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Variability of ankle kinematics in professional cyclists: consequence on saddle height adjustment

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Abstract: Bike-fitting methods based on the knee kinematics have been developed to determine the optimal saddle height. Among them, the Ferrer-Roca method advises a knee angle between 30 and 40° in the sagittal plane when the crank arm is aligned with the seat tube while pedalling. However, the foot orientation varies between individuals and can influence the knee angle throughout the pedalling cycle. The objective of this study was to measure the inter-individual variability in joint kinematics of professional cyclists and to evaluate the influence of the ankle angle modification on the knee angle during pedalling. Seventeen professional cyclists performed a 3-min pedalling test at 150 W and 80 rpm on their personal road bike mounted on an Elite Turno® ergometer (Elite, Fontaniva, Italia). The knee and ankle angles were measured using 2D kinematic analysis. The average knee angle (38°) was in the optimal range of 30–40°, but great variability was observed between individuals (coefficient of variation of 11.8% and 9.4% for knee and ankle angles, respectively). Moreover, five of them had a knee angle greater than 40°. In addition, their ankle angle was 15% lower than that of cyclists who had a knee angle between 30 and 40° ($50 \pm 4°$ vs. $58 \pm 4°$, $p < 0.05$). The results suggest that the knee angle observed when professional cyclists use their preferred saddle height varies among individuals and is related to the foot orientation while pedalling. The maximum knee extension angle is lower for the cyclists who accentuate the dorsiflexion but greater for those who pedalled with a plantarflexion. This implies that the saddle height adjustment method based on the knee kinematics while pedalling should consider both the knee and ankle angles.

Keywords: Joint kinematics; Injury prevention; Performance; Comfort

1. Introduction

Proper saddle height in cycling can increase performance (Peveler et al. 2007; Peveler 2008; Ferrer-Roca et al. 2014), improve perceived comfort (Priego Quesada et al. 2017; Millour et al. 2019a; Bini 2020), and prevent overuse injuries (Holmes et al. 1994; Bini et al. 2011).

Saddle height corresponds to the distance between the centre of the bottom bracket and the top of the saddle measured in the alignment of the seat tube (Millour et al. 2019a). Numerous studies have investigated saddle height adjustment optimisation based on anthropometric and/or kinematic measurements (Millour et al. 2019a; Millour et al. 2019b).

Nowadays, the authors suggest the use of kinematic methods based on the knee angle (angle between the thigh and leg with 0° corresponding to complete knee extension) because they would take into account individual differences in foot, tibia, and thigh lengths (Bini and Hume 2016). The knee angle can be measured in static conditions (i.e., at rest) and whilst cycling (i.e., during pedalling). In static conditions, a knee angle of 25–35° when the pedal is at the bottom dead centre (i.e., the lowest point of the pedalling cycle) is recommended to prevent overuse injuries (Holmes et al. 1994), while a knee angle closer to 25° would be more suitable for performance improvement (Peveler et al. 2007; Peveler 2008). Several studies have found differences of 5 to 10° between the static and during pedalling assessment of the knee angle due to the pelvic tilt in the coronal plane (Farrell et al. 2003) and the plantarflexion that increases during pedalling (Peveler et al. 2012; Bini and Hume 2016; Millour et al. 2019b). Therefore, Ferrer-Roca et al. (2012) have proposed a knee angle between 30 and 40° when the crank arm is aligned with the seat tube during pedalling. The knee angle assessment whilst cycling would be more representative of usual practice conditions (Peveler et al. 2012; Millour et al. 2019b).

In addition to the fact that the ankle angle (i.e., angle between the leg and foot) is dependent on the conditions of measurement (i.e., static or whilst cycling), it has been shown that this joint angle can vary considerably according to the pedalling technique. García-López et al. (2016) have shown that professional cyclists increase the ankle range of movement and present higher positive impulse proportion mainly due to a lower resistive torque during the upstroke in comparison to lower-level cyclists. However, Kautz et al. (1991) observed an important variability in the pedalling technique of elite cyclists. Indeed, they would present inter-individual differences in the foot orientation throughout the pedalling cycle, which would have the effect of changing the orientation of the forces on the pedals. Peveler (2008) pointed out that some precautions must be taken for the saddle height adjustment whilst cycling because of the different kinematic configurations used by cyclists. While some cyclists pedal "heel up", others prefer to pedal "heel down" or "ankle" (i.e., large ankle range of movement during the pedalling cycle). However, no study has evaluated the influence of the foot orientation on the knee kinematics during pedalling.

The objectives of this study were (1) to identify if the knee angle of professional cyclists is within the optimal range of 30–40° (Ferrer-Roca et al. 2012) when they used their preferred saddle height, (2) to measure the inter-individual variability in joint kinematics of professional cyclists and (3) to evaluate the influence of the ankle angle on the knee angle during pedalling. The hypothesis was that pedalling technique, and in particular foot orientation, influences the knee angle during pedalling and should be taken into account for a precise saddle height adjustment based on knee kinematics.

2. Methods

Participants

Seventeen professional cyclists volunteered to participate in this study. Their characteristics (age, height, and body mass) are presented in the Table 1. Prior to the experiment, the cyclists and the team staff (coach, physician, and physiotherapists) were informed of the risks and benefits of the study and all the participants provided a written informed consent form. The study was approved by the Biomedical Research Ethics Committee of the local institution in accordance with the Declaration of Helsinki and was conducted in agreement with the ethical guidelines (Harris and Atkinson 2011).

Protocol

During the first training camp, the cleat position of the cyclists was optimised using a ML Cleat® device (Morphologics, Saint-Malo, France; Figure 1) by aligning the centre of the cleat with the first metatarsal head (Silberman et al. 2005). The saddle and handlebar positions were adjusted considering the recommendations of the ML

Postural System® (Morphologics, Saint-Malo, France) and the feeling of the cyclists.

Figure 1: Measurement of the length between the first metatarsal head and the heel of the cyclist using ML Cleat® in order to optimise the cycling cleat position.

All the cyclists then had one month (between the first and second pre-season training camp) to either validate the saddle height position or to modify it according to their feeling of comfort during their training sessions. The position at the end of this month of adaptation was considered as the final position that would be used throughout the season and was therefore taken into account during the experimental tests. The average preferred saddle height is presented in Table 1.

During the second training camp, cyclists completed a 3-min submaximal pedalling test at 150 W and 80 rpm on their personal road bike mounted on an Elite Turno® ergometer (Elite, Fontaniva, Italy). This low intensity and short exercise time were chosen to limit the influence of the fatigue induced by the intensive program during the training camp on the measures. In fact, all the cyclists performed the protocol at the end of the day after a long and/or intense training session and thus, had to optimize their recovery as much as possible for the next days. This ergometer allows to control the crank mechanical power output (PO) and the pedalling cadence by managing the brake resistance. Cyclists were instructed to maintain a constant PO and cadence throughout the pedalling exercise in order to reduce the influence of these variables on the joint angles in the sagittal plane (Bini et al. 2010a; Peveler et al. 2012). To measure the knee and ankle angles during the maximum knee extension while pedalling, markers were placed on the left lower limb of each participant at the greater trochanter, lateral femoral epicondyle, lateral malleolus, and fifth metatarsal head (Price and Donne 1997). The anatomical points were determined by palpation by the same experimenter for all cyclists to reduce the inter-experimenter variability. In accordance with the study of Millour et al. (2019a), a high-resolution digital camera (Go Pro Hero 3®, Go Pro, San Mateo, California, United States, resolution 1280 × 1080 pixels) was placed 4 m away and perpendicular to the cyclists. Prior to the pedalling exercise, a rectangular shape was positioned in the camera field to correct the parallax during the video analysis. Joint kinematics were measured at 60 Hz during the last minute of the exercise. Joint angle data of 10 consecutive pedalling cycles were analysed using Kinovea (Kinovea V0.8.24, Kinovea open source project, www.kinovea.org). A correction of distortion was also made using this software.

Statistical analysis

The data of knee and ankle angles for all participants are presented in the text as mean ± standard deviation. In addition, the coefficient of variation (CV, %), defined as the ratio of the standard deviation to the mean, was calculated. Next, the knee angle of each cyclist was compared to the optimal range of 30-40° proposed by Ferrer-Roca et al. (2012). Participants were then classified into two groups: those who had a knee angle in the optimal range of 30 to 40° and those who had a knee angle outside of this range. The statistical analysis was performed using the Past software (version 3.18; Øyvind Hammer, Natural History Museum, University of Oslo, Norway). The normality of the distribution and the homogeneity of the variances were tested using Shapiro-Wilk and Levene tests, respectively. Unpaired Student's t-tests were used to compare the knee and ankle angles for these two groups. Statistical significance was set at $p < 0.05$.

Table 1: Participant's characteristics, mean ± standard deviation

Number	17
Age (years)	28 ± 5
Height (m)	1.80 ± 0.05
Body mass (kg)	70 ± 7
Preferred saddle height (m)	0.761± 0.028

3. Results

The mean of knee and ankle angles were 38.0 ± 4.5° and 55.3 ± 5.2°, respectively, but we observed an important variability between cyclists (CV of 11.8% and 9.4% for the knee and ankle angles, respectively). Although the average knee angle was in the range of 30–40° recommended by Ferrer-Rocca et al. (2012), five cyclists had a knee angle greater than 40°. We then classified the participants into two groups, those who had a knee angle in the range of 30–40° (group 1, N = 12, mean ± standard deviation = 35 ± 3°) and those who had a knee angle higher than 40° (group 2, N = 5, mean ± standard deviation = 43 ± 2°) (Figure 2). The knee angle of these two groups was different from 17.9% ($p < 0.05$). In addition, the ankle angle of group 1 was 15% greater than that of group 2 (58 ± 4 ° vs. 50 ± 4°, $p < 0.05$).

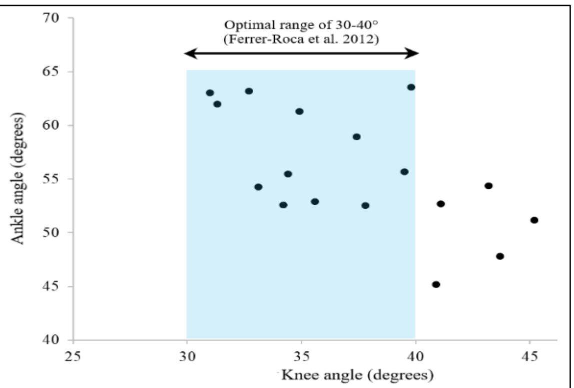

Figure 2: Relationship for each cyclist between the knee and ankle angles. The blue coloured area corresponds to the optimal range of knee angle of 30–40 ° proposed by Ferrer-Rocca et al. (2012). Five cyclists have knee angle values greater than this range.

Figure 3 shows two different pedalling techniques that affect the relationship between the knee and ankle angles. The cyclist with a smaller knee angle exhibited a greater ankle dorsiflexion during the maximum knee extension (Figure 3A). Conversely, the cyclist with a larger knee angle exhibited a greater ankle plantarflexion during the maximum knee extension (Figure 3B).

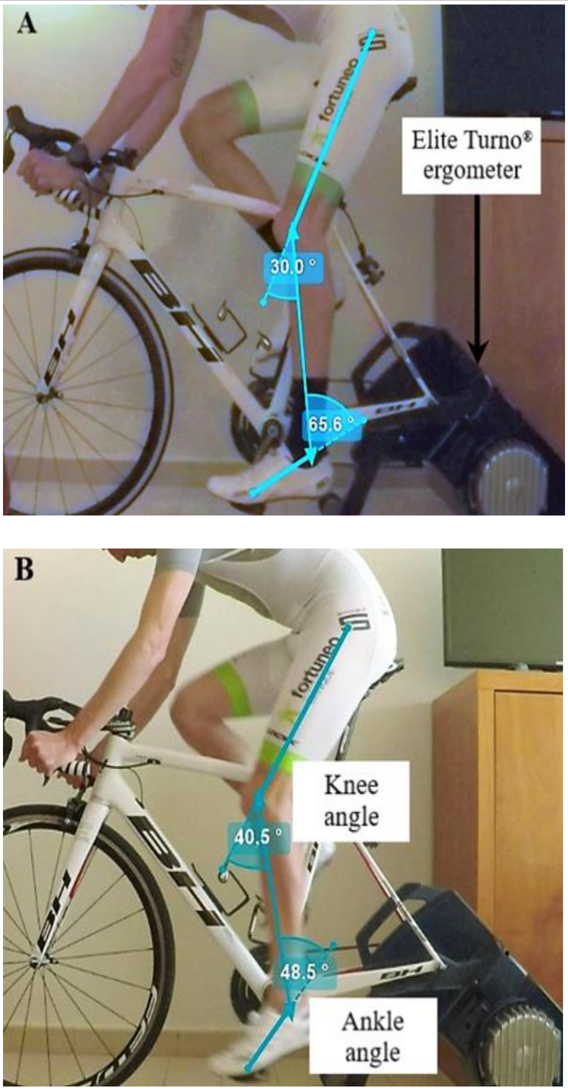

Figure 3: Typical values of knee angle and ankle angle measured while pedalling when the crank arm is aligned with the seat tube in two professional cyclists using different pedalling techniques (A: Extended knee/Dorsiflexion; B: Flexed knee/Plantarflexion) (GoPro® images displayed in Kinovea® software).

4. Discussion

The objectives of this study were to evaluate the inter-individual variability of ankle and knee angles in professional cyclists and to identify if the ankle angle affects the knee angle during its maximum extension. The results show that professional cyclists have a great variability of joint angles and may exhibit different foot orientations that can influence knee angle. Therefore, we can suggest that the ankle angle should be considered for an accurate saddle height adjustment based on knee kinematics.

The kinematic analysis indicated that cyclists had an average knee angle of 38.0 ± 4.5°, within the recommended range of 30–40° (Ferrer-Roca et al. 2012). It appears that this knee angle is close to the higher limit of the range. This confirms the results of several studies which have shown that recreational and professional cyclists preferentially had a knee angle higher than 35° (Bailey et al. 2003; Garcia-Lopez et al. 2016; Millour et al. 2019a; Bini 2020). However, Figure 2 highlights a large inter-individual variability in the knee angle, with some had a knee angle close to the lower limit of 30° while five cyclists pedalled with a knee angle greater than 40°. Millour et al. (2019a) also found a large variability in the knee angle between recreational cyclists (CV of ≈ 14%) when they pedalled with their preferred saddle height. From these results, we can suggest that cyclists use different knee angles during maximum knee extension, perhaps to optimise their comfort on the bike.

Figure 2 shows that the cyclists who pedalled with a low knee extension angle accentuated the dorsiflexion. Conversely, those who used a large knee extension angle increased the plantarflexion. These observations are identical to what happens between the transition from the static position to the pedalling movement. Indeed, it has been shown that the static knee angle when the pedal is at the bottom dead centre is 5 to 10° less than the knee angle whilst pedalling, which would be partly due to the larger ankle dorsiflexion (Peveler et al. 2012; Bini and Hume 2016). Peveler et al. (2012) suggested that the optimisation of the cyclist's position should consider individual anthropometry as well as the pedalling technique, including the foot orientation. In another study, Peveler (2008) discussed different foot orientations during pedalling, notably “heel up” or “heel down”, which may influence the result of the saddle height adjustment method based on the knee angle. The results of the present study corroborate these observations and suggest that the individual pedalling technique, particularly the orientation of the foot during the maximum knee extension, could significantly modify the knee angle during pedalling. Thus, cyclists who pedal with plantarflexion when the knee is fully extended may have a higher knee angle than those pedalling with dorsiflexion.

The results of the current study highlight the strong inter-individual variability in the joint kinematics of professional cyclists. Some authors indicated that high-level cyclists present greater positive impulse proportion, lower resistive torque during the upstroke and greater ankle range of movement (Garcia-Lopez et al. 2016). This different pedalling technique could explain the differences in muscular recruitment patterns (i.e., anterior tibial, posterior tibial, long fibula, lateral gastrocnemius, soleus) observed between novices and elite cyclists (Chapman et al. 2008). However, as in the present study, Kautz et al. (1991) identified important inter-individual differences in the ankle kinematics in elite cyclists, which modified the orientation of the forces on the pedals and can lead to changes in lower limb joint mechanical work. A previous study observed that the ankle angle increased when the saddle was 3 cm higher than the reference position, which had the effect of accentuating mechanical work in this joint in order to minimise loads exerted on the knee (Bini et al. 2010b). In addition, ankle kinematics play a key role in the transfer of the force to the pedal (Bini et al. 2010c). We can therefore suggest that the different pedalling techniques used by professional cyclists would lead to different biomechanical responses that could affect performance and risk of injury during cycling. However, changing the pedalling technique of trained cyclists by introducing an additional pull-up action during the upstroke (Korff et al. 2007) or a greater dorsiflexion throughout the pedalling cycle (Cannon et al. 2007) would have immediately a negative impact on the gross efficiency. On the other hand, increasing the pushing force during the downstroke (Korff et al. 2007) or the plantarflexion throughout the pedalling cycle (Cannon et al. 2007) would not alter the gross efficiency. However, the effect of long-term training with a new pedalling technique remains unknown since these previous studies did not give cyclists enough time to adapt to changes in pedalling technique (Mornieux and Stapelfeldt 2012).

The low intensity (150 W) and the short exercise time (3 min) constitute the main limits of the current study as some studies showed the influence of the PO (Kautz et al. 1991; Bini et al. 2010; García-López et al. 2016) and the fatigue (Bini et al. 2010b) on joint angles while pedalling. The experimentation was carried out as part of a pre-season training camp to do tests with several professional cyclists. However, the constraints linked to the important training loads during the training camp, which required optimal recovery phases, did not allow us to set up a more demanding protocol. Further research is therefore needed to determine whether a higher level of PO associated with a longer exercise time could reduce the inter-individual variability of joint kinematics observed in professional cyclists.

5. Practical implications

The present study suggests that professional cyclists present a high variability in their ankle and knee kinematics, probably due to their individual pedalling technique. The results showed that the maximum knee extension angle is lower for the cyclists who accentuate the dorsiflexion and greater for those who use a plantarflexion. Therefore, it appears essential to consider the ankle angle during a saddle height adjustment based on the knee kinematics. These recommendations could help practitioners, bike-fitting professionals, researchers, and clinicians to avoid saddle height adjustment errors that could reduce the performance and increase the risk of overuse injuries during cycling.

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7. Conflict of interest

No potential conflict of interest was reported by the authors.

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