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Effects of Different Chainring Designs on Cycling Performance: Oval Versus Circular

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Abstract

Professional road cycling requires high endurance and power output for optimal performance. Oval chainrings, a recent innovation, aim to minimize dead spots during pedal revolutions and enhance cycling performance. This study compared the effects of circular (C-ring) and oval (Q-ring) chainrings on power output and maximum oxygen consumption ($\dot{V}O_{2Max}$) during an incremental exercise test. Twenty male elite cyclists (mean age ± SD: 19.90 ± 1.86 years) participated in a randomized study. They underwent two incremental maximal tests separated by 48 hours, using both chainring types. The test began with participants pedaling with a 200-watt load in their preferred cadence. During the first six-minute period, the load was increased by 50 watts every two minutes, and then the test continued to increase by 25 watts every two minutes. The test was completed at the point where the participant was exhausted. The results indicated significant differences in favor of Q-rings for $\dot{V}O_{2Max}$ ($p = 0.006$) and power output ($p = 0.014$), while heart rate and cadence remained similar. High correlations were found between $\dot{V}O_{2Max}$/power output and heart rate mean/max. Linear regression analysis revealed that power output accounted for 52% (Q-ring) and 64% (C-ring) of the variance in $\dot{V}O_{2Max}$. Theoretical advantages of Q-rings include optimizing pedal force distribution, which may enhance mechanical performance. Previous studies have shown mixed results regarding the effects of non-circular chainrings on cycling performance, indicating methodological disparities. Overall, this study suggests that Q-rings may improve road cycling performance by increasing power output. However, further research is needed to explore their efficacy across various cycling scenarios.

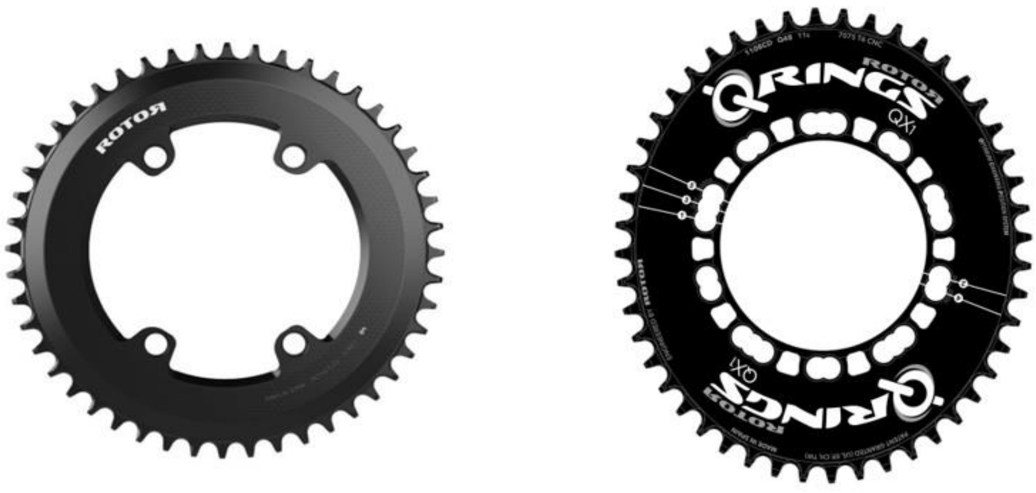
Key Words: VO2Max, chainrings, cycling performance, power output

1. INTRODUCTION

Professional road cycling is a sport that requires extreme endurance. Athletes cycle approximately 30,000–35,000 km each year, and their annual racing season averages 90 racing days. Despite the long duration of cycling competitions, such as three-week races, athletes must maintain peak physical condition due to the high intensity of exercise. Lucia et al. (1999) examined the power output of athletes in professional stage road cycling races, such as the Tour de France, the Tour of Italy, and the Tour of Spain. They showed that the absolute power output during the 60-minute stages was approximately 400 watts. Furthermore, it was also stated that this high power output, at or near maximum in professional road cycling races, is a prerequisite for cycling with high body mass (≥6 W/kg) (Palmer et al., 1999).

Power output is the primary metric used to assess efficiency in cycling. It is measured by power meter equipment mounted on athletes' bikes, which determines power output using angular velocity and torque data. One of the crucial components of influencing the power output is cadence. Cadence can be defined as the number of pedals cycled in one minute. Studies found the optimal cadence range is between 90 and 105 (Chavarren and Calbet, 1999). However, it is important to note that this range can vary among athletes. For instance, professional athletes tend to perform better when pedaling at their preferred speeds (Leirdal and Ettema, 2011; Faria, 1984).

Many parameters affect the performance of cyclists including technical equipment. For example, oval chainrings, which have become popular recently, have a shape that resembles an egg rather than a circular shape like conventional chainrings (Figure 1).



a. Circular Chainring (C-ring) **b**. Oval Chainring (Q-ring)

Figure 1. Circular (a) and Oval (b) chainrings.

Oval chainrings aim to increase cycling performance by reducing the 'dead spots' that occur at the upper and lower points of each pedal revolution, compared to circular chainrings. This design aims to increase power output by minimizing the loss of muscle work throughout the pedal cycle caused by dead spots, which lead to power loss (O'Hara et al., 2012; Neptune and Kautz, 2001; Hue et al., 2007; Bini and Dagnese, 2012). Thus, the objective of this study was to examine the impact of two distinct chainring

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designs, circular (C-rings) and oval (Q-rings), on the power output and maximum oxygen consumption ($\dot{V}O_{2max}$) of cyclists during an incremental exercise test.

2. MATERIAL & METHODS

Participants

According to the power analysis, a paired t-test required a total sample size of 19 with the following input parameters: Effect size f = 0.70 based on a previous study (Cordova et al., 2014), alpha = 0.05 and 80% power (GPower, 3.1.9). Twenty licensed elite category cyclists volunteered for the study (Table 1). During the training period, which lasted from October until April when the tests started, the individuals cycled an average of 400±50 km each week. None of the individuals had ever used a Q-ring before. Participants were informed about the possible risks and benefits before the study and signed an informed consent document before the study started. This study was approved by the Fenerbahçe University Non-Interventional Clinical Research Ethics Committee (No: 19.2022fbu) and was conducted in accordance with the Declaration of Helsinki.

Table 1. participants' physical characteristics

Variable (n=20)	Mean	SD±	Minimum	Maximum
Age (years)	19,90	1,86	18	23
Body Weight (kg)	70,61	8,43	58	95,80
Body Height (cm)	175,45	6,86	161	187

SD: Standard Deviation.

Experimental approach and procedures

Participants were informed about the study protocol before the anthropometric measurements were performed. All measurements were conducted in the same laboratory between 08:00 a.m. and 12:00 p.m. Humidity (39% ± 1.5%) and air temperature (21 °C) in the laboratory were constantly monitored and kept constant.

Two different evaluation sessions were held for the participants, one using the Q-ring and the other using the C-ring. The sessions were conducted 48 hours apart and were assigned randomly. The incremental tests were performed with a Smart Trainer (Tacx Flux s, Netherlands). Participants performed the tests by attaching the racing bike to the smart trainer. Smart trainers allow for precise exercise load application through computer software (Tacx Desktop App, Netherlands) while also enabling the use of a racing bike. All participant test results were recorded on a smartwatch for bikes (Garmin Edge530, USA). Heart rates were recorded with a heart rate chest strap (Polar Electro Oy, Kempele, Finland).

Maximal Oxygen Consumption Test

The participants' oxygen consumption values were measured with the PNOE (Palo Alto, CA, USA) brand metabolic analyzer. Approximately three hours before the test, the device was heated by connecting it to the power supply. Before and after each measurement, the device was calibrated according to the manufacturer's instructions. The antibacterial filter was inserted into the tip of the mask, and after each measurement, all parts including the mask were disinfected. Only one participant and two researchers were found in the measurement environment, and no entrances or exits were made to the laboratory while the tests were ongoing. After 10 minutes of warm-up, the participants started the test by pedaling with a 200-watt load in their preferred pedal cycle. During the first six-minute period, the load was increased by 50 watts every two minutes, and then the test continued to increase

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by 25 watts every two minutes. The test was completed at the point where the participant was exhausted (Harnish et al., 2001; Beam and Adams, 2013; Aslan et al., 2011).

The following criteria were considered for the $\dot{V}O_{2max}$ measurement to be considered valid: 1) Plateau in $\dot{V}O_2$ despite the increase in exercise intensity (No change over 2.1 ml.kg.min is observed), 2) respiratory exchange ratio (RER) of 1.1 and above, 3) exceeding 90% of the person's maximum heart rate, 4) score of ≥17 on the BORG scale. (Borg, 1998). The $\dot{V}O_2$ reach to the plateau was considered sufficient to validate the $\dot{V}O_{2max}$ measurement. All other criteria were expected to be met if the plateau could not be reached.

Statistical analysis

All statistical analyses were performed in SPSS 24 for Windows (SPSS, Inc., Chicago, IL). The Shapiro-Wilk test was employed to determine whether the data was normally distributed and it was found that the data was normally distributed. Student's paired t-tests (two-tailed) were used to compare the differences in $\dot{V}O_{2max}$, heart rate, power output, and cadence data in measurements made with Q-ring and C-ring. Pearson correlation analysis was conducted to determine the relationship between $\dot{V}O_{2max}$, heart rate, power output, and cadence data. Additionally, a linear regression analysis was performed to determine the effect of power output data on $\dot{V}O_{2max}$. Statistical significance was determined at $p<0.05$.

3. RESULTS

It was observed that there was a statistically significant difference in the $\dot{V}O_{2Max}$ and power output data obtained by the participants using Q-ring and c-ring. However, there was no statistically significant difference in mean and maximum heart rate and power output data (Table 2). Figure 2 showed that the participants' $\dot{V}O_{2Max}$ and power output data were higher when using Q-ring.

Table 2. Obtained data from tests performed using Q-rings and C-rings.

Variable (n=20)		Mean	SD±	t	p
$\dot{V}O_{2Max}$ (ml·kg^{-1}·min^{-1}) Mean (±SD)	Oval	57,76	8,29	3,09	**0,006****
	Circular	56,13	7,84		
Heart Rate (bpm) Mean (±SD)	Oval	177,45	11,75	1,74	0,098
	Circular	175,55	11,46		
Heart Rate (bpm) Max (±SD)	Oval	193,2	10,69	0,74	0,469
	Circular	192,4	10,32		
Power Output (watt) Mean (±SD)	Oval	279,35	38,57	2,71	**0,014***
	Circular	269,85	31,15		
Cadence (rpm) Mean (±SD)	Oval	93,15	5,86	-0,58	0,568
	Circular	93,85	5,15		

**p < .05, **p < .01, ***p < .001; $\dot{V}O_{2Max}$: Maximum Oxygen Consumption; SD: Standard Deviation.*

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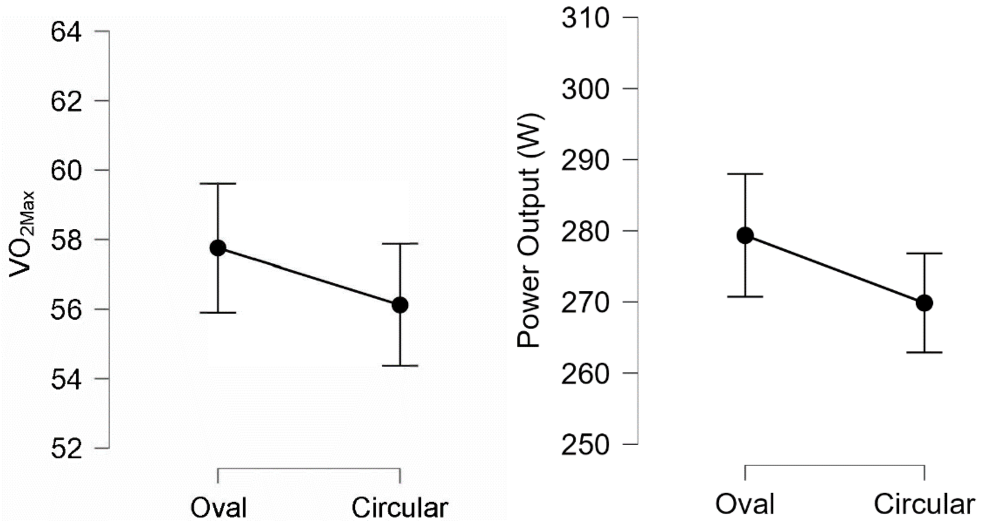

Figure 2. Comparison of participants' $\dot{V}O_{2Max}$ and power output data.

Table 3 showed a high correlation between $\dot{V}O_{2Max}$ and power output data in measurements made with both q-ring and c-ring (P<0.001). Similarly, there was a high correlation between heart rate mean and heart rate max data with both chainrings (P<0.001). However, a significant correlation was found only in measurements made with the C-ring for heart rate mean and cadence data (P<0.05). It can be concluded that the relationship between cadence and heart rate mean results was found only in c-ring use since the participants did not have a history of Q-ring use.

Table 3. Pearson's correlation analysis of variables measured during the incremental test for the Q-rings and the C-rings.

	Q-rings		**C-Rings**	
	r	**P**	**r**	**P**
$\dot{V}O_{2Max}$ (ml·kg^{-1}·min^{-1}) - Hr Mean (beats·min^{-1})	−0.048	0.842	−0.098	0.681
$\dot{V}O_{2Max}$ (ml·kg^{-1}·min^{-1}) - Hr Max (beats·min^{-1})	0.113	0.636	0.075	0.752
$\dot{V}O_{2Max}$ (ml·kg^{-1}·min^{-1}) - Power Output (W)	**0.723*** **	< .001	**0.801*** **	< .001
$\dot{V}O_{2Max}$ (ml·kg^{-1}·min^{-1}) - Cadence (rpm)	0.128	0.590	0.137	0.565
Hr Mean (beats·min^{-1}) - Hr Max (beats·min^{-1})	**0.921*** **	< .001	**0.944*** **	< .001
Hr Mean (beats·min^{-1}) - Power Output (W)	−0.271	0.248	−0.241	0.307
Hr Mean (beats·min^{-1}) - Cadence (rpm)	0.253	0.282	**0.493***	0.027
Hr Max (beats·min^{-1}) - Power Output (W)	0.020	0.932	−0.031	0.895
Hr Max (beats·min^{-1}) - Cadence (rpm)	0.219	0.354	0.422	0.064
Power Output (W) - Cadence (rpm)	−0.079	0.740	−0.052	0.829

* $p < .05$, ** $p < .01$, *** $p < .001$; *Hr: Heart Rate;* $\dot{V}O_{2Max}$*: maximum oxygen consumption.*

According to Table 4, it was determined that the power output data accounted for 52% of the variance in $\dot{V}O_{2Max}$ measurements with the Q-ring, and 64% of the variance in $\dot{V}O_{2Max}$ measurements with the C-ring.

Table 4. Regression analysis of power output data measured during the incremental test for the Q-rings and the C-rings.

	Standardized Coefficients Beta	Std. Error	t	p	R Square
Power Output (W) (Q-rings)	,723	0,35	4,442	**.000*****	,523
Power Output (W) (C-rings)	,801	0,35	5,675	**.000*****	.641

Dependent Variable: $\dot{V}O_{2Max}$; **P<0,05 **p<0,01 ***p<0,001*

4. DISCUSSION

The main findings of this study were: (1) In the incremental exercise test performed using Q-Ring and C-Ring, a significant difference favoring Q-Ring was found in $\dot{V}O_{2Max}$ and power values. However, no significant difference was observed in heart rate and cadence data. (2) Pearson's correlation analysis revealed a high significant relationship between $\dot{V}O_{2Max}$ - power output and heart rate mean - heart rate max for both Q-ring and C-ring. Only C-ring showed a significant relationship between heart rate mean and cadence. (3) The linear regression analysis showed that the power output data explained 52% of the variance in $\dot{V}O_{2Max}$ for Q-ring and 64% for C-ring.

The Q-ring designs potential benefit is predicated on the idea that it maximizes the force applied to the pedal. This is achieved by designing the uppermost point of the gear's ovality to increase power distribution (Figure 1). Noncircular chainrings bring the maximum gear torque to the downward thrust part of the pedal, specifically at a point 15-20° below the horizontal axis (Cordova et al., 2014; Ericson and Nisell, 1988). This is because the highest thrust is generated when the crank arm is on the horizontal axis. The concurrent increase in thrust and the diameter of the Q-ring collectively enhance the mechanical efficacy of pedaling. In addition, it also causes a decrease in the negative momentum effect that occurs during the pedal pull-up phase (Ericson and Nisell, 1988).

Several publications have published findings indicating statistically significant improvements in anaerobic performance during tests conducted with the Q-ring (Santalla et al., 2002; Faria et al., 2005). Hue et al. (2001) found an increase in cycling performance in an all-out 1-km laboratory test using a non-circular chainring. In contrast to these studies, there are some studies showing that non-circular chainring designs do not improve the gross efficiency of cycling (Ratel et al., 2004; Hull et al., 1992; Cullen et al., 1992; Belen et al., 2007). These differences in the results can be explained by the methodological differences in the studies, such as the structure of the performance test, caddence (rpm), bike fitting, the participant's use of a racing bike instead of an ergometer, the participant's ability to use their own bike, etc. These factors have been demonstrated to exert a profound influence on the performance of cyclists in numerous studies (Patterson and Moreno, 1990; Passfield and Doust, 2000; Takaishi et al., 1998; Majerczak et al., 2008; Córdova et al., 2004).

It is important to note that the mean power output values were higher for the Q-rings than for the C-rings in the incremental exercise test (279.35 ± 38.57 vs. 269.85 ± 31.15 W, respectively). This difference in favor of Q-rings is consistent with the findings of other authors who have used the noncircular chainring (Rodríguez-Marroyo et al., 2009). Therefore, it appears that using Q-rings may lead to improved on-road cycling performance. Therefore, it can be concluded that Q-rings could positively contribute to cycling performance in time trials involving a continuous load. However, the determinants of performance in individual time trials are much more complex, and the test protocol established in this study is not entirely suitable for reaching these conclusions (De Koning et al., 1999; Abbiss and Laursen, 2005).

5. CONCLUSION

In conclusion, the present study found that non-circular chainrings, also known as Q-rings, had a significant impact on the physiological responses to the incremental exercise test, (mean power output and $\dot{V}O_{2Max}$). The increase in power output when using Q-rings suggests that Q-rings improve road cycling performance. However, further extensive studies are necessary to determine whether this design of Q-rings can enhance performance in other cycling tests.

Author Contributions

All the authors equally contributed to the article.

Ethics Information

University: Fenerbahçe University Non-Interventional Clinical Research Ethics Committee

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Conflict of Interest

The authors declare no conflict of interest.

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