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RESEARCH ARTICLE

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Analysis of the pedaling biomechanics of master's cyclists: A preliminary study

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Abstract

The crank torque represents the kinetics of the propulsive torque within the crank cycle. These kinetics are one of the important determinants of cycling performance. At our knowledge, works in literature concerning the pedaling pattern of master cyclist is lacking although this group of cyclists concerns the majority of practitioners. The purpose of this experimentation is to study the biomechanics of cycling in masters cyclists during an incremental test. Eleven trained masters cyclists (53.5 ± 4.1 years) have participated at this study. The results indicate that the master cyclists have a significant asymmetry (30 ± 8 to 23 ± 13 %) during the pedaling exercise at all power output level tested in this study (100, 150, 200 and 250 W). The present preliminary study suggests that the pedaling pattern asymmetry observed in the master cyclists should be taken into account to prevent knee or muscle overuse injuries.

Keywords: pedaling biomechanics, cycling, master population

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Introduction

The difference in performance between the 40 km time trial cycling specialists is not entirely dependent on some physiological variables (Coyle et al. 1991). A study in which were measured: 1) The maximum oxygen consumption, 2) The lactic anaerobic threshold, 3) The use of muscle glycogen, 4) The type of muscle, and 5) Enzyme activity, has allowed drawing the hypothesis that the cycling performance could be partially related to biomechanical factors related to individual pedaling technique (Coyle et al. 1991). Moreover, the experienced cyclists consume less oxygen per unit of power output, than cyclists of lower level (Coyle et al. 1992). It seems that these differences in oxygen consumption are not entirely due to physiological factors (twitch muscle fiber type), but also in biomechanical parameters (Coyle et al. 1991; Coyle et al. 1992; Kautz and Hull 1995). It seems obvious that the physical potential of the athlete is one of major parameters in the cycling performance. However, it seems important to study how the energy generated by muscular contraction is converted into a propulsive energy on the pedal. The application of forces on the pedal is the last link in the conversion of metabolic energy into mechanical energy to drive the pedal.

The crank torque represents the kinetics of the propulsive torque (N.m) within the crank cycle. These kinetics are one of the important determinants of cycling performance (Coyle et al. 1991), since it represents an important variable of the power output (power output (W) = torque × pedal velocity (rad s^{-1})). The torque is determined by the product of the effective force (Fe) (applied perpendicularly to the crank arm) and the length of the crank arm (m)(Torque = Fe × length of the crank arm). Thus, Fe represents the propulsive force in cycling. From a mechanical point of view, the ideal situation when riding a bicycle is to exclusively generate a constant Fe (Patterson and Moreno 1990). The analysis of the pedaling asymmetry is important for several reasons (Carpes et al. 2007). The asymmetry may negatively affect the performance. The pedaling biomechanics analysis can serve to alert the cyclist's consciousness that the pedaling induces asymmetry. Quantifying the pedaling asymmetry across different crank torques and exercise intensities can help the coaches to program for example a strategy of lower limb strength training. Finally, using a pedaling pattern with a force equally delivered by both legs may reduce the risk of premature fatigue and overuse injuries. Most of studies have been focused on the optimization of the pedaling pattern on recreational and elite cyclists (e.g. Coyle et al. 1991). Also, the bilateral asymmetry during running and cycling is well documented in a review article (Carpes et al. 2010). To the best of our knowledge, no study has reported the characteristics of the pedaling pattern of master cyclists. However, this population of cyclists is most vulnerable to the risk of muscular or joint overuse (50-60 years). In addition, this group of cyclists concerns the majority of practitioners.

Thus, the purpose of this experimentation is to study the biomechanics of cycling in masters cyclists during an incremental test.

Materials and methods

Subjects

Eleven master cyclists (Table 1) performing: regular training, long distance cycling events (200 km) and races in the UFOLEP French cycling federation during the season voluntarily participated in this study. The experience of cycling of the subjects was 15 ± 11 years. Prior to the protocol they have not mentioned muscular or articular injuries. Moreover, prior to make cycling tests, and after they have received full explanation concerning the aim and purpose of the present study, the subjects had to write informed consent. The study was approved by the ethics committee of the local institute and it was conducted in accordance with the ethical guidelines (Harriss and Atkinson 2009).

Table 1. Physiological parameters of the subjects

Subjects	Age (years)	Distance traveled per year (km)	Height (cm)	Mass (kg)	Body fat (%)
1	56	7000	172	79.1	18.7
2	47	4500	181	72.5	14.7
3	53	5000	168	68.7	19.1
4	58	6000	176	66.4	13.9
5	59	5500	170	72.6	21.3
6	56	10000	178	74.7	18.9
7	51	7000	179	75.3	18.9
8	57	14000	170	69.1	18.2
9	52	6000	169	68.2	18.6
10	53	10000	180	70.6	15.3
11	47	8000	183	72.8	19
Average	53.5 ± 4.1	7545 ± 2815	175 ± 5	71.8 ± 3.7	17.9 ± 2.2

Materials

Mechanical power output and the pedaling pattern were measured (200 Hz) using the SRM Training System instrumented crank (scientific model, precision 0.5%, Germany) like several previous studies (e.g. Bertucci et al. 2005 and 2007, Carpes et al. 2007). The validity of the SRM has been previously shown by Jones and Passfield (1998). Before each test, the SRM was calibrated according to the manufacturer's recommendations (the zero power offset was reset although the setting of the zero offset does not substitute for a standardised calibration). However, the standardised calibration rig (i.e. the resetting of the SRM "frequency versus torque" slope) was performed just a few days before our first test day by the SRM manufacturer in Germany and resulted in an accuracy of ± 0.5% (manufacturer's proclamation). The SRM was mounted on a bicycle race (10.2 kg) equipped with clipless pedals. The rear wheel of the bicycle was fitted on the Basic Tacx ergometer (Tacx, Wassenar, Netherlands). Before the start of each test, each cyclist has adjusted his position. The tires were inflated to a pressure of 700 kPa.
Heart rate beat by beat (RR interval) was recorded during all experimental sessions using the Polar S810 heart rate monitor (Polar, Kempele, Finland).

Protocol

The heart rate of subjects was recorded at rest for 5 minutes in a sitting position. The cyclists had to perform an incremental progressive exercise during 18 minutes. The exercise was beginning at a power output of 100 W during 10 min, then the intensity increased in increments of 50 W during 3 minutes up to reach a 200 W, then the last step was performed at 250 W during 2 min (Figure 1). The subjects could control their power output using the feedback on the SRM display.
The SRM sampled (10 Hz) and stored the power output (W), the pedaling cadence (rpm) and the propulsive torque (N.m, 200 Hz) using the methods described in the study of Bertucci et al. 2005. The biomechanical values were stored and averaged during the last 30 seconds of each stage of the incremental test. The propulsive torque measured takes into account the combined muscular work of the two lower limbs during a crank cycle.
The crank angle at 0° corresponds to the vertical position of the left crank arm (pedal in high position). In this study, the torque at DPtop is the minimal torque in sector 1 of pedaling (left crank arm near the top position, 315° - 45°). The torque at DPbot is the minimal torque in sector 3 of pedaling (left crank arm near bottom position, 135° - 225°). The left peak torque (Tpeak Left) is the maximal torque in sector 2 (left crank arm near bottom position, 45° - 135°). The right Tpeak Right, is the maximal torque in sector 4 (left crank arm near bottom position, 225° - 315°).
The asymmetry index (AI, %) were computed according to the study by Carpes et al. 2007. In line with this previous study, an arbitrarily value of AI ≥ 10 % of difference among the lower limbs was used to determine a threshold in order to assign a significant or non-significant asymmetry score. The dominant lower limb was defined by the lower limb which produces the higher torque during the pedaling power phase (between a crank angle of 45 to 135° for the left lower limb or between 225 to 315° for the right lower limb). The AI was the percentage of difference between the dominant and the non-dominant lower limbs.

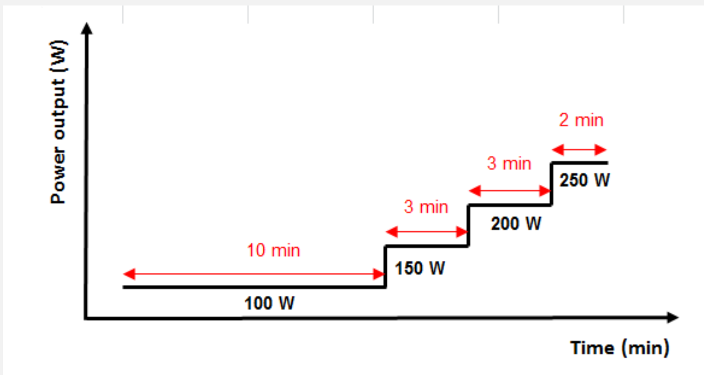

Figure 1. Description of the incremental test.

Statistical analyses

The data of the protocols were tested for normality and homogeneity of variance and turned out to be not normally distributed. Thus, the analyses of differences between the biomechanical pedaling values (i.e asymmetry) were assessed with paired (non-parametric) Wilcoxon tests. Significance was set at $p \leq 0.05$. Data are presented as mean values ± standard deviation.

Results

The mean heart rates (Figure 2) were 106 ± 8, 121 ± 9, 139 ± 8, and 156 ± 10 bpm at 100, 150, 200 and 250 W, respectively. The mean maximal heart rate value was 163 ± 11 bpm.
The pedaling pattern values were shown in the tables 2 and 3 and in the figures 3 and 4.
The results indicated that the master cyclists lower $T_{\text{peak Left}}$ ($p<0.05$) compared with $T_{\text{peak Right}}$. There is no difference between the torque at DP_{top} and at DP_{bot}.
The mean AI were 30 ± 8, 27 ± 15, 28 ± 17 and 23 ± 13 % for the power output of 100, 150, 200 and 250 W, respectively.

Discussion

The aims of this preliminary study were to analyze the pedaling biomechanics of master during incremental exercise.
Our results indicate (table 2 and figures 3 and 4) that the master cyclists have a significant asymmetry during the pedaling exercise at all power output level tested in this study. Except for one subject, the AI values were higher than the AI threshold of 10 %. The mean AI values were between 30 ± 8 % at 100 W to 23 ± 13 % at 250 W. The highest value of AI was close to 60 %. Previous studies have described force asymmetry during cycling between 5 to 42 % (Carpes et al. 2008). Our results show that the master cyclists tested in the present study have very high values of AI. Carpes et al. 2008 have studied the pedaling asymmetry during an incremental test. They have shown that the amateur competitive cyclists tested have a significant asymmetry (AI higher than 25 %) at the beginning of the test corresponding to 90 % of their maximal oxygen consumption. However, these cyclists have no asymmetry at the end of the test for intensities higher than 91 % of their maximal oxygen consumption. The results of Carpes et al. 2008 suggest that the pedaling symmetry is influenced by the exercise intensity. In the range moderate to low intensities, the exercise is sustained by an asymmetric torque production and when the intensity exercise increases, the fatigue process leads the cyclists to generate equality of torque output between limbs (Carpes et al. 2008). In our study the incremental tests have not been

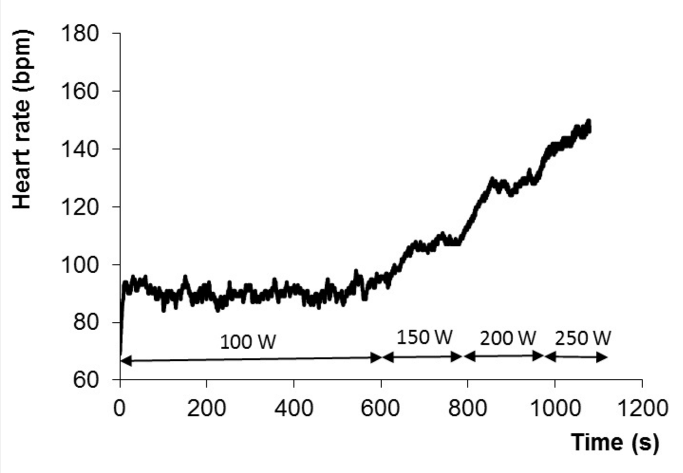

Figure 2. Example of heart rate measurement during the test (subject N10)
The mean power output for each stage were 101 ± 3, 154 ± 4, 205 ± 3 and 252 ± 3 W. The mean pedaling cadence for each stage were 79 ± 3, 78 ± 2, 78 ± 2 and 79 ± 3 rpm.

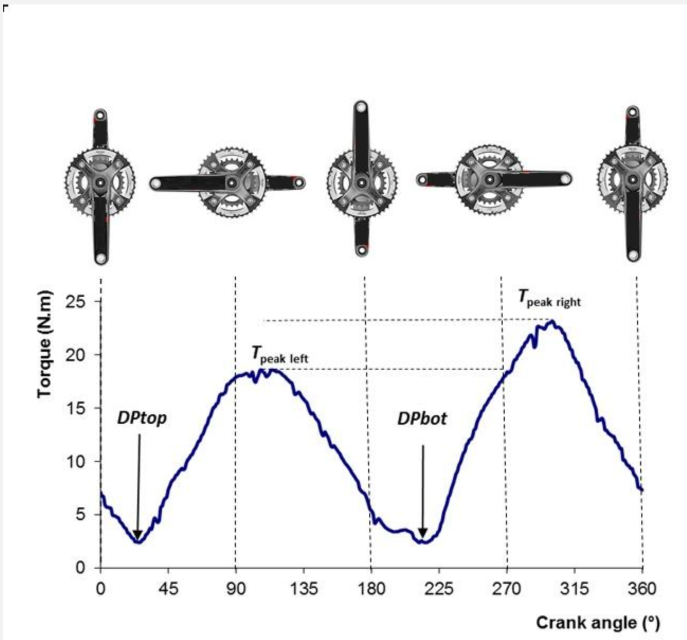

Figure 3. Torque according to the crank angle for subject 1 at 150 W.

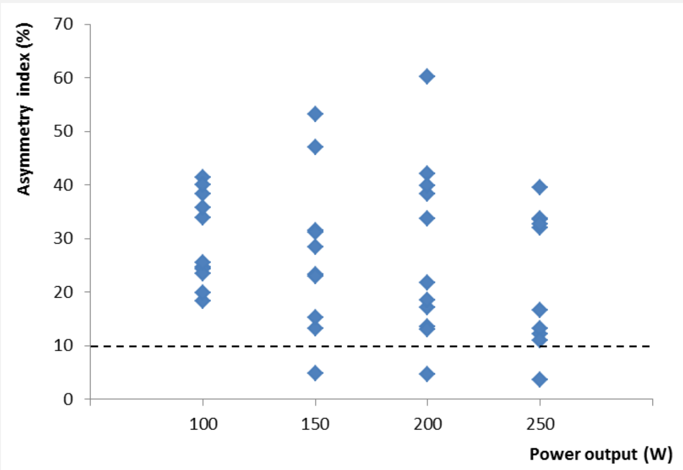

Figure 4. Plot of the asymmetry index (AI) for each cyclist for different power output during the incremental test. The dot line indicates the asymmetry threshold used in this study. AI: 10%.

performed to the maximal intensity in the goal to prevent a health problem for the master cyclists. However, the last stage corresponds to a high value of heart rate for master cyclists (163 ± 11 bpm). In this condition of test at the last stage, the mean AI was very high (23 ± 13 %). It is interesting to note that Bini et al. 2007 have not shown pedaling asymmetry during incremental test for 11 cyclists. The difference compared with the previous studies should be in part explained by the high variability of force symmetry between subjects (Smak et al. 1999). In the present study there are 10 master cyclists with a high level of AI and one with a very low AI value.

Table 2. Min and max values of the torque in left and right lower limbs for different power output.

Power output (W)	$T_{peak\ left}$ (N.m)	$T_{peak\ right}$ (N.m)	Torque at DP_{top} (N.m)	Torque at DP_{bot} (N.m)
100	19.2 ± 3.7	21.8 ± 2.5	4.3 ± 1.5	4.6 ± 1.9
150	27.5 ± 2.9	34.8 ± 4.2 *	7.5 ± 1.2	7.7 ± 2.3
200	34.4 ± 4.7	42.9 ± 3.5 *	10.4 ± 3.5	11.0 ± 3.3
250	43.0 ± 2.6	52.5 ± 6.6 *	12.9 ± 3.4	14.2 ± 4.7

* Significantly different from Max Peak Left ($p<0.05$)

Table 3. Crank angle at $T_{peak\ left}$, $T_{peak\ right}$, DP_{top} and DP_{bot} during the incremental test.

Power output (W)	*Crank angle at $T_{peak\ left}$ (°)*	*Crank angle at $T_{peak\ right}$ (°)*	*Crank angle at DP_{top} (°)*	*Crank angle at DP_{bot} (°)*
100	99 ± 14	260 ± 15	24 ± 17	191 ± 8
150	98 ± 13	263 ± 11	27 ± 6	182 ± 9
200	92 ± 16	253 ± 13	17 ± 18	180 ± 9
250	89 ± 13	246 ± 11	15 ± 18	180 ± 8

Smak et al. 1999 have studied the influence of the different cadences (60 to 120 rpm at the work rate of 250 W) on the pedaling symmetry. They have shown that the group of cyclists (n=11) tested has not a significant pedaling asymmetry according to the pedaling cadence. However, they indicate a high variability between the cyclists. For two cyclists the AI decreases according to the pedaling cadence and for two other cyclists the AI increases according to the pedaling cadence. In the present study the pedaling cadence has been similar during the test and thus cannot affect the AI.

Smak et al. 1999 have shown that the positive average power of the dominant leg was significantly lower than that of the non-dominant leg. They also indicated that the non-dominant leg could have a negative action (negative crank torque production) during the pedaling recovery phase. It is obvious that the pedaling asymmetry can alter the cycling performance. The cause of this asymmetry can have several explanations: 1) a coordination deficit or 2) a significant muscle atrophy on one of the limbs. The analyse of the pedaling asymmetry can be used to quantify an strength training program with the goal to increase the force of the non-dominant lower limbs if there is an muscular atrophy. This program could be performed on the bicycle using a low pedaling cadence with high power output level in the goal to generate high values of crank torque. The use of a special crank arm like the Powercranks (Powercranks, Walnut Creek, CA) could also be used. The training with this crank arm to allow independent pedal work by each leg during cycling can increase the pedalling efficiency (Luttrell and Potteiger 2003).

The traditional strength training could have also a great importance. Hansen et al. 2012 have shown that twelve weeks of heavy strength training in addition to their usual endurance training could improve the pedaling efficacy. The pedaling pattern could be improved, for example by performing exercises with feedback on the torque (Henke 1998). In this way the rider can adjust itself the asymmetry.

To help coaches and researchers to analyze and prevent the causes of the pedaling asymmetry it should be interesting to use the infrared thermography as a non-intrusive tool of investigation. This technology is useful to measure the skin temperature and may help to understand the link between an asymmetry in the pedaling process and the resulting temperature maps. Hildebrandt et al. 2010 indicated that any significant asymmetry of more than 0.7 °C can be defined as abnormal and may indicate a physiologic or anatomical variant in the loco-motor system. Reduced skin temperature has also been implicated in musculoskeletal disorder. This muscular disorder could be explained in part the cyclist asymmetry. The link between the pedaling biomechanics and the IR thermography will be tested in a further study.

Conclusion

A biomechanical analysis of trained master cyclists pedaling was conducted in the laboratory. This preliminary study that should be confirmed in further experiments with more subjects indicates that masters cyclists have a significant pedaling pattern asymmetry from a relatively low level of power output (100 W) to higher intensity (250 W). Thus, a special attention has been paid to the pedaling pattern in master cyclists in the goal to optimize the performance and reduce the risk of overuses.

Practical applications

The biomechanical pedaling of master cyclists should be analysed to detect a possible asymmetry.

The cause of pedalling asymmetry could be analysed using for example the electromyographic or lower limbs force muscular capacity measurements.

The asymmetry could be limited using for example 1) the strength muscular protocol, 2) the force pedaling feedback, or 3) the specific crank like Powercranks.

Acknowledgment

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Conflict of interest

None.

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