THE INFLUENCE OF CYCLISTS' COMPETITIVE LEVEL AND EXERCISE INTENSITY ON CRANK TORQUE VARIABILITY DURING PEDALLING

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The purpose of this study was to analyse the influence of competitive level and pedalling intensity on crank torque variability. Seventy-two cyclists (Club, Elite, Professional) pedalled at 200, 250 and 300 W on a cycle ergometer that recorded crank torque. Multiple-trial variability (average standard deviation) and complexity (Sample Entropy) analyses were applied. Both competitive level and pedalling intensity showed a significant effect on Sample Entropy values of crank torque, with a significant interaction between the two factors, while average standard deviation was only affected by pedalling intensity. In conclusion, pedalling intensity had a differential effect on both crank torque multiple-trial variability and complexity, while the last has shown a bigger potential for fine discrimination between performance levels in cyclists.

KEYWORDS: cycling, movement variability, kinetics.

INTRODUCTION: Pedalling technique (*i.e.,* kinematics and kinetics) is different in expert cyclists when compared to novice cyclists (Chapman *et al.*, 2009; García-López *et al.*, 2016). Expert cyclists show a higher ankle range of motion and different hip-ankle coordination (García-López *et al.*, 2016), a higher activation of the knee flexor muscles of the rear leg, and a decrease in the peak propulsive force of the front leg (Takaishi *et al.*, 1998; Theurel *et al.*, 2012), which has been related to their ability to delay the fatigue during prolonged pedalling efforts. Movement variability in sports has been extensively studied in the last few years (Preatoni *et al.*, 2013) because it could be related to both sports' performance and injury risk (Bartlett *et al.*, 2007). Previous studies observed relationships between movement variability during pedalling and both competitive level and pedalling intensity. Expert cyclists showed lower coordination variability than novice cyclists (Chapman *et al.* 2009; Sides & Wilson, 2012), and a decrease in the muscle action variability as pedalling intensity increased (Enders *et al.* 2013; 2015). To the best of our knowledge, no previous study has analysed pedal or crank force variability. Several approaches have been proposed in the literature to analyse movement variability highlighting the linear and non-linear measures (Preatoni *et al.*, 2013). Linear measures quantify the magnitude of variability between cycles (*e.g.;* multiple-trial variability), while non-linear measures (*e.g.;* sample entropy) quantify dynamic and temporal aspects of time series and provide greater insight into the regularity and complexity of underlying motor control (Stergiou and Decker, 2011). Although both approaches are used to evaluate movement variability, it has been suggested that their behaviour could be different and probably the standard deviation may not adequately analyse the dynamics of behaviour (Slifkin and Newell, 2000).
Therefore, the purposes of the present study were (1) to analyse the effect of the cyclists' competitive level and pedalling intensity on the crank torque variability and (2) to examine whether there would be a different interpretation when multiple-trial variability and complexity measurements are used to analyse the movement variability.

METHODS: Seventy-two cyclists participated in the present study (24.7 ± 5.4 yr, 69.0 ± 6.0 kg and 178.7 ± 5.0 cm). They were divided in three homogeneous groups (n= 24) of competitive levels (Level 1= club; Level 2= elite; Level 3= professionals), according to their cycling training volume per season (5000-15000, 15000-30000 and more than 30000 km, respectively) (García-López *et al.*, 2016). They performed three sets of 5-min submaximal pedalling (200, 250 and 300 W) at a constant cadence (~90 rpm) with a 6-min rest between sets. The tests were carried out on an electromagnetically braked cycle ergometer (Lode Excalibur Sport),

using their own cycling shoes and bike geometries. This 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).
To assess the multiple-trial variability, an ensemble average curve from 20 complete cycles of crank torque series from the right leg (symmetry between both legs was assumed) were calculated for each cyclist and pedalling intensities, as well as mean and standard deviation of each data point on average curve. The average standard deviation across all points composing the average curve was calculated. Thus, the total variability of the continuous curve was represented as a single value (James, 2004). To examine the time-dependent structure of crank torque dataset, the sample entropy (SampEn) was calculated. SampEn measures the probability that similar sequences of m points in the time series remain similar within a tolerance level (r) when a point is added to the sequence (m + 1 sequences) (Preatoni *et al.*, 2013). m = 2 and r = 0.35 were selected, considering the minimization of the maximum entropy relative error. Lower SampEn values reflecting a high system regularity and low complexity and high values representing a low system regularity and high complexity.
A two-way repeated measure of analysis of variance was performed on the SampEn and multi-trial variability values to test the effects of competitive level (between-participant factor) and pedalling intensity (within-participant factor) on movement variability. The statistical significance level was set at $P < .05$. When an interaction effect was identified, Bonferroni-corrected pairwise post-hoc comparisons were made between pedalling intensities and competitive levels. The magnitude of the differences was considered to be trivial (ES < 0.2), small (0.2 ≤ ES < 0.5), moderate (0.5 ≤ ES < 0.8) and large (ES ≥ 0.8) (Cohen, 1988).

RESULTS:

Multiple-trial variability analysis (Figure 1) showed no significant effect of competitive level ($F = 2.08$; $P = .13$) and a significant effect of pedalling intensity ($F= 18.93$; $P < .05$), without level x intensity interaction ($F = 1.57$; $P = .19$). Standard deviation values increased as pedalling intensity raised, and the magnitude of the differences ranged from small (200 *vs.* 250 W, Cohen's d = 0.5; 250 *vs.* 300 W, Cohen's d = 0.3) to moderate (200 *vs.* 300 W, Cohen's d = 0.7). Sample entropy analysis (Figure 2) showed significant effects of competitive level ($F = 5.72$; $P < .05$), and pedalling intensity ($F = 104.09$; $P < .05$), with a level x intensity interaction ($F = 2.95$; $P < .05$). Entropy values decreased as pedalling intensity increased, and the magnitude of the differences ranged from moderate (250 *vs.* 300 W, Cohen's d = 0.7) to large (200 *vs.* 250 W, Cohen's d = 1.0; 200 *vs.* 300 W, Cohen's d = 1.7). Entropy values also decreased as pedalling intensity increased, and the magnitude of the differences ranged from trivial (Elite *vs.* Professional, Cohen's d < 0.1) to small (Club *vs.* Elite, Cohen's d = 1.0; Club *vs.* Professional, Cohen's d = 0.4).

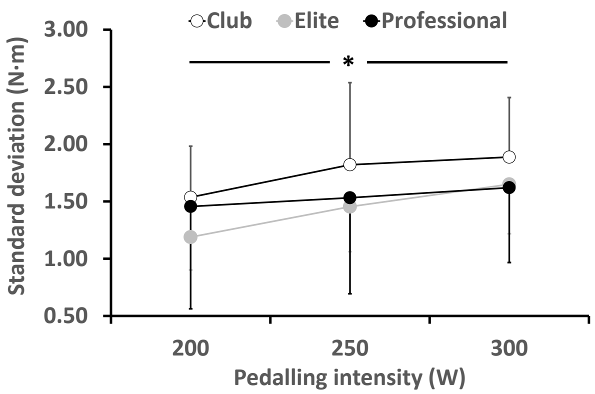

Figure 1: Multiple-trial variability values according to the cyclists' competitive level (Club, Elite, Professional) and pedalling intensity (200, 250 and 300 W). Significant effect of pedalling intensity (*)

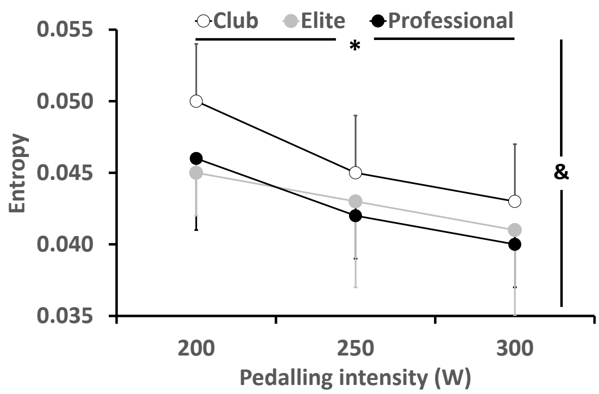

Figure 2: Sample entropy values according to the cyclists' competitive level (Club, Elite, Professional) and pedalling intensity (200, 250 and 300 W). Significant effects of pedalling intensity (*) and cyclists' competitive level (&)

DISCUSSION: The primary outcome of the study was to demonstrate a clear effect of pedalling intensity on crank torque multiple-trial variability (*i.e.;* it increased) and complexity *(i.e.;* it decreased) (Figures 1 and 2). The decrease of SampEn as pedalling intensity increased (Figure 2) in is agreeance with previous studies that observed a low muscular activation variability when the pedalling power was increased (Enders *et al.*, 2013; 2015). According to these authors, these findings could be justified because, as pedalling power is increased, the biomechanical constraints of the cycling task require a more precise muscular coordination pattern of the movement (*i.e.,* the solution space decreases as the muscular demand of the task increases). Consequently, the body specifies the control strategy on these task-relevant movement parameters in a similar way to the minimal intervention principle (Enders *et al.*, 2013). This principle states that the central nervous system preferentially corrects deviations in movement that have a negative effect on performance (*i.e.,* task-relevant errors). Correcting these deviations requires energy, so the central nervous system selectively reduces variations in local variables (*e.g.,* joint dynamics) that affect the task goals (*e.g.,* limb dynamics) (Selgrade, & Chang, 2015), which could explain the above-mentioned results. Another important finding was that, as pedalling intensity increased, multiple-trial variability increased (Figure 1), while complexity showed an opposite trend (Figure 2). This is in accordance with previous studies that observed a different effect of exercise intensity on both variables (Slifkin and Newell, 2000), so these two parameters of movement variability must be interpreted in a different way.

Non-linear analysis (SampEn) was more sensitive than linear analysis (multiple-trial variability) to detect the effect of pedalling intensity and performance level (and its combined effect) on crank torque variability. According to the results of SampEn (Figure 2), a small effect of competitive level on complexity was observed. It could be possible that high-level cyclists show an adaptation to their highest training volume, decreasing the SampEn. Previous studies observed a tendency to decreasing the SampEn of the anterior-posterior ground reaction forces in high skilled race walkers compared to low skilled ones (Preatoni *et al.*, 2010). On the contrary, according to the results of multiple-trial variability (Figure 1), it could be possible that variability within the perceptual-motor system is not functional for cycling performance, being pedalling a task that does not need variability (Sides & Wilson, 2012). However, the fact that pedalling intensity was identical for all cyclists (Club, Elite and Professional) could support the hypothesis that the competitive level had an effect on SampEn, because Elite and Professional cyclists pedalled at a lower relative intensity than Club cyclists did (*i.e.,* their maximal aerobic power is presumably higher). In other words, at the same relative intensity the differences in SampEn could be largest, because a clear effect of pedalling intensity in SampEn has been proved. Likewise, a combined effect of pedalling intensity x competitive level was observed in the analysis of SampEn, meaning that the SampEn values decreased more in Club cyclists than in Elite and Professional ones as pedalling intensity increased (Figure 2). It could be explained by the homogenous increase of pedalling intensity (*i.e.,* 50 W) in all groups of cyclists, which could imply a higher relative increase of intensity in the low-level cyclists than in high-level cyclists. Finally, not obtaining any differences between Elite and Club Cyclists (Figures 1 and 2) could be due to: a) the lower increase of relative intensity of pedalling in Professional cyclists when compared to Elite ones (as already explained); b) Elite cyclists had a very high training volume per year (> 15.000 km); c) the fact that some Elite cyclists belonged to under-23 teams of the same team as Professional cyclists did (*i.e.;* cyclists with possibilities to reach the professional level).

The main limitation of the present study was to use the same absolute pedalling intensities in all groups of cyclists (*i.e.,* 200, 250 y 300 W). Therefore, future studies could verify if the competitive level affects crank torque variability during pedalling when using similar relative intensities. Likewise, it must be highlighted that the present study analysed the crank torque as a kinetic variable, which is highly determinant of the pedalling intensity (by multiplying it to the crank rotation velocity). This variable could present less variability than other kinetic variables, such as force applied to the pedal, which could be explored in future studies.

CONCLUSION: Crank torque multiple-trial variability (standard deviation) and complexity (SampEn) are affected by the pedalling intensity, which could be due to the changes in biomechanical constraints and to the minimal intervention principle. The SampEn analysis is more sensitive than the multiple-trial variability analysis to detect the influence of pedalling intensity and cyclists' competitive level. Taking into account the complexity results, it seems that the crank torque time series regularity increases (SampEn decreases) as competitive level increases, which could be due to an adaptation to the highest training volume. However, further studies should confirm this hypothesis using similar relative pedalling intensities.

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