

# Comparison of Biomechanical Criteria in Cycling Maximal Effort Test

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**Abstract.** The purpose of this paper was to evaluate a new set of biomechanical parameters for performance assessment in laboratory sprint cycling.

Two groups of seven cyclists, one at elite level, the other at regional level, performed sprint tests in seated and standing positions against 0.8 N/kg resistive loads on the T1670 Basic ergo-trainer (Tacx, Netherlands). A classic racing bicycle was equipped with an SRM Training System (Schoberer, Germany). Two sets of biomechanical parameters were defined: one "classical" and one "new" set of parameters. The relation between crank torque and crank angle was carefully studied and a selection of characteristic criteria for assessing the cycling performance was proposed. In order to quantify the differences in the pedalling technique, new criteria were introduced, such as the time interval during which the instantaneous power exceeded 90 % of the maximal power output as a proportion of the pedal downstroke ( $RMPD_{90}$ ).

The results show 1) that the cyclo cross cyclists can generate high level of power output during sprint test (close to 18W/kg) and 2) there is no significant difference between regional level and elite level concerning the set of biomechanical parameters classically employed. However, the new set of biomechanical parameters ( $RMPD_{90}$ ) revealed differences between the pedalling characteristics of the elite level and regional level groups.

The results of the present study suggest that the analysis of the sprint test performed with classical set of biomechanical parameters can be completed using the  $RMPD_{90}$  as a supplementary fitness criterion.

**Keywords:** Cyclo-cross, sprint test, maximal effort, performance assessment.

## 1. Introduction

To optimise a training programme and to improve performance it is crucial to know the athletes characteristics. Usually a cyclist performs several test protocols to determine : e.g. 1) the maximal oxygen consumption value (incremental protocol) 2) mechanical power output at the maximal oxygen consumption, 3) time to exhaustion at the maximal oxygen consumption, 4) power output at the anaerobic threshold, 5) time to exhaustion at the anaerobic threshold (steady state protocol), 6) the critical power, 7) the mean maximal power output during 30s (Wingate test) and 8) the force velocity test (sprint test) to determine the maximal power output in particular. The capacity to reach peak values of the power output ( $PO_{max}$ , W) appears to be important e.g.: in track-cycling, at the end of the road race (sprint), at the start of the mountain bike competition (1, 2). Different protocols have been used to measure the  $PO_{max}$  of the lower limb e.g.: squat jump test, counter movement jump test, or Margaria staircase test (3, 4, 5). For the jump test the  $PO_{max}$  can be measured with 1) an accelerometer device e.g. Myotest (Acceltec, Swiss), 2) a linear encoder or infrared contact mat e.g. Musclab (Ergotest technology, Norway), 3) other devices e.g. Optojump (Microgate, Italy) to acquire flight and ground-contact times, or 4) with a force plate (e.g. AMTI, USA). Usually the cyclists  $PO_{max}$  are evaluated with more specific tests, such as Wingate or force-velocity tests on a cycle ergometer corresponding to 30 and 6-8 s of maximal effort, respectively (6, 7). This last test can be used to extrapolate the athlete's muscle characteristics such as the theoretical maximal force  $F_0$  and the theoretical maximal pedalling cadence  $V_0$ .  $F_0$  and  $V_0$  correspond to the intercept of the force-velocity relationship with the force axis and pedalling cadence axis, respectively (8). In a sprint test,  $PO_{max}$  is obtained at combined

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optimal values of force (N) and pedalling cadence ( $V_{opt}$ ). The  $V_{opt}$  during force-velocity is related to muscle fibre type composition (9). In this study, the optimal pedalling cadence was found to be significantly correlated to the proportion of fast twitch fibres of the knee extensor muscle ( $r = 0.87$ ) and the  $PO_{max}$  expressed per kilogram of body mass ( $r = 0.86$ ). The capacity to achieve high  $PO_{max}$  values depends in part of the lower limb muscular force-velocity characteristics. Dorel et al. (1) have studied the torque and power-velocity relationships of the track world class cyclists. They indicates that during the 200 m flying start (qualifying race for the "match sprint" competition) track cyclists use pedalling cadences greater than  $V_{opt}$  as measured *via* force-velocity tests on a cycle ergometer. In laboratory tests the crank length and the pedalling cadence have been shown to be important determinants of  $PO_{max}$  (10). However, in this last study the  $PO_{max}$  data were sampled at a low frequency which limited the analysis of exercise at maximal intensity (below 8 s). At sub-maximal intensity the pedalling characteristics (the pedalling torque profile) have been studied for each cycle using a high data-acquisition frequency (11, 12, 13, 14, 15, 16, 17). These studies have allowed differences in the crank torque profile to be characterised between: 1) uphill and level conditions, 2) elite and recreational cyclists, 3) standing and seated positions. This type of analysis has also been used to study pedalling asymmetry, particularly in sub-maximal effort intensities (16, 17, 18, 19).

To the best of our knowledge, no studies have analysed the sprint test performance from the pedalling torque profile. The main aim of the present study was: to identify a set of biomechanical parameters from the propulsive pedalling torque that could be used to analyse a sprint performance. In order to achieve these objectives, two different groups of cyclo-cross cyclists were studied: an elite level group (EG) and regional level group (RG). Two sets of parameters were defined and used: a "classical" and a "new set" of parameters. We hypothesised that the new biomechanical parameters obtained from pedalling torque profile would be able to discriminate between the cyclists of EG or RG.

Several studies have focussed on mountain bikes, to elucidate, for example, the effect of the front or dual suspension (20, 21, 22, 23), the exercise intensity (24, 25, 26), or the physiological characteristics of mountain bikers (2, 27). However, to the best of our knowledge, no studies have looked at the maximal power output produced by cyclo-cross cyclists during a sprint test. The results of the present study may also provide data concerning the EG and RG cyclo cross cyclists characteristics.

## 2. Materials & Methods

### 2.1. Subjects

Fourteen healthy male adults participated in the present study with informed content, which was carried out in compliance with local ethical guidelines. Two groups of seven cyclists were created: an elite level group (EG) and a regional level group (RG). The cyclists in the EG (body mass  $72.6 \pm 7.5$  kg, height  $1.84 \pm 0.08$  m, age  $21.0 \pm 3.9$  years) were in the French national cyclo-cross team (performing in european and world championships) or had already achieved the peak level of international cyclo-cross racing. The cyclists with the RG (body mass  $69.2 \pm 6.5$  kg; height  $1.78 \pm 0.06$  m, age  $20.9 \pm 4.3$  years) performed well in regional races (with victories). Measurements were performed at the end of their race period. Cyclists with knee or leg pain were precluded from the tests.

### 2.2. Test protocol

To measure the crank torque profile, *i.e.* the crank torque ( $CT$ , N.m) according to the crank angle and the pedalling cadences (rpm), the bicycle was equipped with an SRM Training System (scientific model Schoberer, 0.5% accuracy, Germany). The SRM validity has been previously demonstrated by Martin et al. (28), and Jones (29). A standardized calibration procedure (*i.e.* the resetting of the SRM "frequency versus torque" slope) was performed just a few days before the first test day by the manufacturer. The SRM power control units were zeroed (resetting of the zero offset frequency) prior each trial. The  $CT$  and crank angles values were sampled at 250 Hz and stored in a computer *via* a cable. The software used in SRM and  $CT$  analysis was calibrated according to the manufacturer's instructions.

The tests were performed under laboratory conditions on a classic racing bicycle (mass: 9 kg, crank length 0.175 m) equipped with clip-less pedals fixed on a T1670 Basic ergo-trainer (Tacx, Netherlands). The bicycle tyre pressure was inflated to 700 kPa. Throughout each trial laboratory conditions were maintained: ambient temperature 20-22 °C. Before the beginning of the test, each cyclist adjusted the bicycle to his usual cycling position. A front wheel support was used to maintain the bicycle in the horizontal position. The pedalling resistance during sprints was adjusted using an ergo-trainer electromagnetic brake using the method described by Ravier et al. (30) and Bertucci et al. (31). Calibration of the friction force applied on the

flywheel (Ff, N) was performed according to the subject's mass (0.8 N/kg) at 50 rpm pedalling cadence. The pedalling resistance was considered optimal when the theoretical mechanical power (Pth, W) computed from equation (1) was reached on the SRM ' screen display.

$$P_{th} = F_f \cdot \omega \cdot D \quad (1)$$

where  $\omega$  (revolutions per second) is the pedalling cadence and D (m) the distance traveled by the flywheel for each complete revolution of the pedal.

### 2.3. Classical set of biomechanical parameters

The "classical" set of biomechanical parameters used in this study is routinely used in order to assess the performance of cycling exercise at maximal intensity (sprint test). The classical parameters measured in the 8 s sprint test were: mean pedalling cadence (rpm) and optimal pedalling cadence ( $V_{opt}$ ) (Fig 1 and Fig 2).  $V_{opt}$  was defined like the pedalling cadence at  $PO_{max}$ . The  $PO_{max}$  was determined as the maximal PO value calculated from the propulsive torque measured (250 Hz) during each pedal downstroke and the mean pedalling cadence values for each pedalling cycle.

Moreover, the maximal PO was determined using the SRM "powercontrol" variable averaged at 10Hz ( $PO_{maxSRM}$ ). Figure 2 shows the  $PO_{maxSRM}$  of two cyclists of one EG and one RG with average biomechanical values obtained from the seated sprint test using the Ravier et al. (32) methods

The classical biomechanical parameters (criteria) calculated were:  $PO_{max}$ ,  $PO_{maxSRM}$  the ratio between the  $PO_{max}$  and body mass (BM), the theoretical maximal force F0 and the theoretical maximal pedalling cadence V0. F0 and V0 correspond to the intercept of the force-velocity relationship with the force axis and pedalling cadence axis, respectively (8).

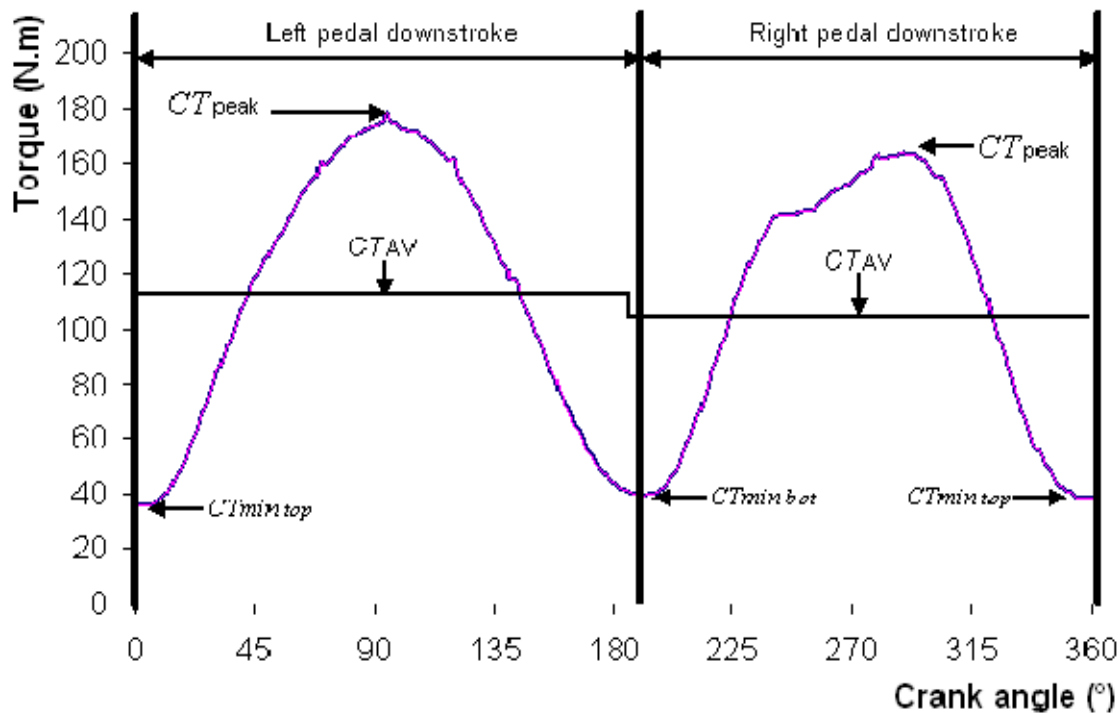


Fig 1: Determination of the peak propulsive torque ( $CT_{peak}$ , N.m), the crank angle at the minimal CT value when the pedal was at the top ( $CT_{min_{top}}$ , °) and bottom ( $CT_{min_{bot}}$ , °) position, and mean crank torque ( $CT_{AV}$ , N.m) for each pedal downstroke.

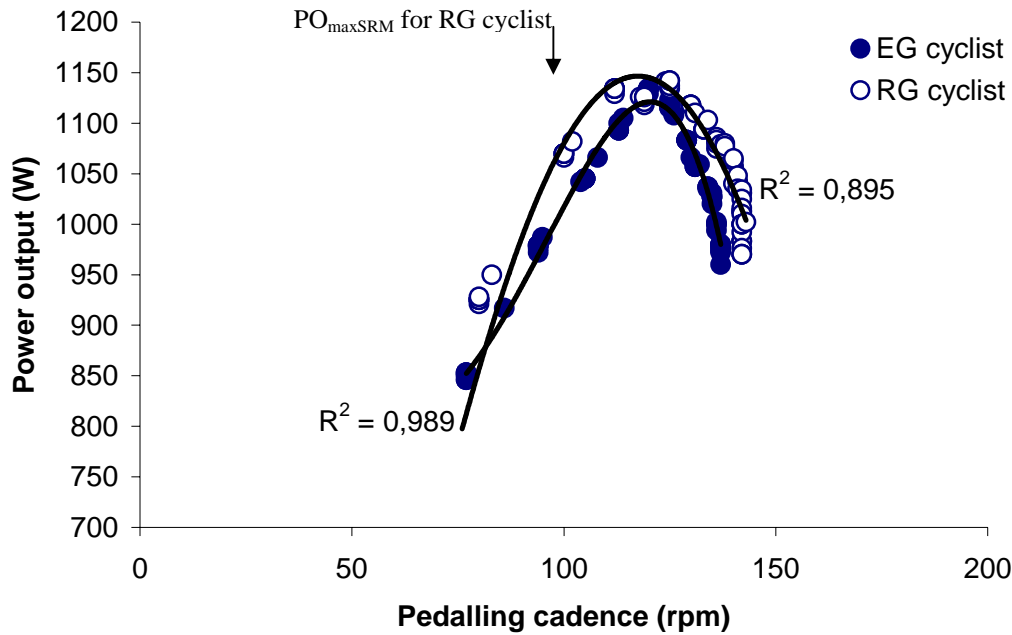


Fig. 2 : Power output according to the pedalling cadence (10 Hz) obtained from the seated sprint test of one cyclist of EG and RG. EG : Elite level group, RG : Regional level group,  $PO_{maxSRM}$ : Peak of power output value (10 Hz, W)

The crank profile torque was measured from the SRM device with the same procedure than Bertucci et al. (11) and Carpes et al. (17).

The first three pedalling cycles (corresponding at the  $PO_{max}$  values during sprint test) were selected for analysis of the pedalling pattern, using the method described by Bertucci et al. (11). The crank angle at the minimal  $CT$  value ( $CT_{mintop}$ ) when the pedal was in top position (close to the vertical orientation) was determined as the crank angle when the  $CT$  profile was lowest in the crank angle sector from 315 to 45°. The crank angle at the minimal  $CT$  value ( $CT_{minbot}$ ) when the pedal was in bottom position was determined as the crank angle when the  $CT$  was lowest in the crank angle sector from 135 to 225°. The pedal downstroke was defined as being between the two minimal values of propulsive torque (corresponding to  $CT_{mintop}$  and  $CT_{minbot}$ ) using the Arsac et al. (33) procedure. The peak  $CT$  values ( $CT_{peak}$ ) were determined for each pedal downstroke. Figure 1 illustrates an example of the analysis for the  $CT$  profile in one subject, recorded at 250 Hz and averaged over the first three pedalling cycles.

The  $PO$  was calculated according to the  $CT$  values and the pedalling cadence ( $n$ ) values for each pedalling cycle using :

$$PO = CT \times \varpi = CT \times \frac{2\pi}{60} n \tag{2}$$

where  $\varpi = 2\pi n/60$  was the crank angular velocity ( $rad.s^{-1}$ ).

The average values for  $PO$  ( $PO_{AV}$ ) were calculated (Fig. 3) for each downstroke following Arsac et al. (33).

The ratio between the  $PO_{max}$  values and the body mass ( $BM$ ) was calculated to take into account anthropometric differences between the cyclists. The same ratio was calculated for the  $CT_{peak}$ ,  $PO_{AV}$  and  $F0$ .

So, finally the defined set of “classical” criteria consisted of :

- 1)  $PO_{max}$  (250Hz, W),
- 2)  $PO_{maxSRM}$  (10Hz, W)
- 3)  $PO_{max}$  (W) /  $BM$  (kg),
- 4)  $PO_{AV}$  (W),
- 5)  $PO_{AV}$  (W) /  $BM$  (kg),

- 6)  $F_0$  (N),
- 7)  $F_0$  (N) / BM (kg),
- 8)  $V_0$  (rpm),
- 9)  $V_{opt}$  (rpm),
- 10) Mean cadence during the sprint test (rpm),
- 11)  $CT_{peak}$  (N.m) / BM (kg),
- 12) Mean cadence on the three first pedalling cycle (rpm)

## 2.4. New set of biomechanical parameters

A “new” set of biomechanical parameters was proposed in order to identify a new performance determinant, to be compared with the “classical” set of parameters:

- Relative Maximal Power Duration ( $RMPD_{90}$ ) criterion.  $RMPD_{90}$  was defined as the crank angle interval ( $^\circ$ ) which the instantaneous PO remained higher than 90% of the  $PO_{max}$  during left and right downstroke (Fig. 3);

-  $RMPD_{70}$  was defined as the crank angle interval during which the instantaneous PO remained higher than 70% of the  $PO_{max}$ .

- Average values for  $CT$  ( $CT_{AV}$ ) were calculated for each pedal downstroke. The ratio between the  $CT_{AV}$  values and the body mass (BM) was calculated to take into account one important anthropometric characteristic of the studied cyclists.

The “new “ set of biomechanical parameters were calculated on the first three pedalling cycle of the sprint test.

So, finally the defined “new” set consisted of :

- 1)  $RMPD_{90}$  ( $^\circ$ ),
- 2)  $RMPD_{70}$  ( $^\circ$ ),
- 3)  $CT_{AV}$  (N.m),
- 4)  $CT_{AV}$  (N.m) / BM (kg).

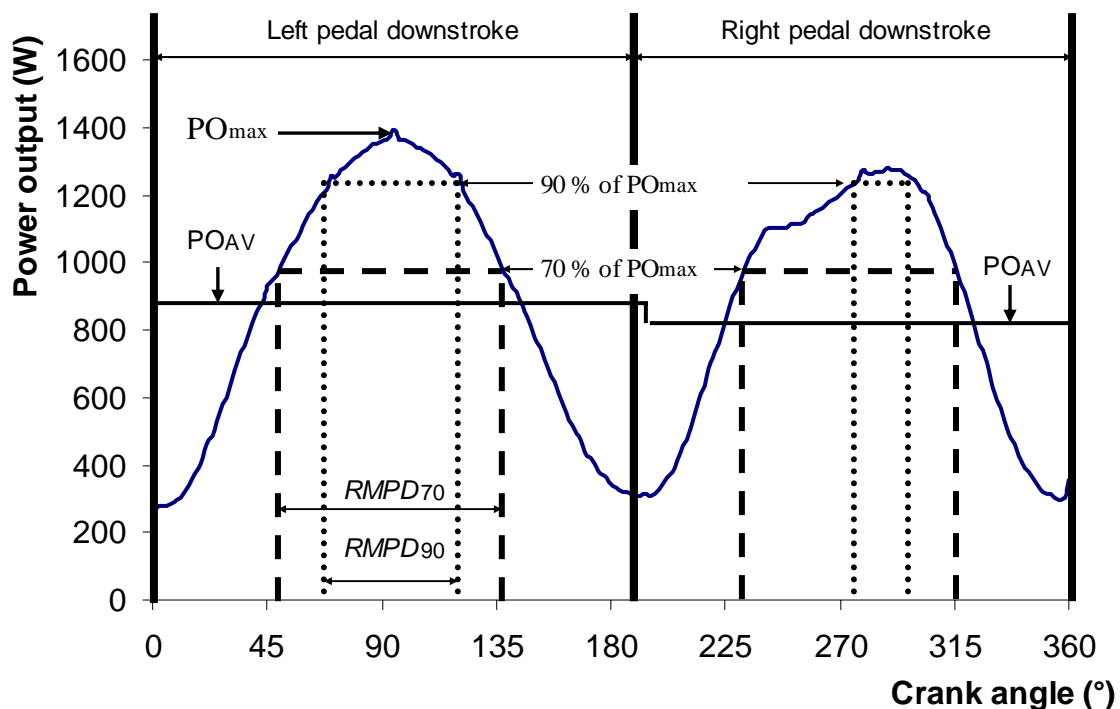


Fig. 3 : Determination of the maximal power output value ( $PO_{max}$ , 250 Hz, W), relative maximal power duration ( $^\circ$ ) higher than 90 and 70 % of  $PO_{max}$  ( $RMPD_{90}$  and  $RMPD_{70}$ ), and mean power output value ( $PO_{AV}$ , W) for each pedal downstroke.

## 2.5. Statistics

Data are presented as mean values  $\pm$  standard deviation. After a test of the normality of the variance, the difference between the two cyclist groups was determined using the non-parametric Wilcoxon test between the elite and regional groups for each biomechanical variable ( $p < 0.05$ ).

## 3. Results

Table 1 shows the classical set of biomechanical parameters. No significant ( $p < 0.05$ ) difference was observed between RG and EG with these parameters. Table 2 shows the new set of biomechanical parameters. In the seated position, the RG  $RMPD_{90}$  tended ( $p < 0.09$ ) to be lower than EG  $RMPD_{90}$  and RG  $RMPD_{70}$  tended ( $p < 0.06$ ) to be higher than EG  $RMPD_{70}$ . In the standing position, EG  $RMPD_{90}$  and  $RMPD_{70}$  were significantly ( $p < 0.05$ ) higher than RG  $RMPD_{90}$  and  $RMPD_{70}$ . Figure 4 shows power-crank angle curve, which shows the typical  $RMPD_{90}$  difference between the EG and RG cyclists.

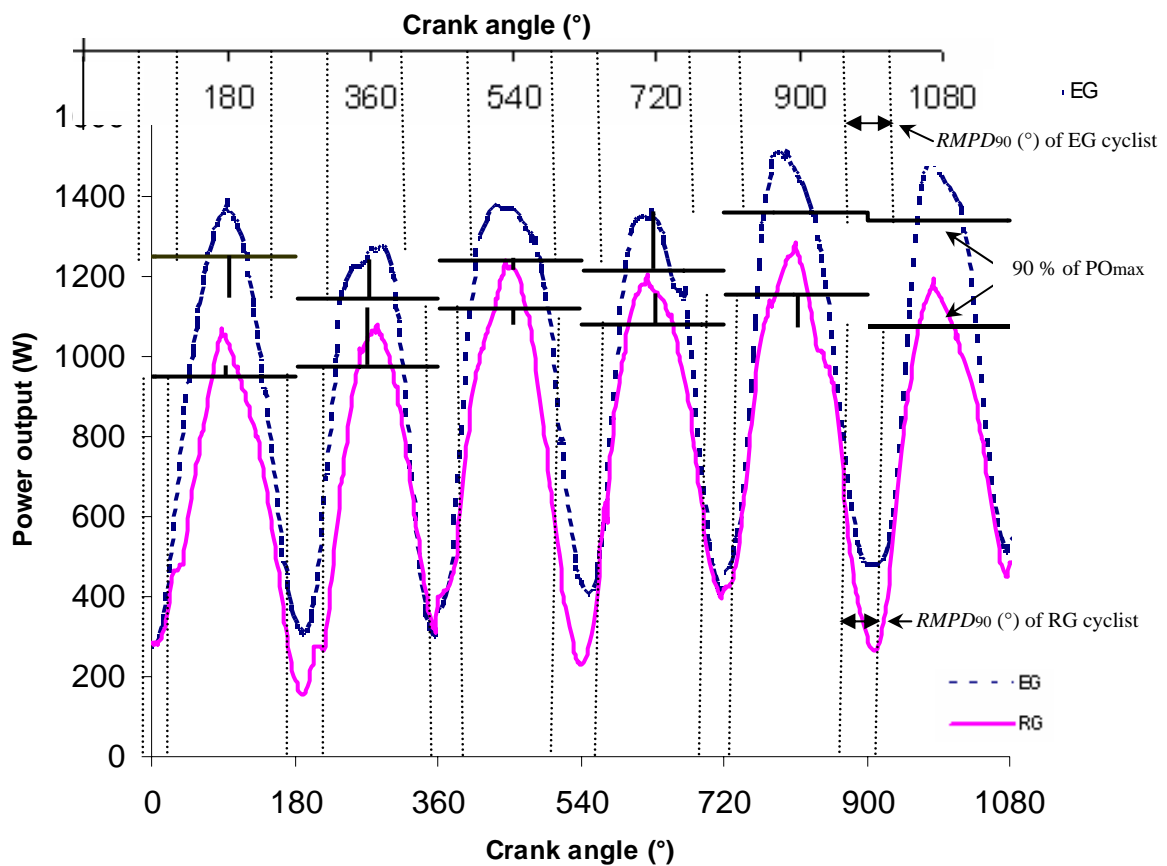


Fig. 4 : Sprint test analysis with the new set of biomechanical parameters for one cyclist of EG and RG.

$RMPD_{90}$  : Relative Maximal Power Duration when PO exceeded 90 % of the  $PO_{max}$  (°),  $PO_{max}$  : Peak of power output value (250Hz, W), EG: Elite level group, RG : Regional level group.

## 4. Discussion

### 4.1. Classical set of biomechanical parameters

Table 1 shows the results of the classical set of biomechanical parameters such as  $PO_{max}$ ,  $PO_{maxSRM}$ ,  $PO_{AV}$ ,  $CT_{peak}$ ,  $F_0$ ,  $V_0$ , mean pedalling cadence, maximal cadence,  $V_{opt}$ ,  $PO_{max} / BM$ ,  $PO_{AV} / BM$ ,  $CT_{peak} / BM$  and  $F_0 / BM$ . None of these classical parameters were significantly ( $p < 0.05$ ) different between RG and EG. These

results suggest that the classical set of biomechanical parameters could not distinguish cyclo-cross cyclist performance level. The  $PO_{\max}$  and  $PO_{\max} / BM$  values of this study were higher than the values obtain by Baron (2) in off-road national level mountain bikers ( $18.3 \pm 2.4$  vs  $14.9 \pm 1.1$  W/kg, respectively). These differences could be explained by three factors. First, that the same power meter was not used for the PO measurements in the two studies (Fitrocycle ergometer for Baron (2) and SRM in the present study). To the best of our knowledge the validity of PO measurement of Fitrocycle ergometer (Fitronic, Braislava, Czech Republic) has not been assessed. Secondly, the sampling rates of the two power meters used in the two studies were different (100 Hz for Baron study vs 250 Hz in our study). Thirdly, Baron (2) used an isokinetic sprint test whereas we used a non-isokinetic sprint test. The cyclo-cross EG cyclists  $PO_{\max}$  and  $V_{\text{opt}}$  in seated position were lower than the track cyclists (1) ( $1314 \pm 181$  vs  $1600 \pm 116$  W,  $94.5 \pm 12.2$  vs  $132 \pm 4.7$  rpm, respectively). The cyclo-cross EG cyclists  $CT_{\text{peak}}$  in standing position was lower than the Australian elite track cyclists (34) ( $167 \pm 29$  vs  $266 \pm 20$  N.m). According to Hautier et al. (9) these results suggest that the knee extensor muscle of track cyclist contains a higher proportion of fast twitch fibres compared with cyclo-cross cyclists. This conclusion is in accordance with the cyclo-cross exercise characteristics, which were relatively similar to those observed in mountain bike exercise, but mountain bike races are longer than cyclo-cross (120-180 vs 45-60 min, respectively). Also, mountain bikes are equipped with one or two suspensions. The mountain bike race requires cyclists with high aerobic power (24). In both sports the exercise intensity is high, averaging 90 % of the maximal heart rate (2, 24). However, the cyclo-cross EG cyclists had  $PO_{\max}/BM$  values close to the world class track cyclists ( $18.3 \pm 2.4$  vs  $19.3 \pm 1.3$  W.kg<sup>-1</sup>, respectively). The high  $PO_{\max} / BM$  value suggests that this biomechanical parameter is an important one for the cyclo-cross cyclist. These results are in line with Baron (2) who suggested that a maximal anaerobic power was an important determinant of the performance in off-road cycling.

Table 1: Classical set of biomechanical parameters

	<i>Seated position</i>		<i>Standing position</i>	
	RG	EG	RG	EG
<b><math>PO_{\max}</math> (W)</b>	1287.0 ± 157.7	1314.3 ± 181.5	1504.6 ± 223.8	1541.4 ± 191.6
<b><math>PO_{\max SRM}</math> (W)</b>	1067.5 ± 120.7	1072.3 ± 198.0	1153.7 ± 161.4	1161.6 ± 160.4
<b><math>CT_{\text{peak}}</math> (N.m)</b>	153.7 ± 24.2	153.4 ± 27.9	170.3 ± 25.4	167.1 ± 29.6
<b><math>PO_{AV}</math> (W)</b>	867.0 ± 112.3	891.8 ± 135.7	966.7 ± 152.0	1010.5 ± 142.7
<b>Mean cadence for the three first pedalling cycle (rpm)</b>	80.5 ± 12.8	83.5 ± 17.6	84.9 ± 4.8	90.5 ± 20.6
<b><math>V_{\text{opt}}</math> (rpm)</b>	84.3 ± 6.0	94.5 ± 12.2	96.6 ± 16.3	93.8 ± 10.1
<b><math>V_0</math> (rpm)</b>	293.8 ± 62.6	258.8 ± 14.5	292.2 ± 70.8	299.9 ± 34.6
<b><math>F_0</math> (N)</b>	822.4 ± 134.9	873.3 ± 83.3	862.2 ± 111.6	922.6 ± 123.3
<b><math>PO_{\max} / BM</math> (W.kg<sup>-1</sup>)</b>	17.6 ± 2.2	18.3 ± 2.4	20.6 ± 3.1	21.5 ± 3.0
<b><math>CT_{\text{peak}} / BM</math> (N.m.kg<sup>-1</sup>)</b>	2.1 ± 0.3	2.1 ± 0.3	2.3 ± 0.3	2.3 ± 0.3
<b><math>PO_{AV} / BM</math> (W.kg<sup>-1</sup>)</b>	12.5 ± 1.4	12.4 ± 1.9	14.0 ± 1.9	14.1 ± 2.0
<b><math>F_0 / BM</math> (N.kg<sup>-1</sup>)</b>	11.9 ± 1.6	12.1 ± 0.6	12.5 ± 1.1	12.8 ± 1.6
<b>Mean cadence during sprint test (rpm)</b>	121.1 ± 15.2	123.6 ± 15.5	114.8 ± 9.9	119.5 ± 11.5
<b>Maximal cadence (rpm)</b>	137.3 ± 19.8	142.4 ± 20.1	132.1 ± 9.4	137.3 ± 14.2

No significant differences were observed between RG and EG ( $p < 0.05$ ).

RG : Regional level group, EG: Elite level group,  $PO_{\max}$  : Peak of power output value (250Hz, W),  $PO_{\max SRM}$  : Peak of power output value (10Hz, W),  $CT_{\text{peak}}$  : The peak torque value (N.m),  $CT_{\text{mintop}}$  : Crank angle at the minimal

CT value when the pedal was in top position ( $^{\circ}$ ), CT<sub>minbot</sub> : Crank angle at the minimal CT value when the pedal was in bottom position ( $^{\circ}$ ), V<sub>opt</sub> : Pedalling cadence at PO<sub>max</sub> (rpm), V<sub>0</sub> : Theoretical maximal pedalling cadence V<sub>0</sub> (rpm), F<sub>0</sub> : Theoretical maximal force (N), BM : Body mass (kg), PO<sub>AV</sub> : Average of the PO values during a pedal downstroke (W).

#### 4.2. New set of biomechanical parameters

Table 2 and Fig. 4 show the results of the new set of biomechanical parameters like  $CT_{AV}$ ,  $CT_{AV} / BM$ ,  $RMPD_{90}$  and  $RMPD_{70}$ . The results of the present study indicate that in the seated and standing positions, RG  $RMPD_{90}$  tended ( $p < 0.09$  and  $p < 0.05$ , respectively) to be lower than EG  $RMPD_{90}$  ( $49.4 \pm 12.0$  vs  $55.6 \pm 11.9$   $^{\circ}$  and  $46.1 \pm 8.6$  vs  $56.0 \pm 10.6$   $^{\circ}$  respectively). In the seated and standing positions, RG  $RMPD_{70}$  tended ( $p < 0.06$  and  $p < 0.05$ , respectively) to be higher than EG  $RMPD_{70}$  ( $95.7 \pm 13.1$  vs  $90.7 \pm 11.7$   $^{\circ}$  and  $84.6 \pm 9.1$  vs  $90.9 \pm 19.0$   $^{\circ}$ , respectively). These results suggest that the EG generate high PO (higher than 90 % of PO<sub>max</sub>) values during a larger proportion of the pedal downstroke compared with the RG. They also suggest that the propulsive torque repartition during pedaling cycle differed between RG and EG. Coyle et al. (13) have previously studied during exercise at submaximal intensity differences in crank torque profile, vertical and horizontal forces applied to the pedal (for a single lower limb) between road cyclist EG and RG. During 30 min time trial the  $CT_{peak}$  was higher (+ 13 %) for EG compared with RG at a low mean PO of 162 W and a pedalling cadence of 90 rpm. This last study indicates that for submaximal intensity exercise the road cyclist EG use a pedalling strategy different to RG. Coyle et al. (13) suggests that the different pedalling strategy between EG and RG could be explained by the ability of the EG to recruit a relatively larger proportion of muscle with each pedalling cycle. In the present study there was no significant difference in  $CT_{peak}$  values between EG and RG. However, it is possible that this muscle recruitment characteristic could explain the higher  $RMPD_{90}$  in the EG compared with the RG during a sprint test. This hypothesis could be confirmed by further studies using electromyography.

The RMPD differences between RG and EG could be explained either by the possibility that RG cannot generate high PO values over an extended period during a sprint test, or that the EG have developed (with intensive training) a specific pedalling technique. A high RMPD<sub>90</sub> value indicates that the athlete is characterized by a continuous region of maximal forces, the accelerations being well represented at the beginning and end of the pedal downstroke. In other words, a cyclist who has a high RMPD applies a significant force on the pedal for a longer time and reaches the maximal CT level faster. These preliminary results were obtained from the SRM device and suffice to measure the downstroke propulsive torque of one leg and the upstroke propulsive torque of the other leg. We encourage further studies to confirm the difference between RG and EG using two instrumented pedals capable of measuring the tangential and radial pedal forces such as Sanderson 16 performed at submaximal intensity.

Table 2: New set of biomechanical parameters

	<i>Seated position</i>		<i>Standing position</i>	
	RG	EG	RG	EG
<b><math>CT_{AV}</math> (N.m)</b>	103.1 $\pm$ 13.5	103.1 $\pm$ 14.9	108.9 $\pm$ 13.8	110.0 $\pm$ 17.7
<b><math>CT_{AV} / BM</math> (N.m.kg<sup>-1</sup>)</b>	1.4 $\pm$ 0.2	1.4 $\pm$ 0.2	1.5 $\pm$ 0.2	1.5 $\pm$ 0.2
<b><math>RMPD_{90}</math> (<math>^{\circ}</math>)</b>	49.4 $\pm$ 12.0 <b>t<sub>2</sub></b>	55.6 $\pm$ 11.9	46.1 $\pm$ 8.6 *	56.0 $\pm$ 10.6
<b><math>RMPD_{70}</math> (<math>^{\circ}</math>)</b>	95.7 $\pm$ 13.1 <b>t<sub>1</sub></b>	90.7 $\pm$ 11.7	84.6 $\pm$ 9.1 *	90.9 $\pm$ 10.0

\* : Significant differences between RG and EG ( $p < 0.05$ )

t<sub>1</sub> : tendency to be different between RG and EG ( $p < 0.06$ )

t<sub>2</sub> : tendency to be different between RG and EG ( $p < 0.09$ )

RG : Regional level group, EG: Elite level group,  $CT_{AV}$  : Average of the CT values during an pedal downstroke (N.m), BM : Body mass (kg),  $RMPD_{90}$  : Relative Maximal Power Duration when PO exceeded 90% of the PO<sub>max</sub> ( $^{\circ}$ ),  $RMPD_{70}$  : Relative Maximal Power Duration when PO exceeded 70% of the PO<sub>max</sub> ( $^{\circ}$ ).

The ability to generate a high PO of short duration plays a vital role for the off-road cyclists in a mass

start event during steep climbing, when sprinting to pass slower riders at the end of a race (2) and when rolling resistance is increased due to soil consistency (*i.e.* mud). However, the present study revealed no difference in  $PO_{max}$  between RG and EG. It is possible that the EG can produce its  $PO_{max}$  value over a longer time (as suggested by the higher  $RMPD_{90}$ ) and more times than RG. This could suggest that EG have lower limb muscle with higher endurance for high PO. This hypothesis could be partly tested *e.g.* by analysis of the drop of power output during the Wingate test or using a Hautier et al. (35) procedure consisting of several sprint exercise repetitions.

### 4.3. Conclusion

The results of the present study show that there is no significant difference between RG and EG concerning the set of biomechanical parameters classically employed (8, 9, 10, 30, 31) to analyse the sprint test. However the new set of biomechanical parameters such as  $RMPD_{90}$  and  $RMPD_{70}$  discriminated between RG and EG (especially in the standing position). The  $RMPD_{90}$  results indicate that EG cyclo cross cyclists can generate a higher propulsive torque over a greater range of crank angles during the pedalling cycle of the sprint test than RG. It may be interesting for the coach to utilize  $RMPD_{90}$  as a fitness criterion.

## 5. Glossary

EG	Elite level group
RG	Regional level group
BM	Body mass (kg)
CT	Crank torque (N.m)
$CT_{peak}$	The peak torque value (N.m)
$CT_{mintop}$	Crank angle at the minimal CT value when the pedal was in top position (°)
$CT_{minbot}$	Crank angle at the minimal CT value when the pedal was in bottom position (°)
PO	Power output (W)
$PO_{max}$	Peak of power output value (250Hz, W)
$PO_{maxSRM}$	Peak of power output value (10Hz, W)
$F_0$	Theoretical maximal force (N)
$V_0$	Theoretical maximal pedalling cadence $V_0$ (rpm)
$V_{opt}$	Pedalling cadence at $PO_{max}$ (rpm)
$RMPD_{90}$	Relative Maximal Power Duration when PO exceeds 90% of the $PO_{max}$ (°)
$RMPD_{70}$	Relative Maximal Power Duration when PO exceeds 70% of the $PO_{max}$ (°)
AV	Average
$CT_{AV}$	Average of the CT values during an pedal downstroke (N.m)
$PO_{AV}$	Average of the PO values during an pedal downstroke (W)

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