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SHORT COMMUNICATION

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Effect of pedalling rates on physiological response during endurance cycling

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Abstract This study was undertaken to examine the effect of different pedalling cadences upon various physiological responses during endurance cycling exercise. Eight well-trained triathletes cycled three times for 30 min each at an intensity corresponding to 80% of their maximal aerobic power output. The first test was performed at a freely chosen cadence (FCC); two others at FCC–20% and FCC+20%, which corresponded approximately to the range of cadences habitually used by road racing cyclists. The mean (SD) FCC, FCC–20% and FCC+20% were equal to 86 (4), 69 (3) and 103 (5) rpm respectively. Heart rate (HR), oxygen uptake ($\dot{V}O_2$), minute ventilation ($\dot{V}_E$) and respiratory exchange ratio (R) were analysed during three periods: between the 4th and 5th, 14th and 15th, and 29th and 30th min. A significant effect of time ($P<0.01$) was found at the three cadences for HR, $\dot{V}O_2$. The $\dot{V}_E$ and R were significantly ($P<0.05$) greater at FCC+20% compared to FCC–20% at the 5th and 15th min but not at the 30th min. Nevertheless, no significant effect of cadence was observed in HR and $\dot{V}O_2$. These results suggest that, during high intensity exercise such as that encountered during a time-trial race, well-trained triathletes can easily adapt to the changes in cadence allowed by the classical gear ratios used in practice.

Keywords Cadence · Oxygen uptake · Triathletes · Fatigue

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Introduction

During training or racing, experienced cyclists or triathletes usually select a relative high pedalling cadence, close to 80–90 rpm. The reasons behind the choice of such a cadence are still controversial and are certainly multi-factorial. Several assumptions relating to neuromuscular, biomechanical or physiological parameters have previously been proposed.

The concept of a most economical cadence is generally supported by experiments where cadences have been varied from the lowest to the highest rates and a parabolic oxygen uptake ($\dot{V}O_2$)-cadence relationship has been obtained. Nevertheless in reality, extreme cadences such as 50 or 110 rpm are very rarely used by road cyclists or triathletes. Simple observations have shown for example that on a flat road at 40 km·h^{-1} cadences ranged from 67 rpm with a 53:11 gear ratio (GR) to 103 rpm with a 53:17 GR. During an up-hill climb at 20 km·h^{-1}, cadences ranged from 70 rpm with a 39:17 GR to 103 rpm with a 39:25 GR. Thus, the range of cadences adopted by cyclists using these common GR may vary from 70 to 100 rpm, which corresponds to approximately 85 rpm ± 20%.

The effect of exercise duration upon cycling cadence has not been well studied. The freely chosen cadence (FCC) has seemed to be relatively stable during high intensity cycling exercise of 30 min duration (Brisswalter et al. 2000) but the FCC was found to decrease during 2 h of cycling at sub-maximal intensity (Lepers et al. 2000). In a non fatiguing situation, the FCC is known to be higher than the most economical cadence. However, a shift in the energetically optimal rate during exercise towards the FCC has recently been reported by Brisswalter et al. (2000). These observations raise a question concerning the choice of any particular GR by road racing cyclists and thus of a pedalling rate and the physiological consequences of this choice for exercise duration.

Therefore, the purpose of this study was to investigate whether the use of cadences 20% lower or higher than the freely chosen one during high intensity endurance exercise induced different changes in metabolic parameters as fatigue occurred.

Methods

Subjects

Eight well-trained male triathletes volunteered to participate in this study. The physical characteristics of the subjects are given in Table 1. They were informed in detail of the experiment and gave written consent prior to all tests.

Experiment procedures

Each subject completed four tests during a 3 week period. Each session was separated by at least 72 h. All experiments were conducted using an electromagnetically braked cycle ergometer (Type Excalibur, Lode, Groningen, The Netherlands) of which the seat and handlebars are fully adjustable to the subject's dimensions. The ergometer was also equipped with racing pedals, and toe clips allowing the subjects to wear cycling shoes. The first session was used to determine the maximal oxygen uptake ($\dot{V}O_{2max}$) of the subjects. The $\dot{V}O_{2max}$ test began with a warm-up at 100 W lasting 6 min, after which the power output was increased by 25 W every 2 min until the subjects were exhausted. The three other sessions were composed of a 10 min warm-up ride followed by a 30 min submaximal test at 80% of the highest power sustained for 2 min (P_{max}). The first of these three sessions was performed at the FCC which corresponded to the cadence that the subjects spontaneously adopted within the first 5 min. During the last 25 min of this test, subjects were asked to maintain a similar cadence. For the two other tests, subjects rode in a random order at FCC–20% or FCC + 20%. The heart rate (HR) was monitored continuously, and gas exchanges were collected at three periods: between the 4th–5th (period 1), the 14th–15th (period 2), and 29th–30th (period 3) min. The HR, $\dot{V}O_2$, minute ventilation ($\dot{V}_E$) and respiratory exchange ratio (R) for these three periods were analysed.

Statistical analysis

A two-way ANOVA (time×cadence) was performed using HR, $\dot{V}O_2$, $\dot{V}_E$ and R as dependent variables. When a significance of $P<0$ 0.05 was obtained using the ANOVA, Tukey post-hoc multiple comparisons were made to determine differences either among pedal rates or among periods.

Results

Mean (SD) FCC were 86 (4) rpm, therefore FCC–20% and FCC + 20% corresponded to 69 (3) and 103 (5) rpm, respectively (Table 1).

A significant time effect ($P<0.01$) was found at the three cadences in HR, $\dot{V}_E$ (Table 2). The rise in $\dot{V}O_2$ between the 5th and the 30th min corresponded to 11.0 (7.4)%, 10.3 (6.9)% and 9.9 (3.7)% at FCC–20%, FCC and FCC + 20%, respectively. Between the 5th and the 30th min $\dot{V}_E$ increased by 35.4 (17.4)%, 28.7 (10.9)% and 21.2 (5.2)% at FCC–20%, FCC and FCC + 20%, respectively. No significant differences appeared among the three cadences.

A significant effect of cadence was found in $\dot{V}_E$ and R in the first part of the exercise (Table 2). Post-hoc tests showed that $\dot{V}_E$ was significantly greater at FCC + 20% compared to FCC–20% at the 5th and 15th min but not at the 30th min. Similarly, R was significantly greater at FCC + 20% in comparison to FCC–20% and FCC at the 5th and 15th min but not at the 30th min. In $\dot{V}O_2$ and HR, no significant effect of cadence was observed.

Discussion

The main finding of this study was the absence of significant differences in physiological parameters among the three different pedalling rates (FCC, FCC–20% and FCC + 20%) despite a significant effect of exercise duration.

Increases in HR, $\dot{V}O_2$ and $\dot{V}_E$ at the end of 30 min of cycling at 80% of P_{max} observed in this study were similar to previous observations made in well-trained triathletes (Brisswalter et al. 2000). Several hypotheses have been proposed to explain the so-called *drift* in $\dot{V}O_2$ at high power outputs, such as an additional oxygen cost of higher rates of $\dot{V}_E$, increasing muscle and body temperatures and/or changes in muscle activity patterns and/or in fibre type recruitment (for a review, see Whipp 1994). Barstow et al. (1996) examined the physiological responses of subjects to intense exercise (half way between the estimated blood lactate threshold and $\dot{V}O_{2max}$) lasting 8 min for a range of pedalling frequencies between 45 and 90 rpm. Their results showed that the slow component of $\dot{V}O_2$ was significantly affected by fibre type distribution but not by pedalling rates. Similarly, Billat et al. (1999) have shown that for high intensity exercise (95% $\dot{V}O_{2max}$), a pedalling rate 10% lower than the freely chosen one induced the same $\dot{V}O_2$ slow component.

In the present study, in the range of pedalling rates used habitually by road cyclists (from 70 to 100 rpm), no significant effects of cadence were found upon the rises in $\dot{V}O_2$ during 30 min of endurance exercise. Also, our data are quite different to those of Brisswalter et al. (2000) who

Table 1 Characteristics of subjects and cadences adopted [mean (SD)]. *FCC* Freely chosen cadence, P_{max} maximal aerobic power, $\dot{V}O_{2max}$ maximal oxygen uptake

Age (years)	Mass (kg)	Height (cm)	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	P_{max} (W)	FCC (rpm)	FCC–20% (rpm)	FCC + 20% (rpm)
28 (3)	74 (5)	183 (5)	64.1 (4.5)	384 (31)	86 (4)	69 (3)	103 (5)

Table 2 Mean (SD) oxygen uptake ($\dot{V}O_2$), ventilation ($\dot{V}_E$), heart rate [percentage maximal heart rate, (%HR_{max})], and respiratory exchange ratio (*R*) associated with the three cycling cadences examined. *FCC, FCC–20%, FCC+20%* Freely chosen cadence

	$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})			$\dot{V}_E$ (l·min^{-1})			HR (% HR_{max})			*R*		
Min	5	15	30	5	15	30	5	15	30	5	15	30
FCC–20% Time effect	55.0 (4.7)	56.2 (5.5)	61.2 (7.5)[a,b]	102.2 (13.4)	111.5 (14.6)[a]	138.8 (26.8)[a,b]	84.6 (1.9)	89.5 (2.8)[a]	93.3 (3.5)[a,b]	0.95 (0.07)	0.96 (0.05)	0.93 (0.04)[b]
FCC Time effect	57.6 (2.8)	57.3 (2.3)	63.4 (3.9)[a,b]	110.3 (12.5)	115.4 (15.4)	141.6 (24.8)[a,b]	84.3 (2.9)	89.6 (2.7)[a]	92.9 (2.2)[a,b]	0.96 (0.05)	0.96 (0.03)	0.96 (0.05)
FFC+20% Time effect	55.4 (1.9)	58.0 (2.8)[a]	60.7 (2.8)[a,b]	117.7 (15.2)[c]	131.0 (18.2)[a,c]	140.5 (19.1)[a,b]	86.4 (2.6)	90.7 (2.3)[a]	93.8 (2.1)[a,b]	1.02 (0.04)[c,d]	1.01 (0.04)[c,d]	0.98 (0.05)[a,b]

Time effect:
[a]Represents significant differences with respect to the 5th min
[b]Represents significant differences with respect to the 15th min
Cadence effect:
[c]Represents significant differences between FCC+20% and FCC–20% at the same time
[d]Represents significant differences between FCC+20% and FCC at the same time

examined cadences between 50 and 110 rpm. However, such a discrepancy could be explained by the relatively small range of cadences used in the present study. The only difference observed between cadences in this study occurred in $\dot{V}_E$ and *R* in the first part of the exercise. High pedalling rates induced greater $\dot{V}_E$ at the 5th and 15th min of exercise, which were associated with higher *R* values (>1.0). These data suggest a higher contribution of anaerobic metabolism to power production in the first 15 min at FCC+20%. Moreover, they corroborate those of Zoladz et al. (2000) who showed that beyond 100 rpm there is a decrease in external power that can be delivered at a given $\dot{V}O_2$ with an associated earlier onset of metabolic acidosis. Importantly, this could be disadvantageous for maintained high intensity exercise. However, in the present study, such a specificity at the highest pedalling rates did not affect the continuation of the exercise since similar values of $\dot{V}_E$ and *R* were found at the end of the exercise at all three cadences.

The mean cadence spontaneously adopted by the triathletes in this study [86 (4) rpm] corroborated previous results obtained from trained cyclists or triathletes (Brisswalter et al. 2000; Lepers et al. 2000). Although it has been shown that pedalling rates could affect:

1. The maximal power during a 10 s sprint (Zoladz et al. 2000)
2. The power generating capabilities following high intensity cycling exercise close to 90% $\dot{V}O_{2max}$ (Beelen and Sargeant 1993)

the reasons behind the choice of a particular cadence during endurance cycling and the corresponding GR by cyclists remain unclear.

We recently showed that cycling exercise at different pedalling rates induced changes in the neural and contractile properties of the quadriceps muscle but no significant effects of cadence were found when considering a range of FCC±20% (Lepers et al., in press). Moreover, in the present study the FCC did not appear to be more energetically optimal than FCC–20% or FCC+20%, either at the beginning or at the end of the exercise. Brisswalter et al. (2000) have recently shown that the theoretical energetically optimal pedalling rate, corresponding to the lowest point of the parabolic $\dot{V}O_2$–cadence relationship, shifted progressively over the duration of exercise towards a higher pedalling rate (from 70 to 86 rpm) which was closer to the freely chosen one. Therefore, a minimisation of energy cost seems not to be a relevant parameter for the choice of cadence, at least in a non fatigued state. Actually, the choice of cadence adopted by cyclists during endurance exercise seems dependent upon factors other than the metabolic cost. Biomechanical and neuromuscular hypotheses have already been proposed to explain the choice of the pedalling rate during short-term high intensity exercise. However, such interesting hypotheses need to be explored during prolonged exercise.

In conclusion, the results of the present study showed that, for high intensity endurance exercise corresponding to a time trial race for example, the use of cadences in a range corresponding to the classical GR induced similar physiological effects. These data suggest that well-trained triathletes can easily adapt to the changes in cadence used habitually during racing. Further investigations are necessary to target the mechanisms involved in the choice of pedalling rate during prolonged cycling.

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