set  
209 at  $P = 0.05$  level for all analysis. All calculations were made with Statistica (Release 5.5,  
210 Statsoft, Tulsa, USA).

## 211 **Results**

### 212 *Graded test.*

213 Mean MAP value was  $353.6 \pm 52.9$  W and mean  $\dot{V}O_2$  max value was  $4419.0 \pm 692.6$  ml.min<sup>-1</sup>  
214 <sup>1</sup>; corresponding to  $61.2 \pm 9.2$  ml.min<sup>-1</sup>.kg<sup>-1</sup>. The VT<sub>1</sub> and VT<sub>2</sub> represented respectively  $52.7 \pm$   
215  $6.3$  and  $86.0 \pm 4.7\%$   $\dot{V}O_2$  max. Mean HRmax,  $\dot{V}CO_2$  max,  $\dot{V}_E$  max and RERmax values were  
216  $186.3 \pm 9.8$  beats.min<sup>-1</sup>,  $4785.9 \pm 752.1$  ml.min<sup>-1</sup>,  $189.9 \pm 20.4$  l.min<sup>-1</sup> and  $1.18 \pm 0.03$ ,  
217 respectively. Mean blood lactate concentration value was  $13.7 \pm 3.4$  mmol.l<sup>-1</sup> and mean  
218 HRmax achieved  $96.8 \pm 4,8\%$  of theoretical maximal HR.

### 219 *Constant-power tests.*

220 During constant-power tests (CPT) set at p $\Delta$ 50 (equal to  $328.0 \pm 45.1$  W), the average value  
221 of SCPR was  $94.3 \pm 3.8$  rpm. Exhaustion time recorded at SCPR was significantly longer than  
222 at + 15% SCPR ( $465.1 \pm 138.6$  vs  $303.0 \pm 42.5$  s, respectively;  $P < 0.05$ ).

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

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

234 No relationship was reported between the variation of time constant of the primary  $\dot{V}O_2$   
235 component (i.e.  $\tau_1$ ) and the decrease of exhaustion time in CPT at + 15% SCPR ( $r = 0.17$ ;  $P >$   
236  $0.05$ ). Finally, the decrease of exhaustion time ( $-31.1 \pm 15.7\%$ ) was significantly related to  
237 changes of  $A_1'$  ( $17.0 \pm 29.6\%$ ;  $r = -0.87$ ;  $P < 0.02$ ) and end- $\dot{V}O_2$  ( $16.7 \pm 21.4\%$ ;  $r = -0.87$ ;  $P <$   
238  $0.02$ ) computed during the CPT set at + 15% SCPR (Figure 2).

## 239 **Discussion**

240 The aim of this study was to assess the endurance time and parameters of oxygen  
241 consumption kinetics during heavy constant-power test under two different pedal rate  
242 conditions (spontaneously chosen pedal rate: SCPR vs + 15% SCPR). As hypothesised, the  
243 endurance time decreased in CPT cycled at + 15% SCPR with no change both on  $\dot{V}O_2$  fast  
244 and slow components. No relationship was reported between the variation of time constant of  
245 the primary  $\dot{V}O_2$  component (i.e.  $\tau_1$ ) and the decrease of exhaustion time in CPT at + 15%  
246 SCPR that was inconsistency with hypothesis. However, the decrease of performance in CPT  
247 at + 15% SCPR was related to changes of amplitude of fast  $\dot{V}O_2$  component and global  $\dot{V}O_2$   
248 response.

249 To make a valid description of  $\dot{V}O_2$  kinetics during heavy exercise for all subjects, a  
250 normalization of the exercise intensity with reference to both  $VT_2$  and  $\dot{V}O_{2max}$  was chosen  
251 (i.e., we used the “ $\Delta$ ” concept; [29]). This approach seems to be preferable to normalize the  
252 exercise intensity by  $\dot{V}O_{2max}$  alone, because the latter can lead to differences in metabolic

253 and perceptual stress, depending on the proximity of the exercise intensity to the  $VT_2$  [16].  
254 The mean  $\dot{V}O_2$ max estimated during the graded test was in accordance with the values  
255 determined in subjects who are specifically trained in cycling [6, 8, 9]. Nevertheless, the  
256 anaerobic threshold solved by ventilatory analysis (i.e.  $VT_2$ ) occurred at a higher percentage  
257 of  $\dot{V}O_2$ max. Thus, the power output at  $\Delta 50$  represented a higher fraction of maximal aerobic  
258 power (MAP) than previously computed in cyclists [8] or in untrained subjects [2, 10]. In the  
259 present study, cyclists were able to maintain  $p\Delta 50$  (corresponding to  $93.2 \pm 3.7\%$  MAP)  
260 during  $7 \text{ min } 45 \text{ s} \pm 2 \text{ min } 19 \text{ s}$  at SCPR. In triathletes, Billat et al. [8, 9] reported exhaustion  
261 time equating to  $10 \text{ min } 37 \text{ s} \pm 4 \text{ min } 11 \text{ s}$  and  $13 \text{ min } 32 \text{ s} \pm 4 \text{ min } 52 \text{ s}$  during exercise  
262 cycled respectively at 90% MAP and  $p\Delta 50$  (corresponding to  $86.3 \pm 1.9\%$  MAP). Thus,  
263 considering the hyperbolic relationship between relative power output and exhaustion time  
264 [21], the present results are in agreement with these previous studies. Many authors (Takaishi  
265 et al., 1998; Ericson et al., 1986) have shown that cycling training have a significant effect on  
266 the pedal skill and legcoordination. Hence, experienced cyclists have been chosen in this  
267 study in order to limited the probable effect of pedal skill on the exercise tolerance in supra-  
268 SCPR condition. Moreover, Takaishi et al. (1998) suggested that pedalling skills influence the  
269 preferred cadence selection up to high pedal rate (80-90 rpm). Supported by the assumptions  
270 of Takaishi et al. (1998), the average SCPR value reported in the present study ( $94.1 \pm 4.1$   
271 rpm) confirmed the subject's cycling experience.

272 Many authors (McNaughton and Thomas, 1996; Hill et al., 1995; Carnevale and Gaesser,  
273 1991) have shown in inexperienced cyclists that high pedal rates (90, 100 and 110 rpm)  
274 compromise endurance performance compared to lower pedal rates (50 and 60 rpm). In the  
275 present study, the increase of 15% of SCPR ( $94.1 \pm 4.1$  vs  $108.3 \pm 4.7$  rpm) induced a  
276 significant decrease in exhaustion time of cycling exercise performed at  $p\Delta 50$  ( $31.1 \pm 15.7\%$ ).  
277 McNaughton and Thomas [20] reported no significant difference on power asymptote of the

278 hyperbolic power-duration relationship between the two high pedal rate conditions (90 and  
279 110 rpm) that is not in accordance with the present results. Nevertheless, pedal rate values of  
280 90 rpm or 110 rpm could influence similarly the power-duration relationship parameters in  
281 inexperienced cyclists who adopt generally low SCPR values. Hill et al. (1995) reported no  
282 significant difference on the parameters of power-duration relationship between the lower  
283 pedal rate (60 rpm) and preferred pedal rate (from 83 to 89 rpm) in recreational active  
284 subjects. Similarly, Billat et al. [8] reported no significant difference on exhaustion time  
285 during tests cycled at SCPR and  $-10\%$  SCPR ( $82.5 \pm 10.0$  vs  $73.4 \pm 8.9$  rpm) in triathletes.  
286 From all these data, we can concluded that pedal rate at SCPR or slightly slower make it  
287 possible to optimise the endurance time and that an increase of pedal rate over SCPR leads to  
288 a decrease of cycling exercise tolerance.

289 The majority of time-based parameters of the  $\dot{V}O_2$  kinetics fitted from the regression is in  
290 accordance with those computed in active or trained subjects during heavy exercise (Carter et  
291 al., 2000; Barstow et al., 1996; 1993). However, it was surprising to notice that the adjustment  
292 of primary component was slow (i.e. high  $\tau_1$  value) in this group of trained cyclists. Indeed,  
293 some studies have shown a faster  $\dot{V}O_2$  on-kinetic adjustment in individuals with higher  
294  $\dot{V}O_2$  max values and after endurance training program (Chilibeck et al. [11] and Phillips et al.  
295 [22]). In the present study, there was no recovery between warm-up cycled at  $VT_1$  and  
296 exercise performed at  $p\Delta 50$  increasing the  $\dot{V}O_2$  value at the onset of CPT ( $2300 \text{ ml}\cdot\text{min}^{-1}$ ). In  
297 previous studies (Carter et al., 2000; Barstow et al., 1996; 1993), the constant-load exercise  
298 take place after a period of rest or unloaded cycling and the  $\dot{V}O_2$  baseline was in a range from  
299 400 to  $1000 \text{ ml}\cdot\text{min}^{-1}$ . Thus, it could be put forward that a lower difference between  $\dot{V}O_2$   
300 baseline and primary  $\dot{V}O_2$  steady state could induce a slow down of  $\dot{V}O_2$  adjustment in the  
301 early minutes of heavy exercise.

302 As hypothesised, no significant difference was observed in amplitudes (i.e.; in  $A_0'$ ,  $A_1'$ , and  
303  $A_2'$ ) or in time-based parameters (i.e.,  $TD_1$ ,  $TD_2$ ,  $\tau_0$ ,  $\tau_1$ ,  $\tau_2$ ) between the two pedal rate  
304 conditions. In a previous study, Barstow et al. [2] have shown that changing pedal rate, from  
305 45 to 90 rpm, does not alter the overall characteristics of  $\dot{V}O_2$  kinetic. Moreover, Billat et al.  
306 [8] have shown that decrease of 10% SCPR have no influence on the difference in  $\dot{V}O_2$   
307 between 3 and 6-min of heavy exercise. From the present results and those of previous  
308 studies, it was reasonable to conclude that a variation of  $\pm 15\%$  of SCPR in experienced  
309 cyclists has any significant effect on the  $\dot{V}O_2$  kinetics.

310 No significant difference was reported in end-values of  $\dot{V}O_2$ , HR and blood lactate  
311 concentration, except for end- $\dot{V}_E$  that is in accordance with the results of Chavarren and  
312 Calbet (1999). The larger “drift” of  $\dot{V}_E$  during supra-SCPR conditions can be related to the  
313 mechanism of respiratory control from muscular input (Duranti et al., 1991). Indeed, an  
314 increase of pedal rate corresponds to an increase in the muscle activation-relaxation rate and  
315 in the muscle shortening velocity. Takaishi et al. (1996; 1994) have shown that SCPR was  
316 closely related to the pedal rate minimizing the neuromuscular fatigue in working muscles and  
317 Beelen and Sargeant (1993) have found a 14% greater reduction in maximal peak power after  
318 a prior 6-min exercise at 120 rpm compared to 60 rpm. Thus, an increase of SCPR decreasing  
319 the exercise tolerance could be linked to neural and muscular factors such as a relatively  
320 greater contribution of fatigue-sensitive fibres, an increase of firing rate and/or progressive  
321 recruitment of additional motor units . Moreover, no relationship was reported between the  
322 variation of time constant of the primary  $\dot{V}O_2$  component (i.e.  $\tau_1$ ) and the decrease of  
323 exhaustion time in CPT at + 15% SCPR that was inconsistency with hypothesis. From this  
324 result, it seems reasonable to suggest that the difference of exercise tolerance was not in

325 relation to the oxygen delivery to the active muscles in the first minutes of CPT which  
326 highlights the unclear relation between the  $\dot{V}O_2$  kinetics and the fatigue process.  
327 Nevertheless, the decrease of exhaustion time was correlated with variations of amplitude  
328 both of fast  $\dot{V}O_2$  component and global  $\dot{V}O_2$  response. Higher the increase of amplitude of  
329 the primary  $\dot{V}O_2$  component and global  $\dot{V}O_2$  response, higher the decrease of exhaustion time  
330 in CPT at + 15% SCPR. These changes of  $\dot{V}O_2$  amplitude between the two pedal rate  
331 conditions could explain the inter-individual variations in the decrease of exhaustion time  
332 (from 15 to 60%). According to previous study (Goldnick et al., 1974; Vollestad and Blom,  
333 1985), the work intensity in the present study corresponds to an intensity exercise at which  
334 fast twitch (FT) fibres are recruited in addition to the slow twitch (ST) fibres. This fibre type  
335 is known to be less efficient energetically than ST fibres (Wills and Jackman, 1994).  
336 Moreover, Sargeant (1994) suggested that FT fibres may be recruited preferentially for the  
337 same external power output when contraction velocity is high. Thus, it could be speculated  
338 that cyclists who recruit a greater FT fibres in the early minutes of CPT at + 15% SCPR  
339 present a greater amplitude of the fast  $\dot{V}O_2$  component and  $\dot{V}O_2$  response leading to a  
340 decrease of exercise tolerance.

#### 341 Conclusion

342 The SCPR makes it possible cyclists to continue for longer at heavy exercise, in comparison  
343 to a 15% increase of SCPR. This decrease of CPT performance observed at + 15% SCPR was  
344 not associated with change in  $\dot{V}O_2$  kinetics and could be related to a greater activity of  
345 working muscles, neuromuscular fatigue and FT fibres recruitment. However, higher the  
346 increase of amplitude of the primary  $\dot{V}O_2$  component and global  $\dot{V}O_2$  response, higher the  
347 decrease of exhaustion time in CPT at + 15% SCPR. In practical terms, these results suggest  
348 that it is better for competitive cyclists to adopt pedal rate close to these ones frequently used



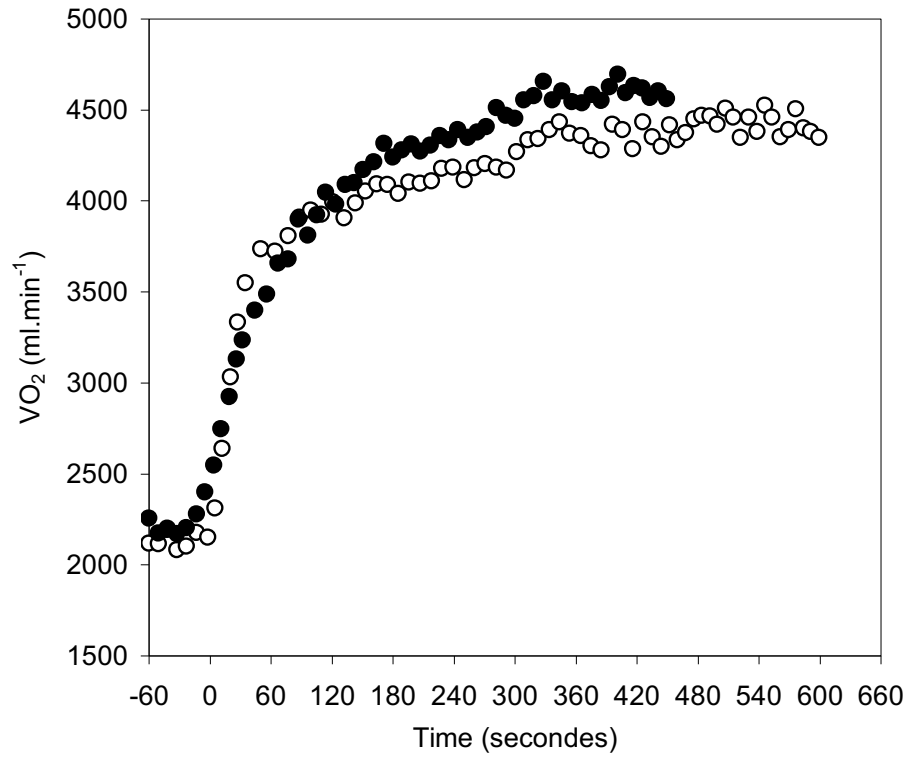
349 during training in order to optimise their road race performance, essentially during high  
350 intensity phases. However, using limited crank gear, cyclists were obliged to adopt pedal rate  
351 greater than 100 rpm during phases where the speed was greater to 55 km.h<sup>-1</sup> (back wind,  
352 descent, finish of flat stage). Thus, the capacity to maintain the aerobic demand regardless of  
353 the increase of pedal rate could be assumed like factor associated to the performance in road  
354 race.

355

356 **Table and Figures**

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

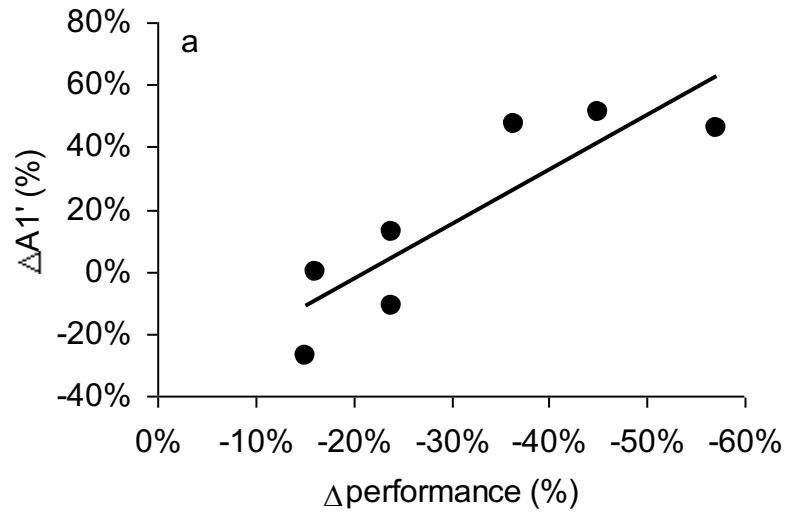
|     | Variable                                | SCPR           | + 15% SCPR     |
|-----|---|----------------|----------------|
| 361 | $\dot{V}O_2(w)$ (ml.min <sup>-1</sup> ) | 2338.3 ± 181.5 | 2282.3 ± 194.7 |
|     | $A_0'$ (ml.min <sup>-1</sup> )          | 364.3 ± 121.0  | 405.1 ± 171.6  |
|     | $\tau_0$ (s)                            | 14.8 ± 4.8     | 21.2 ± 8.9     |
| 362 | TD <sub>1</sub> (s)                     | 25.1 ± 7.5     | 18.3 ± 8.5     |
|     | $A_1'$ (ml.min <sup>-1</sup> )          | 1227.8 ± 303.5 | 1458.4 ± 426.1 |
|     | $\tau_1$ (s)                            | 30.0 ± 13.5    | 44.6 ± 16.3    |
|     | TD <sub>2</sub> (s)                     | 255.8 ± 41.9   | 232.7 ± 26.4   |
|     | $A_2'$ (ml.min <sup>-1</sup> )          | 345.8 ± 130.9  | 384.8 ± 204.4  |
|     | $\tau_2$ (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 <sup>-1</sup> ) | 1573.6 ± 291.1 | 1843.2 ± 549.6 |



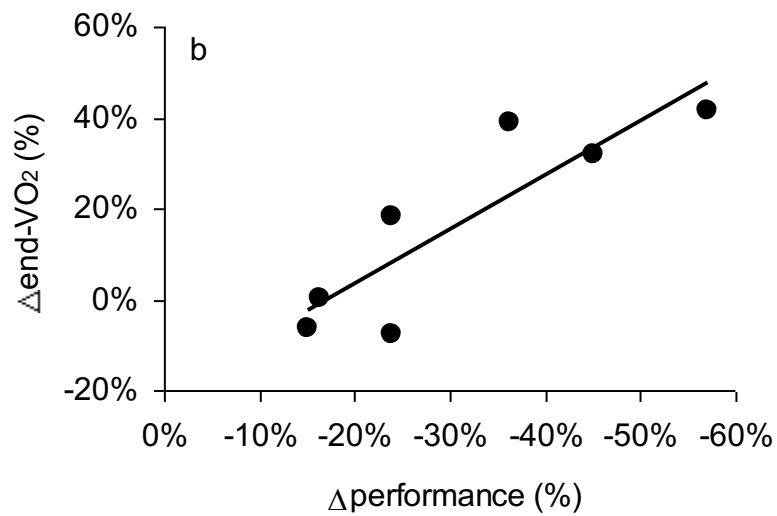
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364 Figure 1. Example of oxygen uptake ( $\dot{V}O_2$ ) response in 1 subject during a constant-power test  
 365 (p $\Delta$ 50) at spontaneously chosen pedal rate (SCPR, ○) and + 15% SCPR (●).

366



367



368

369 Figure 2. Relationship between the decrease of exhaustion time (i.e.  $\Delta\text{performance}$ ,  $-31.1 \pm$   
 370  $15.7\%$ ) and a) the variation of amplitude of  $\dot{V}O_2$  fast component (i.e.  $\Delta A_1'$ ,  $17.0 \pm 29.6\%$ ;  $r =$   
 371  $-0.87$ ;  $P < 0.02$ ) b) the variation of amplitude of the global  $\dot{V}O_2$  response (i.e.  $\Delta\text{end-}\dot{V}O_2$ ,  $16.7$   
 372  $\pm 21.4\%$ ;  $r = -0.87$ ;  $P < 0.02$ ) computed between CPT cycled at  $+15\%$  SCPR and at SCPR.

373