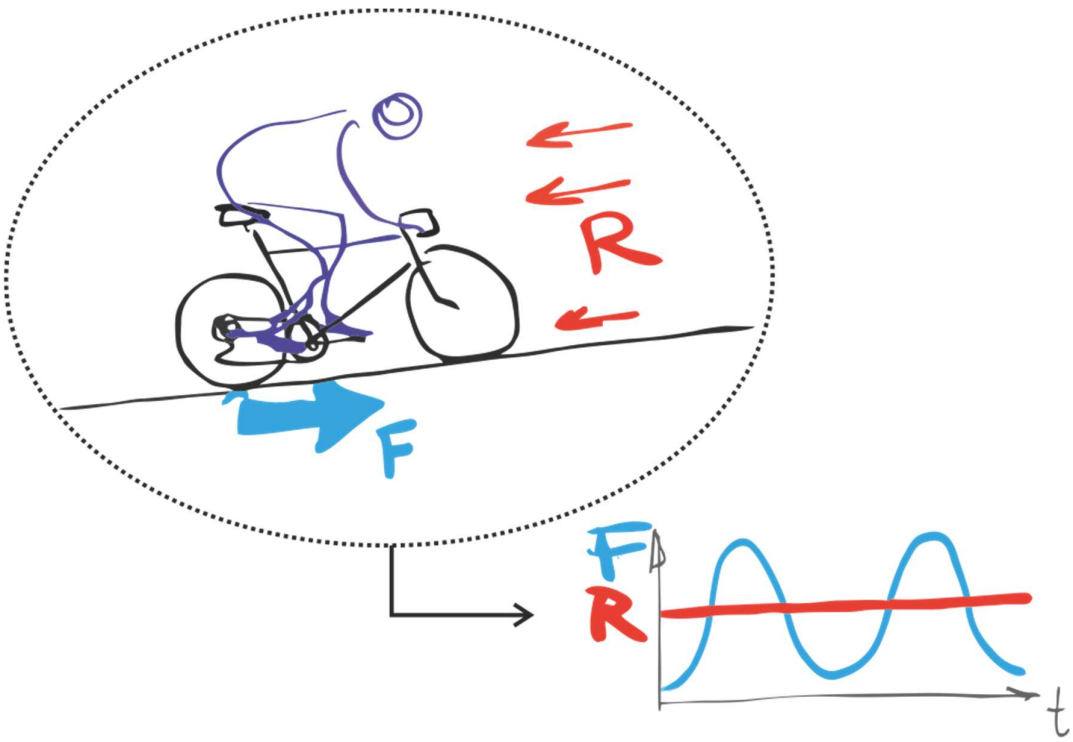
BASIC CYCLING BIOMECHANICS

Figure 1



For simplification, let us consider the following pedaling conditions:

- maintained Speed and Slope ⇒
  v ≈ constant ⇒ R = constant (simplification)
- maintained Power ⇒
  $\mathbf{P_{powermeter}}$ is **constant = Average P** during a pedal revolution
- Zero Drive Train losses ⇒ $\mathbf{P_{wheel} = P_{pedal} = P}$
- Zero "Road" Friction ⇒ $R = R_{wind} + R_{slope}$

$$\mathbf{P_{powermeter} = R \cdot v \quad ; \quad P = F \cdot v = T \cdot \omega}$$

(**T** is the pedaling Torque; **ω** is the rotational pedaling speed, proportional to **v**)

Let see now how the Force, and therefore the Torque, is delivered by the cyclist:

Figure 2: *we know that Pedaling Torque looks like this:*

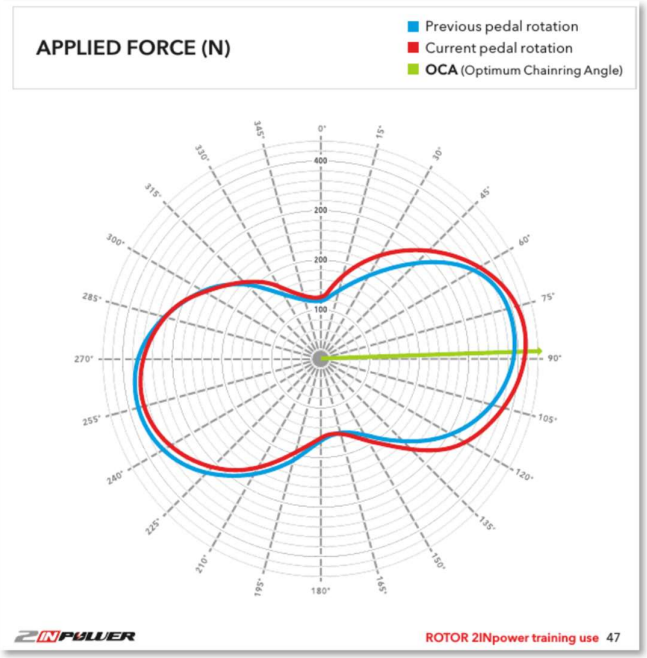


Figure 3: *Representing both legs separately*

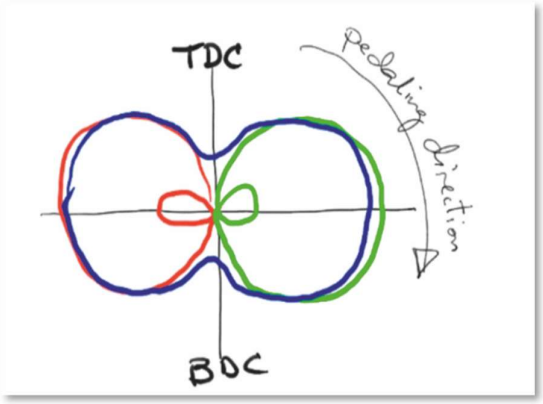
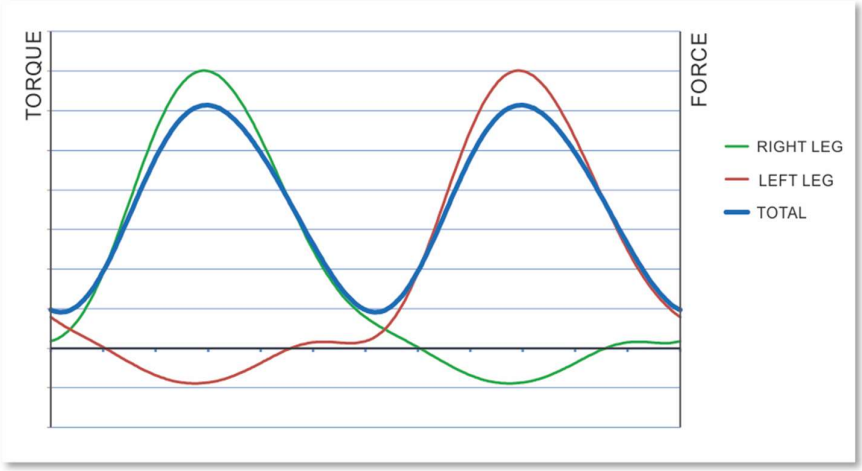


Figure 4: The combination of both legs results in a sinusoidal shape of the output



$P = F \cdot v$; $F - R = m \cdot a$ (the mass corresponding to the whole system [cyclist+bicycle])

considering **$R \approx K$ (constant)**

1. When climbing: **v** is LOW ⇒ **K** is HIGH ⇒ **F** is HIGH ⇒ **a** is HIGH
2. Pedaling on Flat: **v** is HIGH ⇒ **K** is LOW ⇒ **F** is LOW ⇒ **a** is LOW

Figure 5: sinusoidal Force vs. Constant Resistance

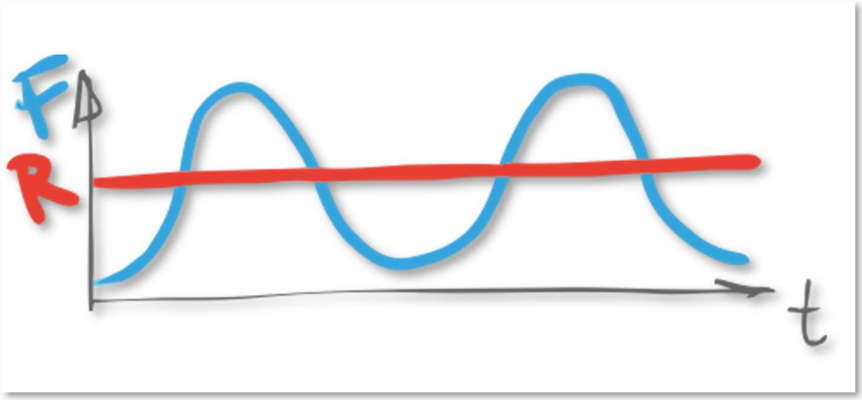
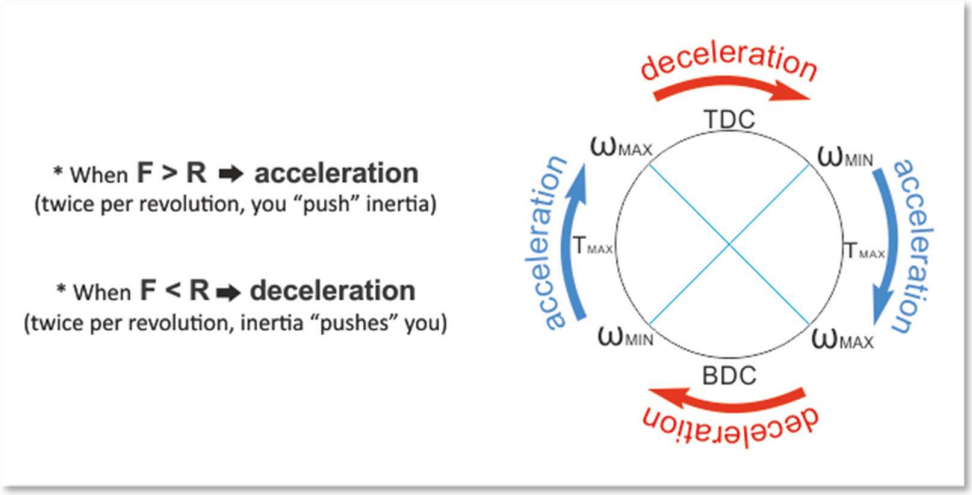


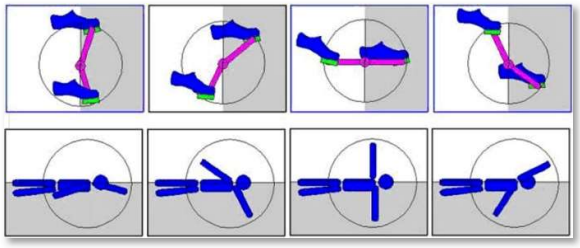
Figure 6: did you imagine this?



Trying to Improve Cycling Biomechanics

At the beginning of my cycling life, in the early 80's, once I understood the cycling physics principles I have exposed, I first tried to improve my power by ankling technique and adjusting the bike geometry and my position on the bike, a bit later I became obsessed about modulating my output by using oval chainrings… But it was the Biopace time and my older brother and friends made me to forget that "crazy" idea (…for a while). And 10 years later, after struggling so much with the dead spots, the idea of imitating (with the cranks) the arms of a swimmer, "forced" me to start with ROTOR:

Figure 7



The cranks were going slower during the downstroke and faster during the upstroke, having therefore variable equivalent chainring size during the whole revolution:

Figure 8

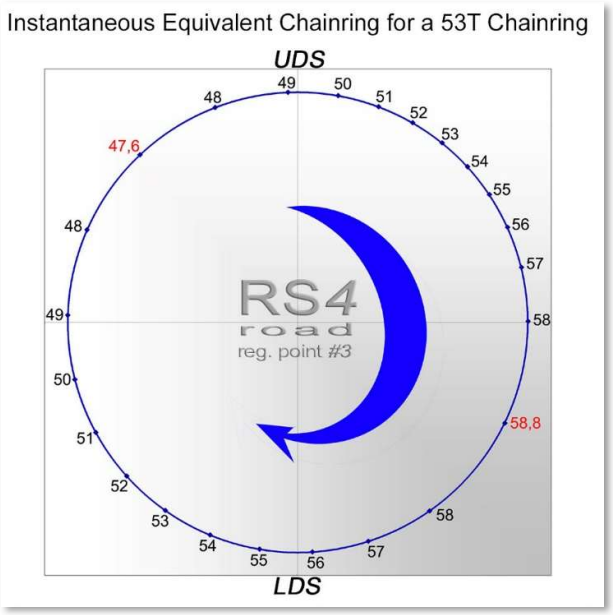


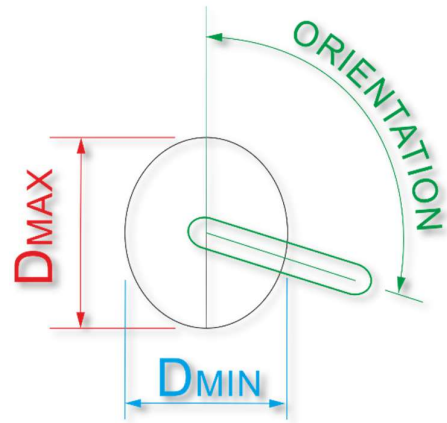
Figure 9

With the original ROTOR SYSTEM, we learned a lot about cycling, not only the sport but the market as well. And although we managed to win a lot of races (our sponsored cyclists) and we were very welcomed by many doctors and therapists, especially for how it worked for the knees… In the end, it was a too expensive, complex, and heavy product for such a small company to survive… And, in 2005, we packed all that knowledge into a much easier concept, an OVAL chainring which we called Q-Ring (the "Q" due to the orientation of the crank relative to the oval "O"). As a resume: we knew where to locate the maximum effective chainring size, but as well that this location should be adjustable.

What's about the use of OVAL chainrings?

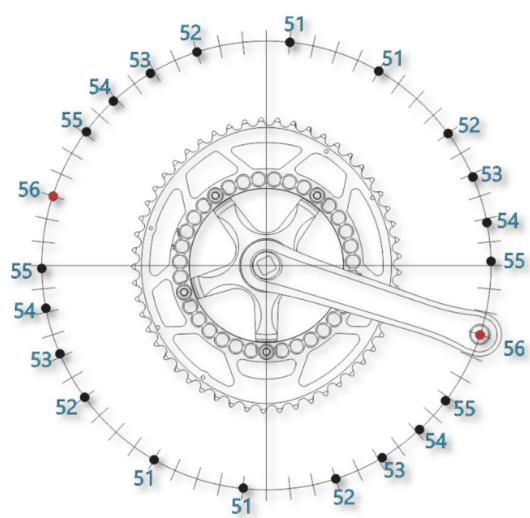
OVAL, and whichever noncircular or OVOID Chainrings are mostly characterized by having 2 parameters: stretching ratio or **OVALITY**, which it can be defined by [1-D_{MAX}/D_{MIN}]% , and **ORIENTATION**, defined by the clockwise angle formed between DMAX and the crankarms line.

Figure 10



An OVAL chainring works like an automatic shifting system: having a different effective chainring size along with the complete pedal revolution to adapt the instantaneous leverage of your crankset to the potential of your legs at each pedal position. This is, in general, by increasing the mechanical advantage near the dead spots by reducing the effective chainring size around them.

Figure 11: Instantaneous effective chainring size for a Q-Ring 53t at OCP#3



In general, for mechanics, considering a shifting system:

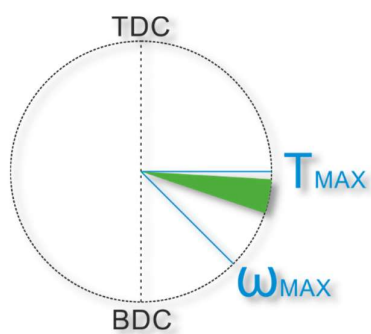
- if the resistance force does not vary, the bigger the speed is the bigger the chainring size we would use. In this case, shifting depends just on the INERTIA

- if the inertia does not vary, the bigger the resistance force is, the smaller the chainring size we would use. In this case, shifting depends just on how much force we can deliver
- …but normally we are dealing with a mix of these 2 cases, reaching more speed/inertia always after having less resistance or more force… For what the maximum chainring size (or smallest mechanical advantage) should happen sometime in between these two instants.

Going back to pedaling a bicycle, not every cyclist applies forces at the pedals the same way, but on average, cyclists apply MAX TORQUE at the horizontal during the downstroke, where the force applied to the pedal (mainly vertical for balancing our weight against Gravity) is tangential to the pedal trajectory.

Assuming $\mathbf{T_{MAX}}$ at 90° from TDC and $\boldsymbol{\omega_{MAX}}$ near 135° as a consequence of a sinusoidal delivered pedaling Torque, make sense to orientate the major Diameter of the chainring related to the crank arm, so that maximum effective chainring size happens between said to positions.

Figure 12



We have seen how different it can be comparing when pedaling FLAT vs. CLIMBING (for maintained speed at the same maintained power). The bigger the acceleration is during the downstroke, the more delayed position for the maximum effective chainring size should happen… so that you could consider that a single ORIENTATION value could not work for both pedaling conditions. But it is not the same the ORIENTATION, as an installation value crank-to-chainring, that the angular position where the maximum effective chainring size takes place:

Figure 13: at High Speed

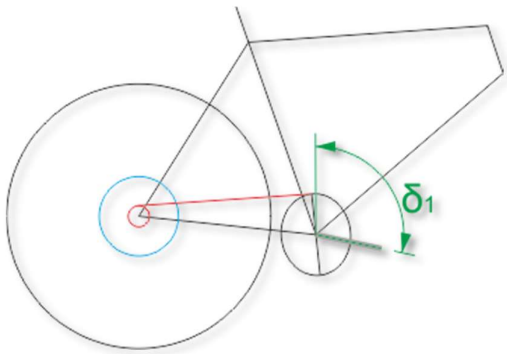
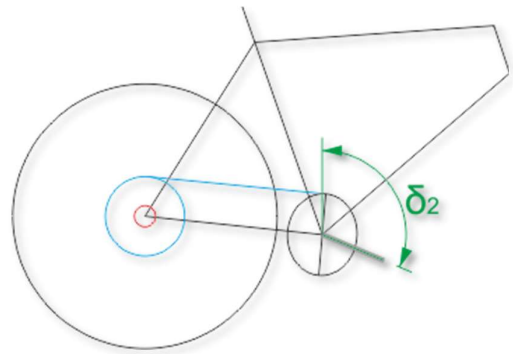


Figure 14: at Low Speed



The **maximum effective chainring size (MECS)** happens just when the tractioned chain is perpendicular to D_{MAX}, defining the angle Delta **(δ)** from TDC to the crankarms line at that instant. This value depends not only on the ORIENTATION but as well on the gear combinations.

- If it is positioned too close to $\mathbf{T_{MAX}}$: it is going to be difficult for climbing, but as well to accelerate (when it is not the case of maintained speed)
- If it is positioned too far from $\mathbf{T_{MAX}}$ (closer to $\boldsymbol{\omega_{MAX}}$):
accelerations are going to be boosted but sacrificing the top speed pace.

OVAL vs. ROUND CHAINRINGS

For a chainring, whichever shape non-round is usually called OVAL. It would be "OVOID" a more appropriate term, which includes the ellipse, the oval, and those more complex shapes as it's the case of Osymetric chainrings… But Marketing rules.

Even for the biggest fan of OVAL chainrings, ORIENTATION is a crucial factor, so much that it is a much better option to use ROUND chainrings than using a wrong ORIENTATION when using OVALs.

Due to the obviousness of the effect of Dead Spots, they have been present in cycling History, for more than 150 years, but until recent years, not having, in general, any approximately proper ORIENTATION which could result in a good performance. Right now, in the market we could say that exist 3 families:

- ***Osymetric***: having big OVALITY and noticeably short ORIENTATION

- ***ROTOR Q-Rings***: moderate in OVALITY and customizable on ORIENTATION, having multiple marks with OCP values around one most preferred value called OCP#3
- ***OTHERS*** (like absoluteBlack, Wolf Tooth, OneUp, and many others) which have come to the bike industry after the success of the other two, and they have remarkably close OVALITY and ORIENTATION values as a Q-Ring at OCP#3

Figure 15: Osymetric

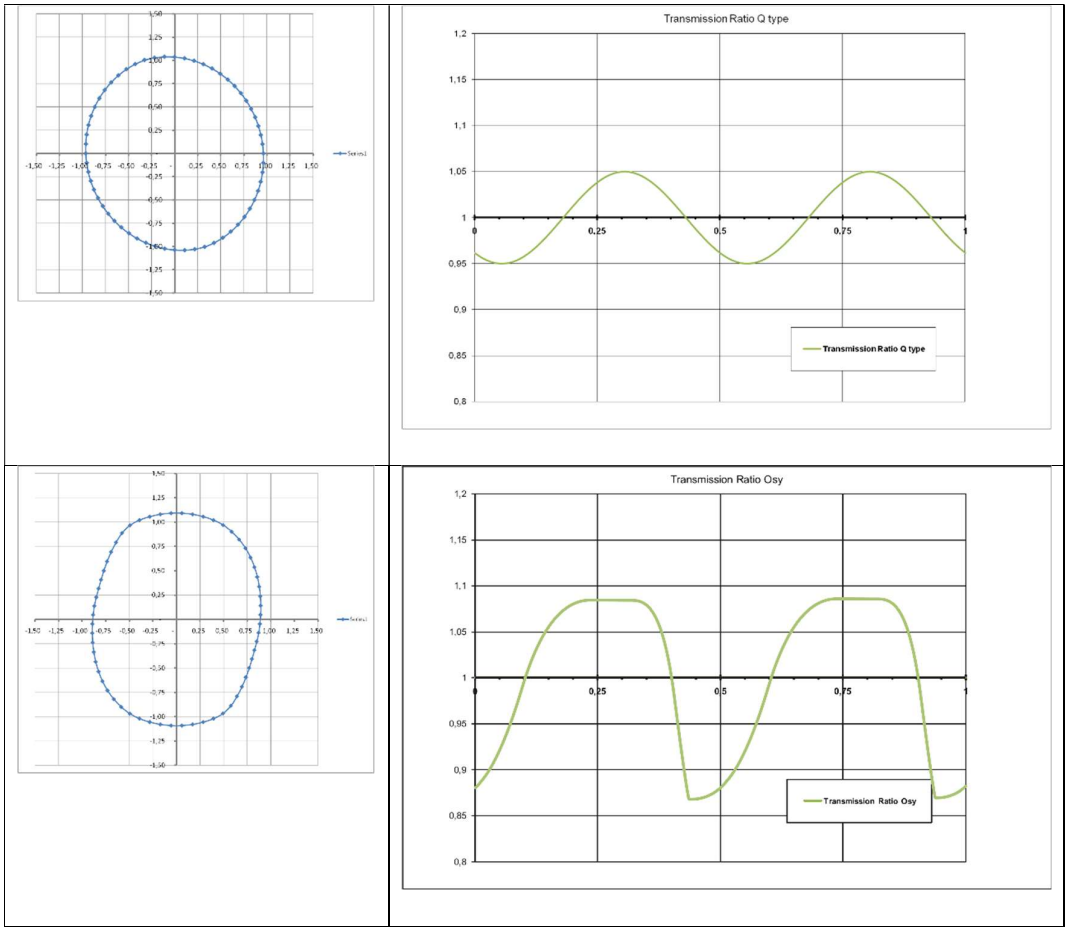
Figure 16: ROTOR Q-Ring

Figure 17: absoluteBLACK

The first two brands have been collecting huge success in racing along the past 15 years:

- Osymetric is very well known for succeeding in big Tours and TT races (including Ironman). Based on its unique ORIENTATION which increasing the effective chainring size too soon in the downstroke, is only useful (IMHO) for those riders who push on the pedals earlier that the average. And having more OVALITY, the ORIENTATION factor becomes even more important.
- ROTOR Q-Rings, succeeding in all kinds of races and disciplines, at ROAD, MTB, TRIATHLON, CX… (and even HANDBIKE): Olympics, World Championships, big Tours… Climbing, Sprinting, or at TT. And for these results, different kinds of ORIENTATIONS have been used.

Figure 18: *Gearing function graph*



* Then, are OVAL chainrings beneficial?

There are not scientific conclusions out of the different researches coming from these companies, but here it is a fact: having a smaller gear at the dead spots and a bigger gear when the cyclist applies more torque, modulates the output, the force he puts on the wheel, making it more even for improved traction. This is just Geometry, Mathematics and Physics. Therefore, there is a benefit on slippery conditions which is an advantage in MTB, GRAVEL, or CX. Furthermore, the more even tension on the chains could improve the chain's lifespan.

Another typical benefit is about knee health or comfort in case of the upper dead spot is hurting your knee…

There are not too much published about this last point, but same as shifting soften those moments of big efforts at joints or muscles, when using OVAL chainrings, if the ORIENTATION is correct, the resulting modulation of the effective gear, make pedaling more comfortable, especially at the knee joint for applying torque to the wheel.

Reducing the effective chainring size at the dead spots helps to soften tension at the knee when it is at its maximum flexion, bringing the logical benefit… but if ORIENTATION is wrong and the maximum effective chainring size (the big resistance) appears, for example, too late in the downstroke, you will feel like "stepping in a hole" and another kind of knee pain will be generated, caused by the use of the OVAL chainrings (if you don't correct that wrong ORIENTATION). It is not strange to read at different internet forums people who have found this kind of knee problems after using OVAL chainrings.

Then about performance, the only data we do have is a list of historic victories at the most important races... And considering that usually at the professional races roughly 1 to 3% of the cyclists are using OVAL the results are impressive. You could think it is because we the brands are paying to the best ones, but actually, only the Big Brands can do that, and they do it for ROUND…

We could consider the variation of the shape of the OVAL chainring as a shifting system, which in general in a vehicle is good because we can reduce or increase gear when we need it, mainly based on the speed, slope, and inertia. Therefore we can imagine a shifting timing "robot", corresponding to that ORIENTATION, becoming a critical factor, based on the geometry of your legs, on your position on the bike, on the different inertias coming from your legs at a regular cycling cadence, but also on the inertia of the complete system [cyclist+bike]. Consider that, when pedaling, we are accelerating and decelerating the bike (with the cyclist) twice every pedal revolution. And it is mainly because this acceleration that the maximum effective chainring size must be delayed regarding the position where max torque is located. If you are at a trainer, all the inertia of the system may vary significantly, which easily results in different ideal timing for this modulation of the instantaneous effective chainring size.

Given the same input, I cannot say at all that using one chainring with a different shape you are going to multiply your power output. In fact, in the tests we have carried out over the past 15 years, we have never found differences below the Threshold Power. It is from there when trying to reduce the suffering on the effort, any help coming from the use of an appropriate OVAL chainring might help the cyclist, for example by reducing the fatigue at the muscles' fibers due to the smaller peak efforts, thanks to said modulation, or just by reducing pain or stress on the knees.

As an example, think about a cyclist riding a fixie and comparing him with his regular bike equipped with a shifting groupset. He does not have more power in his regular bike, but if the terrain is hilly, he will be able to ride with more comfortable cadences saving himself from some suffering, and at the end going faster, having, therefore, generated more power.

Other considerations could be done, and I would say, somehow must be done in the future: We are talking about marginal gains, that could be enough to differentiate the first guy in the podium from the other two, which normally would not have a clear statistical significance. Then, other parameters could be considered when you make the switch to OVAL: crank length, cleats position, saddle's position (height and setback)...

There is one important consideration: when you are seated at the saddle, the pedaling circle itself is "ovalized" as a result of the ankle-play: actually you modulate the leverage, softening the effective chainring size at the beginning of the downstroke by flexing, and the opposite later by extension of the ankle, therefore varying the rotational speeds at your knees. When you pedal standing out of the saddle, the "ovalization" of the pedal revolution is even more exaggerated due to the balancing side to side of the bicycle, and the slight relative movement forwards and backward between the bike and the cyclist.

And it is due to the necessity of the ankle-play for what we have the "normal" cleat position in our cycling shoes. But remember that the insertions of the calves behind the knee joint result in a flexion force, while it is by the extension force of the knee when the main pedaling power is delivered by the quads, being therefore the ankle-

play an antagonist work. By using OVAL chainrings, there is no need for such a big job for the calves with the ankle-play, allowing then to reduce this antagonist work looking for a marginal gain over there.

- Let me introduce my personal "biomechanics": Due to some injury that happened last summer in my right knee, and after 2 recovery months, my balance dropped approximately from 50/50 to 67/33. The pain there has not disappeared, but right now I am using shorter cranks by 5mm and, changing my cyclist shoes (mid-sole solution by BIOMAC.biz), have the cleats placed much backward than whichever normal cyclist shoes allow for, and as a consequence, I have had to change the saddle position far downwards and a bit forward, resulting in a much better balance of 55/45.-

Figure 19: my cycling shoes

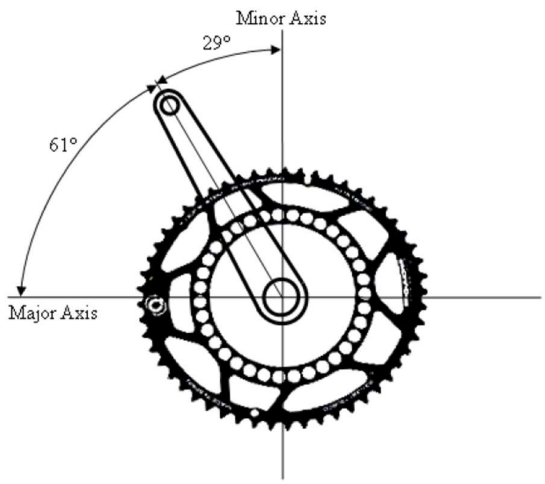
* What says "Science" about OVAL chainrings?

There are more than a few papers, but not at all any definitive conclusion…

We have for example this study, coming from the highest scientific level, called: “Noncircular Chainrings Do Not Influence Maximum Cycling Power” (Chee-Hoi Leong, Steven J. Elmer, and James C. Martin), but for this research, they used a completely out of range ORIENTATION value, so much that it was approx. -45° out... Imagine a World

Cup race but our cyclists obliged to shift down before the uphill is coming, and to upshift before finishing the slope at the climbs… easily the conclusion could be that fixies are a better option for racing… Then, IMO, at least the title could have been less pretentious, because what they have demonstrated is that the Noncircular Chainrings don't work with that particular ORIENTATION they have chosen for this study, which is out of the range of the tested products, and which looks like the static geometrical solution for the legs' muscles, without considering their masses, the whole system masses neither all the accelerations involved.

Figure 20: using an ORIENTATION out of OCP range



Another study which some "conclusions" is a mathematical model called: *"Comparative biomechanical study of circular and non-circular chainrings for endurance cycling at constant speed" (at www.noncircularchainring.be)* which solution supports a quite different ORIENTATION value (approx. -33° out) than the real world asks for: Remember that Q-Rings are adjustable (some of the models even along the 360°, 1 by 1 degree) and always the ORIENTATION average for the people using them is around OCP#3 (~110°), and that is the reason all the other brands (with fixed OCP due to ROTOR patents) use approximately this same orientation. Therefore, knowing this model is so different from the real pedaling experience, I assume that something really important is missing (as it could be to consider instantaneous "constant speed" which means no total inertia variations) and, as it is, same as the previously mentioned study, we should not consider its results.

There are many other studies, some showing slight improvements, and in the end, it is very difficult to have any significant conclusion, but usually, you can see that some of the subjects under the study have performed quite well using the OVAL chainrings. This could be explained because the chosen ORIENTATION for the study was the good one for their personal use (or maybe they can adapt faster than others to new biomechanics). The point to consider is that usually for these tests they never try to adapt the ORIENTATION to specific inertia of the lab braking system used as a bicycle, neither to adjust for each subject/cyclist with his individual preferred ORIENTATION… For example, would you make a research about using running shoes versus running barefoot for Athletes, if when testing the shoes all of them must be restricted to the same size? Then you would easily find that using running shoes is good for some but not for all, and you would never find statistical evidence to recommend their use.

* Then, are we going to be faster by using OVAL chainrings?

Imagine, you have been with cyclists who nobody expects to win, following training sessions from the car, making tests with the CompuTrainer, designing and manufacturing the ring sizes they request, and looking for the best combination as it was not only ORIENTATION but crank length as well… We have been assisting riders for many years, and it is a fantastic experience when you go to whichever race… even the World Championships or the Tour de France, with just 1 cyclist using OVOIDS (Q-Rings in my case) who results to be the winner.

Figure 21: OCP - CompuTrainer Test 2008

Later most of the time it has been not just 1 cyclist in the race using OVOID chainrings... and many more victories came. We could even enjoy at the Olympics, in the same race, gold, silver, and fourth place.

ROTOR has been sponsoring several Teams in which less than half of the riders were using Q-Rings, but they collected the big majority of the victories for the Team during the whole season.

Now more companies are pushing as well to be at the races, and whichever brand it could be, for those cyclists whose ORIENTATION is fine, by using OVOID chainrings, they are going to succeed. The confirmation is going to come.


50 m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* How to know if your ORIENTATION is OK?

Of course, we can adapt to different race/pedaling conditions taking advantage of the ankle-play (ankling) and shifting gears, but because the pedaling conditions are widely spread during a “race”, considering the range of useful cadences and different positions, more forward or backward in the saddle, or even out of the saddle, etc. only if we target it properly will have a really useful OVAL chainring.

ORIENTATION is a more critical parameter for ROAD racing than for MTB, in the same way as having a shorter gap between consecutive gears is a must for ROAD. For this last and considering the 15 years of experience in elite and professional racing I would say we have a reasonable range of ±2° for which we can use OVAL chainring with good results when for MTB it would be a wider range, let say something like ±4°.

The amplitude of these ranges is such that having only one and appropriate ORIENTATION option (the one that ROTOR names OCP #3) it can fit about 50% of the riders for ROAD and about 75% for MTB.

For example, imagine the ORIENTATION is too short, by just 4° (which for Q-Rings means that you are using 1 unit of OCP numbers under your best one…) Then, at a general pedaling pace, you were finding too much resistance very soon during every downstroke and losing acceleration ability, and for compensation of both, you would be correcting by using ankle-play, and shifting gear for reducing that bigger resistance by increasing cadence, and at the end, due to the compensation by ankling, you would be making an extra effort with your calves.

In the opposite, if your ORIENTATION is too long, you were finding too low resistance at the beginning of the downstroke and, at a normal cadence, having very good acceleration ability but difficulty to keep a high-speed pace, what could be the case of some comments like “stepping in a hole”… In this last case, you would be correcting using shifting for a bigger gear to increase the perceived resistance. Therefore, it is reasonable to hear some people saying that the “oval” rings make you reduce the cadence, and vice versa, always depending on how well each OVAL oriented for their particular biomechanics. One quick check in order to see if your ORIENTATION is Ok, is when you pedal in the top of your range of cadence, because pedaling so fast you lose the ability, by using the ankle-play, to adapt to a non-optimal variable rotational speed: inherent to a non-best ORIENTATION of the ovoid shape of the ring, you would have a bumpy feeling as if the bike is jumping (following the alternating inertias of your legs).