PREFERRED CYCLING CADENCE CHARACTERISATION FROM MUSCLE PARAMETERS COMPARED WITH MOVEMENT ECONOMY

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The purpose of this study was to characterise the preferred cycling cadence (PC) using biomechanical and physiological parameters. Seven male cyclists have cycled at 60, 75, 90, 105 rpm, and PC. The movement economy (physiological parameter) and angular impulse (biomechanical parameter) values at each pedalling rate were analysed. Results showed that the pedalling rate minimising angular impulse and PC were similar (p<0.05), although there were differences between the most economical pedalling rate and PC. Thus, it may be inferred that the choice of the preferred pedalling rate is associated with muscular effort rather than with oxygen consumption.

KEY WORDS: cycling, muscle moment, movement economy

INTRODUCTION:

Understanding the patterns and criteria used by nervous system to perform certain functions is fundamental to understand the functioning of the human body. According to Prilutsky *et al.* (1997), animals perform their locomotor movements in an optimised way, but the criterion of optimisation depends on the final purpose. In a long-distance journey, for instance, the criterion would be the energetic economy; to escape from a predator, velocity is the determinant factor.

To minimise the energy expended during a race, trainers and athletes try to optimise the movement pattern. The study of forces and moments allows assessing the mechanism associated with pedalling as well as the muscular efforts involved. This is helpful in the attempt to understand the aetiology of the choice of higher cadences regardless of the physiological detriment. Lafortune & Cavanagh (1983) pointed out that most experiments on cycling have investigated physiological (pedalling rate, heart rate, oxygen consumption, cyclist's efficiency) or biomechanical (pattern of force application, bilateral asymmetry, and pedalling effectiveness) aspects. This reality has not changed considerably in the last two decades, i.e., the number of studies connecting these two aspects is still small. Studies hardly ever assess both aspects simultaneously, a fact that impoverishes the understanding of the phenomena related to cycling.

The present study aimed at connecting the two aspects, since it calculates biomechanical (muscle moments) parameters and uses physiological parameters (oxygen consumption and ventilatory threshold), as a means of quantifying a relative intensity of effort. Thus, the purpose of this study was to characterise the cyclists' choice of a preferred cadence from biomechanical and physiologic parameters.

METHOD:

Seven male individuals who take part in national-class events on a regular basis were tested. Data were collected in two trials that took place in different days. In the first trial, the individual underwent a maximal oxygen consumption *ramp* test for the determination of the ventilatory threshold and its corresponding load. The physiological parameters (oxygen consumption and carbon dioxide production specifically) were used as a means of setting the subjects' relative intensity of effort, based on the ventilatory threshold determination. In the second trial, after warming up, each subject cycled for 30 s at each of the following cadences: 60, 75, 90, 105 rpm, and his preferred cadence (PC) (which was set in the previous trial) after having his oxygen consumption stabilised (5 minutes approximately).

The net forces and moments at the joints were obtained by using the inverse dynamics technique. To obtain the kinetic parameters, a dynamometrical pedal by Dreyer *et al.* (2001) was used. The pedal records the normal and tangential forces applied on it.
For the measurement of the kinematic variables, the Peak Performance (Peak Performance Inc. Englewood, CO) video system was used. The reference anatomical points used were the following: greater trochanter of femur, representing the hip joint; lateral epicondyle of femur, representing the knee joint; lateral malleolus, representing the ankle joint; and a point on the trunk to determine the hip angulation. A point located on the lateral base of the pedal to delimitate the foot/pedal segment, which is considered a single segment, replaced the base of the fifth metatarsus, traditionally used to delimitate the foot segment. The pedal and crank angles were measured by marking a central point of rotation (crank axis) and two points representing the lateral surface of the pedal. For an accurate measure of the pedal angle, those points were located on the edge of a rod fixed onto the lateral surface of the pedal.
To assess the physiological parameters, the movement economy variable, which is calculated by dividing the mean power of each cycle by the oxygen consumption corresponding to each individual's ventilatory threshold, was used. For the assessment of the biomechanical parameters, it was decided to analyse a variable that might represent muscular effort. The parameter selected was the total angular impulse, obtained by adding up the muscle moment values along time (10 consecutive cycles for each athlete), on the three joints (ankle, knee, and hips), and calculating the time integral for each of the cycles analysed. Then, a single representative value of each variable for each cycle was obtained.
The values were plotted as a function of the cadences, and a polynomial function was calculated in order to describe the behaviour of each of the variables (movement economy, total angular impulse). Physiologically, the maximal point of the interpolated function for movement economy represents "the most economical" cadence. From the biomechanical viewpoint, the minimal point of the interpolated function for total angular impulse represents the cadence requiring "the slightest muscular effort". The differences between the maximal values of the movement economy function and the minimal values of the total angular impulse function were compared with the value of the function corresponding to each individual's PC. For this comparison, first a Shapiro-Wilk normality test and then a paired *t* test were applied. The significance level adopted was $p < 0.05$.

RESULTS:

Figure 1 shows the interpolated functions for total angular impulse for the seven cyclists analysed. All the interpolated functions are second-degree polynomials with $r^2 > 0.97$. Figure 2 shows the interpolated functions for movement economy for the seven cyclists analysed.

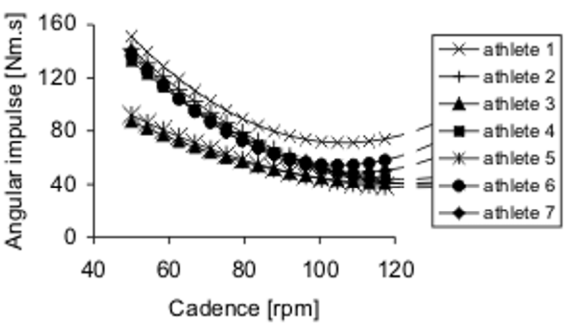

Figure 1: Angular impulse polynomial functions for the 7 athletes as a function of the cadences.

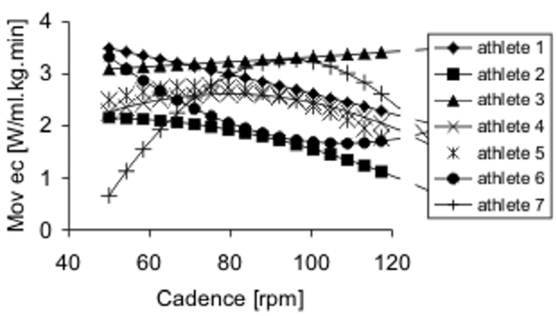

Figure 2: Movement economy polynomial functions for the 7 athletes as a function of the cadences.

The interpolated functions consist of second and third-degree polynomial functions with $0.3 < r^2 < 0.97$. Despite being significant, some correlation values were very low, demonstrating that the interpolated functions do not represent movement economy accurately. Even though, for comparison purposes, those functions that presented the highest r^2 values were used. Results showed no significant differences between the cadence minimising muscle moment and PC ($p>0.05$). On the other hand, there are statistically significant differences between the most economical cadence and PC.

DISCUSSION:

Many studies have been conducted in the attempt to explain why the most economical cadence obtained by using the movement economy calculation is different of PC. Observing Figure 1, within the range of velocities analysed, 60 rpm was the cadence with the highest muscle moment values, thus indicating that the hardest effort is exerted at this velocity. As the velocity is increased, muscular effort decreases, attaining a minimal value near the athlete's PC, and increases again at very high velocities. According to Takaishi *et al.* (1996), at very low cadences, it is necessary to generate a great force to do a particular work. This amount of force decreases as the velocity is increased, until reaching an optimal value of force *vs.* velocity (PC) relation. At very high cadences, the intensity of effort generated is also high due to the increase in agonist/antagonist musculature co-contraction. This was evidenced by Neptune & Herzog (1999), who decomposed the torque on pedal to determine the percent negative work produced by musculature at very high cadences. An increment in negative work, whether it occurs, would evidence the need for an increment in positive work and, consequently, in muscular effort. As the cadence is increased, negative muscle work increases as well, thus confirming the hypothesis that muscular effort is intensified at higher cadences, due to an increasing difficulty of coordination as the velocity is raised.

Considering the hypothesis that the choice of PC is associated to muscular effort, Marsh *et al.* (2000) established a relationship between the sum of the absolute moments on the ankle, knee, and hip joints, and the pedalling rhythm. The sum of the absolute moments represents the total muscular effort generated to perform a particular activity. In the present study, two hypotheses were tested: (1) that PC coincides with the minimisation of the sum of the moments, and (2) that this is not dependent on the individual's experience. According to the data obtained in this study, the individuals' PCs, even not being those that minimise oxygen consumption, are similar to the ones minimising the sum of joint moments. Considering that the net joint moment is directly related to muscular effort, it can be affirmed that the individuals prefer a cadence with a higher metabolic cost, but with a slighter muscular effort. Hence, this approach is especially relevant in terms of the type of effort to which the athlete is being submitted, as well as to understand the choice of a particular cadence rather than others. This optimised relation of force *vs.* velocity would explain the athletes' choice of different cadences, in which an individualised optimisation factor (muscular effort minimisation ability) would be under consideration.

Figure 2 shows the interpolated functions for movement economy for the seven cyclists analysed. Differently from the interpolated functions for muscle moment, the functions related to movement economy presented no pattern among them. Moreover, in the results found in literature, the most economical cadences were the lowest (Takaishi *et al.*, 1996; Marsh *et al.*, 2000), and the results of the present study revealed no pattern for the movement economy curves.

The type of protocol used is a factor to consider. Most studies use moderate-effort protocols. The present study used a power corresponding to the athlete's ventilatory threshold, which requires a strenuous effort. Marsh & Martin (1997) analysed different groups of individuals at several levels of powers and concluded that the athlete's power output does not affect movement economy. However, Woolford *et al.* (1999) demonstrated that, using different bicycles, maximal oxygen consumption of the seven athletes analysed had not varied, but the load corresponding to ventilatory threshold had changed. Considering each athlete's different adaptation to the bicycle used in the test, this factor might account for the variability in the movement economy curves. In all studies found in literature, the bicycle power was the controlled variable, and oxygen consumption was measured. In the protocol used in this study, the controlled variable was oxygen consumption, and the power generated by the bicycle was measured. This protocol was adopted in order to individualise the protocol; however; the effects of controlling oxygen consumption on movement economy calculation have not been described yet in literature.

CONCLUSION:

From the results obtained in this study, it may be inferred that the choice of a particular cadence is associated with muscular effort rather than to oxygen consumption at this cadence.

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