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Effects on the crank torque profile when changing pedalling cadence in level ground and uphill road cycling

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Abstract

Despite the importance of uphill cycling performance during cycling competitions, there is very little research investigating uphill cycling, particularly concerning field studies. The lack of research is partly due to the difficulties in obtaining data in the field. The aim of this study was to analyse the crank torque in road cycling on level and uphill using different pedalling cadences in the seated position. Seven male cyclists performed four tests in the seated position (1) on level ground at 80 and 100 rpm, and (2) on uphill road cycling (9.25% grade) at 60 and 80 rpm.The cyclists exercised for 1 min at their maximal aerobic power. The bicycle was equipped with the SRM Training System (Schoberer, Germany) for the measurement of power output (W), torque (N m), pedalling cadence (rpm), and cycling velocity (km h^{-1}). The most important finding of this study indicated that at maximal aerobic power the crank torque profile (relationship between torque and crank angle) varied substantially according to the pedalling cadence and with a minor effect according to the terrain. At the same power output and pedalling cadence (80 rpm) the torque at a 45°crank angle tended ($p<0.06$) to be higher (+26%) during uphill cycling compared to level cycling. During uphill cycling at 60 rpm the peak torque was increased by 42% compared with level ground cycling at 100 rpm.When the pedalling cadence was modified, most of the variations in the crank torque profile were localised in the power output sector (45° to 135°).

Keywords: Cycling; Crank torque profile; SRM training system; Uphill terrain; Level terrain

1. Introduction

The last years, the winners of the 3-week stage races (i.e. Giro d'Italia, Tour de France, Vuelta a Espana) were usually riders who excelled in the hilly climbing sections of the races. Moreover, many elite cyclists claim difficulties using a specific gear ratio in the first hilly stage. This could possibly be due to changes in pedalling biomechanics (cycling position, pedalling cadence, crank torque profile), between level ground and uphill road cycling. Most of the investigations conducted on pedalling biomechanics in cycling were focused on laboratory conditions. The lack of research on uphill road cycling is partly due to the difficulty in obtaining data during road cycling. In the laboratory, the uphill cycling studies have used classical ergometers (Patterson and Pearson, 1983; Kautz et al., 1991; Swain and Wilcox, 1992; Caldwell et al., 1998; Li and Caldwell, 1998; Padilla et al., 1999) or treadmills (Heil, 1998; Hansen et al., 2002a,b). Caldwell et al. (1998) have studied the crank torque profile of level ground and uphill cycling in seated position on a Velodyne ergometer (at 82 and 65 rpm, respectively). They were not able to show if a change in road slope (0–8%) had an influence on crank torque profile because the two conditions studied did not have the same pedalling cadence. Hansen et al. (2002a,b) have studied level ground and uphill cycling on a treadmill by changing the

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Nomenclature

T_{peak}	peak propulsive torque (N m)
$T_{0\,deg}$	torque at 0°crank angle (N m)
$T_{45\,deg}$	torque at 45°crank angle (N m)
$T_{90\,deg}$	torque at 90°crank angle (N m)
$T_{135\,deg}$	torque at 135°crank angle (N m)
$T_{180\,deg}$	torque at 180°crank angle (N m)
DP_{top}	top dead point (deg)
DP_{bot}	bottom dead point (deg)
T_{delta}	the difference between the peak torque and the T-DP_{top} was calculated (N m)
L_{80}	level terrain at 80 rpm
L_{100}	level terrain at 100 rpm
U_{60}	uphill terrain at 60 rpm
U_{80}	uphill terrain at 80 rpm

slope and crank inertial load (kg m^2). The crank inertial load varied with the gear ratio and the mass (kg) of the cyclist (Martin et al., 1997; Fregly et al., 2000; Hansen et al., 2002a,b). When cyclists ride in the field, they need to change their gear ratio according to the slope, thus affecting the pedalling cadence. Thus, during uphill cycling the crank inertial load is lower than in level ground conditions. Hansen et al. (2002a,b) have shown that the crank torque profile was modified by varying the crank inertial load. They showed that during cycling with a high crank inertial load value, peak crank torque was significantly higher (+5%) compared with a low crank inertial load value. However, compared with the field, the simulation of the cyclist's crank inertial load is not similar in the laboratory due to the inertia of the ergometer flywheel. With a non-modified classical ergometer (like Monark ergometer) it is also difficult to simulate the habitual body position of the cyclist.

The crank torque represents the kinetics of the propulsive torque (N m) within the crank cycle. These kinetics are a determinant of cycling performance (Coyle et al., 1991), since it represents an important variable of the power output (power output (W) = torque × pedal velocity (rad s^{-1})). The torque is determined by the product of the effective force (Fe) (applied perpendicularly to the crank arm) and the length of the crank arm (m)(Torque = Fe × length of the crank arm). Thus, Fe represents the propulsive force in cycling. From a mechanical point of view, the ideal situation when riding a bicycle is to exclusively generate a constant Fe (Patterson and Moreno, 1990). However, such a situation is not possible during pedalling. Indeed, the crank cycle is sub-divided into four 90° power output sectors (Faria, 1992). Considering that the 0°crank angle corresponds to the vertical position of the left crank arm (pedal in high position), sectors 1 (between a 315° and 45°) and 3 (between 135° and 225°) are associated with the top (DP_{top}, see nomenclature) and the bottom (DP_{bot}) dead point of the crank cycle, respectively. When the pedal is in these two sectors, the crank torque is minimal. Sector 2 (between 45° and 135°) corresponds to the push-down phase, and sector 4 (between 225° and 315°) to the pull-up phase. When the pedal is moving downward, a greater force is generated (push-down phase) compared with the phase where the pedal is moving upward (pull-up phase). The optimisation of the crank cycle in cycling can contribute to improvements of performance (Coyle et al., 1991).

To the best of our knowledge, the characteristics of the crank torque during level ground and uphill road cycling are not clear and have not been studied.

The first aim of this study was to analyse the crank torque profiles in level ground and uphill road cycling in the seated position at the same pedalling cadence (80 rpm) and power output. The second aim was to analyse the effect of changing pedalling cadence on the crank torque profiles at the same power output during level ground and uphill road cycling. The torque was measured with the SRM training system device. The first hypothesis of this study was that uphill and level cycling at the same pedalling cadence and power output would elicite different crank inertial loads, which would result in changes in crank torque profiles, especially on DP_{top}, DP_{bot} and on peak torque (T_{peak}). We hypothesised that the crank torque value at DP_{top}, DP_{bot} and on T_{peak} would decrease on uphill road cycling when the crank inertial load value would be low.

The second hypothesis was that a change of pedalling cadence on level ground and uphill road cycling would elicite an alteration of torque values especially in the power sector (sector 2). Possibly, the torque values would be differently altered when the pedalling cadence changes in level ground compared to uphill road cycling.

2. Methods

2.1. Subjects

Seven male competitive cyclists (age 25.5±4.9 years, height: 1.78±0.04 m, body mass: 70.6±5.0 kg, maximal aerobic power (MAP): 322±40 W), in their preparative training period of the race season, participated in the study. Each subject was informed of all details of the testing and signed an informed consent.

2.2. Instrumentation

Each subject rode on a classical race bicycle (10.2 kg) equipped with "clipless" pedals during the field tests. Before beginning the test, the cyclist adjusted the bicycle to his habitual cycling position. The bicycle tire pressure was inflated to 700 kPa and was equipped with the SRM training system (scientific model Schoberer, 0.5% accuracy, Germany). The validity of the SRM has been previously shown by (Martin et al. 1998). The SRM device is a precision strain-gauge-based crank arm and sprocket dynamometer that radio-transmits data to the SRM screen (Powercontrol unit) fixed on the handlebars. The SRM sampled (10 Hz) and stored the power output (W) the cycling velocity ($km\,h^{-1}$) and the pedalling cadence (rpm). To measure the torque (200 Hz) the powercontrol unit was connected via a cable to a computer located in a car which followed the cyclist. Before the experimental procedure the SRM and the torque analysis software were calibrated according to the manufacturer's recommendations (offset of powermeter slope of powermeter). In the field the mean temperature was $22 \pm 2°C$ and the wind velocity ($m\,s^{-1}$) was measured by using an anemometer (Jules Richard Argenteuil France accuracy $= \pm 2\%$) and varied from 0 to $1.4\,m\,s^{-1}$.

2.3. Test protocol

The first test day subjects performed a continuous incremental test in the laboratory to determine MAP. Cyclists performed the MAP test on a modified Monark ergometer (818 E Varberg Sweden). A race saddle "clipless" pedals and race handlebars (Ergostem system Look France) permitted a better adjustment of the cyclist's habitual position. Subjects rode on the Monark ergometer for 2 min at 120 W after which the power output was increased by 30 W every 2 min until exhaustion. The pedalling cadence was maintained constant at 80 rpm throughout the test. MAP was determined as the final power output in which at least 1 min of exercise was maintained. The experimental protocol in the field was composed of two tests on level ground at 80 (L_{80}) and 100 rpm (L_{100}) and two tests on uphill road cycling (9.25% grade) at 60 (U_{60}) and 80 rpm (U_{80}). The standard bicycle gear ratios (smallest gear ratio: 39×28) available on the bike did not allow the cyclists to maintain the same cadences for both level and uphill terrains (keeping power output constant). The frequencies of 100 and 60 rpm were close to the range of frequencies habitually used in level ground and uphill cycling by elite cyclists. The cadence of 80 rpm allowed the comparison of the crank torque profile between level ground and uphill cycling. Subjects performed a 5 min warm-up period before the first test. All tests were performed during 1 min in the seated position at their MAP as previously determined in the laboratory. There was a 5 min rest period between the trials. The tests were performed at MAP because a lower power output would not permit the use of a cadence of 80 rpm on a uphill grade of 9.25%. The appropriate gear ratio to produce the required power output and cadence for each subject was determined during a warm-up phase. The subject used the SRM unit screen display fixed on the handlebars to maintain the MAP. The subjects were also required to maintain the same body position (hands on the brake hoods) during all four tests to minimise biomechanical changes due to their body position on the bicycle. If the average power output and pedalling cadence during the 1 min test was not within ± 15 W and ± 2 rpm respectively of the desired instructions the test was not taken into account. In this case another test was performed (Table 1).

2.4. Measured variables

The power output, the pedalling cadence, the torque according to the crank angle and the cycling velocity were stored during each test condition from which the last 30 s were averaged together. In this study the DP_{top} was the crank angle when the torque was minimal in sector 1 (left crank arm near top position 315–45°) while torque at DP_{top} represented the torque value at this crank angle. The DP_{bot} was the crank angle when the torque was minimal in sector 3 (left crank arm near bottom position 135–225°) while torque at DP_{bot} represents the torque value at this crank angle. The T_{peak} was the maximal torque in sector 2. The T_{peak}, the torque at DP_{top}, the torque at DP_{bot} and the torque corresponding to angles of 0°($T_{0\,deg}$) 45°($T_{45\,deg}$)

Table 1
Mean pedalling cadence, cycling velocity, power output and crank inertial load of the cyclists during experimental conditions

Cycling condition	Pedalling cadence (rpm)	Power output (W)	Cycling velocity ($km\,h^{-1}$)	Crank inertial load ($kg\,m^2$)
U_{60}	61.1 ± 1.9	325 ± 43	15.0 ± 0.8	42 ± 3.7
U_{80}	80.8 ± 1.6	325 ± 39	14.8 ± 0.7	23 ± 1.6
L_{80}	82.2 ± 1.6	322 ± 40	38.3 ± 1.4	158 ± 19
L_{100}	99.0 ± 1.3	325 ± 35	38.7 ± 1.5	107 ± 15

The crank inertial load was calculated from the equation of Hansen et al. (2002a,b).
L_{80} : level terrain at 80 rpm, L_{100} : level terrain at 100 rpm, U_{60} : uphill terrain at 60 rpm, U_{80} : uphill terrain at 80 rpm.

90°($T_{90\,deg}$) 135°($T_{135\,deg}$) and 180°($T_{180\,deg}$) were determined with respect to the left lower limb (Fig. 1). Fig. 1 shows an example of the method of analysis of the crank torque profile for one subject in U_{60} recorded at 200 Hz and averaged over 30 s. The crank angle at 0°corresponds to the vertical position of the left crank arm (pedal in high position). The difference (T_{delta}) between the T_{peak} and the torque at DP_{top} was calculated ($T_{delta} = T_{peak} - \text{torque at } DP_{top}$). The crank inertial load (Table 1) was calculated following the method of Hansen et al. (2002a,b).

2.5. Statistics

The mean differences between the experimental conditions in (1) T_{peak}, (2) torque at DP_{top} and torque at DP_{bot}, (3) crank angle at T_{peak}, (4) crank angle at DP_{top} and DP_{bot}, (5) $T_{0\,deg}$, $T_{45\,deg}$, $T_{90\,deg}$, $T_{135\,deg}$, $T_{180\,deg}$ and (6) T_{delta} were determined from Tukey-Kramer matched-pairs test ($p<0.05$). Data are presented as mean values ± standard deviation.

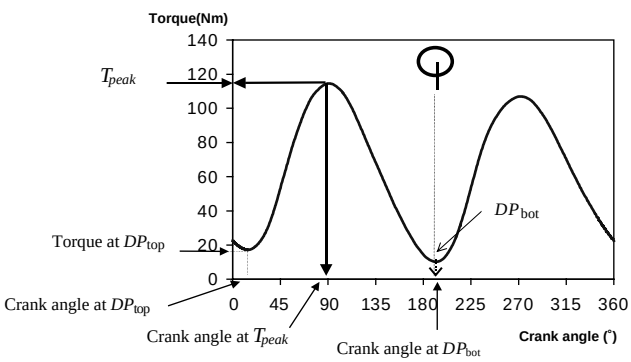

Fig. 1. Method used for the determination of maximal and minimal torque. T_{peak} : Peak propulsive torque (N m); DP_{top} : top dead point (deg); DP_{bot} : bottom dead point (deg).

3. Results

3.1. Effect on the crank torque profile of the cycling conditions (level ground vs. uphill cycling)

For L_{80} $T_{45\,deg}$ (22.8 ± 5.6 N m) tended ($p<0.06$) to be lower compared with U_{80} (+26%)(Fig. 2). The other measured variables were no significantly different between L_{80} and U_{80}.

3.2. Effect on the crank torque profile of varying pedalling cadence (60–100 rpm) on the same terrain (level ground or uphill)

Our results indicate that on the same terrain torque applied to the crank arm increased in the power output sector when the pedalling cadence decreased. During L_{80} $T_{90\,deg}$ and $T_{135\,deg}$ were higher compared with the L_{100} (+19% and +14% respectively)(Fig. 3). The T_{peak} and T_{delta} during U_{60} were significantly ($p<0.01$) higher (close to 30%) than L_{80} and U_{80} (Table 2).

On level ground our results indicate that the crank torque profile occurred later in the crank revolution when the pedalling cadence was increased. The crank angle at DP_{top} and DP_{bot} during L_{80} was significantly

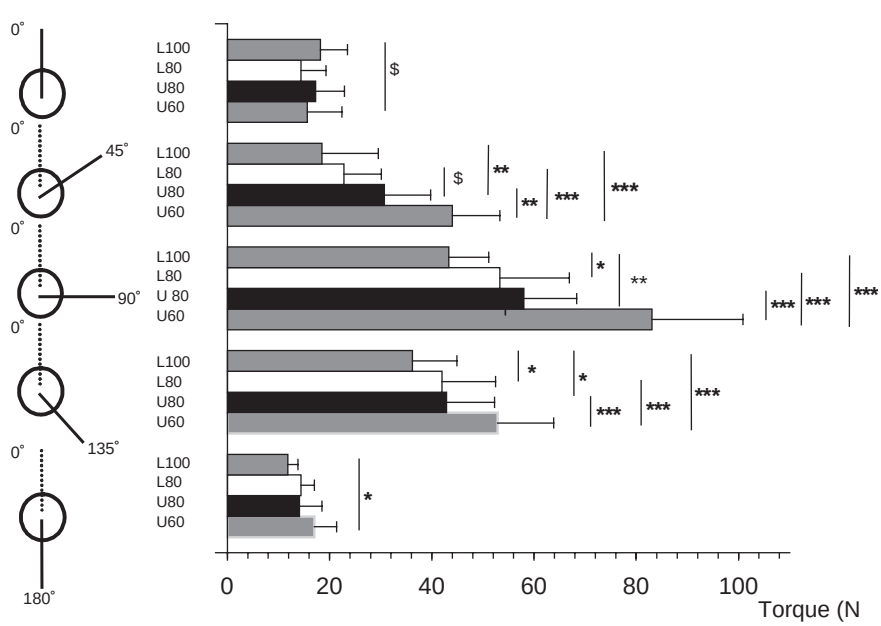

Fig. 2. Mean torque at 0°, 45°, 90°, 135° and 180° measured during the exercise at maximal aerobic power on uphill and level terrains at different pedalling cadences. *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$; $: $p<0.06$. L_{80} : level terrain at 80 rpm; L_{100} : level terrain at 100 rpm; U_{60} : uphill terrain at 60 rpm; U_{80} : uphill terrain at 80 rpm

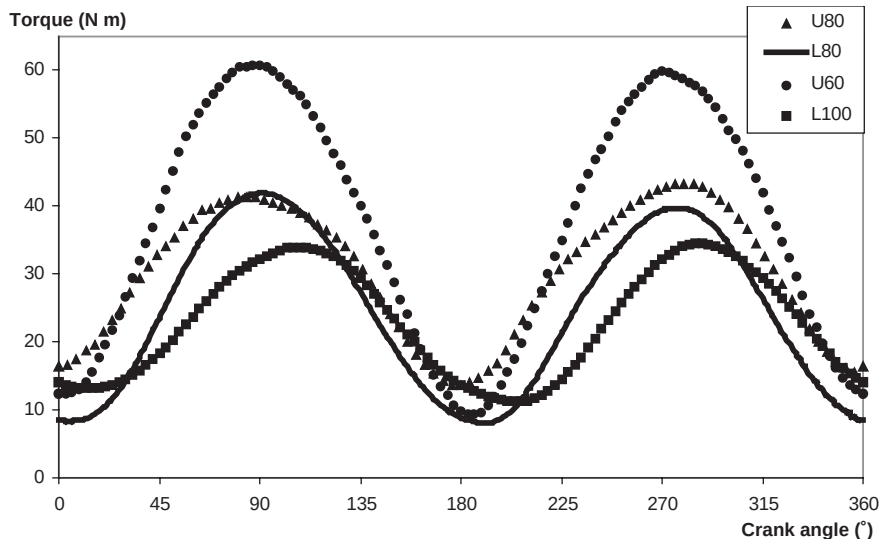

Fig. 3. Crank torque profile measured during the exercise at MAP on uphill and level terrains at different pedalling cadences for one subject. L_{80} : level terrain at 80 rpm; L_{100} : level terrain at 100 rpm; U_{60} : uphill terrain at 60 rpm; U_{80} : uphill terrain at 80 rpm.

Table 2
Mechanical variables of the crank cycle

Cycling condition	U_{60} Mean ± *SD*	U_{80} Mean ± *SD*	L_{80} Mean ± *SD*	L_{100} Mean ± *SD*
T_{peak} (N m)	84.8±18.0	59.2±10.1[a]	60.1±12.5[a]	49.1±8.1[a]
Crank angle at T_{peak} (°)	90.1±10.5	90.7±11.5	95.0±11.8	97.3±10.7
Torque at DP_{top} (N m)	11.8±2.6	10.5±4.3	11.5±5.6	11.4±7.2
DP_{top} (°)	8.4±4.9	10.7±11.4	15.3±5.9[a]	24.6±10.8[a,b,c]
Torque at DP_{bot} (N m)	9.6±0.9	9.3±2.8	9.8±4.2	9.8±4.7
DP_{bot} (°)	189.5±4.4	191.4±10.3	196.9±6	209.3±8.2[a,b,c]
T_{delta} (N m)	73.0±16.6	48.7±11.4[a]	48.5±15.6[a]	37.7±13.9[a]

T_{peak} : peak propulsive torque (N m); T-DP_{top} : torque at top dead point (N m); T-DP_{bot} : torque at bottom dead point (N m); T_{delta} : the difference between the peak torque and the T-DP_{top} (N m); L_{80} : level terrain at 80 rpm; L_{100} : level terrain at 100 rpm; U_{60} : uphill terrain at 60 rpm; U_{80} : uphill terrain at 80 rpm.

[a] significantly ($p<0.05$) different from the U_{60}.
[b] significantly ($p<0.05$) different from the U_{80}.
[c] significantly ($p<0.05$) different from the L_{80}.

lower ($p<0.001$) compared with L_{100} (15.3±5.9 vs. 24.6±10.8 and 196±6.0 vs. 209.3±8.2° respectively) (Table 2 and Fig. 3).

3.3. Effect on the crank torque profile of varying pedalling cadence (60–100 rpm) on different terrains (level ground vs. uphill cycling)

When the pedalling cadence was modified it was always the power output sector that was the most affected. During U_{80} $T_{45\,deg}$ $T_{90\,deg}$ and $T_{135\,deg}$ were significantly higher (Fig. 2) compared with L_{100} (+40% +26% and +16% respectively). The T_{peak} and $T_{45\,deg}$ to $T_{180\,deg}$ during U_{60} were significantly higher $p<0.001$) than L_{100} (Table 2 and Fig. 2).

4. Discussion

The hypotheses of this study were that a change (1) in terrain (i.e. level ground vs. uphill cycling) and (2) in pedalling cadence (60–100 rpm) would elicit different crank torque profiles. The first important finding of this study is that during U_{80} the crank torque profile was only slightly modified compared with L_{80}. We have shown that between these two conditions, there was only a tendency for a difference ($p<0.06$) in $T_{45\,deg}$. The

second important finding is that the crank torque profile during L_{100} was significantly different compared with the crank torque profiles during U_{60} and U_{80}.

4.1. Level ground cycling at 80 rpm vs. uphill cycling at 80 rpm

For U_{80}, $T_{45\,deg}$ (Fig. 2) had a tendency to be higher ($p<0.06$) compared with L_{80} (30.7 vs. 22.8 N m). This tendency to be different can be explained by a change of crank inertial load between these conditions. For L_{80}, the crank inertial load was higher (6.7 time) compared with U_{80}. Between L_{80} and U_{80} there was no difference in T_{peak} and T_{delta}. These results are different compared with those of Hansen et al. (2002a,b). They found differences in T_{peak} and T_{delta}, between cycling with high and low crank inertial load at the same pedalling cadence and power output. This different finding could be explained by the fact that Hansen et al. (2002a,b) did not use the same method as the present study (treadmill vs. field). On the treadmill in the laboratory, the mean cycling velocity is imposed by the motor of the treadmill. In these conditions the mean cycling velocity is easily controlled. In real road cycling conditions, the cycling velocity is less easily controlled and oscillates more (like the power output and the pedalling cadence) close to the target velocity, compared with the laboratory conditions. The difference between our results and those of Hansen et al. (2002a,b) could also be explained by the fact that the slope was lower in our study (9.25 vs. 10.9%) and the variation of crank inertial load between uphill and level conditions was different (10 vs. 76 kg m^2 for Hansen et al. (2002a,b) and 23 vs. 158 kg m^2 in our study).

4.2. Propulsive torque

For U_{60}, the T_{peak}, T_{delta} (Table 2), and $T_{45\,deg}$ to $T_{135\,deg}$ (Fig. 2) were significantly higher compared with $U_{80,}$ $L_{80,}$ and L_{100}. At a pedalling cadence of 80 rpm (U_{80} and L_{80}), $T_{45\,deg}$ to $T_{135\,deg}$, (Fig. 2) were significantly higher compared with L_{100}. These results indicate that for the same power output the torque applied to the crank arm decreases when the pedalling cadence increases. These differences could be explained in part by the changes in pedalling cadences. Higher peak torque for the lower cadences has previously been reported in different laboratory studies (Patterson and Moreno, 1990; Sanderson, 1991; Caldwell et al., 1998). It can be predicted by physical laws. For a given power output, if the pedalling cadence decreases, the mean torque concomitantly must increase.

4.3. Crank angle

For U_{60}, the crank angle at the DP_{top} and DP_{bot} was significantly lower compared with L_{100} (-16.2° and -19.8°, respectively)(Table 2). Also, for L_{80} and U_{80}, the crank angle at DP_{top} was significantly lower compared with L_{100} (15.3 ± 5.9° vs. 24.6 ± 10.8° and 10.7 ± 11.4° vs. 24.6 ± 10.8°, respectively) (Table 2). These results indicate that the DP_{top} and DP_{bot} during L_{100} occured later in the crank revolution compared with U_{80}, U_{60} and L_{80}. This result is in accordance with Caldwell et al. (1998) who have shown that the crank angle at T_{peak} for uphill cycling at 65 rpm was lower compared to level ground cycling at 82 rpm (86 vs. 94°). In our study the crank angle differences at the dead points could be explained by crank inertial load variations (Table 1). Crank inertial load varies according to the gear ratio and the bicycle and cyclist mass (kg)(Voigt and Kiparski, 1989; Fregly et al., 1996; Martin et al., 1997; Hansen et al., 2002a,b). For U_{60}, L_{100} and U_{80}, the crank inertial load was respectively, 1.8, 4.5 and 6.8 time higher compared with L_{80}. Hansen et al. (2002a,b) have shown that on a treadmill, crank inertial load differences induced crank torque profile alterations. These results suggest that in road cycling, a change in crank inertial load is associated with a modification of crank torque profile.

4.4. Implications for training and choice of pedalling cadence on uphill road cycling

The results of this study with between the cycling exercises at MAP on uphill (U_{60} and U_{80}) and level terrains (L_{80} and L_{100}) indicate that changes in terrain or pedalling cadence involved modifications in the relationship between the torque and crank angle (Fig. 3). Thus, the relationship between the force applied on the pedal and crank angle was modified. This suggests that in each condition ($U_{60,}$ $U_{80,}$ L_{80} and L_{100}) the active muscles operate across different portions of their active force–length relationship and at different muscular contraction velocities. Thus, due to training specific alterations in force-length and muscular contraction velocity (Morrissey et al., 1995), to optimise cycling performance, it appears necessary to train in specific conditions (uphill road cycling and level ground, low and high cadences) in order to develop these specific muscular adaptations.

Our results also indicate that when the pedalling cadences were the same (U_{80} and L_{80}), the crank torque profile differences were minimal, despite the difference in field conditions (level ground vs. uphill). This suggests that the muscle activity pattern is almost similar at the same cadence and is not influenced by grade. However, competitive cyclists generally climb hills at lower pedalling cadences (close to 70 rpm)(Lucia et al.,

2001) than when cycling in level ground conditions, despite several studies suggesting that using higher pedalling cadences could improve performance (Patterson and Moreno, 1990; Swain and Wilcox, 1992; McNaughton and Thomas, 1996; Neptune and Herzog, 1999; Marsh et al., 2000). Using higher pedalling cadences during uphill cycling could : (1) reduce the muscle mass used to stabilise the trunk, (2) reduce cycling velocity oscillations, (3) increase blood flow and oxygenation to working muscles (Swain and Wilcox, 1992; Takaishi et al., 2002) and (4) decrease the crank inertial load to reduce the stimulation of mechanoreceptors in the lower limbs (Hansen et al., 2002a,b). Moreover, higher pedalling cadences allow an important reduction of mean torque and T_{peak}. For the same power output, the mean torque at 80 rpm is 25% lower compared with the mean torque at 60 rpm. A reduction of peripheral muscular and neuromuscular fatigue can be obtained by increasing the pedalling cadence (Patterson and Moreno, 1990; Sanderson, 1991; Sargeant, 1994; Takaishi et al., 1994, 1996, 1998). There is a discrepancy in the literature with respect to the most economical cadence. Some studies have shown that the high pedalling cadences were associated with an increase in oxygen consumption compared with the lower pedalling cadences (Widrick et al., 1992; Marsh and Martin, 1993) but others did not show significant differences on physiological variables (Hagberg et al., 1981; Chavarren and Calbet, 1999; Lepers et al., 2001; Millet et al., 2002). However, it appears that the cyclist's preferred cadence was always higher than the most economical cadence at low (Marsh and Martin, 1993, 1997), moderate (Neptune and Herzog, 1999) and high (Nielsen et al. 2004) exercise intensity. Using the most economical cadence does not always signify that the most optimal cadence is used. The decreased muscle stress (by increasing pedalling cadence) could contribute to a greater relative recruitment of ST muscle fibers which have greater fatigue resistance and a higher mechanical efficiency, despite increased oxygen consumption caused by increased repetitions of leg movements (Takaishi et al., 1998, 2002). Also, Swain et al., 1992 have shown that uphill cycling was more economical at higher pedalling cadences. Moreover, all one-hour records on track were performed with pedalling cadences higher than 100 rpm (Sargeant, 1994).The reasons why some cyclists use lower cadences during hill climbing are not totally clear, although in some cases it appears to be a limitation of gearing options. It was reported that in the Tour de France of 1991, the Motorola Team members used a gear combination of 39×25 (Swain and Wilcox, 1992). With this gear ratio the cyclist used sometimes (road slope of 20%) a pedalling cadence of approximately 45 rpm (Swain and Wilcox, 1992). From a mathematical model (Grappe et al., 1997; Martin et al., 1998) it is possible to estimate the necessary gear ratio. At a power output close to 400 W (anaerobic threshold of elite cyclists of Padilla et al. (1999)), with a pedalling cadence of 100 rpm for a cyclist of 80 kg on a 10% uphill road cycling, it is necessary to use a gear ratio of 39×31 or a triple chainrings. This suggests that cyclists who want to use a high pedalling cadence when cycling uphill (with a high slope), must employ a triple chainrings in order to have appropriate gear ratios.

Our data indicate that the crank torque profile (relationship between torque and crank angle) in road cycling at MAP varies according to the pedalling cadence and with a minor effect to the field conditions (level ground vs. uphill). Most variations were localised in the power output sector (45–135°) and at DP_{top} and DP_{bot}. Also, our results show that when the pedalling cadences are the same, the crank torque profile differences are minimal between level ground and uphill road cycling. Thus, to limit variations of the muscular activity pattern, pedalling cadences close to 80–100 rpm could be used both during level ground and uphill cycling.

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