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PRELIMINARY REPORT ON Q-RINGS

ANALYSIS OF PHYSIOLOGICAL AND BIOMECHANICAL EFFECTS OF OVAL VARIABLE GEARED CHAINRINGS (Q-RINGS) IN COMPARISON TO CONVENTIONAL CIRCULAR CHAINRINGS.

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BACKGROUND ISSUES OF STUDY.

There have been several studies focusing on analysing the activity of muscles involved in pedalling. (1,2,3,4,5). Most of them analyse physiological factors, including determinant variables in sport performance, such as: maximum oxygen consumption (VO2 Max.), Maximum Heart Rate, Aerobic & Anaerobic thresholds, Maximum Lactate levels, mechanical efficiency, etc. (6,7,8).

According to Ericsson and Nisell (10), Pedalling strength is not constant during the pedalling cycle (9,10,11). This is demonstrated in that the tangential force is at its greatest when the cranks are close to horizontal alignment. Nevertheless, these authors remark the existence of two points in the tangential force cycle. These being the Upper Dead Spot (UDS) and the Lower Dead Spot (LDS), both placed at cranks vertical alignment. To increase pedalling mechanical efficiency, there have been several proposals of non circular chainrings, most of which accelerate the up and down stroke (12,13). For example, Cullen et al. (12) & Hull et al. (13) described an elliptical chainring ("Shimano Biopace"), the maximum angular speed of which occurred when the angle of the cranks was at 66º and 246º from UDS. Additionally, Hull et al. (13) introduced an elliptical shape "Eng 10" whose maximum speed was obtained when cranks angles were 100º and 280º from the UDS. All these chainrings had in common the particularity that crank arms were placed so that the diameter perpendicular to the crank arms was the smallest and the parallel diameter the largest.

In the 1980's another ovoid (elliptical) chainring called "O.Symetric Harmonic" was developed, which was different from "Shimano Biopace" and "Eng 10". Authors of studies on these chainrings point that with their design, pedalling effort is harmonized (14, 15, 16). These authors conclude that even though "Harmonic" chainrings were designed to optimize pedalling, no advantages were obtained in the cyclist's physiological response to sub-maximal and maximal efforts, compared with conventional circular chainrings (17). This chainring had the characteristic that the crank arms were placed approximately perpendicular to the greatest diameter and that the parallel diameter was the smallest. (The opposite to the two previously mentioned systems).

Today, Rotor Componentes Tecnológicos, S.L., has developed a new type of oval chainring "Variable Gear chainrings (Q-rings)". Q-Rings imitate pedalling biomechanics of Rotor Cranks (18, 19) during pedal downstroke, when cyclist generates their greatest power. This means that when the pedal is descending, the Q-ring progressively modulates the immediate gear, according to leg's immediate capacity. Thus, Q-rings increase the diameter at the same time as the cyclist increases the force applied to the pedal during the downstroke. After this, Q-rings reduce the immediate gear ratio when passing through the Dead Spots, acting similarly to a circular chainring with a smaller diameter (less teeth), reducing stress on the knees (figure 1).

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Q-rings place the maximum gear moment (when the chainring's maximum diameter transfers propulsion forces to the rear wheel) when the pedal is around 15-20º below the horizontal axis on the downstroke. This is because the tangential forces are higher around the horizontal axis. Based upon this, Q-rings place the maximum gear of the oval in such a way as to optimize cyclist's power delivery.

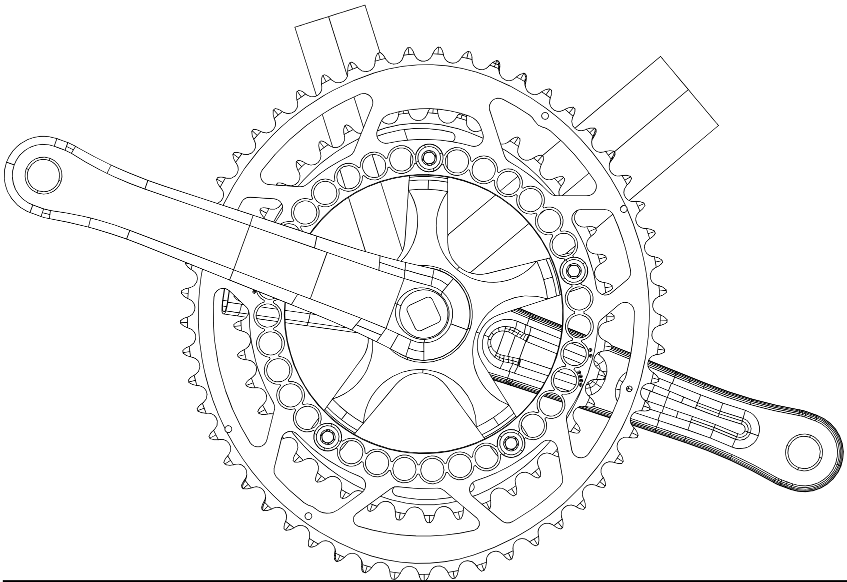

Figure 1: conventional cranks fitted with Q-Rings

For example, on a 53 Tooth chainring, an equivalent chainring diameter of 51 Teeth applies around the UDS (figure 2). Once past the UDS, when the pedal starts the downstroke and tangential component of force applied on the pedal increases, the diameter of the Q-ring increases proportionally. The Q-Ring increases the equivalent gear progressively until it reaches 56 teeth, which is located (~15º) beyond the maximum power moment (~ horizontal axis).

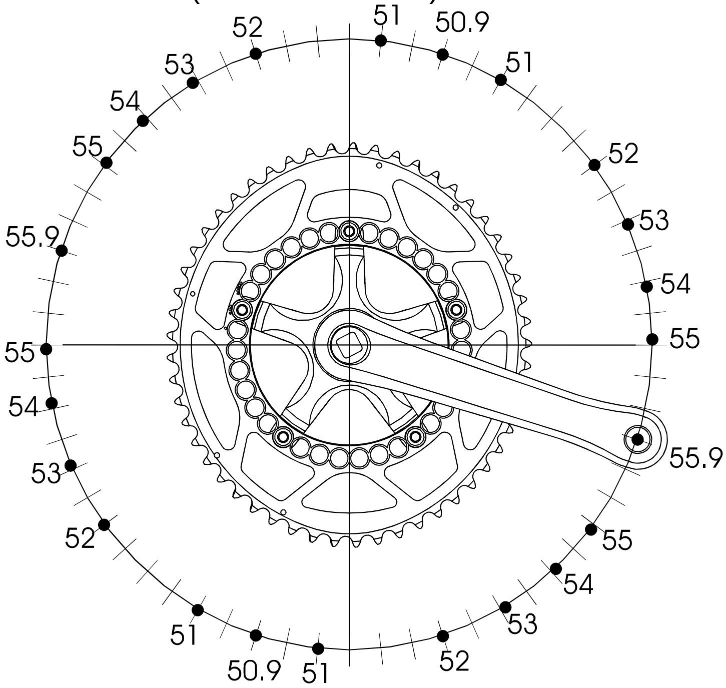

Figure 2: Instantaneous equivalent chainring size for a 53T chainring

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Additionally, Q-rings have the unique attribute of allowing for the orientation of their ovalization to be changed in regards to the crank. This allows the angle of delay in attaining the maximum effective gear to be adjusted for every cyclist. It est, each cyclist applies his maximum strength at a defined moment (which is individual to each cyclist) in the pedalling cycle: the maximum torque point (MTP). Subsequent to this conjecture, the innovation of Q-rings is that they incorporate a multiple regulation system (OCP System – Optimum Chainring Position). The OCP System allows every cyclist to orient the maximum diameter according to his MTP, allowing customisation of the variable geared ratio transitions for each individual cyclist's biomechanics.

With this innovation, which allows for an easier adaptation for the cyclist once the ideal orientation or regulation of the Q-ring is defined, (it est, the variation of chainrings orientation in reference to the cranks), the person can apply their pedalling potential in a more effective way.

Because they reduce the intensity of the Dead Spot, Q-rings contribute to an increase in pedalling efficiency and, therefore, lead to an improvement in performance. As such, this should be reflected in athletes physiological responses (cyclists, triathletes, duathletes, etc.) while training and competing, as well as in trials or lab and/or field physiological tests. Considering all this information, the intention of this study is to compare physiological data from sub-maximal and maximal tests on elite amateur sub-23 cyclists. These cyclists were monitored as they used both OQC chainrings (Oval Q-Ring chainrings) and NCC chainrings (Normal or Conventional Chainrings).

MATHERIAL AND METHODS.

For this study 8 volunteer Elite-sub23 amateur cyclists from Galiber Cycling Association were used as test subjects (n=8). The study was held during first and second week of training, so it was coincidental with the time in which training starts for the coming competition season (2006). The average age of test subjects was 21,1 +/- 2.1, weight of 69.3 +/- 8,4 Kg., height 175.8 +/-5.9 and Max VO2 70.5 +/-5.3 (ml.Kg-1min-1).

For lab tests a trainer from the brand COMPUTRAINER™ was used, which combines an electromagnetic with an aerodynamic brake, as well as the tire-trainer friction. This trainer machine controls the resistance applied to the wheel by computer. Even so, tests carried out using this trainer, as would happen with any other model or make, cannot guarantee that the results attained would be valid for real world cycling on the road. The advantage is that this computerized trainer allowed for each cyclist to use their most suitable Q-ring regulation setting, thanks to SPINSCAN, a tool which provides information about each individual's pedalling style. Moreover, every cyclist could use his own bicycle for the test. For all tests, same rear wheel (the one subject to friction) was used at the same inflation pressure (8 atmospheres) and for every bicycle, a set of OQC (Q-rings) or NCC (Normal or Circular Chainrings) were used, depending on the correspondent test.

Two days before tests were carried out all test subjects were summoned to the lab to inform them of the study objectives, tests to be done and get their written authorization to proceed. Additionally, clinical backgrounds (history) were collected and physical examinations were carried out. In the same manner, blood specimens were taken for a subsequent biochemical and haematological study, in order to know the physical condition and biological profile of every tester. These tests allowed the exclusion of any subject who could display any signs of pathological illness, or those who were out

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of the range of normal physiological profiles (Criteria by UCI-2005 Medical Committee). The group of the cyclists who were initially to use the OQC pedalled on their bicycles with NCC for 5 minutes on the COMPUTRAINER, in order to obtain SPINSCAN results. According to these results, indicating whether their SPINSCAN was high, medium or low, the OQC were regulated for their bikes. For the other half of the cyclists this was not necessary, because they were to test NCC first, so the SPINSCAN could be made then for them during these tests, determining each subjects optimal regulation for OQC.

So, proceeding every OQC test, the Q regulation, or orientation of the crank in relation to the greatest diameter of the oval chainring, was determined for each individual cyclist.

On the same day of lab tests, blood specimens were taken from each athlete's medial basilic vein. These samples were taken before and just after the maximum effort test on their own bicycle, coupled to an ergometer, in order to determine changes in blood variables.

For analytic veriification we used an auto-analyzer for blood determinates (Coulter Electronics, Ltd.) and biochemicals (Hitachi). Lactate measurements were made, previous puncture with sterile lancets (Boehriinger ®), with micro-method system "Lactate Pro" (digital with testers), based on an amperometric method using and enzymatic reaction. This apparatus requires only 5 Tl, with a variation coefficient of only 3%. Likewise, at the same time measurements were made with an "Accusport", whose results are based on enzymatic method and lactate reflex photometry (with a wavelength of 660 nm). These measurements were made using 20-30 Tl pure blood samples. This method has a good correlation, r=0.90 & r=0.97, in determinations related to YSI 1500 analyzer (reference analyzer used for the validations). Samples were taken before the start of the test, and 1,3 and 5 minutes after finishing it, in order to obtain the maximum lactate levels.

Recordings of the test subject's Heart Rates were taken and saved continuously using a heart rate monitor (Polar – Xtrainer Plus).

Gas composition was monitored breath by breath for the duration of the tests (Medical Graphics System CPX-Plus). For the day before the test, cyclist were recommended to do some light training and eat a diet rich in carbohydrates. Variables calculated on the test were oxygen consumption (VO2), ventilation (VE), Oxygen

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Ventilatory Equivalent (VE – VO2 – 1), respiratory quotient (RER). Subsequently, ventilatory thresholds were measured, attending to the increase of VE-V02-1 without the increase of VE-VC02-1 criteria for the VT1, and increase of VE-VO2-1 in parallel to the increase fo VE-VCO2-1, to obtain the VT2.

STUDY PROTOCOL.

Tests were carried out in three sessions of two days for all test subjects, in different weeks.

During the first and third week, tests were carried out in two consecutive days, for the first day half the group used OQC (regulated for each test subject individually) and the other half used NCC, and on the second day vice versa. Protocol held consisted of 15-20 minutes warm-up on the trainer, and after that a load of 200W (watts) for 4 minutes, prior to the incremental test. The progressive incremental test started at 200W, and from the 5th minute on, 10 watts were added per minute till the tests subject's exhaustion. Gearing used by cyclists was free, but always maintaining a pedalling between 85 and 95 strokes per minute, so cadence stayed around 90-91 pedal strokes per minute. Along the test 4 blood specimens were taken from the test subject's fingertip in order to measure blood lactate levels. Whenever these samples were taken, the time and heart rate were recorded. After 15 minutes recovery pedalling without resistance at 130 heartbeats per minute, the test subject made 4 maximum effort sprints for 20 seconds each, with 40 seconds for recovery in between them. Just before sprints started and at the 1st and 3rd minute after sprints, blood specimens were taken in order to analyze lactate levels.

During the second week, tests were also done over two consecutive days, with half of the group using OQC for the first day and the other half NCC, changing the chainrings around for the second day. Time schedules and conditions were as identical to those of the previous week for every cyclist as possible. The first test, consisting in a sub-maximum trial at 90%, was carried out after warming-up for 20 minutes on the trainer. This 90% was calculated bearing the results from last week in mind. These levels were defined using the average maximum wattage attained by every individual test subject for each chainring type (OQC and NCC), from which the 90% was calculated. Trials consisted of constant pedalling at 90% W_{max} for the maximum possible time. As with the protocol from the previous week, blood specimens were taken at the end of the trial in order to define lactic academia. We must remark that during first day, if the test subject endured this test for over 25 minutes, he was stopped, scoring heart rate and lactate. On the second day of testing, tests were ceased when the test subject continued 8 minutes over his time from the previous day, at which point the subjects heart rate and lactic academia were recorded.

Data presented are arithmetic averages from every moment analyzed, for the scores taken with OQC and NCC.

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RESULTS.

Results obtained are displayed as an average of all data for each of the analyzed circumstances, and are displayed on the following charts (1,2,3). For explanation of the results, statistical variations of results were not considered, due to this being a preliminary study, so more attention was focused on evidential biological characteristics. Obviously, for a bigger group of test subjects and with control of parameters considered as optimal, it would be necessary to do a statistical analysis of the results, so they could be properly published in a scientific publication.

It is observed in the results that when cyclists made the test with OQC they produced slightly more power (around a 3%), together with a slightly lower heart rate (around a 2%) during the progressive incremental test (chart 1).

For the 90% maintained power test, it was observed that with OQC cyclists were capable of continuing for a longer period of time than with NCC. Although there was a significant difference, this has not been numerically quantified as explained by both the statistical discussion above and the fact that tests were ceased when test subjects continued for longer than 8 minutes over times from the day before. This test resulted on a lower production of lactic acid for tests carried out using OQC. Nevertheless, average heart rate measurements during these tests showed no significant differences between OQC or NCC chainrings (chart 2).

For the repetitive maximal sprints for 20 seconds with 40 second recovery interludes, three of the four tests (first, third and fourth) showed that power production was higher with OQC than with NCC (chart 3). The second sprint test showed no differences.

Regardless which chainrings were used, (OQC or NCC) maximum levels of Heart rate and oxygen consumption (VO2 Max) saw no change, which seems logical because they were test where every individual had to keep on pedalling until his maximum (until exhaustion).

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Chart 1. Analized Variables (W, HR-Max , X-HR) on Incremental Maximum Test with Q-Rings (OQC) and Normal Circular Chainrings (NCC).

CHAINRING TYPE	WATTS (W)	MAX. HEART RATE (HR max) (bpm)	AVERAGE HEART RATE (X-HR) (bpm)
OQC	361±29.6	190±8.3	166±9.6
NCC	349±28.8	191±5.1	170±9.1
DIF (Δ-%)	3.3	=	2.3

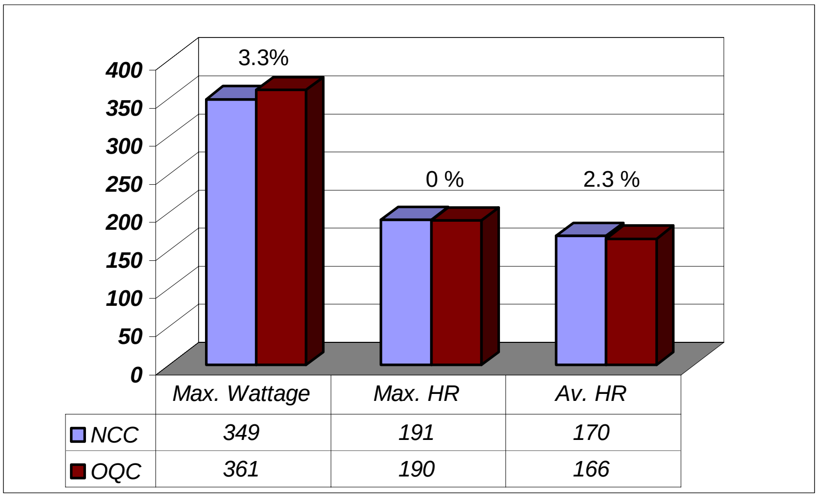

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Chart 2. Analyzed variables (La-Max, HR-Max) on 90% sustained power test (90% of power showed on incremental test) generated with Q-rings (PQ) and normal conventional chainrings (PN).

Chainrings	**Lactate concentration (mmol.l^{-1})**	**Max Herat Rate (HRmax) (bpm)**
OQC	11.9±2.9	189±6.9
NCC	13.1±4.1	190±5.4
DIF (Δ-%)	9.1	=

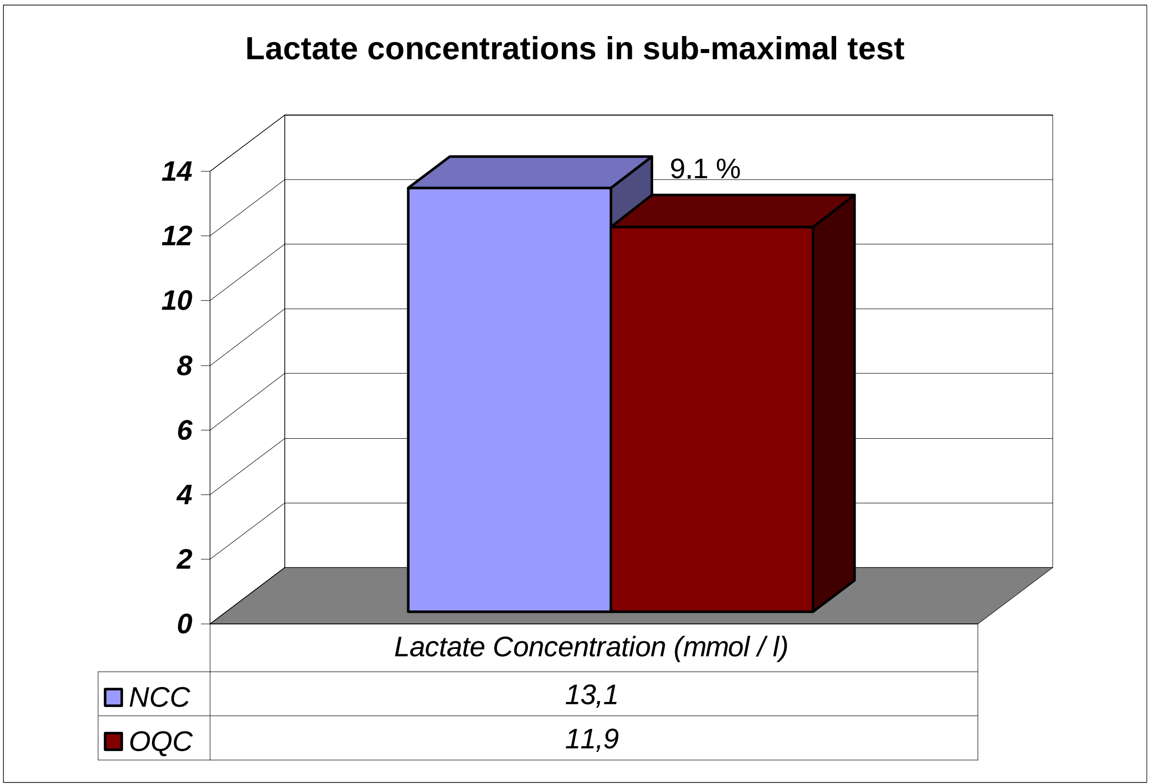

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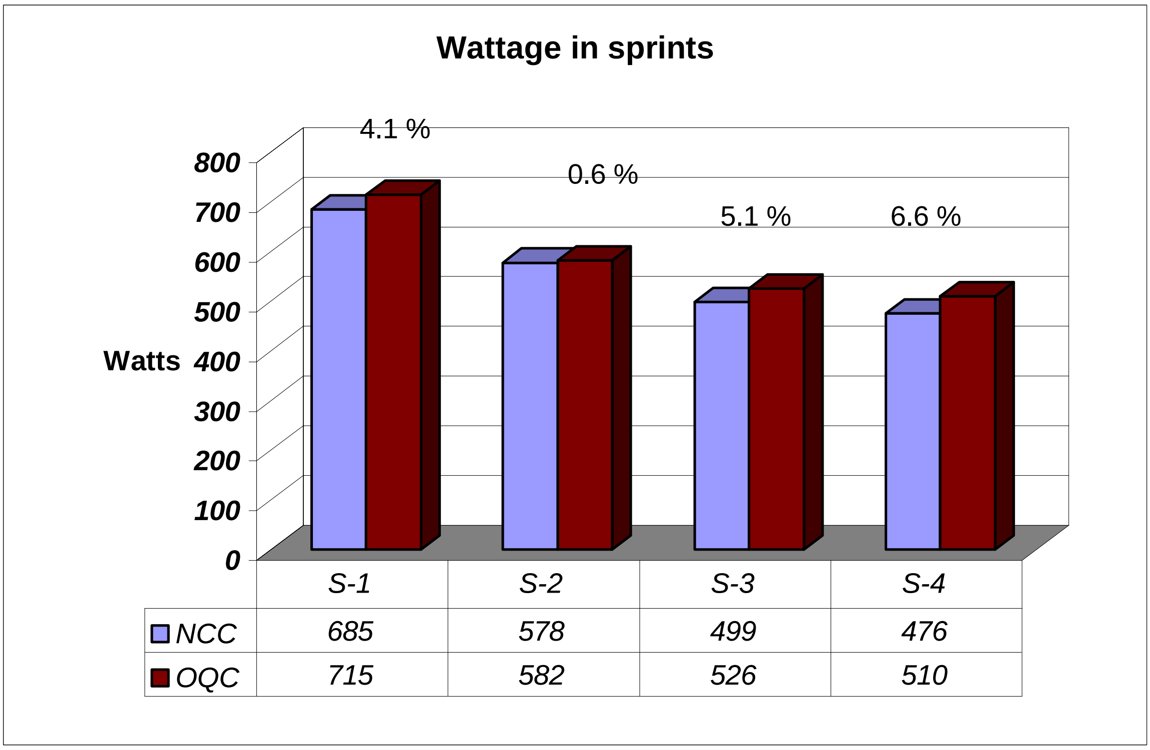
Chart 3. Analyzed Variables (W, HRmax, X-HR) on consecutive short sprints, Developer with Q-Rings (OQR) and Normal Circular Chainrings (NCC).)

SPRINTS	NCC	OQC	DIFERENCE NCC vs OQC (Δ-%)
S-1	685±100	715±74	4.1
S-2	578±62	582±47	0.6
S-3	499±71	526±78	5.1
S-4	476±74	510±84	6.6



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DISCUSSION.

The Fact of not finding differences on Maximum Oxygen Consumption (V02 max) is not considered relevant, because is a maximal test no variations on this aspect where expected. Inciding on this, and concerning to other studies comparing elliptical and circular conventional chainrings' other authors didn't find differences either (12, 15, 20). For example, Henderson et al. (20) found out that maximum VO2 was not different on non fitted cyclists when pedalling on a Monark cicloergometer equipped with circular or oval chainrings for powers of 50, 100 and 200 W. Cullen et al. (12) didn't find relevant differences either, neither in max VO2, nor in heart rate during a sub-maximal test using circular chainrings or elliptical on trained cyclists.

Nevertheless, relevant facts were found. The most significant in this preliminary study has been to observe that when cyclists did the 90% on established maximum test (average of all measurements obtained with OQC and NCC), they were able to maintain the effort they were required for longer when using OQC. Besides, on the sprints made after the maximum effort test, cyclists using OQC were able to release (although only a small percentage) a higher power on each of the sprints, in comparison when they were using NCC.

Another remarkable fact of this study is that after 90% power maximum effort test a lower lactic acid production was observed at the end of the test, even when same heart rate was reached. This fact can be understood as an indicator of a lower metabolic requirement when using OQC in comparison with the NCC requirements, moreover when it comes together with a longer effort time at a 90% of the maximum power.

The fact that during repetitive sprints a higher power delivery was scored by the OQR against NCC, could be understood also as a higher biomechanical efficiency indicator, together with the previous noticed better metabolic efficiency. So, on the same maximum test consisting on 4 sprints, a power delivery of 4% higher for the OQP was obtained. Even when this percentage differences are small, in the sphere of high level competition they could be decisive for the final result, especially on continuous and maximum effort exertion seen in disciplines such as Time Trials.

Given the fact that no difference on Oxygen Consumption was found between the chainring types, this could suggest that physiological demands were non significant. This would be coincident with Kautz's and Neptune's opinions (3), authors whose opinion is that internal work to move the legs could be not independent from external work to overcome pedal resistance. But in our study, even when no relevant variations in maximum heart rate and maximum oxygen consumption are detected, from a metabolic point of view, a lower lactic acid production is observed in the 90% sustained load test. Inciding on this, in a study carried out by Santalla et al. (19) analyzing Rotor Cranks pedalling system, (also aimed to eliminate pedalling dead spots), an improvement on mechanical efficiency was observed. These authors (19) explain this in that when the leg is on the pushing faze from the highest position, it could help the other leg's work, which is involved in maximum descendent force application.

Normally legs are accelerated and decelerated by the muscles, resulting in an increase and decrease of the energy supplied. But with OQR power delivery seems to be more continuous, with less variations, (which is confirmed by the cyclist who made the test's impressions). This could explain why lactate production is lessened in some fashion simply by the contribution of a continuous and harmonic pedalling. These changes on the energy flow for the external work, incise on the requirements for the internal work mentioned before.

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Altogether, we think that, for experienced cyclists whose muscle coordination is already perfect, the use of a chainring providing certain energy savings could be beneficial. This, especially in situations where a maximum effort is required such as in time trials, sprints, spurts and climbs. Apparently, regulation settings of Q-rings could be the key for the differences in performance obtained.

Considering previous arguments, we consider it necessary to carry out a complementary electromyographyc study (EMG), together with a metabolic study analyzing the biomechanical factors affected by physical activity. These tests would need to be carried out in both in lab as presented and in the field (for example a training ride of 3-4 hours). This study could provide valuable information in order to check the improvements in pedalling efficiency ascertained; to define which circumstances OQC would be beneficial in and to what degree, so referred pedalling optimization could be customized. Q-rings' novelty regarding their regulation options can contribute to a more precise vision of physiological, metabolical and biomechanical variations arising from non circular chainring use.

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