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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 ± 138.6 vs 303.0 ± 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⁻¹. 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 τ_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 ± 4.2 yr; height 1.77 ± 0.03 m; body mass
88 72.3 ± 3.6 kg; weekly hourly volume of training 12.1 ± 2.6 h.wk⁻¹) 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 (VT₁ and VT₂)
- 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 VT₂ and $\dot{V}O_2\max$ (p Δ 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 $34 \text{ km}\cdot\text{h}^{-1}$ 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 $34 \text{ km}\cdot\text{h}^{-1}$ to $5 \text{ km}\cdot\text{h}^{-1}$. 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 $\dot{V}O_2\text{max}$, 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 $25 \text{ W}\cdot\text{min}^{-1}$. To ensure that $\dot{V}O_2\text{max}$ 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 K4b², 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 K4b² 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 K4b² 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 O₂ ($\dot{V}_E / \dot{V}O_2$) and CO₂ ($\dot{V}_E / \dot{V}CO_2$)
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⁻¹.kg⁻¹ with
141 the increase in exercise intensity. The single indices used individually in order to determine
142 VT₁ and VT₂ for each subjects were VE, VCO₂, VE/ $\dot{V}O_2$ and VE/ VCO₂. The following
143 criteria were employed in selecting the thresholds: According to Wasserman et al. (1973),
144 VT₁ was defined as the minimal load at which VE/ $\dot{V}O_2$ exhibited a systematic increase
145 without a concomitant increase in VE/VCO₂. VT₂ corresponded to the minimal work rate at
146 which the increase in VE/ $\dot{V}O_2$ went with an increase of VE/ VCO₂ (Wasserman and McIlroy,
147 1964). Beaver et al. (1986) defined VT₁ and VT₂ as the work rates associated with a first and
148 a second non-linear increase of VE and VCO₂. According to the criteria outlined above, three
149 independent investigators blindly reviewed the plots of each index and made individual
150 determinations of VT₁ and VT₂. Extrapolation of the relationship between $\dot{V}O_2$ and power
151 output for exercise at sub-VT₂ 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[®] 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 Δ 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 (± 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 VT₁ 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 VT₁; A₀, A₁, A₂ are
 188 the asymptotic amplitudes for the exponential terms; τ_0 , τ_1 , τ_2 are the time constants; TD₁,
 189 TD₂ are the time delays. The phase 1 term was terminated at the start of phase 2 (i.e., at TD₁)
 190 and assigned the value for that time (A₀')

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

192 The amplitude of phase 1 (A₀') and the amplitude of phase 2 (A₁) were added to calculate the
 193 amplitude at the end of the primary component (A₁'). The slow component at the end of
 194 exercise (A₂') 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 A₁' and
 196 A₂' 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 Levenne 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 ± 52.9 W and mean $\dot{V}O_2$ max value was 4419.0 ± 692.6 ml.min⁻¹
214 ¹; corresponding to 61.2 ± 9.2 ml.min⁻¹.kg⁻¹. The VT₁ and VT₂ 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 ± 9.8 beats.min⁻¹, 4785.9 ± 752.1 ml.min⁻¹, 189.9 ± 20.4 l.min⁻¹ and 1.18 ± 0.03 ,
217 respectively. Mean blood lactate concentration value was 13.7 ± 3.4 mmol.l⁻¹ 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 Δ 50 (equal to 328.0 ± 45.1 W), the average value
221 of SCPR was 94.3 ± 3.8 rpm. Exhaustion time recorded at SCPR was significantly longer than
222 at + 15% SCPR (465.1 ± 138.6 vs 303.0 ± 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 ± 552.6 vs 4125.5
225 ± 702.8 ml.min⁻¹, respectively), end-HR (175.3 ± 3.7 vs 179.8 ± 4.8 beat.min⁻¹, respectively)
226 and blood lactate concentration (12.9 ± 5.2 vs 13.2 ± 3.6 mmol.l⁻¹, respectively), except for
227 \dot{V}_E where the mean end-value of CPT at + 15% SCPR was significantly higher (136.1 ± 13.9
228 vs 165.3 ± 25.6 l.min⁻¹; $P < 0.01$).

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. τ_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. τ_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 “ Δ ” 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 ± 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 ± 4.1 vs 108.3 ± 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 ± 10.0 vs 73.4 ± 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 τ_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 , τ_0 , τ_1 , τ_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. τ_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

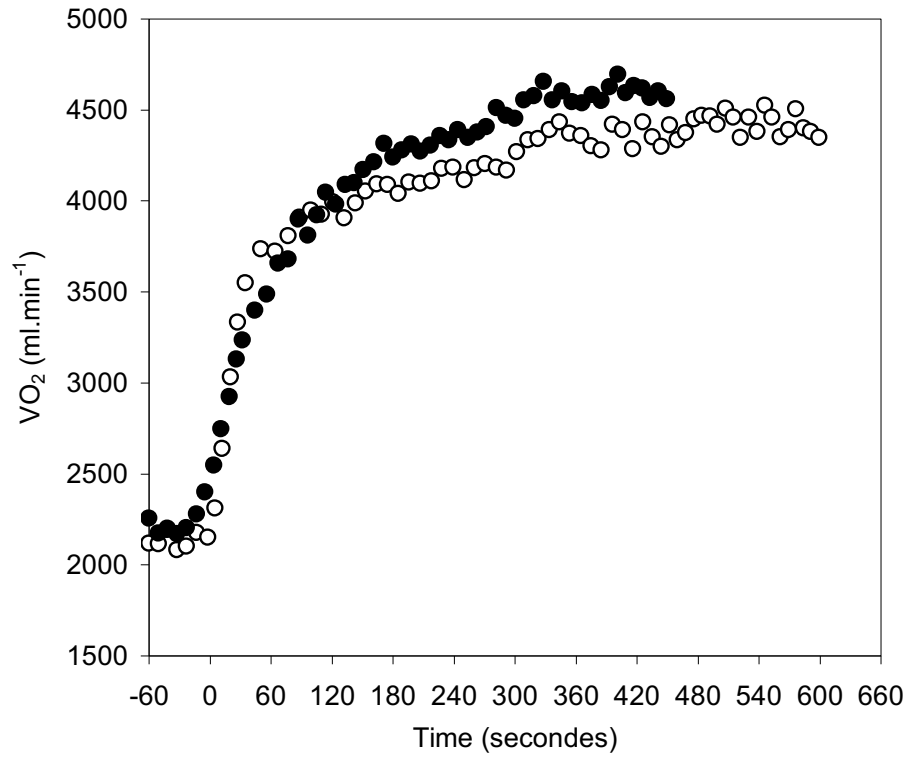
349 during training in order to optimise their road race performance, essentially during high
350 intensity phases. However, using limited crank gear, cyclists were obliged to adopt pedal rate
351 greater than 100 rpm during phases where the speed was greater to 55 km.h⁻¹ (back wind,
352 descent, finish 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. A₂' (A₂'/EE $\dot{V}O_2$) relative contribution of the slow component
 360 to a net increase in $\dot{V}O_2$ at end exercise.

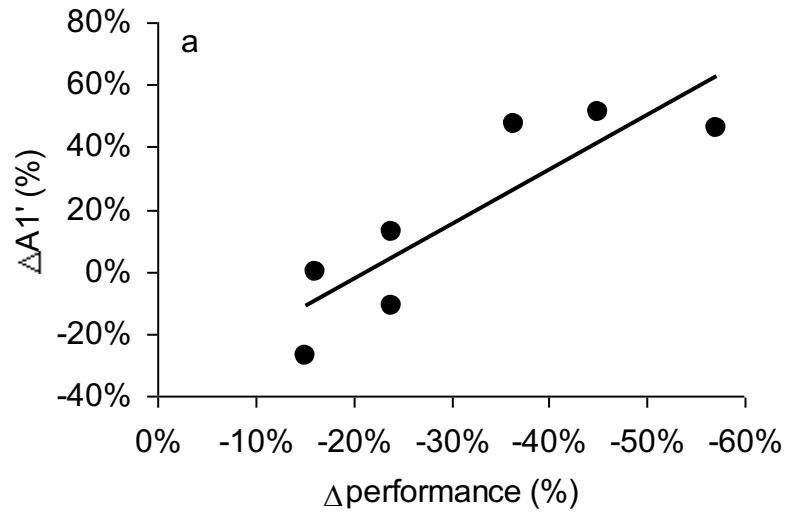
	Variable	SCPR	+ 15% SCPR
361	$\dot{V}O_2(w)$ (ml.min ⁻¹)	2338.3 ± 181.5	2282.3 ± 194.7
	A ₀ ' (ml.min ⁻¹)	364.3 ± 121.0	405.1 ± 171.6
	τ ₀ (s)	14.8 ± 4.8	21.2 ± 8.9
362	TD ₁ (s)	25.1 ± 7.5	18.3 ± 8.5
	A ₁ ' (ml.min ⁻¹)	1227.8 ± 303.5	1458.4 ± 426.1
	τ ₁ (s)	30.0 ± 13.5	44.6 ± 16.3
	TD ₂ (s)	255.8 ± 41.9	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



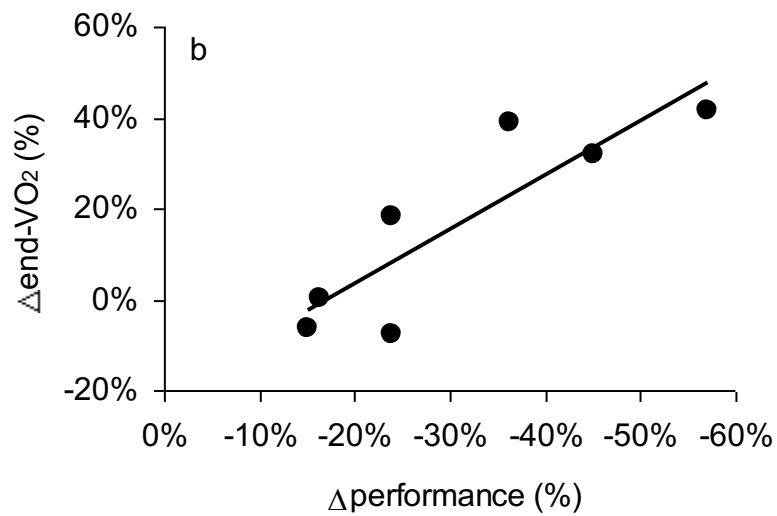
363

364 Figure 1. Example of oxygen uptake ($\dot{V}O_2$) response in 1 subject during a constant-power test
 365 (p Δ 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