ORIGINAL INVESTIGATION (ARTIGO ORIGINAL)

PEDALING ANALYSIS IN BMX BY TELEMETRIC COLLECTION OF MECHANIC VARIABLES

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Abstract

CAMPILLO, P.; DOREMUS, T.; HESPEL, J.-M. Pedaling analysis in BMX by telemetric collection of mechanic variables. Brazilian Journal of Biomotricity. v. 1, n. 2, p. 15-27, 2007. The purpose of the study was to analyze the influence of crank lengths of the pedals on several kinematic and dynamic variables of pedaling. Nine national or international level subjects performed 3 series of 3 consecutive accelerations of 20 meters with 3 different crank lengths: 175, 180 and 182 mm. A telemetric acquisition system conceived and adapted specifically to an experimental BMX made it possible to collect the data of 2 dynamometers placed on the transmission crown and 2 velocity pick-ups fixed at the level of the teeth of the crown and the back hub. The results showed that on an acceleration phase of 20 m, linear velocities of the BMX equipped with cranks of 182 were significantly ($P<0.001$) higher Vb^{182} (6.8 ± 2.4 m.s^{-1}) and Vb^{175} (5.8 ± 1.9 m.s^{-1}). These results were the consequence of angular velocities significantly different in $P<0.01$ ωp^{182} (10.3 ± 4.3 rad.s^{-1}) and ωp^{175} (9.4 ± 4.8 rad.s^{-1}), which was not the case for the forces Fp^{175} (641.3 ± 190.6 N) and Fp^{182} (604.3 ± 210.9 N). These results allowed some of these sportsmen to reconsider the use of 182 mm cranks.

Key-words : Cycling; Crank arm; Power

Introduction

The MotoCross Bicycle or BMX, created in 1968 on the West Coast of the United States was inspired by the Motorbike (MX). Teenagers imitated the motorized practice with their bikes and adapted the tracks to their machines. This track, 400 meters long and 6 to 8 meters wide, is composed of a start line and a finish line distinct from each other, and a variable number of obstacles and turns. In April 1981 the International Federation of BMX was created and the first World Championships took place in 1982 (Dayton – Ohio; United States). The BMX developed quickly as a specific sport. After several years, its competitive regulations had more points in common with the codes of cycling than with those of Cross-country Motorbike. Since January 1993, the BMX has totally become integrated into the International Cycling Union.

In events, eight riders compete during a one-lap race to be the fastest. Races last between 30 and 50 seconds, according to the shapes of the track. The first 4 drivers are selected to the quarter, semi, or to the final, according to the number of registered riders. The term “BMX” corresponds to the practice but also to the name of the machine. The frame, made of aluminium or steel (chromium-molybdenum: Cr/Mo), is quite small (frame size from 950 to 1025 mm): the height of the saddle rod is between 290 and 325 mm, the upper tube is from 540 to 560 mm, the steering column angle is about 74°, the saddle rod is about 71°. The gear ratios used are small and unique (40/15, 43/16, 41/15, 44/16), the cranks are long (from 175 to 185 mm) and the wheels are 20 inches (i.e 0.5 m).

BMX has been the subject of few biomechanical and/or physiological studies. Currently, the consultation of the main bibliographical on-line research engines on that kind of theme (such as Sportdoc, Pubmed, Pascal) emphasizes this lack by the limited number of works. Mainly, they are cases of accidents due to the practice of BMX, which are registered by the medical circle. There has been a study of BMX and its different categories of encountered traumatologies (ILLINGWORTH, 1985; WORRELL, 1985; PARK & DICKSON, 1986; JOHNSON & FAIRCLOUGH, 1987; BROGGER-JENSEN et al., 1989; MOYES et al., 1990; SENTURIA et al., 1997). The theoretical medium to approach a biomechanical research in BMX is that of the cycling and its experimentation mostly on traditional bicycles (BELLUYE & CID , 2001; MARAIS & PELAYO, 2003). The difficulties of adjusting the equipment according to the anthropometrical characteristics, like for cyclists, are major preoccupations for the BMX riders.

The aim of our study was first to create a specific telemetric acquisition system for BMX practice. Secondly, we tested the system with a sprint test comparing the influence of different cranks lengths (175, 180 and 182 mm) on the linear speed of the BMX relating to the acquisition of several mechanical variables such as the speeds of the crank gear (ωp in rad.s^{-1}) and of the bike (Vb in m.s^{-1}), the strength (Fp in N) and the power (Pp in W).

Equipment and Methods

Subjects

Nine national or international level subjects took part voluntarily in this study. They were explained the realization conditions and they consented to the participation in writing. The age, the height and the weight were respectively 19.2 ± 1.7 years, 177.9 ± 7.2 cm and 74.6 ± 9.4 kg. Other anthropometrical characteristics were taken down like the fat mass 10.2 ± 4.6 %, lengths: tibia

42.4 ± 2.1 cm, femur 44.4 ± 2.4 cm, inside leg measurement 82.7 ± 4.2 cm and foot 27.2 ± 1.3 cm, so as to adjust and normalize as well as possible the subjects in the experimental BMX.

Procedures

After a standardized warm-up of 20 minutes (10 minutes riding on BMX track, stretching, 5 progressive accelerations on 20 m), each biker did 3 series of 3 consecutive accelerations of 20 m (Figure 1). Between each series, a 5 minute recovery was imposed. From a start with the pedals on horizontal position, the BMXer rode as fast as possible. For each acceleration series, the crank length (type PROFILE USA) was changed according to a random order: L^{175}, L^{180}, L^{182} mm. The bikers did their accelerations with automatic pedals (brand Shimano or type DX). This choice was justified by the present use in BMX, currently, the actual evolution of the BMX for races tends towards the use of these pedals. The gear ratio (44/16), reduction ratio between the number of teeth on the front chain wheel (44) and the back (16) allows a development of 4.38 m per pedal lap. Knowing that this development fluctuates according to the diameter of the "active" wheel, which depends on the tyre section, of the tyre pressure (6 bars) and of the cyclist weight.

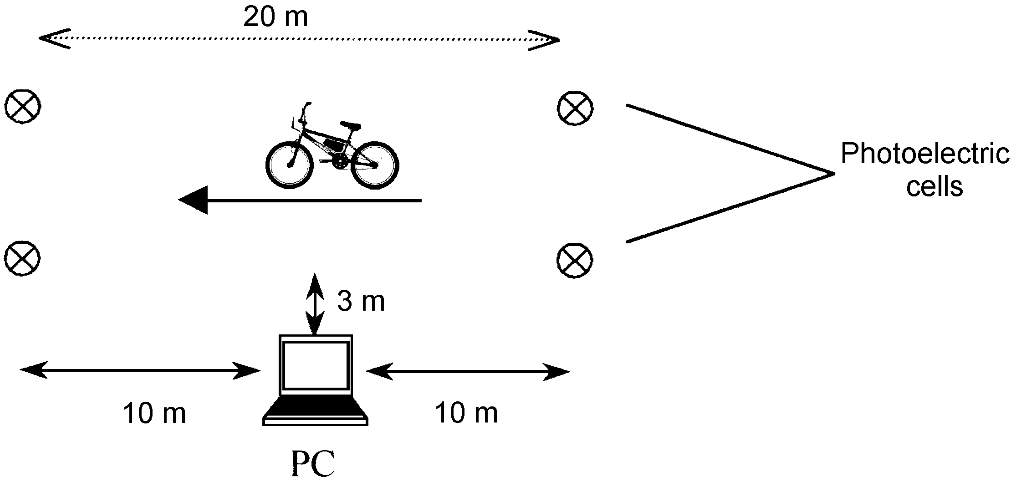

Figure 1 - Recording system of duration and average speeds, on a 20 m distance, through the medium of photoelectric cells. Positioning of the telemetric acquisition system of the mechanical variables of BMX.

Equipment

All the participants used the same experimental BMX, set according to the wishes of the rider. Many factors were taken down thanks to the telemetric system on the experimental BMX: angular speeds of the wheel ωw ($rad.s^{-1}$) and of the front chain wheel ωc ($rad.s^{-1}$), the linear speeds of the bike Vb ($m.s^{-1}$), strength Fc (N) and power Pc (W) at the level of the chain wheel and calculation of the speeds ωp, the strengths Fp and the powers Pp of the pedals. The cyclo-

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ergometer (Figure 2) allowed us to make telemetric acquisitions (maximum distance: 150 m) on the track because of its specific resistance to the constraints, linked to the BMX racing and above all to the jump shocks. The machine was composed of several modules: A, B or C.

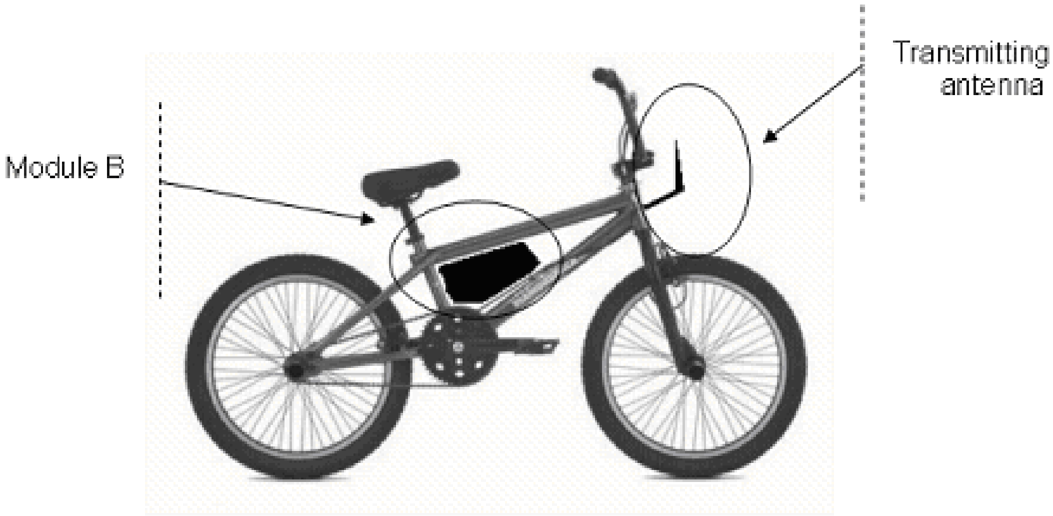

Figure 2 - The experimental BMX with the B module and the transmitting aerial localizations.

The A module (Figure 3) is a microprocessor system which made possible the processing of the strength sensor, set up on the front chain wheel, and the transmission of data by a magnetic coupler to the main measure box (B) (Figure 2). This electronic part, according to the Cms miniature technology, was embedded on the front chain wheel and was coated with a supple resin. It was equipped with an input for Omicron strength sensor. There was an 8 bits resolution, a 150 Hz sampling and power supplied by 2 alkaline batteries (R6 Type) ensured 30 minutes autonomy of functioning. The B module collected the data of the A module (connection by a magnetic coupling) in particular the angular and the crank gear position, but also the rear wheel angular speed. The C module developed around a microprocessor made possible the communication between the B module by radio frequency and with a PC. Inductive sensors set at the level of the teeth of the crown and of the rear hub made it possible to measure the angular speed of the crank gear and of the rear wheel. Utilization constraints measured were linked to the front chain wheel of transmission, in others words, the crown. Indeed, two dynamometers (Omicron) were set on the crank gear crown (A Module, Figure 3), and measured the torque of strength developed by the pilot according to the variables used: the gear ratio and the crank lengths. These two sensors linked two front chain wheels juxtaposed. One had integrated cranks, the other was composed of the crown teeth. Cinematic and dynamic values of the telemetric acquisition system were checked positioning the BMX on an ergo cycle (Cateye CS 1000, Cateye Osaka, Japan). Results showed no significant difference between the values of both systems. 2 pairs of photoelectric cells of the type Speedtrap II – TS 175 (Brower Timing systems, Salt Lake City, Utah, USA) were disposed on each extremity of the 20 m acceleration. They measured duration and average speeds of the sprints realization.

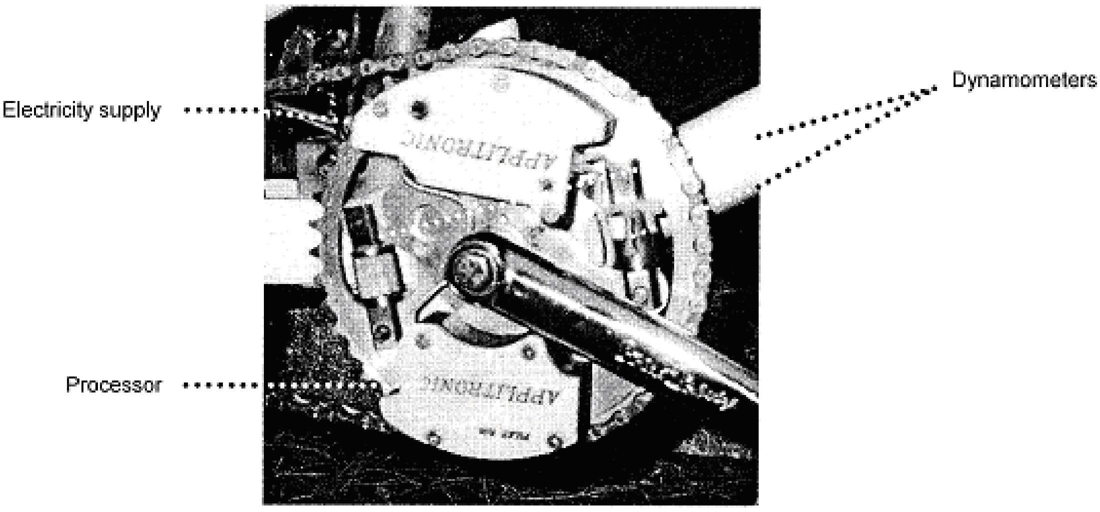

Figure 3 - A module. Transmission crown provided with strength captors.

Statistical analysis

The average and the standard deviations were calculated for each parameter studied above all for ωp, Vb, Fp, Pp. The Friedman test, non-parametric equivalent of a measuring system, repeated three times (Ts1, Ts2, Ts3) was realized to appreciate the variations between each sprint. The analysis procedure of united varied (ANOVA) was done for each variable between 4 pedaling cycles of a sprint repetition and between the 3 crank lengths. Linear relations (Spearman test) were tested between the cranks which seemed appropriate and the anthropometric measures of the subjects. For all analyses, differences were considered significant at $P < 0.05$.

Results

For each test carried out, the telemetric acquisition system made it possible to collect and visualize lines and values of instantaneous and simultaneous variations of strength, of angular speed and of power at the gear mechanism collectors level. From these values, respective results were calculated at the level of the extremity of crank length (Figure 4). These data were analyzed through maximal, minimum and medium values for each of the four laps of a crown (44 teeth). The instantaneous linear speed (Vb) of the BMX, represents the essential variable to assess the mechanical consequences of the changes of crank length on the system. The average speed of the vehicle can also be calculated through performances on 20 m obtained by photoelectric cells. There are not significant differences between the speeds measured with the photoelectric cells and the speeds obtained from telemetric acquisitions.

As 180 mm (L^{180}) crank lengths are the most used in BMX, the data collected with other lengths of crank 175 mm (L^{175}) and 182 (L^{182}) were compared in percentage (Figure 5a et 5b) in relation to the use of these lengths of crank (L^{180}).

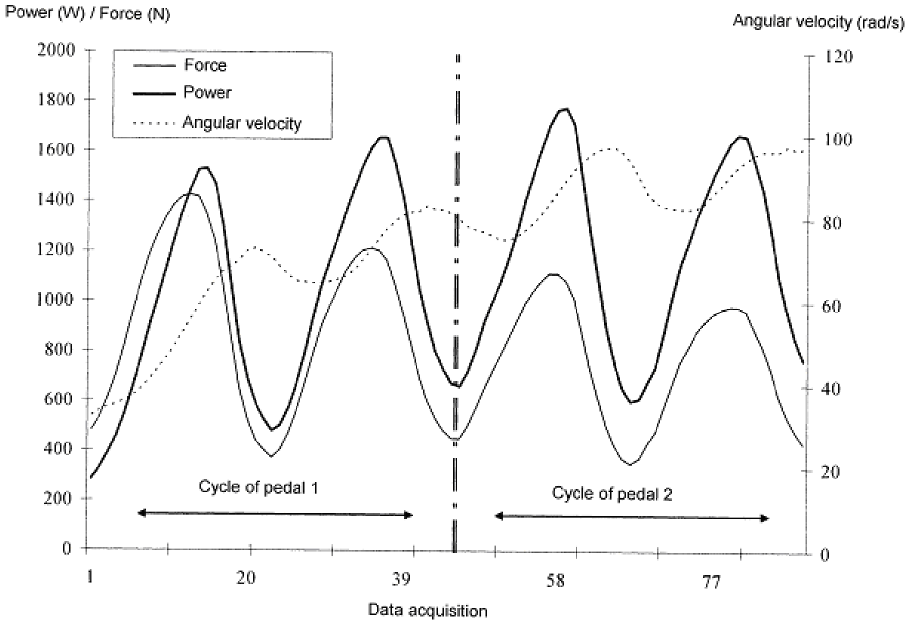

Figure 4 - Evolution representation of these three mechanical variables during two cycles of pedaling (cycle 1 and cycle 2), by way of an example for a subject. On two laps of a 44 teeth crown, are calculated at the level of the pedal: the speed (rad.s^{-1}) the strength (N) and the power, consequence of these two variables (W).

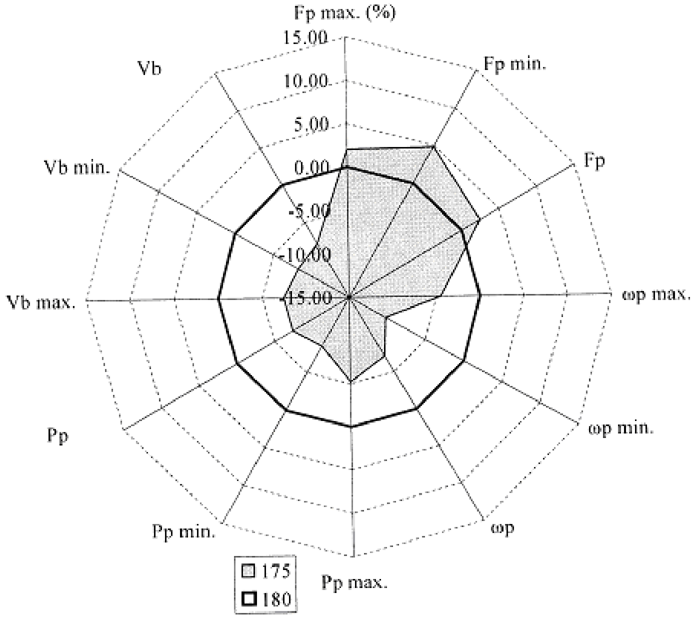

Figure 5a - Graph showing in percentage (%) the differences existing between BMX and the others in relation to the use of a crank of length 180 mm and a crank of length 175 mm. Specific values (maximal “max.» minimum “min.” and medium “med.”) of strength (Fp), of angular speed (ωp), of power (Pp) and linear speed of the BMX located on each of the four cycles, are averaged and compared.

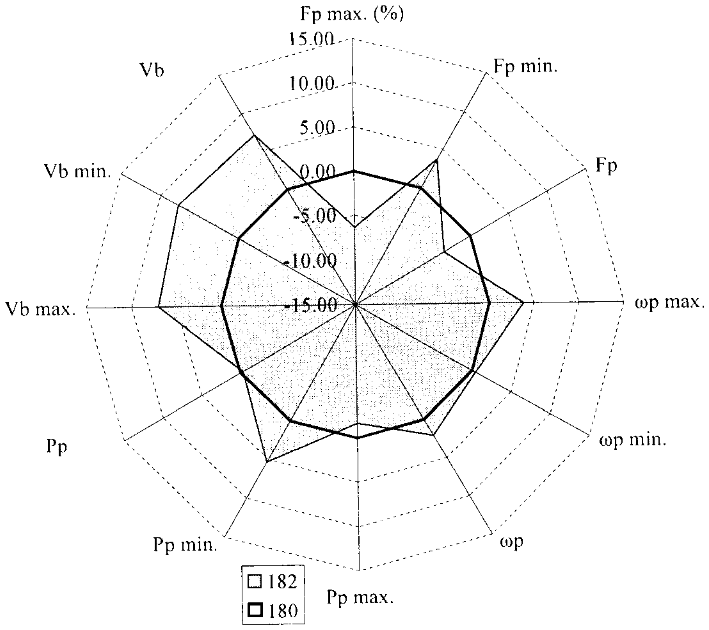

Figure 5b - Graph showing in percentage (%) the differences existing between BMX and the others in relation to the use of a crank of length 180 mm and a crank of length 172 mm. Specific values (maximal “max.”, minimum “min.” and medium “med.”) of strength (Fp), of angular speed (ωp), of power (Pp) and linear speed of the BMX located on each of the four cycles, are averaged and compared.

BMX Group developed with the cranks of 182 mm higher angular average speed (10.2 ± 3.7 rad.s^{-1}) than with the use of the cranks L^{175} (9.3 ± 4.8 rad.s^{-1}) and L^{180} (9.9 ± 3.6 rad.s^{-1}) . Differences were revealing at $P<0.01$ in particular through values of maximal angular speeds, which were superior to 4% at L^{180} and to 8% at L^{175}.

The strength generated on pedals comparatively decreases according to the lengths L^{175} (641.3 ± 190.6 N), L^{180} (625.6 ± 174.1 N), L^{182} (604.3 ± 210.9 N) for better performances in 20 m sprints. Cranks of 182 mm enables BMXers to reach the fastest acceleration phases on this distance. Indeed, speeds are significantly different according to the use of crank lengths ($P<0,001$). We determine linear average speeds with L^{182} of 6.8 ± 2.4 m.s^{-1} respectively faster than with L^{175} of 5.8 ± 1.9 m.s^{-1} and L^{180} 6.3 ± 2.3 m.s^{-1}. We notice a certain advantage to use L^{182} cranks on this short distance.

In other respects, average strengths (Pp^{175}) obtained with cranks of 175 mm (Pp^{175} = 1050.3 ± 312.2 W) are inferior to those which are developed with 180 mm cranks (Pp^{180} = 1134.6 ± 315.6 W) and with 182 mm cranks (Pp^{182} = 1131.1 ± 394.8 W) but without presenting significant differences. The use of L^{182} cranks are characterized by minimum values which hold up above of those of L^{180} (5.4%) and of L^{175} (8.5%). Finally, the analysis of variance shows, for all the variables studied, significant differences (ANOVA) between the 4 cycles of pedalling of each repetition with $P<0.001$. Which is logical because BMXers start from a static position. Whereas with the beginning of the cycle, the sportsmen, must primarily generate a maximum of force, to make inertia leave with the BMX-BMXer system. In the other cycles, the subjects develop their power by the compromise forces – speed. In this report/ratio, the angular velocity gradually will become more important. In addition, between 3 repetitions, for each of the crank lengths L^{175}, L^{180}, L^{182}, one does not significant differences between the 3 repetitions, respectively for each length of L^{175} cranks, L^{180} and L^{182}.

Discussion

Currently cycling is composed of several disciplines: traditional cycling, race cycling, mountain bike and bicycle motocross (BMX). BMX is a discipline less well known than the others whereas it appeared in the early seventies in the United States, at the same time as other Californian sports, «fun» sports as they are called or extreme (surf, roller, skateboard…). During this decade, this sport was introduced in other continents and throughout Europe from 1978 onwards. However, in spite of an increasing number of BMX riders it remains a topic rarely studied experimentally. The objective of our study has been double. On the one hand, participate in the elaboration of a mechanical and telemetric measurement instrument specific to BMX and on the other hand, to test acquisitions on a 20 m sprint, in order to optimise rationally the choice of crank lengths, which are made in an empiric way by the BMXers. A good BMX rider is supposed to have explosive strength, excellent driving coordination, very high technical skills and good tactical spirit. In this discipline, the race does not last more than 40 seconds and forces the sportsman to generate the maximum strength with a gear ratio selected according to feelings. Very few, indeed no studies, have been carried out about the optimization of adjustments of BMX equipment. This is a paradox compared to the many studies which concern the factors of optimization of biomechanics of pedaling (DE GROOT et al., 1994). Moreover, in BMX, at the time of the competitions, the subjects are not sitting on the saddle. It should be stressed that this position makes it possible to use more total mass of the subjects and thus to develop more power. The analysis of this position remains specific compared to the majority of the explanatory models when the subjects are in sitting position (YOSHIHUKU & HERZOG, 1990; YOSHIHUKU, 1996).

The review of the literature reveals that the effectiveness of the pedaling is influenced by various parameters: the level of power and the frequency of pedaling, the phase of the revolution of the pedal, the interface foot - pedal but also the pattern of pedaling (ERICSON & NISELL, 1988; PATTERSON & MORENO, 1990). As many variables as it was possible to acquire with our telemetric measuring instrument and that during the drive and the competition. It would be advisable to reduce the times of treatment and communication of the results to return a logic of optimization of the sound movement by biofeedback transferred by the helmets. Initially information biofeedback could relate to the linear velocity of the BMX. This first simple informational signal could gradually be enriched with the results of the average application of the mechanical power exerted by the plate. According to specific sets of themes of optimization of the pedaling, instantaneous information on the angular velocities of the pedals or the forces which are applied there, will be invaluable assets of interactions machine-sportsman.

The analytical and specific treatment of the variables by turn of plate makes possible a fine analysis of the pedaling of each sportsman. It is possible to center the attention of the sportsman on certain negative aspects discovered. On the majority of the curves of forces, one notes that the share in force of one foot is equal to that of the other foot, with the existence of two dead points. However, other layouts reveal in a ponderal or constant way imbalances in the pushes per half-turn of pedals. Increasing the length of the lever of the crank can generate or accentuate this type of defect. Changing the length of the crank can disturb the coordination of the cyclist and thus the optimal production of power. It would be advisable to analyze, according to the lengths of cranks, the optimal relationship between the angular velocity and the forces developed according to these maximum powers. The realization of monthly force - speed tests will better inform BMXers about the optimal and specific driving structure of sound pedaling according to the evolution of their muscular force in the course of a season. But the decomposition of the pedaling in several phases and especially the concomitances of actions and reactions between the two legs make the adjustments difficult.

The analysis of pedal movement appears problematic because it breaks up into four well defined and specified phases: push (high dead point), pressure, the repulsion (low dead point), traction. The phase of pressure presents in the significant variations with a peak, which corresponds to the development of useful force (KAUTZ & HULL, 1993). The force of a foot is at the maximum when the pedal passes to the horizontal, however its work begins with the crossing of the vertical and finishes soon afterwards. The repulsion, rejecting the pedal as quickly as possible, joins the push of the other foot. It is necessary to reduce to the minimum the time of these two phases to obtain a "round" pedaling. Traction, rising the pedal with the foot, joins the pressure of the other foot. In order to better determine the prospects for optimization it would be advisable to compare at the time of the pedaling this simultaneity of the antagonistic muscles and the protagonists in BMX like Jorge and Hull (1986) in cycling. All the more so as the use of the automatic pedals accentuates its effect (CAPMAL & VANDEWALLE, 1997; HINTZY et al., 1999).

It is with cranks of 182 mm that BMXers develop linear maximum speeds higher than with the other lengths of cranks ($P<0.01$). The significant difference in the angular velocities is mainly the consequence. Cyclists try to exploit their possibilities of maximum force on all the circumference of the crown. It is advisable to pedal "round" by attenuating the fluctuations of forces during the crossing of the zones of high and low points dead. Thus four subjects out of nine cyclists had this "round" type of pedaling, with cranks of 175 or 180 mm, but it remains difficult with 182. The other BMXers had results corresponding to traditional curves, i.e. curves of torque presenting two quite characteristic minima. Other curves presented more dead points than the normal: this phenomenon being explained by a problem of coordination, accentuated by the automatic pedals. This problem was all the more significant as certain subjects were not accustomed to the use of automatic pedals. The prospect of not to being able to free oneself from the pedals during a possible fall still slows down this type of use.

Other essential elements spring from the work on the pedaling. This movement is essentially an extension and flexion chain of the hip and the knee, with as fix point, the articulation of the hip. Moreover, the rotation of the foot is not a natural movement, but the consequence of this pressure on the crank. Hence the necessity of a pedaling technique so as to fulfill efficiently this rotation. On the other hand, the element, which determines the performance, is the strength of extension muscles of the leg, the pedaling technique having only a secondary influence. Moreover, the efficiency of the pedaling increases with the difficulty of the effort. In fact excessive increasing of the pedaling rhythm is not necessary.

The description of the pedaling cycle seems necessary for a better understanding of muscular actions during the different phases of pedaling in BMX. It would be interesting to combine with the telemetric acquisition of mechanical variable, an electro-myographic study for a better understanding of the work of particular muscular groups. Some authors have already done so on bicycles: Gregor et al. (1985); Jorge & Hull (1986); Brown et al. (1996) and more recently Mileva & Turner (2003). In order to draw up a precise assessment, it would be interesting to measure the consequences of the use of these various lengths of cranks on certain spectroscopic parameters of physiology neuromuscular of the principal muscles concerned in the pedaling (TAKAISHI et al., 2002; MIURA et al., 2000).

An ambiguity remains on the consequences caused by the modification of the length of the lever on the motor scheme of the pedaling in short or long term. Indeed, taking into account the phase of adaptation left out of the protocol, the modification of the length of crank which appears unfavorable for the performance for one period of short adaptation could prove more interesting in the long term with training. A tendency which remains difficult to appreciate taking into account the planning of training and the competitive calendar of the high level sportsmen. Some technological modifications (Feet holders) produce technical improvements and clear and abrupt performances. While others and for the major part, cause less revealing modifications of profits and depend on the utilization period.

Conclusion

The experimental BMX appears to be an interesting instrument of analysis and technical adjustment. It leads to an interpretation and a possible optimization of the pedaling cycle from acquisitions made on the spot at training sessions and competitions. The kinematic and dynamic characteristics collected could result in adapting the choice of the material according to specific characteristics of the configuration of the track of the competition and the physical condition of the sportsman. Lastly, it would be advisable to exploit this measuring instrument in a specific manner on the techniques of crossing as well as bumps. In particular the cycle of pedaling before and after the bumps on the techniques of take-up after the turns in order to optimize the technical integration of the recognition of the tracks.

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