Preferred pedalling cadence in professional cycling

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ABSTRACT

LUCÍA, A., J. HOYOS, and J. L. CHICHARRO. Preferred pedalling cadence in professional cycling. *Med. Sci. Sports Exerc.*, Vol. 33, No. 8, 2001, pp. 1361–1366. **Purpose:** The aim of this investigation was to evaluate the preferred cycling cadence of professional riders during competition. **Methods:** We measured the cadence of seven professional cyclists (28 ± 1 yr) during 3-wk road races (Giro d'Italia, Tour de France, and Vuelta a España) involving three main competition requirements: uphill cycling (high mountain passes of ~15 km, or HM); individual time trials of ~50 km on level ground (TT); and flat, long (~190 km) group stages (F). Heart rate (HR) data were also recorded as an indicator of exercise intensity during HM, TT, and F. **Results:** Mean cadence was significantly lower ($P < 0.01$) during HM (71.0 ± 1.4 rpm) than either F and TT (89.3 ± 1.0 and 92.4 ± 1.3 rpm, respectively). HR was similar during HM and TT (157 ± 4 and 158 ± 3 bpm) and in both cases higher ($P < 0.01$) than during F (124 ± 2 bpm). **Conclusion:** During both F and TT, professional riders spontaneously adopt higher cadences (around 90 rpm) than those previously reported in the majority of laboratory studies as being the most economical. In contrast, during HM they seem to adopt a more economical pedalling rate (~70 rpm), possibly as a result of the specific demands of this competition phase. **Key Words:** CYCLISTS, HEART RATE, PEDALLING FREQUENCY

Previous research has shown that the preferred pedalling cadence of trained cyclists during laboratory testing is usually 90–100 rpm (11,25). However, there are scarce data demonstrating that the optimal pedalling rate (i.e., that eliciting the lowest oxygen uptake, lactate, or ventilatory threshold) is close to the aforementioned preferred cadence (13). Indeed, the findings of most studies conducted on untrained and/or trained individuals suggest that during constant-power laboratory tests pedalling at low rates (~50–60 rpm) results in lower oxygen uptake ($\dot{V}O_2$), lactate, ventilation ($\dot{V}E$), heart rate (HR), blood/muscle lactate, or ratings of perceived exertion (RPE) than pedalling at 90–100 rpm (3–7,11,15,20). Furthermore, the lowest cadences (~50–60 rpm) have been reported to be the most efficient (3,5,7,9,11). Nevertheless, some authors have shown that the most economical cadence increases linearly with power output (3,5). The latter phenomenon could partly explain the fact that trained cyclists (i.e., those accustomed to generating high power outputs) tend to spontaneously adopt higher pedalling rates than nontrained individuals. Experienced cyclists may select high pedalling cadences to minimize local muscle stress (23). Both the factors lower RPE (15) and improved hemodynamics (10) could also contribute to the subjective choice of higher cadences by trained cyclists, even though the metabolic cost is actually greater.

Most studies designed to explore cycling cadence are, however, limited by the fact that subjects are tested in a laboratory setting (riding a stationary bicycle ergometer in the majority of cases). Constant-power tests performed under laboratory conditions hardly mimic actual cycling (i.e., wind resistance, inertia characteristics, level vs uphill roads, rapid accelerations, and decelerations during a race). Additionally, most of the earlier work on preferred cadence used untrained or well-trained amateur subjects (3–7,9,11,15,20). Consequently, the data from these studies may not be applicable to professional cyclists. Indeed, it is has been well documented that professional cyclists exhibit remarkable physiological characteristics compared with their elite, amateur counterparts, which may explain their superior performance (16,18,19,25). Professional riders, for example, can tolerate high workloads (~400 W or ~90% of $\dot{V}O_{2max}$) for longer periods of time (18,25). Furthermore, professional cyclists must tolerate this type of effort for up to 3 weeks in the sport's major tours (Giro d'Italia, Tour de France, and Vuelta a España). In contrast, races for elite amateurs rarely are longer than 5 days and typically are only single-day events. To the best of our knowledge, no previous study has examined the preferred cadence of professional cyclists during the sport's three major stage races. Hence, the primary purpose of this study was to evaluate the preferred cycling cadence of professional cyclists during the 3-wk road races mentioned above. Specifically, we sought to determine the preferred cadence in the three main competition phases of these stage races. Namely, uphill cycling in the high mountain passes (7.2% mean grade), individual time trials of 40–60 km generally run on flat terrain, and the long, flat stages typically run at high speeds and in large

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groups. A secondary goal was to examine the possible relationship between the preferred cadence in these three disciplines and the exercise intensity, as determined from HR data collected during them.

MATERIAL AND METHODS

Subjects. After approval from the ethical committee of the Complutense University, seven professional road cyclists from a leading world team were selected for this investigation. The subjects signed an informed consent to participate in the experiments. Their mean (±SD) age, height, body mass, and body mass index (BMI) was 28 ± 1 yr, 180.7 ± 1.6 cm, 67.6 ± 2.7 kg, and 20.7 ± 0.6, respectively. A previous physical examination (including ECG and echocardiographic evaluation within the previous months) ensured that each participant was in good health. All are highly competitive in the professional category.

Laboratory testing. Each subject reported to the laboratory during the competition period of the season (in April–May) before participating in one or two of the three main stage-races for professional riders (Giro d'Italia, Tour de France, and Vuelta a España) in order to perform a maximal exercise test. The tests were performed on a bicycle ergometer (Ergometrics 900; Ergo-line; Barcelona, Spain) after a ramp protocol until exhaustion. This type of protocol has been used for the physiological evaluation of professional cyclists in several previous studies conducted in our laboratory (16–19). Starting at 20 W, the workload was increased by 25 W every minute, and pedalling cadence was kept constant at 70–90 rpm. A pedal-frequency meter was used by the subject to maintain this cadence. Each exercise test was terminated either: 1) voluntarily by the subject, 2) when pedalling cadence could not be maintained at 70 rpm (at least), or 3) when established criteria of test termination were met (1). The subjects adopted the conventional (upright sitting) cycling posture throughout the tests. All the tests were performed under similar environmental conditions (21–24°C, 45–55% relative humidity).

During the tests, gas exchange data were collected continuously using an automated breath-by-breath system (V_{max} 29C; SensorMedics; Yorba Linda, CA) to calculate the following variables: $\dot{V}O_2$, $\dot{V}E$, ventilatory equivalents for oxygen and carbon dioxide ($\dot{V}E \cdot VO_2^{-1}$ and $\dot{V}E \cdot CO_2^{-1}$, respectively), respiratory exchange ratio (RER), and end-tidal partial pressure of oxygen ($PETO_2$) and carbon dioxide ($P_{ET}CO_2$). The ventilatory thresholds 1 and 2 (VT_1 and VT_2, respectively) were also identified. VT_1 was determined using the criteria of an increase in both $\dot{V}E \cdot \dot{V}O_2^{-1}$ and end-tidal partial pressure of oxygen ($PETO_2$) with no concomitant increase in $\dot{V}E \cdot \dot{V}CO_2 - 1$ (8). VT2 was determined using the criteria of an increase in both the $\dot{V}E \cdot \dot{V}O_2^{-1}$ and $\dot{V}E \cdot \dot{V}CO_2^{-1}$ and a decrease in $PETCO_2$ (8). VT_1 and VT_2 were detected by two independent observers. If there was disagreement, the opinion of a third investigator was obtained. HR (bpm) was continuously monitored during the tests using a telemeter (Polar Xtrainer Plus; Polar Electro OY; Kempele, Finland).

Data analysis during actual cycling. Each subject finished at least one of the three tour races during the 1999 season. In each daily stage of one of these races, they wore a telemeter (Polar Xtrainer Plus), consisting of a heart rate monitor and a cycle-computer in one single unit. The wireless device measures HR, distance, time, speed, and cadence during performance. The receiver unit placed on the cyclist's wrist continuously records data, using coded transmission, from sensors on the cyclist's chest (HR), wheels (distance and speed), and bicycle frame and pedal cranks (cadence). Recorded data were later analyzed using a computer program (Polar Xtrainer Plus), which permits the selection of specific periods of the race.

We analyzed data (means of 15-s intervals) from each subject during the three major phases of the competition: F (long, flat stage ridden at average speeds greater than 40 $km \cdot h^{-1}$, within a large group of cyclists); TT (individual time trials of 40–60 km on an overall level terrain); and HM (high mountain ascents of 7.2% mean grade ridden at speeds lower than 25 $km \cdot h^{-1}$ either individually or within a small group). When calculating the mean cadence for a selected time period, the computer program automatically excludes those 15-s intervals with no pedalling at all (cadence = 0 rpm).

The specific characteristics of F, TT, and HM are shown in Figure 1. For each of the subjects, we recorded data from two TT, five F, and five HM of either Giro d'Italia, Tour de France, or Vuelta a España (Table 1). During the TT and F, we recorded data throughout the entire stage (from start to finish). During the HM, we specifically selected only those phases corresponding to the ascent of mountain passes classified as *hors* category by race organizations and that are usually assigned to the second part of "typical" stage in the Pyrenees, Alps, or Dolomites (i.e., including 3–5 high mountain ascents and descents with some flat terrain between each pass). This prevented us from obtaining data corresponding to those phases (descents or level terrain) that do not reflect specific uphill performance. We selected the core part (20–40 min duration) of the ascents of the most famous mountain *cols* in the history of professional road cycling. The proportion of level or low upgrade (<4%) terrain in several of these mountain roads is null.

Statistics. Results are expressed as means ± SEM. Once the Kolmogorov-Smirnov test was applied to ensure a Gaussian distribution of the results, mean values of pedalling cadence during F, TT, and HM were compared using a one-way analysis of variance (ANOVA), as were average values of HR and cycling speed. Finally, correlation coefficients between both cycling speed and exercise intensity (HR) on the one hand, and pedalling cadence on the other, were calculated for all the types of terrain and within each of F, TT, and HM. The level of significance was set at 0.05 for all statistical analyses.

RESULTS

The values of the most important physiological variables recorded during the testing sessions are shown in Table 2.

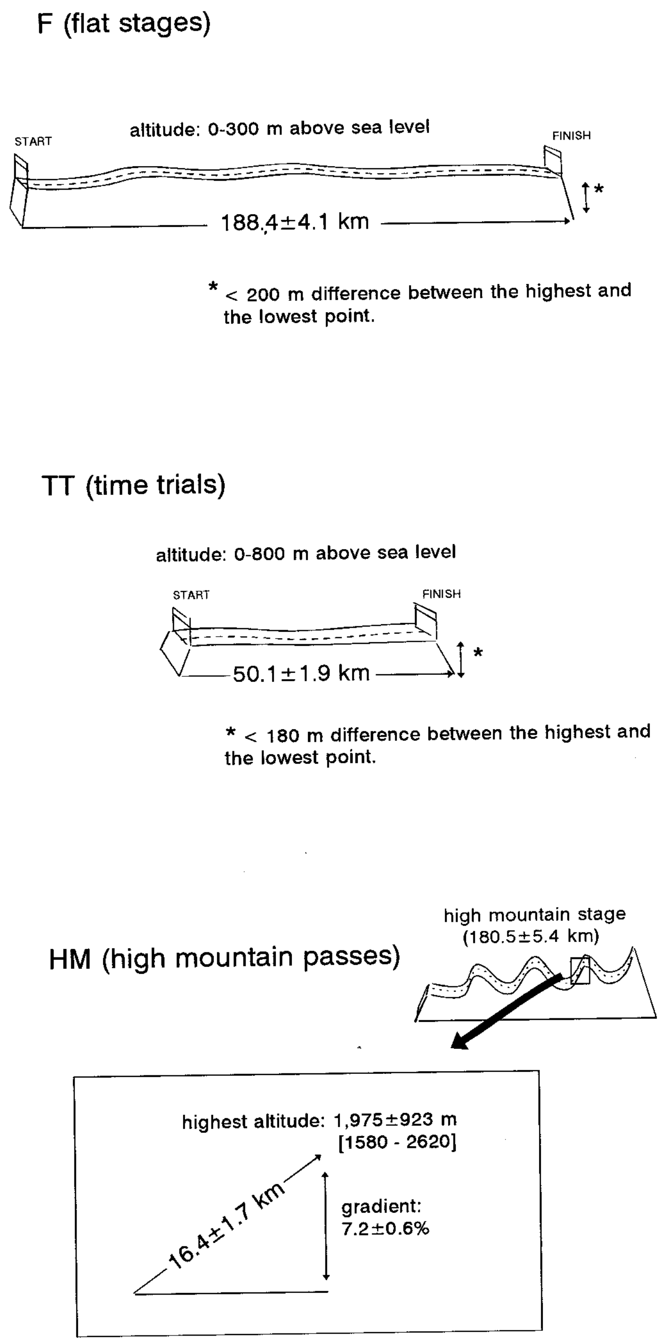

FIGURE 1—Description of the specific characteristics of F (flat stages), TT (time trials), and HM (high mountain ascents).

Mean cadence and speed were significantly lower ($P < 0.01$) during HM (~70 rpm) than both F and TT (~90 rpm) (Table 3). HR was similar during HM and TT and in both cases higher than during F ($P < 0.01$). Figure 2 shows an example of data collection from the same subject in HM and TT: exercise intensity, as inferred from HR, was similar in these two phases of competition, but pedalling cadence differed considerably. In F, the percentage time with cadence zero averaged ~16% of the total duration of exercise. This included several bouts (duration < 1–2 min) of freewheel cycling interspersed throughout the stage, e.g., short descents, or brief recovery periods after accelerations of the peleton. Lowest means of cadence (80–90 rpm) were obtained from the larger, more powerful cyclists, whereas lighter riders tended to adopt faster pedal speeds (90–100 rpm). Maximum individual values of cadence obtained in each F averaged 126.3 ± 1.5 rpm. Pedalling rates above 110 rpm were obtained during short periods (<2–3 min) and mostly corresponded to abrupt accelerations (i.e., “breakaways” from the main group and attacks, last kilometers of the stage, and sprints). In TT, the total amount of time with cadence zero was negligible (1–2% of total) and corresponded only to some road turns. Those cyclists required to perform maximally in this phase of competition (subjects 1 and 2) adopted the highest mean cadences (~95 rpm). Maximum values of pedal rate recorded in each TT averaged 115.0 ± 2.4 rpm. Pedalling cadences above 110 rpm were obtained during short periods (<2 min), i.e., during hill descents of low inclination. In HM, the percentage time with cadence zero was null. The lowest mean values of cadence in this phase of competition (60–70 rpm) were recorded a) during some ascents of great incline (>10% mean gradient, i.e. Mortirolo), or b) in those cyclists (subjects 4–7) not required to perform maximally in this phase of competition. The highest average values (~80 rpm) were recorded in those showing best climbing performance during the long,

TABLE 1. Data collection from the subjects.

Subject	Tour Race in Which Data Were Collected (5 F, 2 TT, and 5 HM in Each Subject)[a]	Team Role
1	Vuelta	Climber and time trialist
2	Vuelta	Climber and time trialist
3	Tour	Climber
4	Vuelta	Team work
5	Vuelta	Team work
6	Tour	Team work
7	Giro	Team work

F (flat stages), TT (time trials), and HM (high mountain ascents), Giro (*Giro d'Italia*), Tour (*Tour de France*), Vuelta (*Vuelta a España*). Explanations for role within the team: climber (required to perform maximally in HM), time trialist (required to perform maximally in TT), team work (required to work for the team in the majority of stages including F, but usually not required to perform maximally in HM or TT).
[a] We collected data from the same five F, two TT, and five HM of Vuelta and Tour in subjects 1, 2, 4 and 5, and in subjects 3 and 6, respectively.

TABLE 2. Main results of laboratory tests.

	Mean ± SEM
Maximum values	
$\dot{V}O_{2max}$ ($L \cdot min^{-1}$)	5.1 ± 0.7
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	76.2 ± 3.0
Power output (W)	517.1 ± 10.8
Power output ($W \cdot kg^{-1}$)	7.6 ± 0.3
HR_{max} (bpm)	192 ± 1
VT_1	
Power output (W)	356.4 ± 10.5
Power output ($W \cdot kg^{-1}$)	5.3 ± 0.2
$\%\dot{V}O_{2max}$	80.3 ± 2.7
HR (bpm)	145 ± 2
$\%HR_{max}$	75.5 ± 0.8
VT_2	
Power output (W)	449.2 ± 10.3
Power output ($W \cdot kg^{-1}$)	6.7 ± 0.1
$\%\dot{V}O_{2max}$	92.1 ± 0.9
HR (bpm)	176 ± 2
$\%HR_{max}$	91.7 ± 0.9

$\dot{V}O_{2max}$ (maximum oxygen uptake), HR (heart rate), VT_1 and VT_2 (ventilatory thresholds 1 and 2, respectively).

TABLE 3. Cadence, heart rate, and speed during actual cycling.

	F	TT	HM
Pedalling cadence (rpm)	89.3 ± 1.0 [80–99]	92.4 ± 1.3 [86–96]	71.0 ± 1.4* [62–80]
HR (bpm)	124 ± 2** [106–137]	158 ± 3 [147–175]	157 ± 4 [140–176]
Speed ($km \cdot h^{-1}$)	43.8 ± 0.8 [38–51]	47.3 ± 0.8 [44–50]	17.2 ± 0.9* [12–25]

All values are expressed as mean ± SEM and range [minimum–maximum].
HR (heart rate), F (flat stages), TT (time trials), and HM (high mountain ascents).
* $P < 0.01$ for HM vs. both F and TT; ** $P < 0.01$ for F vs both TT and HM.

less abrupt ascents (<10% mean gradient) of the Alps and Pyrenees. The maximum individual values in each HM averaged 92.1 ± 2.2 bpm and corresponded mostly to short sprints or accelerations (<1 min) during mountain ascents.

Pedalling cadence was significantly correlated to speed and HR when data from each phase were combined ($P < 0.05$; r = 0.92 and r = −0.40, respectively). Additionally, there was a significant correlation ($P < 0.05$) between cadence and speed within each phase (*F*: r = 0.44; TT: r = 0.66; HM: r = 0.95) and between cadence and HR within HM (r = 0.60).

DISCUSSION

The purpose of the present study was to determine the preferred cadence in the three main competition phases of professional cycling's major tours. Our principal finding was that cadence and intensity data varied according to the demands of each discipline. The cadence and intensity, as reflected by HR, during F, HM, and TT were 89.3 ± 1.0 rpm and 124 ± 2 bpm, 71.0 ± 1.4 rpm and 157 ± 4 bpm, and 92.4 ± 1.3 rpm and 158 ± 3 bpm, respectively.

Exercise intensity, as inferred from HR, was considerably higher in TT than in F. Time trials are usually determinant of final outcomes of tour races. Unlike in F, air resistance is the main force that the cyclist encounters, and thus aerodynamic factors play a major role, especially at high speeds (>40 $km \cdot h^{-1}$) (12). Based on previous research (18,25) and on the fact that the average exercise intensity of all the subjects during TT (HR ~160 bpm or 83%HR_{max}) was between the workloads eliciting VT_1 (75%HR_{max}) and VT_2 (92%HR_{max}), we could speculate that our cyclists generated a mean absolute power output of approximately 400 W during a 60-min period. Moreover, leading time trialists like one of our subjects are able to tolerate high submaximal, constant workloads (close to VT_2 or ~90% $\dot{V}O_{2max}$) during the entire time trial (~60 min) (18). In contrast, during F the cyclists ride as a peleton or group, in which they draft one another. Drafting reduces air resistance, the primary force opposing the riders on such a stage, and lowers energy utilization by as much as 40%. As a result, the energy requirement for cycling may be reduced by as much as 40% (22), which makes the overall exercise intensity rather low-to-moderate (HR ~120 bpm or 62%HR_{max} in our subjects, clearly below that eliciting VT_1, i.e., 75%HR_{max}). A great mastery of technical skills ("drafting" or the ability to avoid crashes) appears to be most important in the majority of stages that most cyclists are able to finish within the same time and that are usually not determinants of the final outcome of tour races (18).

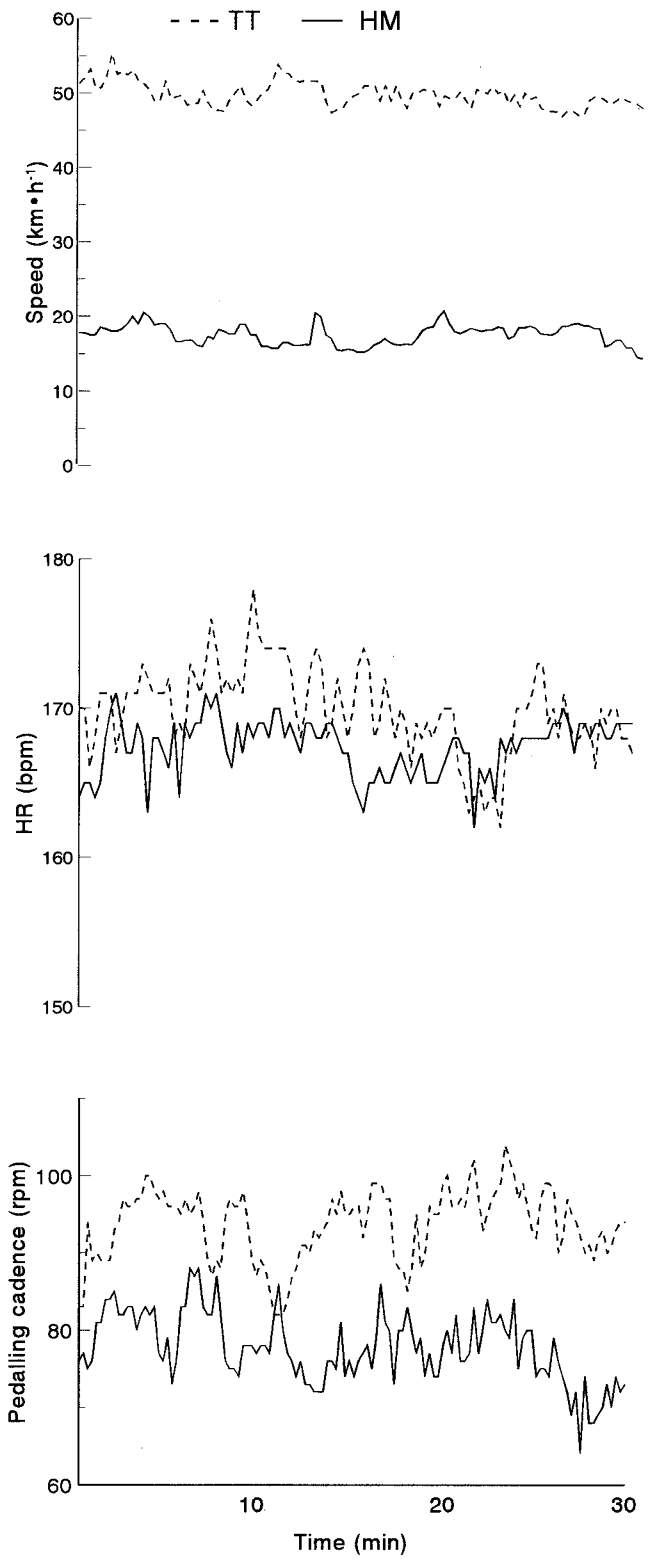

FIGURE 2—Data (means of 15-s intervals) of cycling speed, heart rate (HR), and pedalling cadence of one subject recorded during the central part of a flat time trial (TT) and the second part of a high mountain ascent (HM) to the Galibier (>2000 m altitude). The subject was leading a mountain stage during HM.

Despite the aforementioned difference in exercise intensity, average cadence was similar (~90 rpm) in both TT and F. These high cadences reduce the force used per pedal stroke (15,21), thereby lowering muscle fatigue (especially in Type II fibers—the riders can rely on the more efficient Type I fibers to propel them). Further, the decline in peripheral RPE is more pronounced at the highest power outputs (15). Although the subjects spontaneously adopted fast pedal rates in both phases of tour races, they had to push hard gears to meet the high requirements of competition, i.e., 53 × 13–14 to reach an average speed of 43.8 $km \cdot h^{-1}$ in F, and 54 × 13–14 to reach 47.3 $km \cdot h^{-1}$ in TT. Thus, the selection of slower pedalling rates in both phases of competition would imply the use of extremely high gears during long periods, increasing the risk of muscle injuries. For instance, our subjects should had used 54–55 × 11 (F) and 58–60 × 11 (TT) to maintain the aforementioned speeds at a cadence of 70 rpm. Moreover, those cyclists who seek top performance in TT must perform at an average velocity of ~50 $km \cdot h^{-1}$, which requires riding at 55 $km \cdot h^{-1}$ during long periods of time. Such high speed can only be reached at pedal rates greater than 90 rpm, because lower cadences would require the use of extremely hard gears, i.e., 60 × 11 at 80 rpm. Indeed, the fact that pedalling cadence was significantly correlated to cycling speed during TT ($r = 0.66$) suggests that the ability to adopt high cadences (i.e., > 90 rpm) is an important determinant of TT performance. In our study, the highest mean value (96 rpm) was recorded in the best TT specialist. Although mean exercise intensity is rather low in F, lowering muscle stress is also an important concern in this competition phase. The high average velocities at which the cyclists cover them requires that they push high gears for 4–5 h, which results in muscle damage (18,24). Cumulative muscle damage from these flat stages may negatively affect performance during the latter or the high mountain and time trial stages of the major tours. On the other hand, the use of fast pedal rates require a greater $\dot{V}O_2$ for a given power output (3,5,7,9,11). In this regard, the great aerobic endurance of professional riders (i.e., high resistance to fatigue of Type I fibers) (19) may partly compensate for the lower economy of using faster cadences. Additionally, the improvement in hemodynamics associated with high cadences (10) might also contribute to overcome their greater metabolic cost. Fast pedal speeds can indeed result in a more effective skeletal-muscle pump, which, in turn, increases venous return and muscle blood flow (10). Hagberg et al. (13) also speculate that enhanced blood flow could account for an apparent washout of lactic acid at increased pedalling frequencies. This may represent a major advantage in TT if one considers that lactic acid accumulation significantly increases once VT_2 is reached (8).

The so-called "high mountain stages" require uphill cycling during several 30–60 min periods at intensities close to VT_2 or OBLA (18,25). When climbing at low speeds (~20 $km \cdot h^{-1}$ in *hors* category mountain passes), the cyclist must mainly overcome the force of gravity (26). Because of its effects on gravity-induced resistance, body mass has a major influence on climbing performance (12). A high power output:body mass ratio at maximal or near-to-maximal intensities (of 6 or more $W \cdot kg^{-1}$) is thus a necessary prerequisite for professional riders (19,25). In addition, rolling resistance resulting from the interaction between the bicycle tires and the road surface considerably increases at these lower riding speeds especially when riding on rough road surfaces (12), such as those of most mountain *cols*. To overcome these forces, cyclists frequently switch from the conventional sitting position to a less economical standing posture, which allows them to exert more force on the pedals. As was the case during TT, average HR during HM (HR ~160 bpm or 83%HR_{max}) ranged between that eliciting VT_1 (75%HR_{max} or 80% $\dot{V}O_{2max}$) and VT_2 (92% of both HR_{max} and $\dot{V}O_{2max}$) and might thus correspond to an exercise intensity of approximately 85% $\dot{V}O_{2max}$. Exercise intensity during HM might considerably vary depending on each cyclist's team role. Unlike team leaders or climbing specialists (i.e., subjects 1–3) who must tolerate workloads close to VT_2 during certain HM phases (18), some cyclists are not required to perform maximally during HM and can use more efficient cadences (60–70 rpm) at lower speeds. As a result, the average intensity for the whole group was below VT_2. Despite the fact that exercise intensity was comparable in HM and TT, pedalling frequency was considerably lower in the former, i.e., 71.0 ± 1.4 rpm. Although cyclists could also generate high climbing speeds of 20 $km \cdot h^{-1}$ by using light gears (39 × 23–25) and high cadences (90 or more rpm), they usually tend to push harder gears (39 × 17–21 and rarely 39 × 23) at relatively low cadences, i.e., 20 rpm lower than those used for flat stage. The reason for this choice is not clear. It could be that the specific conditions of climbing performance (negative effect of both the force of gravity and rolling resistance) are too demanding for most cyclists to overcome the higher cardiorespiratory work (i.e., $\dot{V}O_2$, $\dot{V}E$, and HR) related to high pedalling rates. In addition, it should be kept in mind that the summit of most mountain passes is at moderate altitude (~2000 m). For example, to ascend Galibier, riders must perform during 20–30 min at an altitude between 2000 and 2650 m, which may reduce arterial oxygen pressure (PaO_2) below 65 mm Hg (27). Figure 2 shows in fact that the average cadence of the leader of the stage during the ascent to this mountain did not surpass 80 rpm. Effectively, it has been reported that highly trained endurance athletes might suffer gas exchange impairments during acute exposure to hypoxia (27). Some degree of diffusion limitation (14) could be involved. A recent study has indeed reported radiographic evidence of pulmonary edema in trained cyclists after highly intense exercise at moderate altitude (2). Finally, pedalling cadence was significantly correlated to cycling speed ($r = 0.92$) during HM, which suggest that most riders rely on higher cadences (not only harder gears) to achieve top performance during mountain ascents. The highest values (~80 rpm) were recorded in those subjects who were required to perform maximally in this phase of competition. Although the interpretation of our data is partly limited by the small number of subjects ($N = 7$), we could speculate that the specific characteristics of the riders showing the best performance during mountain ascents (low body mass and/or $\dot{V}O_{2max}$ of ~80 $mL \cdot kg^{-1} \cdot min^{-1}$) permits them to tolerate the higher metabolic cost of fast cadences, even in hypoxic environments.

In conclusion, during both the flat group-stages and time trials of tour races, professional riders spontaneously adopt higher cadences (around 90 rpm) than those reported as being most economical in the majority of previous laboratory studies. In contrast, during mountain ascents they seem to adopt a more economical pedalling rate (~70 rpm), possibly due to the specific demands of this competition phase. Finally, top performance in the most determinant phase of the competition (i.e., time trials and mountain passes) seems to be associated, at least in part, with the ability to maintain high pedalling rates.

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