ACUTE EFFECTS OF SMALL CHANGES IN CRANK LENGTH ON TORQUE WAVEFORM DURING SUBMAXIMAL PEDALLING

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The purpose of the present study was to evaluate the acute effects of small changes in crank-arm length and pedalling power on crank torque-angle profile during seated cycling. Twelve amateur cyclists participated and performed 12 sets of 5-min submaximal pedalling on a special cycle ergometer (4 intensities x 3 crank lengths). Principal Component Analysis technique was used to analyse ten crank torque-angle curves of the right leg. A longer crank increased the crank torque of the front leg (30-125º) in order to lift the rear leg (200-320º), contrary to the effect of increasing pedalling power. Furthermore, pedalling with the longest crank required higher torque values after reaching peak torque (110-170º) compared to the shortest ones. In conclusion, contrary to the lore, a longer crank requires a higher mechanical effort compared to a shorter crank for pedalling at the same intensity.

KEYWORDS: cycling, pedalling technique, kinetics.

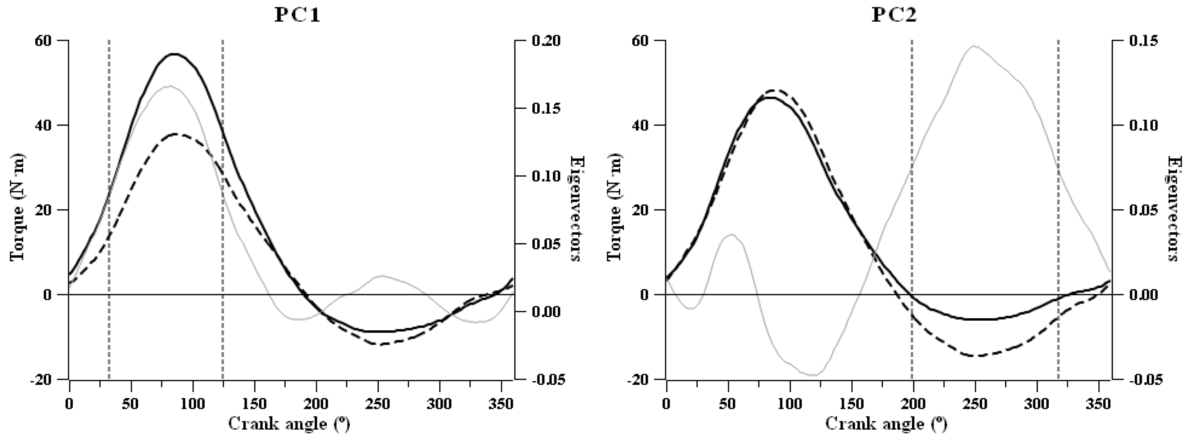
INTRODUCTION: The crank length is one of the bike fitting variables that affect the pedalling propulsive chain in road cycling. A recent study demonstrated that small changes in crank length (5 mm) affected pedalling technique (*i.e.;* kinematics and kinetics) with no significant effect on gross mechanical efficiency (Ferrer-Roca *et al.*, 2017). In fact, during submaximal seated pedalling, a higher maximal crank torque was applied by the front leg with a longer crank due to a greater minimum crank torque applied by the rear leg. Additionally, the maximum flexion and range of motion of the hip and knee joints were significantly higher as the crank length increased, whereas the ankle joint was not affected (Ferrer-Roca *et al.*, 2017).
However, the above-mentioned study only analysed the maximum and minimum values of crank torque and joint angles, but not the torque-angle (kinetics) and angle-angle (kinematics) profiles during the whole cycle of pedalling, discarding a large amount of data which could have changed with the modification of the crank-arm length. It is well known that the analysis of continuous biomechanical variables based on time series data could facilitate the evaluation of differences in the waveform shape without missing relevant information (Floria *et al.*, 2019). Therefore, the main purpose of the present study was to re-analyse the data of the above-mentioned study (Ferrer-Roca *et al.*, 2017) as time series to evaluate the acute effects of small changes in crank-arm length (± 5 mm) on crank torque-angle profile during seated cycling. As secondary purpose, the effect of pedalling power (i.e.; intensity of pedalling) on this profile was evaluated.

METHODS: Twelve amateur cyclists participated in the present study (20.8 ± 2.8 yr, 68.5 ± 6.6 kg, 176.9 ± 6.4 cm, 8.1 ± 3.4 yr of expertise and 4063 ± 1595 km of yearly training volume). They performed four sets of 5-min submaximal pedalling (150, 200, 250 and 300 W) at a constant cadence (91.3 ± 0.8 rpm) in a randomized order with three crank lengths (preferred, +5 mm and -5 mm). Cyclists used their own cycling shoes and their bike geometries were replicated in a validated electromagnetically braked cycle ergometer (Lode Excalibur Sport) where the saddle and handlebar heights were modified when the crank length was changed (*i.e.;* raised and lowered 5 mm with shorter and longer cranks, respectively). This ensured the same effective saddle height (distance from the saddle to the pedal) and the same hip/knee/ankle extension during pedalling (Ferrer-Roca *et al.,* 2017). The ergometer allowed the measurement of the crank torque exerted on the left and right

cranks independently every 2° of a complete revolution (García-López *et al.,* 2016). The mean of 10 complete cycles of the right leg from the minute 4 were selected for further analysis, and 0º was considered as the crank being vertical with respect to the floor at the top dead centre.
A principal component analysis (PCA) was conducted to identify dominant modes of variation within the series data waveforms. The PCA approach used for this study was based on the methods of Deluzio *et al.* (2014). A matrix was created (238 x 180) containing the crank torque-crank angle series data (12 cyclists x 3 crank lengths x 180 angle data per cycle). The PCA resulted in eigenvector components, eigenvalues and scores. The eigenvector components contain principal component loading vectors indicating the direction of variance in the data set. The eigenvalues indicated the amount of variation in the data explained by a given principal component. The scores indicated the degree to which the shape of individual waveform deviated from the average pattern.
To aid in the biomechanical interpretation of the PCA result, single plots with two waveforms high and low were created (Figure 1). High and low waveforms represent the score of the principal component obtained by adding and subtracting a scalar multiple of the eigenvector component to the average waveform, respectively (*Deluzio et al.,* 2014). A convenient scalar multiple is one standard deviation of the corresponding principal component scores. Simultaneously with the high and low scores, the eigenvector component series data was added. As eigenvector component values approached zero, it was interpreted as a small contribution to the main component score, while larger eigenvector components were interpreted as an important contribution to a particular principal component. The crank angles ranges where the eigenvector was higher than half the peak value was limited with vertical lines aiming to facilitate the identification of the changes in the crank torque waveform during the pedalling.
In order to quantify statistical differences between power conditions and crank lengths, a two-way repeated measure of analysis of variance ANOVA was applied comparing the principal component scores. A criterion of 95% of variance explained was used to determine the number of principal components extracted for statistical analysis (Deluzio *et al.*, 2014). The statistical significance level was set at $P < .05$. When an interaction effect was identified, Bonferroni-corrected pairwise post-hoc comparisons were made between the three power conditions and three crank lengths.

RESULTS: The principal component analysis explained the 90% of the pedalling crank torque variance (PC1, PC2 and PC3). PC1 explained the 66%, and represented a higher propulsive phase during pedalling, which was related to both crank length and pedalling power between ~ 30-125º of crank cycle (Figure 1a). PC2 explained the 17% of the variance, and represented a lower resistive phase during pedalling, which was inversely related to the crank length and directly related to the pedalling power between ~ 200-320º of crank cycle (Figure 1b). PC3 explained the 7% of variance, and represented a higher propulsive crank torque after the maximum torque value, which was related to both crank length and pedalling power between ~ 110-170º of crank cycle (Figure 1c). PC1 and PC2 post-hoc analysis demonstrated a higher crank length effect at the lowest pedalling powers, even though interaction between crank length × pedalling power was not found in any principal component (*i.e.;* PC1, PC2 y PC3).

DISCUSSION: The main finding was that small changes in crank-arm length affected to the crank torque waveform during a wide part of the pedalling cycle (~30-125º, 110-170º and 200-320º), and not only the maximum and minimum crank torque values (Ferrer-Roca *et al.,* 2017). A longer crank required greater propulsive crank torque of the front leg (~30-125º) to pedalling at the same intensity and cadence, which was explained by the higher resistive crank torque applied by the rear leg between ~200-320º of crank cycle (crank torque production between the front and rear legs are phase differenced by 180º). This response was contrary to those observed when the pedalling intensity increased. The rear leg progressively applies less resistive crank torque to obtain the same mean crank torque with less propulsive torque, delaying the fatigue of the main front leg extensor muscles (García-López *et al.,* 2016). Another important finding was to observe that both crank length and pedalling power increased the front leg propulsive torque between ~110-170º of the crank angle, after the point where the maximum torque was reached. This could be interpreted as a decrease of the mechanical efficiency, because a greater propulsive crank torque was required to produce the same pedalling power with a longer crank.



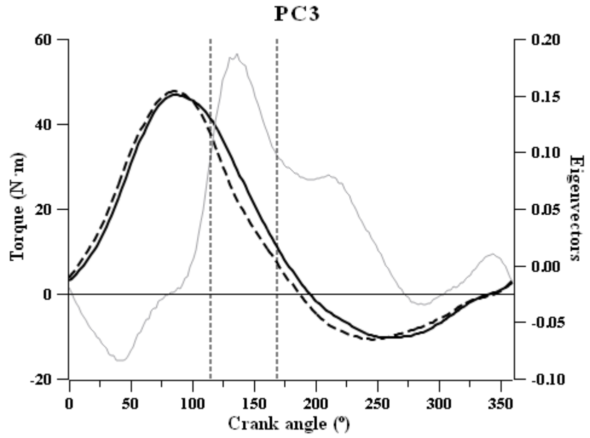


Figure 1: Principal component (PC) and loading vector contributions to crank torque vs crank angle profiles. In all cases, high scorers for each PC are the black solid lines and low scorers are the black dashed lines. The grey solid line represents PC loading vector that is added to and subtracted from the average waveform to represent the waveforms of high and low scorers. Vertical dashed lines indicate regions where the loading vector was higher than half of the peak value.

The results obtained in PC1 (~30-125º) were due to the changes detected in PC2 (~200-320º). Firstly, both legs influence each other, because the crank torque exerted by the two legs (front *vs* rear) is phase differenced by 180º. Secondly, because the effects of increasing both crank length and pedalling power were similar in PC1, but contrary in PC2. In fact, previous biomechanical studies (Korff *et al.,* 2007) found that the crank torque was negative (*i.e.;* resistive) between ~210-330° of crank cycle during seated pedalling, which coincides with the results of the present study (~200-320º). Furthermore, the resistive crank torque decreased when pedalling power increased, in order to raise the mean crank torque without overloading the front leg. This has been recognized as a strategy to delay the muscle fatigue during endurance cycling (García-López *et al.,* 2016; Ferrer-Roca *et al.,* 2017).
Thus, increasing the crank length during submaximal seated cycling should be considered the wrong strategy from a biomechanical point of view, because it requires a higher propulsive crank torque values to compensate the increase of the resistive ones. Only one previous study (Mileva & Turner, 2003) compared the net crank torque and the EMG muscle activation pattern of four muscles of the same leg by changing the crank length (195 *vs* 155 mm). It seems inappropriate to compare our results with this study because they performed wider crank length changes in comparison with the present study (5 mm). Logically, this research did not obtain differences in the net torque by changing the crank length because

the same power and cadence was maintained throughout the study (Power = net torque × angular velocity). Moreover, only the net crank torque was analysed, without establishing separately the contribution of the front leg and rear leg. As we explained previously, the crank torque exerted by each leg can change for the same net crank torque due to different muscle coordinative pattern. In fact, the above-mentioned study observed a higher EMG activity in *anterior tibialis* and soleus, a lower activity in *biceps femoris* and no changes in *rectus femoris* when a longer crank was used. However, the knee and ankle extension joint angles increased with longer cranks, which must not occur if the effective saddle height is well adjusted (Ferrer-Roca *et al.;* 2017). Hence, the present study is the first one that analyses the effects of changing crank length on the crank torque-angle profile. Further studies should analyse the effects of this modification on EMG activity.
The observed changes in PC3 (i.e.; higher propulsive crank torque after the peak torque) when increasing crank length and pedalling power represents a greater mechanical effort to pedal at the same intensity and cadence. There are no previous biomechanical studies in cycling that analysed this aspect, but a similar trend was observed in the vertical jumps with higher performance (Floría et al., 2019), being the vertical jump a supramaximal effort. Therefore, during submaximal efforts at the same intensity and cadence, the increase in PC3 when increasing crank length should be considered as mechanically inefficient.
Finally, the main practical application of the present study is in line with previous studies (Ferrer-Roca *et al.;* 2017), that detected possible long-terms adverse effects increasing the crank length during submaximal cycling. Therefore, in case of doubt between two crank lengths, it is highly recommended to choose the shorter one.

CONCLUSION: This is the first study that analyses the effect of small changes in crank length on the crank torque profile during submaximal pedalling. Taking into account the strategies used by the cyclists when pedalling power increases, a longer crank required a greater mechanical effort during submaximal pedalling (*i.e.;* the front leg must apply a greater propulsive crank torque to compensate the higher resistive one exerted by the rear leg). Thus, contrary to the popular lore, a relatively shorter crank length is recommended to allow an increase in mechanical efficiency of pedalling. Future studies should analyse the changes in EMG activity when using different crank lengths.

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