Cycling performance improvement with oval chainrings after 1 year of adaptation

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Introduction

Cycling is predominantly a cyclical motion by applying forces to the pedals. The forces applied to the pedals within a crank cycle are not constant. The minimal torque is normally produced at the top and bottom points of the crank cycle and the highest somewhere between 90 and 110 degrees crank cycle (Fonda & Sarabon, 2010; Gregor & Conconi, 2000; Hull, Williams, Williams, & Kautz, 1992). Based on the most recent applied science findings (Cheung & Zabala, 2017), pedalling technique optimisation should be predominantly focused on the parts of the crank cycle, where maximum forces/torque are present and not on passive phase (Korff, Romer, Mayhew, & Martin, 2007).

Oval chainrings have been known for a long time, yet still their usage is not common and research is limited (Cordova, Latasa, Seco, Villa, & Rodriguez-Falces, 2014). In theory, oval chainrings enhance cycling performance by increasing the chainring diameter at the point where highest forces are present and decreasing the chainring diameter at when the pedals are over the top/bottom transition (Malfait, Storme, & Derdeyn, 2010). One of the reasons for not wide spread usage might be the lack of evidence supporting the advertised benefits (Malfait, Storme, & Derdeyn, 2012). Some manufacturers report an increase in power output between 3 and 12 % (Strutzenberger, Wunsch, Kroell, Dastl, & Schwameder, 2014), whilst recent studies suggest minimal to no difference (Leong, Elmer, & Martin, 2017).

A study by Strutzenberger et al. (2014) showed that oval chainrings exhibited a decrease in crank velocity and an increase in tangential force in the downward phase. The decrease in sagittal knee joint power and increase in sagittal hip joint power could result in maximising efficiency power production. A theoretical study by Rankin & Neptune (2008) suggests that power output can be increased by utilizing an oval chainring that would allow muscles to generate power for a longer duration during the power phase. On contrary, a recent study by Leong et al. (2017) showed no differences in maximal power output and joint powers.

From a practical point of view, cyclists and manufacturers report that sufficient adaptation phase (that varies between manufacturers) is required to get fully adapted to a new technique. To the best of our knowledge, no studies examined the effects on economy and pedalling technique after longer adaptation phase. Therefore, the aim of this study is to explore the effects of long-term adaptation using oval chainrings on mechanical and metabolic functions during cycling at submaximal intensity. We hypothesise that using oval chainrings will result in (i) an increase in index of effectiveness, (ii) decrease in total force and (iii) increase in gross efficiency.

Methods

Seven male trained cyclists ([mean ± SD] age 33.8 ± 6.8 y, body mass 72.1 ± 8.4 kg, and body height 177.5 ± 4.9 cm) who were using non-circular chainrings (Oval 110/4, AbsoluteBlack, London, UK) for at least one year were recruited. Participants were recreational road riders with no history of muscular-skeletal injuries in the past 5 years and were riding between 3000 and 10000 km a year. Before the experiment each participant signed an informed consent document, which was approved by the Slovenian national medical ethics committee (KME RS 0120-314/2017).

Participants used their own bicycles mounted on a direct-drive ergotrainer (Elite Drivo, Treviso, Italy) and after a 10-minute warm up at 100 W, completed two 5 minute bouts at 75 % of their maximal power. In one of the trials, they used round chainrings, whereas in the other, they used non-circular chainrings from AbsoluteBlack. Trials were completed in a random order and with sufficient recovery between the trials to avoid fatigue effects.

Force pedals (Forped, Cycling Science Ltd., Kranj, Slovenia) were mounted on the participant's bicycle, which recorded vertical (F_V), anterior-posterior (F_{AP}) and medial-lateral (F_{ML}) forces at a sampling rate of 1000 Hz. Two active LED markers were positioned on the force pedal. After volume and orientation calibration following the manufacturer's guidelines for best accuracy and reliability (Mazumder, Kim, & Park, 2011), kinematics were recorded with an active kinematics system at a sampling rate of 250 Hz (3D investigator, NDI Waterloo, Canada). Pedal forces and kinematics data were synchronized through a digital pulse sent from the kinematics system and matched synchronically in the post analysis. Oxygen consumption (VO_2) and Carbon dioxide output (CO_2) were measured continuously using a metabolic chart (Quark4, Cosmed, Rome, Italy). Experimental setup is shown on Figure 1.

Figure 1: Experimental setup

Data analyses were performed using custom written scripts in MATLAB®. Data from the force pedals was first down-sampled to match the data from the kinematics. Force data was filtered using a Butterworth filter, 2nd order with a low cut-off frequency of 10 Hz (Bini & Hume, 2015). All crank cycles from the recording were cut and averaged to form an ensemble average presented on a crank angle scale from the top dead centre (TDC, i.e. 0/360°) over the bottom dead centre (BDC, i.e. 180°) back to the TDC. Crank and pedal angles were calculated from the kinematics on the pedal. The total and effective force was calculated using the kinematic and force data. The effective force was defined as the component that was directed perpendicular to the crank.

Pedalling effectiveness was assessed using the index of effectiveness (IE) computed as the ratio between the impulse of the effective force (F_{eff}) and the impulse of the total force (F_{tot}) applied to the pedal. IE was calculated for the entire pedal cycle and additionally for the downstroke. Total force was averaged for the entire pedal stroke. Average gross efficiency (GE) was calculated as the ratio of work rate over metabolic cost rate calculated from VO_2 and respiratory exchange ratio (RER).

Results were presented as mean ± SD and after tested for normality, they were statistically compared using a paired t-test with the level of significance set to $p < 0.05$.

Results

Figure 2 shows the results for IE across the entire pedal stroke. IE was statistically significantly higher (p = 0.01) using oval chainrings compared to round.

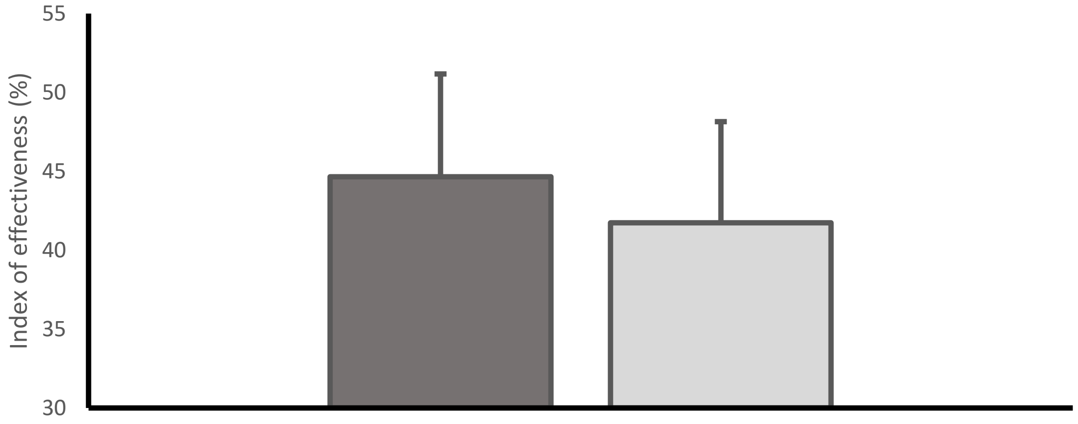

Figure 2: Index of effectiveness for oval (dark bar) and round (light bar) chainrings.

Results for IE of the downstroke phase are illustrated in Figure 3. IE of the downstroke was statistically significantly higher (p = 0.04) using oval chainrings compared to round.

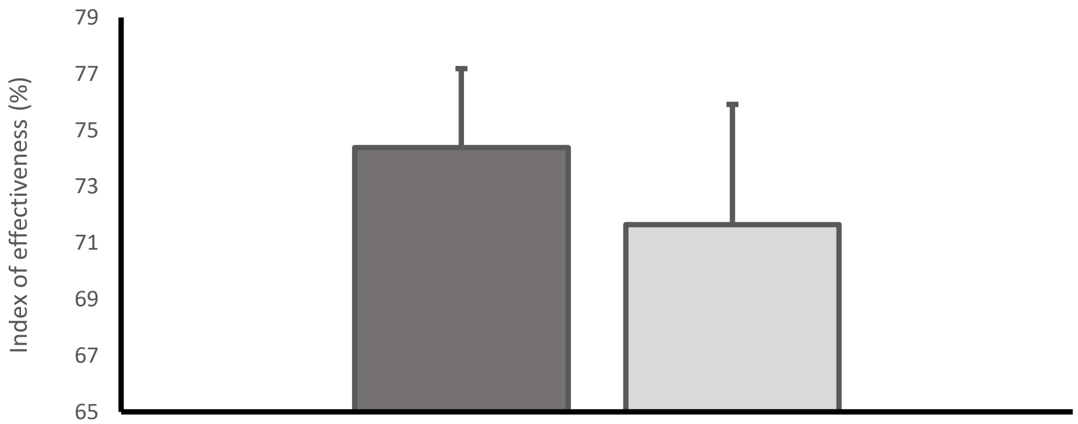

Figure 3: Index of effectiveness of the downstroke for oval (dark bar) and round (light bar) chainrigns.

Average total force was statistically significantly lower (p = 0.04) when using oval compared to round chainrings (Figure 4).

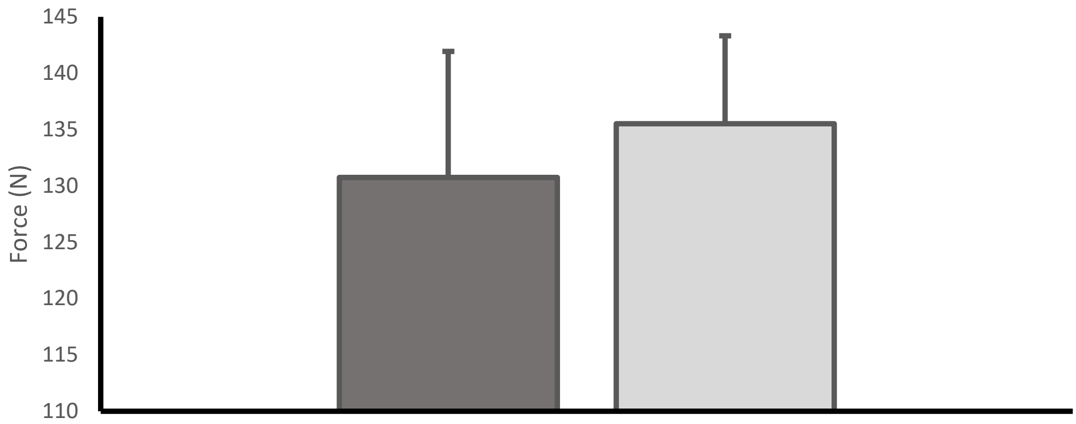

Figure 4: Total force for oval (dark bar) and round (light bar) chainrings.

Gross efficiency results are presented in Figure 5. There was a statistically significant increase ($p = 0.04$) in gross efficiency using oval chainrings compared to round.

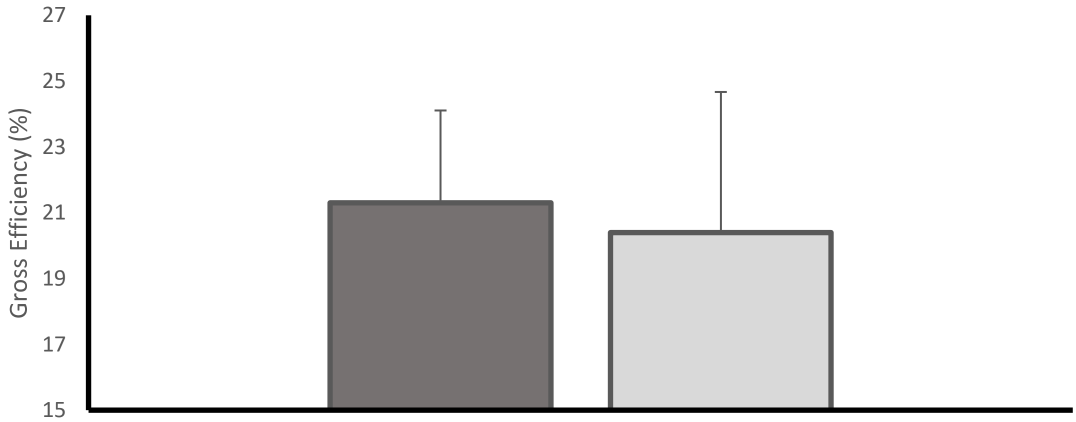

Figure 5: Gross efficiency for oval (dark bar) and round (light bar) chainrings.

Discussion

The aim of this study was to examine the effects of long-term adaptation using oval chainrings on mechanical and metabolic functions during cycling at submaximal intensity. We hypothesised that using oval chainrings will result in an increase in index of effectiveness, decrease in total force and increase in gross efficiency. The results confirm the set hypotheses by showing statistically significant differences in all the parameters measured.

This is the first study that explored the changes in mechanical and metabolic functions during steady-state cycling after a longer adaptation phase. The results showed a significant increase in indices of pedalling effectiveness as well as a significant increase in gross efficiency. One of the reasons that could explain the improvements is the adaptation in ankle joint kinematics. As noted by Leong et al. (2017) one of the observations was a small increase in power absorbed during ankle dorsiflexion. An increase in dorsiflexion during the downstroke was previously found as detrimental to cycling performance (Cannon, Kolkhorst, & Cipriani, 2007). If riders in this study adapted to 'stiff ankle' pedalling technique which allowed muscles to generate power for a longer duration during the power phase, it could result in improved efficiency and effectiveness.

Although the differences in absolute terms (e.g. total force) were not that big (~5 N), they could be interpreted in a different way. If one is pedalling at 90 rpm and is saving 5 N every pedal stroke, it sums to 27000 N (2700 kg) for every hour of cycling. Similar outcomes could be derived from the results on gross efficiency. Based on the results of this study, we can conclude that if using oval chainrings for a longer time, cyclists will spend less energy at a given power output and could potentially ride for longer.

In conclusion, cyclists using oval chainrings for longer time seem to adapt to a better pedalling technique that results in improved performance. Future studies should be carried out to confirm these findings and explore the effects on other parameters of cycling performance (maximal power, time trial performance, etc.).

References

Bini, R. R., & Hume, P. A. (2015). Relationship between pedal force asymmetry and performance in cycling time trial. *The Journal of Sports Medicine and Physical Fitness*, *55*(9), 892–8.

Cannon, D. T., Kolkhorst, F. W., & Cipriani, D. J. (2007). Effect of pedaling technique on muscle activity and cycling efficiency. *European Journal of Applied Physiology*, *99*(6), 659–664.

Cheung, S., & Zabala, M. (2017). *Cycling Sceince*. Champaign: Human Kinetics.

Cordova, A., Latasa, I., Seco, J., Villa, G., & Rodriguez-Falces, J. (2014). Physiological Responses during Cycling With Oval Chainrings (Q-Ring) and Circular Chainrings. *Journal of Sports Science & Medicine*, *13*(2), 410–6.

Fonda, B., & Sarabon, N. (2010). Biomechanics of Cycling. *Sport Science Review*, *19*(1/2), 187–210. https://doi.org/10.2478/v10237-011-0012-0

Gregor, R. J., & Conconi, F. (2000). Anatomy, Biochemistry and Physiology of Road Cycling. *Gregor RJ, Conconi F. Road Cycling: Olympic Handbook of Sports Medicine. Wiley-Blackwell*, 1–17.

Hull, M. L., Williams, M., Williams, K., & Kautz, S. (1992). Physiological response to cycling with both circular and noncircular chainrings. *Medicine and Science in Sports and Exercise*, *24*(10), 1114–22. https://doi.org/10.1249/00005768-199210000-00008

Korff, T., Romer, L., Mayhew, I., & Martin, J. (2007). Effect of pedaling technique on mechanical effectiveness and efficiency in cyclists. *Medicine and Science in Sports and Exercise*, *39*(6), 991–995. https://doi.org/10.1249/mss.0b013e318043a235

Leong, C.-H., Elmer, S. J., & Martin, J. C. (2017). Noncircular Chainrings Do Not Influence Maximum Cycling Power. *Journal of Applied Biomechanics*, *33*(6), 410–418. https://doi.org/10.1123/jab.2017-0035

Malfait, L., Storme, G., & Derdeyn, M. (2010). Comparative biomechanical study of circular and non-circular chainrings for endurance cycling at constant speed. *Mech.Eng., M. Derdeyn, M.Sc.Mech.Eng & Appl.Math*, (May).

Malfait, L., Storme, G., & Derdeyn, M. (2012). Why do appropriate non-circular chainrings yield more crank power compared to conventional circular systems during isokinetic pedaling?, (January), 1–62.

Mazumder, M. M. G., Kim, S., & Park, S. J. (2011). Precision and repeatability analysis of Optotrak Certus as a tool for gait analysis utilizing a 3D robot. *Journal of Engineering and Technology Research*, *3*(2), 37–43.

Rankin, J. W., & Neptune, R. R. (2008). A theoretical analysis of an optimal chainring shape to maximize crank power during isokinetic pedaling. *Journal of Biomechanics*, *41*(7), 1494–1502. https://doi.org/10.1016/j.jbiomech.2008.02.015

Strutzenberger, G., Wunsch, T., Kroell, J., Dastl, J., & Schwameder, H. (2014). Effect of chainring ovality on joint power during cycling at different workloads and cadences. *Sports Biomechanics*, *13*(2), 97–108. https://doi.org/10.1080/14763141.2014.908946