Differences in pedalling technique between road cyclists of different competitive levels

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Title

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Abstract

The purpose of this study was to compare the pedalling technique in road cyclists of different competitive levels. Eleven professional, thirteen elite and fourteen club cyclists were assessed at the beginning of their competition season. Cyclists' anthropometric characteristics and bike measurements were recorded. Three sets of pedalling (200, 250, 300 W) on a cycle ergometer that simulated their habitual cycling posture were performed at a constant cadence (~90 rpm), while kinetic and kinematic variables were registered. The results showed no differences on the main anthropometric variables and bike measurements. Professional cyclists obtained higher positive impulse proportion (1.5-3.3% and $p<0.05$), mainly due to a lower resistive torque during the upstroke (15.4-28.7% and $p<0.05$). They also showed a higher ankle range of movement (ROM, 1.1-4.0º and $p<0.05$). Significant correlations ($p<0.05$) were found between the cyclists' body mass and the kinetic variables of pedalling: positive impulse proportion ($r= -0.59 – -0.61$), minimum ($r= -0.59 – -0.63$) and maximum torques ($r= 0.35 – 0.47$). In conclusion, professional cyclists had better pedalling technique than elite and club cyclists, because they opted for enhancing pulling force at the recovery phase to sustain the same power output. This technique depended on cycling experience and level of expertise.

Keywords: cycling; biomechanics; performance; crank kinetics; joint kinematics.

Introduction

Cycling performance depends on several physiological, training and biomechanical factors (Faria et al., 2005a; 2005b). The influence of some biomechanical factors such as aerodynamics (García-López et al., 2008), bike measurements (Peveler and Green, 2011) or noncircular chainrings (Rodríguez-Marroyo et al., 2009) on cycling performance has been demonstrated. However, the influence of other biomechanical factors such as pedalling technique (i.e. forces applied to the pedals and transferred to the cranks) is still an issue of debate (Gregor et al., 1991; Leirdal and Ettema, 2011; Theurel et al., 2012). This is in contrast to the relative consensus about the influence of the ability to save energy (i.e. pedalling efficiency) on cycling performance (Leirdal and Ettema, 2011; Hopker et al., 2012). Some recent studies have found correlations between the forces applied to the pedals and the pedalling efficiency (Zameziati et al., 2006; Candotti et al., 2007), while others have not (Korff et al., 2007; Mornieux et al., 2008). It seems that the kinetic variables selected to measure pedalling technique (i.e. pedal force effectiveness or ratio between tangential and total force applied to the pedal) could be responsible for this discrepancy (Leirdal and Ettema, 2011).

Although some educational books have affirmed that professional cyclists have better pedalling technique than recreational cyclists (Cavanagh and Sanderson, 1986; Broker, 2003), the few experimental studies on this topic are inconclusive (Sanderson, 1991; Sanderson et al, 2000). Coyle et al. (1991) observed that elite cyclists applied higher force during the downstroke than sub-elite cyclists, but sub-elite cyclists had higher pedal force effectiveness. On the contrary, other studies have shown higher pedal force effectiveness in elite cyclists than non-cyclists (Mornieux et al., 2008). Nevertheless, in both studies elite cyclists applied higher resultant force and effective impulse during the downstroke phase than sub-elite and non-cyclists, respectively; and this could mean a worse pedalling technique for the elite cyclists. It seems that the different absolute power outputs used by both studies to compare elite cyclist with respect to sub-elite and non-cyclists (346 *vs.* 311 W and 274 *vs.* 232 W, respectively) could have conditioned the interpretation of the results (Leirdal and Ettema, 2011).

Using the same absolute power outputs, Sanderson (1991) did not find significant differences in pedalling technique between competitive and non-competitive cyclists while pedalling at 100 and 235 W. These results were justified, in part, by the relatively low power output used for the competitive cyclists. A few years later, Sanderson et al. (2000) compared recreational and competitive cyclists, who pedalled between 100 and 400 W (at 60, 80 and 100 rpm). No significant differences between the two groups were observed for forces or impulses, although recreational cyclists showed a clear trend of generating larger positive and negative impulses than competitive cyclists. These results were justified, in part, by the different anthropometric characteristics of the two groups of cyclists.

None of the previous studies evaluated pedalling kinematics as an important factor of pedalling technique (Bini et al., 2010a). Furthermore, they did not show or compare the bike measurements of the different groups of cyclists, which could affect pedalling kinematics and kinetics (Ferrer-Roca et al., 2011; Bini et al., 2014). Additionally, to the best of our knowledge, no study reported the effects of training on pedalling technique, which could be important when comparing cyclists of different competitive levels and with different training volume along the season. Therefore, the main purpose of this study was to compare the pedalling technique (kinematic and kinetic analysis) in cyclists of different competitive levels (professional, elite and club), taking into account the above-mentioned aspects.

Secondarily, the effect of pedalling power output (200, 250 and 300 W) and the preseason training (professional cyclists) on the pedalling technique were analysed.

Methods

Participants

Thirty-eight road cyclists participated in this study (Table 1) and were classified into three groups or categories according to previous conventions (Ansley and Cangley, 2009): Category 1, professional cyclists from a UCI ProTour Team (n= 11), which cycled more than 30.000 km per season, in training and competition; Category 2, elite cyclists from a UCI Continental Team (n= 13), which cycled between 15.000 and 30.000 km per season; and Category 3, club cyclists belong to different competition teams (n= 14), which cycled between 5.000 and 15.000 km per season. All of them participated voluntarily and none reported any medical problem at the time of the study. They were informed of the procedures, methods, benefits, and possible risks involved in the study, and written consent was obtained before starting the study. It was approved by the University Ethics Committee and met the requirements of the Declaration of Helsinki for research on human beings.

Procedures

All cyclists were assessed at the beginning of their competition season (February–March). Additionally, nine of the professional cyclists were assessed at the beginning of their preseason (November), after a month off training. During the preseason, the professional cyclists performed a progression on the total training volume from 15 to 30 hours per week. Training contents were divided in two main blocks: endurance training and strength training. For endurance training, the cyclists performed a polarized training intensity distribution, ~80, ~15 and ~5 % of total training volume were performed at low (below the ventilatory threshold), moderate (between the ventilatory and respiratory compensation thresholds) and hard intensities (above the respiratory compensation threshold), respectively. The strength training was performed 2 days per week during 4 weeks, and consisted on 3 phases: general (circuit training), general explosive (squat training) and specific (starts and sprints on the bike). During this period, their maximum power output during a ramp protocol (1 min stages) increased from 5.77 ± 0.33 to 7.13 ± 0.63 watts per kilogram, and their respiratory compensation threshold increased from 4.29 ± 0.40 to 5.31 ± 0.36 watts per kilogram. The training during the preseason for the elite and club cyclists was not monitored, and their physical fitness was not evaluated.

The assessment protocol was performed in a one-day session under similar environmental conditions (20–25º C, 60–65% relative humidity). The cyclists arrived at the laboratory (800 m altitude) with their bikes after a 24-hour period with no hard training. Firstly, the cyclists´ anthropometrical characteristics and bikes were measured. After this, the bikes´ measurements (crank inclusive) and the clipless pedals were replicated in the cycle ergometer, where the cyclists performed a 10-min warm-up period at a power output of 100 W, with a 5-min rest before starting the test. The test consisted in three sets of 5-min of pedalling at 200, 250 and 300 W with a 6-min rest in between. These power outputs were selected because they are representative of the effort in professional road cyclists (Vogt et al., 2007) and could be sustained by club cyclists during a short period of time (Pinot and Grappe, 2011). The cyclists received continuous feedback about their cadence and were asked to keep it constant at 90 rpm to avoid any possible influence of cadence on the mechanical variables of pedalling (Neptune and Herzog, 1999). The selected cadence is representative of the seated pedalling cadence during flat stages (Vogt et al., 2007; Rodríguez-Marroyo et al., 2008). Simultaneous kinematic and kinetic analyses of pedalling were performed during the three sets of effort. The position during riding was standardized, with the cyclists' hands on the brakes.

Anthropometric and bicycle measurements

An anthropometric tape (Holtain LTD; Crymych, UK) and a Harpenden anthropometer (CMS instruments, London, UK) were used to measure both bike and anthropometric dimensions. All anthropometric measurements were performed by the same researcher following the international guidelines for anthropometry (Marfell-Jones et al., 2006). Inseam length of the cyclists was recorded as the distance from the ischium to the floor (Ferrer-Roca et al., 2012). Next, the main bike measurements were recorded (Figure 1). The relative saddle height (expressed in percentage) was calculated by dividing the saddle height by the inseam length (Gregor et al., 1991).

*****Figure 1 near here*****

Kinetic analysis

Kinetic analysis was performed on a validated electromagnetically braked cycle ergometer (Lode Excalibur Sport, Lode BV, Groningen, Netherlands) (Reiser et al., 2000), which allowed the measurement of the torque exerted on the left and right cranks independently every 2º of a complete revolution (Dorel et al., 2009; Hansen et al., 2012). Before starting the study, a dynamic calibration procedure was performed (Calibrator 2000, Lode BV, Groninger, Netherlands). Sixty essays between 25-2000 W of pedalling power and 40-120 rpm of pedalling cadence were compared (Calibrator 2000 *vs* Lode Excalibur Sport). The torque measurements showed a coefficient of variation of 0.96 ± 1.20% (95% of confidence interval between 0.72 – 1.19%), and an intraclass correlation coefficient of 0.999 ($p<0.001$). Besides, the zero adjustment was done before each testing session. All complete 5-min intervals of the three sets of pedalling were recorded (LEM software, Lode BV, Groninger, Netherlands). For the kinetic analysis, the mean of ~360 complete revolutions from minute one to minute five were selected, and values of right and left cranks were averaged (Figure 2). The following mechanical variables were directly obtained from the software: pedalling rate, maximum torque and minimum torque. Additionally, torque-time data and crank arm length were exported to ASCI format to calculate the rest of the mechanical variables: positive impulse, negative impulse and the relationship between both variables. This relationship is represented as the positive impulse proportion (expressed in percentage).

$$\text{Positive impulse proportion (\%)} = \frac{\text{positive impulse } \times 100}{\text{positive impulse} + \ |\text{negative impulse}|}$$

*****Figure 2 near here*****

Kinematic analysis

Kinematic analysis of the cyclists' right side was performed assuming symmetry of motion between left and right sides (Heil et al., 1997). Five reflective markers of 10 mm diameter were attached to the skin of the cyclists (greater trochanter, lateral femoral epicondyle and lateral malleolus) and to the bikes (crank and pedal axes of rotation) (Bini et al., 2010a; Ferrer-Roca et al., 2012). A high-speed digital video camera (Sony Handycam HDR-HC7, Sony Inc, Europe, 200 Hz and 720 × 576 pixels) and a floodlight were positioned 4 m away from the sagittal plane, where a calibration frame was placed (1.00 × 1.20 m). Automatic tracking, processing and analysing data were performed by a specific software (Kinescan-IBV, Version 2001, Institute of Biomechanics of Valencia, Valencia, Spain) (García-López et al., 2008). Six complete revolutions were analysed in minutes 2 and 4 of every trial as representative values. Sagittal hip, knee and ankle angles (Figure 2) were determined following previous conventions (Bini and Diefenthaeler, 2010). Angular position values were expressed as flexion (minimum angle) and extension (maximum angle). The range of movement (ROM) was also determined.

Statistical analysis

The results are expressed as mean ± SD. SPSS+ V.17.0 statistical software was used (SPSS, Inc., Chicago, IL, USA). Shapiro-Wilk test was applied to ensure a Gaussian distribution of all variables. Pearson correlation coefficient (r) was used to assess the relationships between variables. The calibration errors and the reliability of the Lode Excalibur Sport ergometer for torque measurements were assessed using the coefficient of variation and the intraclass correlation coefficient (García-López et al., 2013). Multivariable Analysis of Variance (MANOVA) was used to analyse the effect of competitive level (professional, elite and club) and pedalling power output (200, 250 and 300 W) on pedalling technique (kinematics and kinetics), taking into account as covariates the bike and anthropometric dimensions, as well as kilometres of training. One-way Analysis of Variance (ANOVA) was used to analyse the effect of competitive level (professional, elite and club) on cyclists' characteristics and bicycle measurements. ANOVA with repeated measures was used to analyse the effect of the preseason training (professional cyclists) on pedalling technique, taking into account the body mass changes during the preseason as a covariate. Newman-Keuls post hoc analysis was used to establish statistical differences between means. Effect sizes (ES) of the differences (Cohen's *d*) were also calculated (Cohen, 1988). The magnitude of the differences were considered to be trivial (ES < 0.2), small (0.2 ≤ ES < 0.5), moderate (0.5 ≤ ES < 0.8), and large (ES ≥ 0.8). Values of $p<0.05$ were considered statistically significant.

Results

Table 1 shows significant effects of competitive level on age (*d* = 0.83, large effect), cycling experience (*d* = 0.89, large effect), training volume (*d* = 0.65, moderate effect), body mass index (*d* = 0.94, large effect) and distance between the front of the saddle and the middle of the handlebars (*d* = 0.86, large effect).

*****Table 1 near here*****

Table 2 shows significant effects of competitive level on maximum torque (*d* = 0.56, moderate effect), minimum torque (*d* = 1.33, large effect) and positive impulse proportion (*d* = 0.67, moderate effect). Professional cyclists obtained higher positive impulse proportion (between 1.5-2.7% and 1.7-3.3%), and lower maximum (between 2.6-7.0% and 4.9-7.0%) and minimum torques (between 15.4-20.4% and 20.0-28.7%) compared to the elite and club cyclists, respectively. Significant effects of pedalling power output on maximum torque (*d* = 7.90, large effect), minimum torque (*d* = 7.40, large effect) and positive impulse proportion (*d* = 7.74, large effect) were also observed. No significant combined effect of competitive level and pedalling power output on kinetic variables of pedalling was found. However, significant correlations ($p<0.05$) were found between cyclists' body mass and kinetic variables at 200, 250 and 300 W. Heavier cyclists obtained a lower positive impulse proportion (r= -0.59, -0.59 and -0.61, respectively), and minimum torque (r= -0.63, -0.60 and -0.59, respectively) and maximum torque were higher (r= 0.35, 0.42 and 0.47, respectively) to pedalling at the same power output when compared to slim cyclists.

*****Table 2 near here*****

Table 3 shows significant effects of competitive level on ankle ROM (*d* = 1.04, large effect) and hip flexion (*d* = 0.46, small effect). Additionally, pedalling power increased ankle flexion (115.2 ± 7.3, 114.0 ± 6.6 and 112.9 ± 6.7 degrees, respectively; *d* = 0.55, moderate effect) and ankle ROM (21.4 ± 6.4, 22.1 ± 6.0 and 23.5 ± 5.5 degrees; *d* = 0.36, small effect). No significant combined effect of competitive level and pedalling power output on kinematic variables was found.

*****Table 3 near here*****

Table 4 shows a significant decrease in the minimum torque (d = 0.95, large effect) after the preseason training in the professional cyclists group, without changes in the rest of biomechanical variables. However, taking into account the body mass before and after training as covariate (70.0 ± 6.7 *vs* 68.1 ± 5.1 kg, *d* = 2.55, large effect), no significant effect of the preseason on kinetic and kinematic variables was observed.

*****Table 4 near here*****

Discussion

The main outcome of the present study was to demonstrate that competitive level affects pedalling technique in road cyclists (Table 1). Professional cyclists had a better pedalling technique (i.e. higher positive impulse proportion) than elite and club cyclists when pedalling at 200 W or more. This was due to the lower minimum torque during the upstroke (less negative torque values), and to kinematic differences in ankle (increased range of movement). These findings are particularly significant because previous studies have not shown differences in pedalling technique (kinetic analysis) between cyclists of different competitive levels (Coyle et al., 1991; Sanderson, 1991; Sanderson et al., 2000). Additionally, pedalling kinematics was evaluated as an important factor of pedalling technique (Bini et al., 2010a).

To date, there is controversy about the use of pulling technique (less negative torque values during upstroke) in road cycling. Two previous studies analysed the acute effects of changing pedalling technique on physiological (i.e. gross efficiency) and biomechanical variables (i.e. pedal force effectiveness). Briefly, the cyclists were encouraged to active pulling-up action during the upstroke, and biomechanical variables improved (e.g. index of pedal force effectiveness increased between 14.2-23.5%) while physiological variables declined (e.g. gross efficiency decreased between 0.8-1.2%) (Korff et al., 2007; Mornieux et al., 2008). They used sets of submaximal pedalling from 3.30 to 6.00 min. Contrary, a recent study demonstrated that the pulling technique did not affect gross efficiency after 15 min of submaximal pedalling, while negative force during upstroke decreased ~18% (Theurel et al., 2012). In addition, it could reduce muscle fatigue after prolonged cycling exercise by decreasing the activity of the main leg extensor muscles during downstroke (i.e. vastus lateralis and rectus femoris as knee extensor) and increasing the activity of the main leg flexor muscles during upstroke (i.e. rectus femoris as hip flexor, biceps femoris and tibialis anterior) (Mornieux et al., 2008; Theurel et al., 2012).

In the same line of evidence, another recent study obtained an increase in the performance and a reduction of the phase where the negative torque occurs after heavy strength training (Hansen et al., 2012). They hypothesized that a higher hip-flexor muscles strength could have been responsible for these changes, allowing a better lift of the leg mass against gravity, improving the transition around the top dead centre and delaying the fatigue. These two last studies are in consonance with the results of the present study, where the professional cyclists showed less negative torque values during the upstroke than elite and club cyclists (between 15.4 and 28.7%), which could be an adaptation to training. Hip-flexor muscles strength and timing of muscle activity could be better in the professional cyclists, but future studies measuring strength and using electromyography are necessary to confirm this hypothesis. The present study did not change the natural technique of the cyclists, which is an important difference with respect to some of the above-mentioned studies (Korff et al., 2007; Mornieux et al., 2008).

The bike measurements of the different groups of cyclists were registered and compared (Table 1). For example, relative saddle height (percentage of inseam length) of all groups of cyclists was between 109.2-109.5%, into the range of 108.6-110.4%, which was recently recommended (Ferrer-Roca et al., 2012). This is important, because previous studies did not take this aspect into account (Coyle et al., 1991; Sanderson, 1991; Sanderson et al., 2000), and it could have affected the pedalling technique (Bini et al., 2010b; Ferrer-Roca et al., 2012). Besides, in the present study, a multivariable analysis of variance taking into account the bicycle dimensions as covariate was performed. Therefore, the differences in pedalling technique were not due to different bicycle configurations, because only the distance between the front of the saddle and the middle of the handlebars was lower in the club cyclists, possibly due to their less cycling experience, which could imply a more comfortable fit. This difference did not affect the interpretation of the results, because this distance was similar between professional and elite cyclists, while their pedalling technique was different.

Differences in pedalling technique were due to cycling experience (Table 1), which is one of the main factors in achieving a high level of sporting performance (Tucker and Collins, 2012), and specifically a high level of cycling performance (Edwards et al., 2009). Differences were not due to age (similar between professional and club cyclists), body mass index (similar between professional and elite cyclists), cyclists´ body mass or height (similar between the three groups) or training volume at the beginning of the competition season (highest in the professional cyclists). The differences in training volume (3000–4000 km) could not fully justify the differences in pedalling technique, because the effects of cycling ~9000 km in the professional cyclists represented changes in kinetic variables lower than half of the differences between groups (Tables 2 and 4). Additionally, when cyclists' body mass at the beginning and at the end of the preseason was taken into account as covariate, no significant overall effect of this training on both kinematic and kinetics variables was observed. Thus, the decrease in minimum torque could have been due to the loss of body mass and not to the preseason training.

The correlation between the cyclists' body mass and the kinetic variables highlights the importance of taking into account the body mass when different groups of cyclists are compared (assuming that heavier cyclists had greater leg mass). During pedalling at 90 rpm the inertial effect of the legs represented ~ 40% of the total crank torque (Neptune and Herzog, 1999), and this could mean an increase in the minimum torque during upstroke (Sanderson, 1991). Previous studies which compared pedalling technique in road cyclists used groups of cyclists with differences in body mass between 5-7 kg (Sanderson, 1991; Sanderson et al., 2000), and their statistical models did not had into account the body mass as covariate. The non-controlled mass effect on pedalling technique could explain why these studies did not find differences between cyclists of different competitive levels.

The increase in power output affected kinetic variables (Table 2), and the maximum torque during downstroke increased while the torque values during upstroke were less negative, causing better positive impulse proportion as power output increased. These results were in line with previous studies where the main effect of increasing power output at constant cadence was an increase in the maximum force applied to the pedal (Sanderson, 1991; Sanderson et al., 2000). The decrease in minimum torque as power output increased was considered a *"strategy of the rider to improve the effective application of force by reducing the need for the propulsive leg to overcome the recovery leg"* (Sanderson, 1991). Kinetic differences between groups were higher at 250 and 300 W than at 200 W, possibly because it was a relatively low power output for the competitive cyclists to highlight their superior pedalling technique (Sanderson et al., 2000). The present study utilized no more than 300 W of power output because club cyclists were not able to sustain it for 5 min.

The fact that power output affected kinematic variables was in line with a previous study, which demonstrated changes in the ankle joint (higher flexion and ROM), but not at the knee joint (Bini and Diefenthaeler, 2010). These results were very similar to those obtained in the present study when different competitive levels (Table 3) and power outputs (200, 250 and 300 W) were compared, and could be an adaptation of the professional cyclists to pedal normally at highest power outputs. Other studies agreed with these results, showing that ankle joint was more sensitive than the knee joint to changes in pedalling biomechanics (Savelberg et al., 2003; Shan, 2008). The results of the present study showed differences in ankle ROM between the three groups of cyclists (Table 3), and were in accordance with previous observations (Cavanagh and Sanderson, 1986; Chapman et al. 2009). Chapman et al. (2009) also observed that ankle ROM was higher (i.e. 21.5 ± 9.0º *vs* 13.2 ± 7.7º, respectively) and inter-joint coordination was better (i.e. hip *vs* ankle flexion-extension and knee *vs* ankle flexion-extension) in elite cyclists when compared to novice cyclists.

During the preseason, the maximum torque and the positive impulse proportion of the professional cyclists did not change (Table 4). The minimum torque decreased, possibly due to the loss of body mass (~ 2 kg). The major differences were observed at 300 W, possibly because the cyclists highlighted their best potential (Sanderson et al., 2000). The non-significant changes in positive impulse proportion at 200, 250 and 300 W (0.3, 1.0 and 1.4%, respectively) were well below the observed differences between professional and club cyclists (1.7, 2.2 and 3.3%, respectively) (Table 2). To the best of our knowledge, no previous longitudinal studies have investigated the effects of training on the mechanical parameters of pedalling, so it was difficult to compare these results. Monitoring the effect of training on physiological variables such as gross mechanical efficiency is more habitual in the scientific literature (Hopker et al., 2012), but unfortunately, physiological variables were not recorded in this study. Therefore, future studies should solve the main limitations of this study, which were the non-monitored preseason training and physical fitness of the elite and club cyclists, and the non-simultaneous recording of biomechanical and physiological variables (Korff et al., 2007; Edwards et al., 2009; Leirdal and Ettema, 2011; Hopker et al., 2012). Besides, another possible limitation could be to use the greater trochanter measurement instead of the anterior-superior iliac spine to estimate the hip joint centre, although this have little influence on joint angular kinematics (Neptune and Hull, 1995).

Conclusions

Professional cyclists had better pedalling technique than elite and club cyclists, because they needed a lower positive impulse proportion (between 1.5-3.3%) to pedalling at the same power output. This was due to a lower minimum torque during the upstroke (less negative torque values between 15.4 and 28.7%) and to a higher ROM in the ankle joint. The differences in pedalling technique depended on cycling experience (i.e. more years of practice) and level of expertise, and did not depend on other variables such as bike measurements, anthropometry or training volume.

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Table 1. Characteristics (Mean ± SD) of the three groups of cyclists (Professionals, Elite and Club) and their bicycles.

		Professional (n= 11)	Elite (n= 13)	Club (n= 14)	All cyclists (n= 38)
CYCLISTS	Age (yr)	26.7 ± 2.6 *	21.6 ± 1.3 ‡	27.9 ± 7.0	25.4 ± 5.2
	Cycling experience (yr)	14.9 ± 2.3 * †	9.8 ± 1.4	8.3 ± 6.8	10.8 ± 5.1
	Training volume (km)	9091 ± 1841 * †	6719 ± 1327	6208 ± 1547	7245 ± 2693
	Height (m)	178.2 ± 6.4	180.2 ± 3.9	177.5 ± 5.7	178.6 ± 5.4
	Weight (kg)	67.7 ± 5.0	68.0 ± 5.0	70.1 ± 5.6	68.7 ± 5.2
	BMI ($kg \cdot m^{-2}$)	21.3 ± 1.0	20.9 ± 1.1 ‡	22.3 ± 1.6	21.5 ± 1.4
BICYCLES	Saddle height (cm)	76.2 ± 4.7	77.0 ± 2.7	75.0 ± 3.7	76.0 ± 3.7
	Saddle height (%IL)	109.5 ± 2.5	109.4 ± 2.6	109.2 ± 2.3	109.3 ± 2.4
	Saddle back (cm)	7.3 ± 2.0	8.2 ± 1.3	6.8 ± 1.3	7.4 ± 1.6
	Crank arm length (mm)	173.6 ± 1.3	174.6 ± 0.9	173.1 ± 1.5	173.8 ± 1.4
	Handlebar-D (cm)	56.7 ± 4.3 †	56.8 ± 2.1 ‡	54.1 ± 2.7	55.8 ± 3.3
	Handlebar-V (cm)	9.7 ± 1.8	9.2 ± 2.1	7.8 ± 2.5	8.9 ± 2.2

BMI, body mass index. %IL, percentage of inseam length. Handlebar-D, distance between the front of the saddle and the middle of the handlebars. Handlebar-V, vertical distance between the top of the saddle and the handlebar's brake. Significant differences ($p<0.05$): * Professionals *vs* Elite, † Professionals *vs* Club, ‡ Elite *vs* Club.

Table 2. Kinetic analysis (Mean ± SD) of the three groups of cyclists (Professionals, Elite and Club) at different pedalling power outputs (200, 250 and 300 W).

		Professionals (n=11)	Elite (n=13)	Club (n=14)	All cyclists (n=38)
200 W	Maximum torque (N · m)	44.5 ± 3.2	47.6 ± 3.6 *	47.2 ± 3.4 *	46.7 ± 3.7
	Minimum torque (N · m)	-10.4 ± 2.2	-12.3 ± 2.5	-13.2 ± 3.0 *	-12.1 ± 2.8
	PIP (%)	82.0 ± 2.4	80.5 ± 2.6	80.0 ± 2.8	80.7 ± 2.7
250 W	Maximum torque (N · m)	51.2 ± 4.1	54.0 ± 4.6	54.5 ± 3.0 *	53.4 ± 4.1 #
	Minimum torque (N · m)	-9.0 ± 2.1	-11.3 ± 2.5 *	-12.0 ± 2.5 *	-10.9 ± 2.6 #
	PIP (%)	86.5 ± 2.3	84.3 ± 2.5 *	84.1 ± 2.6 *	84.9 ± 2.6 #
300 W	Maximum torque (N · m)	57.2 ± 4.4	58.7 ± 4.5	60.0 ± 2.9	58.7 ± 4.0 # &
	Minimum torque (N · m)	-7.7 ± 2.1	-9.5 ± 2.7 † *	-11.0 ± 1.9 *	-9.5 ± 2.6 # &
	PIP (%)	90.9 ± 2.8	88.2 ± 2.9 *	87.4 ± 2.1 *	88.7 ± 3.0 # &
MEAN	Maximum torque (N · m)	51.0 ± 6.5	53.3 ± 6.2	53.9 ± 6.0 *	58.7 ± 4.0
	Minimum torque (N · m)	-9.1 ± 2.4	-11.0 ± 2.8 † *	-12.1 ± 2.6 *	-9.5 ± 2.6
	PIP (%)	86.5 ± 4.5	84.3 ± 4.1 *	83.7 ± 3.9 *	88.7 ± 3.0

PIP, positive impulse proportion. Significant differences ($p<0.05$): with professional cyclists (*), Elite *vs* Club cyclists (†). Significant differences ($p<0.001$) with 200 (#) and 250 W (&).

Table 3. Kinematic analysis (hip, knee and ankle joints) of the three groups of cyclists (Professionals, Elite and Club). Mean ± SD values of the three power outputs (200, 250 and 300 W).

		Professionals (n=11)	Elite (n=13)	Club (n=14)	All cyclists (n=38)
HIP	Extension (º)	64.9 ± 1.5	62.3 ± 2.6	63.6 ± 2.5	63.4 ± 2.6
	Flexion (º)	21.6 ± 1.9	18.8 ± 2.4 *	19.4 ± 2.9 *	19.9 ± 2.8
	ROM (º)	43.2 ± 1.4	43.5 ± 2.1	44.3 ± 3.4	43.6 ± 2.6
KNEE	Extension (º)	146.4 ± 3.1	146.0 ± 4.0	144.5 ± 2.9	145.4 ± 3.8
	Flexion (º)	70.5 ± 2.9	70.7 ± 2.0	69.6 ± 3.0	70.2 ± 2.7
	ROM (º)	75.8 ± 1.9	75.2 ± 3.6	75.0 ± 4.4	75.2 ± 3.5
ANKLE	Extension (º)	136.5 ± 4.7	136.5 ± 6.4	134.2 ± 6.3	135.8 ± 6.0
	Flexion (º)	112.9 ± 6.6	114.0 ± 6.5	114.6 ± 7.4	113.8 ± 7.0
	ROM	23.6 ± 4.6	22.5 ± 6.1 †	19.6 ± 6.0 *	21.9 ± 6.0

ROM, range of movement. Significant differences ($p<0.05$): Significant differences ($p<0.05$): with professional cyclists (*), Elite *vs* Club cyclists (†).

Table 4. Mean ± SD of the kinetic analysis (at 200, 250 and 300 W) and kinematic analysis (hip, knee and ankle) during pedalling at 200, 250 and 300 W before and after the preseason in professional cyclists.

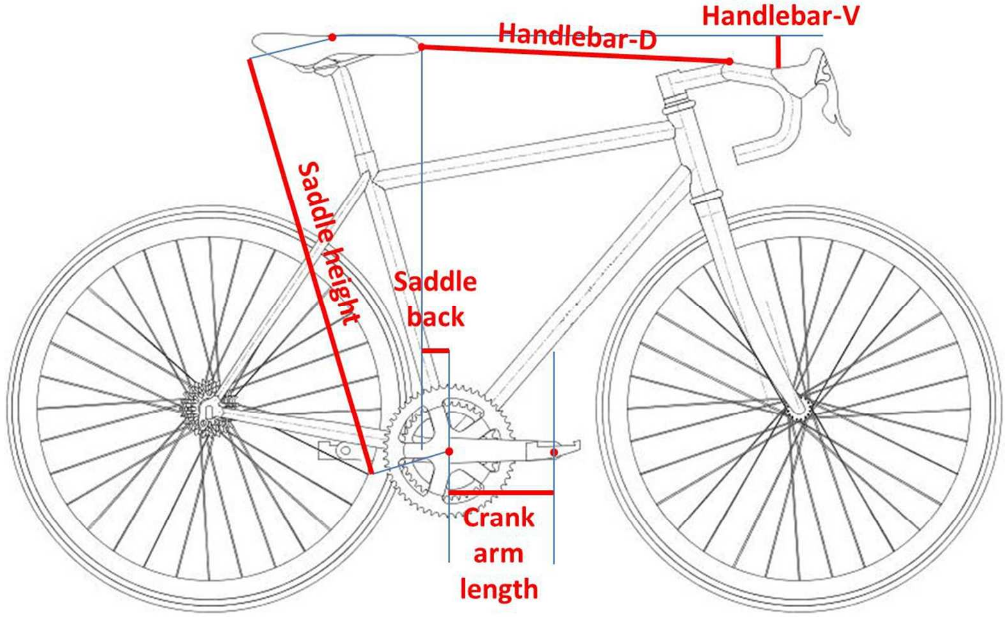
		Before (n=9)	After (n=9)
	Kinetic analysis		
200 W	Maximum torque (N · m)	44.9 ± 3.5	44.1 ± 3.6
	Minimum torque (N · m)	-11.3 ± 3.2 *	-10.3 ± 2.2
	PIP (%)	81.7 ± 3.6	82.0 ± 2.5
250 W	Maximum torque (N · m)	50.8 ± 4.4	50.9 ± 3.2
	Minimum torque (N · m)	-9.7 ± 3.2	-9.0 ± 2.2
	PIP (%)	86.5 ± 3.5	86.5 ± 2.4
300 W	Maximum torque (N · m)	58.6 ± 4.6	58.0 ± 4.7
	Minimum torque (N · m)	-9.0 ± 3.1 *	-7.9 ± 2.7
	PIP (%)	88.1 ± 3.0 *	89.5 ± 2.6
MEAN	Maximum torque (N · m)	50.5 ± 6.7	50.6 ± 6.3
	Minimum torque (N · m)	-10.1 ± 3.6 *	-9.0 ± 2.4
	PIP (%)	85.7 ± 4.7	86.4 ± 4.5
	Kinematic analysis		
HIP	Extension (º)	64.9 ± 1.6	65.1 ± 1.7
	Flexion (º)	21.8 ± 2.0	21.8 ± 1.9
	ROM (º)	43.2 ± 1.5	43.3 ± 1.3
KNEE	Extension (º)	146.4 ± 3.1	146.9 ± 3.6
	Flexion (º)	70.5 ± 2.9	70.5 ± 2.8
	ROM (º)	75.9 ± 2.0	76.4 ± 2.4
ANKLE	Extension (º)	136.0 ± 4.3	136.2 ± 4.5
	Flexion (º)	112.6 ± 6.6	111.5 ± 6.6
	ROM (º)	23.4 ± 4.5	24.7 ± 4.2

PIP, positive impulse proportion. ROM, range of movement. * Significant difference ($p<0.05$).

Figure captions

Figure 1. The main bike measurements: saddle height, saddle back, crank arm length, vertical distance between the top of the saddle and the handlebar's brake (Handlebar-V) and distance between the front of the saddle and the middle of the handlebars (Handlebar-D).

Figure 2. Biomechanical variables analysed during pedalling. Kinetic analysis: torque-angle profile of a complete revolution and main selected variables for analysis. Kinematic analysis: schematic illustration of reflective marker locations and definition of angles.



The main bike measurements: saddle height, saddle back, crank arm length, vertical distance between the top of the saddle and the handlebar's brake (Handlebar-V) and distance between the front of the saddle and the middle of the handlebars (Handlebar-D).
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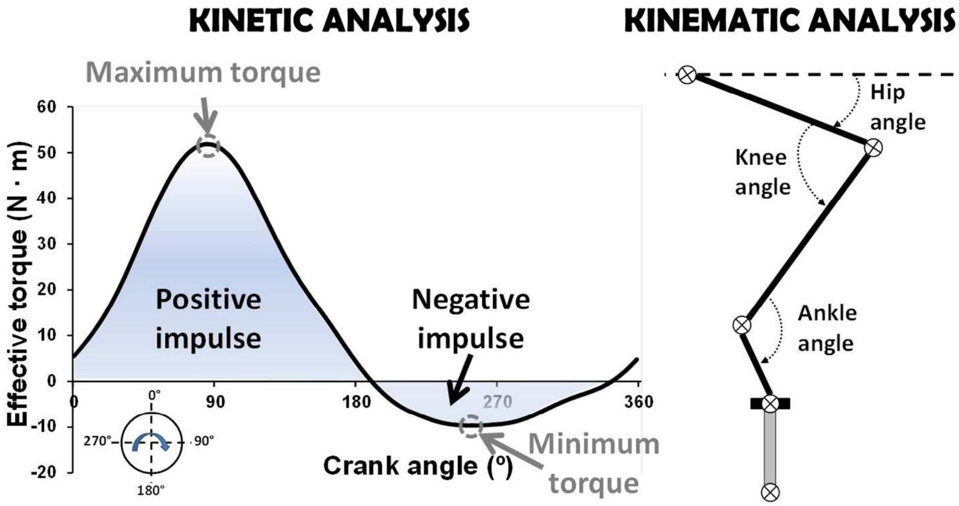

Biomechanical variables analysed during pedalling. Kinetic analysis: torque-angle profile of a complete revolution and main selected variables for analysis. Kinematic analysis: schematic illustration of reflective marker locations and definition of angles.
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