中國機械工程學刊第四十五卷第四期第 329~336 頁(民國一百一十三年)
Journal of the Chinese Society of Mechanical Engineers, Vol.45, No.4, pp329~336 (2024)

Mechanical Performances and Physiological Parameters for Cyclists Riding with Bi-ellipse Sprocket: A Cross-Field Study

Ardi Lesmawanto*,**, Soun-Cheng Wang***
and Shinn-Liang Chang****

Keywords: noncircular sprocket, bi-ellipse shape, pedaling performance.

ABSTRACT

The aim of this study is to compare the pedaling performances of a 32-tooth circular sprocket and four bi-ellipse sprockets with an increasing number of teeth (ranging from 33 to 36 teeth), where the maximum radius of the bi-ellipse sprocket is positioned at a 45-degree angle to the left crank. This comparison is conducted by evaluating both mechanical and physiological parameters. Nine recreational cyclists, with right-leg dominance and a minimum of one hour daily cycling over two years, participated in the study. Indoor tests with a constant cadence at 70, 80, and 90 rpm were performed to assess mechanical performance. Additionally, an incremental maximal test was performed, increasing by 30 watts every 2 minutes until exhaustion, to measure physiological parameters. These physiological parameters were used to confirm the observed mechanical performance. Results showed a significant increase in rear wheel speed with more sprocket teeth. While the 33-tooth sprocket exhibited the lowest peak and downstroke power, the 32-tooth sprocket showed no significant difference compared to the 34 and 35-tooth sprockets in mechanical parameter comparisons. Comparison of physiological parameters confirmed this, as they did not exhibit significant differences among the tested sprockets. This study provides valuable insights into how the number of teeth in sprockets affects pedaling performance, which is essential for cyclists looking to optimize their performance. Moreover, the research contributes to understanding the potential benefits of using bi-ellipse sprockets over circular sprockets in enhancing rear wheel speed and reducing peak and downstroke power during cycling.

Paper Received November, 2023. Revised March, 2024. Accepted July, 2024. Author for Correspondence: Shinn-Liang Chang.

* *Ph.D. student, Department of Power Mechanical Engineering, National Formosa University, Yunlin, Taiwan 632301, ROC.*

** *Lecturer, Mechanical Engineering Department, University of Muhammadiyah Malang, Malang, Jawa Timur 65144, Indonesia.*

*** *Professor, Department of Athletic Sports, National Chung Cheng University, Minxiong, Taiwan 621301, ROC.*

**** *Professor, Department of Power Mechanical Engineering, National Formosa University, Yunlin, Taiwan 632301, ROC.*

INTRODUCTION

A sprocket is an essential part of the bicycle for transferring motion from the cyclist's stroke to the back wheel's rotation. Numerous researchers have studied the effect of noncircular sprockets on bicycle performance. Some investigations reported that the noncircular sprocket used could increase the maximal power output during the downstroke phase (Hintzy et al., 2016), advantageous in facilitating the pedaling to quickly pass the top and bottom dead center, increase the biking speed (O'Hara et al., 2012), reduce knee joint moment (Bisi et al., 2010; Strutzenberger et al., 2014), and reduce the leg muscle work (Hansen et al., 2009; Purdue et al., 2010). However, different studies found no significant difference between circular and noncircular usage in cycling performances (Elvira et al., 2020; Leong et al., 2021; ManuelMateo-March et al., 2021).

In most previous studies, researchers predominantly utilized commercially available noncircular sprockets with symmetrical designs, causing both the left and right legs to pedal in identical sprocket shapes. For most riders, pedaling power between their two legs can vary, with differences ranging from 5% to 20% (Carpes et al., 2010). Additionally, recent findings by Lesmawanto et al. (2022a) suggest that an asymmetric sprocket shape could better accommodate the differing abilities of each leg. Thus, the difference in noncircular sprocket shape between the right and left leg may be hypothesized to affect pedaling performance. Therefore, further investigation into the effects of different sprocket shapes on the performance of the right and left leg sections in pedaling is necessary.

A novel noncircular sprocket design called the bi-ellipse sprocket had been introduced previously by Lesmawanto et al. (2022b). It was designed by combining two half-different elliptical shapes into a sprocket, considering the pedaling torque ratio produced by the left and right leg in the pedaling experiment. With the prototype installed at various positions on the crank, some positions can enhance pedaling efficiency better than using the circular sprocket, specifically when the sprocket is installed at a 45-degree angle towards the crank.

To the best of the author's knowledge, the use of bi-ellipse sprockets has not been extensively explored. Hence, the purpose of this study is to investigate the effectiveness of bi-ellipse sprockets in comparison to circular sprockets. Specifically, the study aims to compare the mechanical performances of circular sprockets with several bi-ellipse sprockets with an increasing number of teeth, with the sprocket maximum radius installed at 45° facing the crank, and utilize physiological performance analysis to validate these findings. We hypothesize that bi-ellipse sprockets will demonstrate better performance compared to circular sprockets at the same pedaling cadences.

This study contributes to filling a gap in knowledge regarding the effectiveness of bi-ellipse sprockets, which have not been extensively explored in previous research. Understanding the performance differences between bi-ellipse and circular sprockets can offer valuable insights for cyclists seeking to optimize their selection of noncircular sprockets and enhance their cycling performance. Additionally, the practical implications of this study extend to the bicycle design and manufacturing industries, potentially influencing the development of more efficient cycling components and contributing to advancements in bicycle technology.

MATERIALS AND METHODS

Bike and the devices

The experiment was conducted using a mountain bike (KHS Alite 1000, California, USA) mounted on an indoor bike trainer (Wahoo Kickr Smart trainer, Atlanta, USA), allowing for indoor experimentation, as shown in Fig. 1. A rotary encoder (ES50, HCTec EZ-measuring, Taiwan) was attached to the bike trainer, enabling the recording of rear wheel speed at a rate of 200 data points per second.

Additionally, the bicycle is equipped with two crank power meters (CrankMeter V.1.0, Chief SI, Taiwan). These power meters consist of a strain gauge configuration used to collect torque and power data. The strain gauge configuration was connected to a Bluetooth transmitter powered by a 3.7-volt lithium battery. Data from the sensors were then transmitted and received by the computer using two dedicated Bluetooth dongles. Both right and left crank power meters provided a data sampling rate of 200 data points per second.

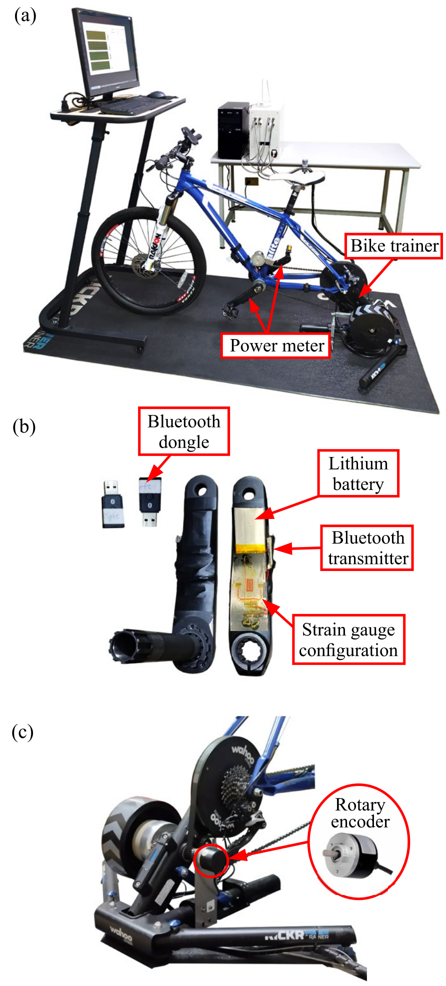

Fig. 1. (a) Bike platform test, (b) Power meter, (c) Rotary encoder attached on the bike trainer.

Power meter calibration

Calibration of the right and left power meters was performed before the study to ensure data accuracy. This calibration process involved applying several standard weights to each crank in a horizontal position, as shown in Fig. 2. These standard weights ranged from 10 N, 110 N, 210 N, 310 N, 410 N, to 510 N.

The torsional load for the calibration process is calculated using Eq. (1) as follows

$$\tau = w \cdot r \qquad (1)$$

where τ is the torque load applied on the crank (N.m), w is the load weight (N), and r is the crank length (m), which a length of 0.17 m used in this study. The various loading variations are presented in Table 1.

During the calibration process, the voltage magnitude generated by the strain gauge when subjected to loading is measured and then aligned with the provided torque load values. Figure 3 illustrates the voltage alignment process under different loading conditions.

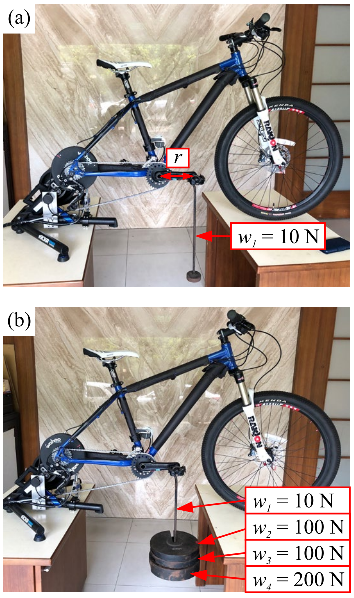

Fig. 2. Load given to the crank during the calibration process, (a) Loading of 10 N, (b) Loading of 410 N.

Table 1. Calculation of torsional loads applied to the crank for the calibration process.

Load number	*w* (N)	*r* (m)	τ (N.m)
1	no load	0.17	0
2	10	0.17	1.7
3	110	0.17	18.7
4	210	0.17	35.7
5	310	0.17	52.7
6	410	0.17	69.7
7	510	0.17	86.7

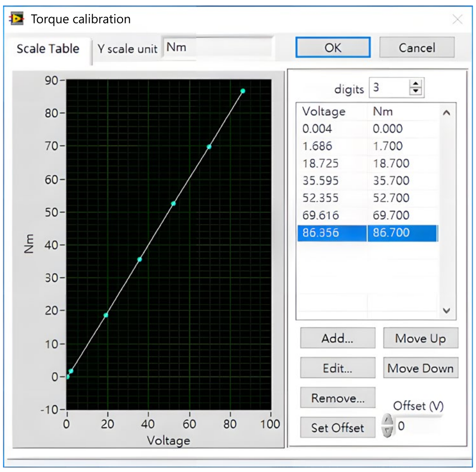

Fig. 3. The process of converting voltage values to torque values on the crank.

Sprockets

The sprockets employed in this test, including a 32-tooth circular sprocket and bi-ellipse sprockets with 33, 34, 35, and 36 teeth, were depicted in Fig. 4. The bi-ellipse sprockets with 33, 34, 35, and 36 teeth were constructed using two half ellipses with respective eccentricities on each side: 0.1 (16 teeth) on the left and 0.46 (17 teeth), 0.6 (18 teeth), 0.68 (19 teeth), and 0.74 (20 teeth) on the right.

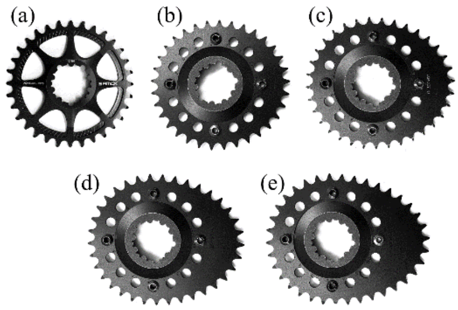

Fig. 4. The sprocket investigated in this study. (a) 32-tooth standard circular sprocket. (b) 16T – 17T left-right combination of 33-tooth bi-ellipse sprocket. (c) 16T – 18T left-right combination of 34-tooth bi-ellipse sprocket. (d) 16T – 19T left-right combination of 35-tooth bi-ellipse sprocket. (e) 16T – 20T left-right combination of 36-tooth bi-ellipse sprocket.

The maximum radius of the sprocket is positioned at 45° toward the left crank to optimize pedaling efficiency (see Fig. 5), as suggested by Lesmawanto et al. (2022b).

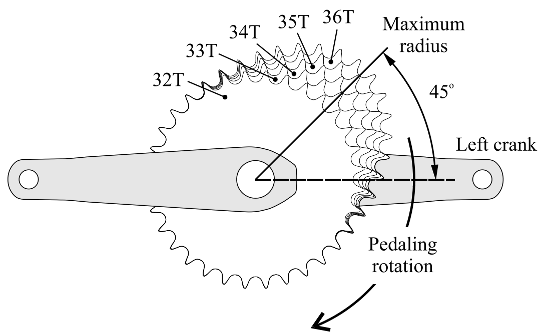

Fig. 5. Position of the maximum sprocket radius of the bi-ellipse sprocket to the crank.

Participants

Nine graduate students from the sports department participated in this test (25.3±1.3 years of age, 74.1±19.8 kg of body mass, and 172.1±9.0 cm of height). They were recreational cyclists who were physically active but had no prior experience using noncircular sprockets. They exhibited right-leg dominance and engaged in cycling for a minimum of one hour daily, whether for transportation, fitness, or recreation purposes. In addition, all cyclists were recruited specifically from the cycling fraternity with at least two years of road cycling experience. After the research plan was explained, the participants filled in a subject consent form and a health status questionnaire. At all times throughout the study, there was permission for each participant to discontinue participation in the experiment without offering any explanations.

Experimental design

In this study, the cycling experiment was conducted in two stages. The first-stage is aimed to investigate the performance differences between circular sprockets and bi-ellipse sprockets with an increasing number of teeth in terms of mechanical performance.

The independent variable in this stage was the number of teeth of the sprocket and the cycling speed (cadence). Three cadence speeds were used: 70 rpm, 80 rpm, and 90 rpm. The variables observed for each cadence speed level included rear wheel speed, average peak power, and average downstroke power. Downstroke power is the average power generated by each crank as the pedal moves from the top position (12 o'clock) to the bottom position (6 o'clock) (Lesmawanto et al., 2022b), while average peak power represents the average of the maximum power produced by both legs. Figure 6 illustrates the definition of the downstroke power and the peak power investigated in this study.

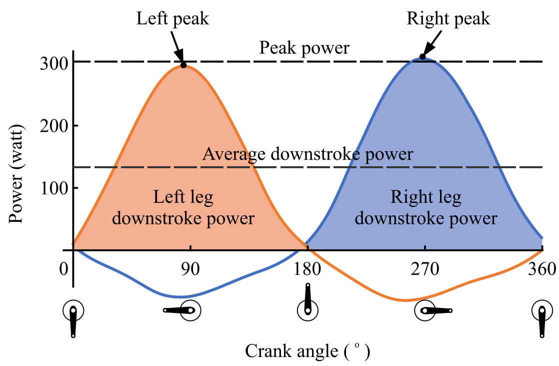

Fig. 6. The mechanical data averaged over one pedaling rotation and its definition.

The second stage consisted of a maximal cycling test aimed at observing the cyclists' physiological parameters. The independent variable in this experiment was the pedaling load and the number of teeth. During the cycling test, the pedaling load was initially set at 60 watts. Every two minutes, the pedaling load was increased by 30 watts until the end of the experiment. The cadence was set to 60 rpm to ensure consistent observation of cycling efficiency since participants were recreational cyclists (Foss and Hallen, 2004). In this study, breath-by-breath cyclist exchange data during this test were recorded using a Cortex gas analyzer (Metalyzer 3B, Cortex Biophysik GmbH, Leipzig, Germany).

The variable data observed in this second-stage test include the ventilatory threshold (Vt) and respiratory compensation point (RCP), exercise economy (EE), which corresponds to the oxygen uptake (VO2), and the maximum power (Wmax).

Ventilatory threshold (Vt) is the amount of air a cyclist breathes in one breath. The respiratory compensation point (RCP) marks the start of oxygen loss from the lungs. Maximum power (Wmax) indicates the cyclist's highest achievable power output. Vt_VO2 is the volume of air inhaled at the moment when Oxygen Uptake (VO2) begins. RCP_VO2 (Respiratory Compensation Point at VO2) signifies the point when VO2 starts. VO2max represents the maximum amount of oxygen the lungs can absorb in a minute. Effective Exercise Volume Oxygen (EEVO2) measures the oxygen uptake efficiency per minute. These parameters are important to determine the endurance performance of cyclists (Lucía et al., 2000).

These parameters were obtained through data processing using the respiratory methodology employed by Lucía et al. (2000), the ventilatory threshold (VT) was determined by the point of an increase in VO2 with no concurrent increase in VCO2. While the respiratory compensation point (RCP) was determined by increasing both VO2 and VCO2. The maximum oxygen uptake (VO2max) was recorded as the highest amount of oxygen consumed per minute when the subject engages in the most intense exercise. It was determined by at least two of the criteria of HRmax $\geq$ 90%, respiratory exchange ratio (RER) > 1.15, or the Borg scale rating of perceived exertion (RPE) $\geq$ 18 (Howley et al., 1995).

Based on previous research indicating that bi-ellipse sprockets perform optimally when the maximum radius is at a 45-degree angle to the crank (Lesmawanto et al., 2022), our hypothesis suggests that bi-ellipse sprockets will outperform circular sprockets at equivalent pedaling cadences in terms of mechanical performance. Specifically, bi-ellipse sprockets are expected to exhibit superior mechanical efficiency, resulting in increased power transmission and cycling economy.

Test procedures

During the cycling tests, all participants used the same bike settings, except for the saddle height. In the initial stage, cyclists were allowed to set the saddle height according to their preference before starting the tests. They were then instructed to warm up by pedaling for 1 minute, followed by a 3.5-minute habituation phase at a pedaling cadence of 70 RPM.

An auditory method, using a metronome with beats per second corresponding to the chosen RPM cadence, was used to help cyclists maintain their cadence. The utilization of a metronome as an auditory support has been proven to improve pedaling movement precision (Fattorini and Rodio, 2019; McCrary and Gould, 2023; Sors et al., 2015).

Pedaling data were collected for 30 seconds. Subsequently, cyclists were instructed to repeat the test at 80 RPM and 90 RPM pedaling cadences, following the same procedure, with a 15-minute rest between trials. Tests on different sprockets were conducted at 24-hour intervals. The order of sprocket usage was randomly selected for each test, meaning that each participant had a different sequence of sprocket usage during the tests. After completing the first test, all the test results were reviewed and analyzed. Based on the first test's significant outcomes, two bi-ellipse sprockets that require further investigation were selected. These sprockets, along with the circular sprocket, will be analyzed in the second stage.

In the second stage test, participants were required to perform a maximum cycling test following a mandatory minimum rest period of 48 hours after the first test. The maximum cycling test was performed according to the maximal exercise protocol of Bunsawat et al. (2017). First, the cyclist begins to warm up by riding for three minutes at a cadence of 60 rpm without load. A metronome with 60 bpm was used to guide the subject to maintain the pedaling cadence auditorily. The test then started by providing a 60-watt pedaling load. Following that, the load was increased by 30 watts every two minutes. The test ended when cyclists were exhausted and stopped pedaling at 60 rpm. The heart rate detection (INW1W, Polar H10, Malaysia) was also used to monitor that the subject had reached maximum exhaustion.

The test with another sprocket was performed after a 48-hour rest period. Each cyclist was asked to not perform strenuous physical work during the rest period. This equipment was always calibrated before conducting the first test of the day.

Result and Discussion

After the experimental data were obtained, all experimental data were calculated on average and processed statistically using IBM SPSS (version 26, IBM Inc., Armonk, NY, USA). The mean difference of each parameter was examined using the repeated measures ANOVA test. Prior to this, the Shapiro-Wilk method and Mauchly's test of sphericity were used to determine the normality and homogeneity of the data, respectively. Subsequently, Fisher's least significant difference (LSD) method was conducted to explore a more comprehensive comparison test. The level of significance was set at $p < 0.05$. All data in tables and graphs are presented as mean ± standard deviation (SD). Table 2 displays the repeated measures ANOVA results for rear wheel speed with different sprockets (32 teeth circular sprocket, and 33 to 36 teeth bi-ellipse sprockets) at a cadence of 70 rpm. It shows that the p-value for the between-group comparison is below 0.000, indicating a significant increase in rear wheel speed associated with the 32 teeth circular sprocket compared to sprockets with a different number of teeth.

Table 2. Repeated measures ANOVA results for rear wheel speed with cadence 70 rpm.

Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*
Between Groups	983.81	4	245.95	134.17	.000
Within Groups	982.45	1	982.45	557.83	.000
Time	56295 2.403	1	56295 2.403	76046. 277	.000
Error	59.22	8	7.403		

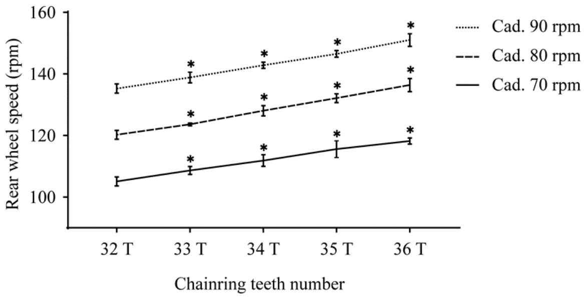

Fig. 7. Rear wheel speed comparison produced by the various number of teeth at different cadences. ($p < 0.05$); *significant difference to 32 teeth at the same cadence.

At each cadence level, pedaling with an increasing number of teeth on the sprocket, ranging from 32 to 36 teeth, resulted in a significant increase in rear wheel speed ($p < 0.05$), as shown in Fig. 7.

The peak power produced with the bi-ellipse sprockets (BC) also significantly increased with the increasing number of teeth, as demonstrated in Fig. 8. However, when compared to the 32-tooth circular sprocket (CC) at each level, the 33-tooth BC exhibited significantly lower peak power (at 70 rpm, $p = 0.011$; at 80 rpm, $p = 0.042$; at 90 rpm, $p = 0.009$). There were also no significant differences observed between the 32-tooth CC, 34-tooth BC, and 35-tooth BC.

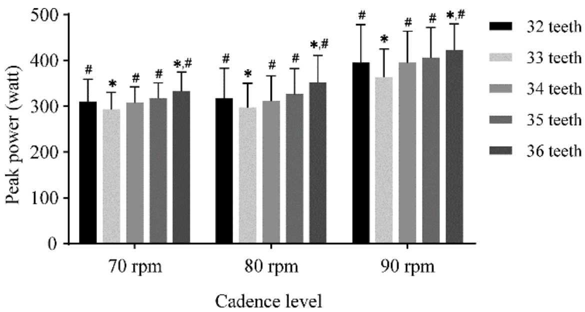

Fig. 8. Peak power comparison at a different cadence using different sprockets; *significant difference to 32 teeth at the same cadence; # significant difference to 33 teeth at the same cadence.

A similar trend was observed for downstroke power, as shown in Fig. 9. The downstroke power with the 33-tooth BC was significantly lower than that with the 32-tooth CC at all cadence levels (70 rpm, p = 0.035; 80 rpm, p = 0.010; 90 rpm, p = 0.043). Likewise, no significant differences were found between the 32-tooth CC, 34-tooth BC, and 35-tooth BC.

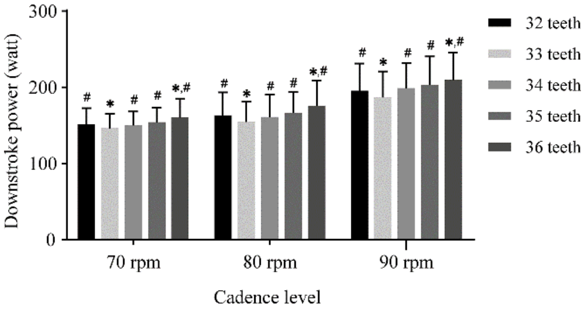

Fig. 9. Average downstroke power during the pedaling test with different sprockets at different pedaling cadences; *significant difference to 32 teeth at the same cadence; # significant difference to 33 teeth at the same cadence.

In the maximum cycling test results (Table 3), all physiological parameters exhibited no significant differences during pedaling with the 32-tooth CC, 33-tooth BC, and 35-tooth BC sprockets. In this comparison, the 34-tooth BC and 36-tooth BC were not included to avoid redundancy because these chainrings have been shown to have no significant impact on mechanical performance.

Table 3. The physiological variables during the maximal cycling test with different sprockets.

Parameters	32T of CC	33T of BC	35T of BC
Vt (watt)	126.9±27.5	125.5±23.4	122.9±25.6
RCP (watt)	170.5±37.9	163.9±30.7	165.1±27.9
Wmax (watt)	222.7±61.7	221.7±56.3	221.1±51.9
Vt_VO2 (ml/kg/min)	21.7±4.3	21.4±3.9	21.0±3.6
RCP_VO2 (ml/kg/min)	26.7±5.2	26.4±5.0	26.6±4.9
VO2max (ml/kg/min)	33.4±7.1	33.5±6.6	33.3±6.4
EEVO2 (ml/kg/min/watt)	0.173±0.04	0.183±0.04	0.174±0.04

In general, raising the sprocket ratio increases pedaling power and rear wheel speed, as reported by Rylands et al. (2017) in Bicycle Motocross (BMX) cyclists using standard circular sprockets. However, our main results showed that while rear wheel speed increased linearly with the number of sprocket teeth, the peak and average downstroke power did not increase linearly.

At all pedaling speeds, the 33-tooth BC sprocket exhibited significantly lower power, both in terms of peak and downstroke power, when compared to the other sprockets. Compared to the 32-tooth CC, the 33-tooth BC produced significantly greater rear-wheel speed with less peak and downstroke power. Meanwhile, the 34 and 35-tooth BC sprockets produced statistically the same peak and downstroke power as the 32-tooth CC, although the rear-wheel speed increased. These results indicate that the 33-35 tooth BC sprockets were more efficient in producing higher speeds compared to the 32-tooth CC.

From the perspective of the subject's physiology, no statistically significant differences were observed in all parameters studied when comparing 33 and 35 teeth BC to 32 teeth CC. This indicates that the 32 teeth CC, 33 teeth BC, and 35 teeth BC, do not sufficiently influence the metabolic cost during the maximal cycling test. These physiological comparisons complement the mechanical performance comparison results.

Basically, the noncircular sprocket was designed by increasing the radius along the power phase to maximize pedaling power in this phase and allow pedaling to pass the top and bottom dead center quickly (Bini and Dagnese, 2012; Cordova et al., 2014). For this reason, most researchers placed the maximum radius at around 90° to the crank using commercial noncircular sprockets to maximize the downstroke power (Hintzy et al., 2016; M.Mateo-March et al., 2012; ManuelMateo-March et al., 2014; O'Hara et al., 2012; Strutzenberger et al., 2014).

However, we took a slightly different approach. Our research plans to investigate the noncircular sprocket, which can produce more efficient pedaling, resulting in greater rear wheel speed by raising the sprocket ratio. Therefore, we placed the largest bi-ellipse sprocket radius at 45° to the crank (refer to Fig. 2), as suggested by Lesmawanto et al. (2022b) and Bisi et al. (2010). According to Lesmawanto et al. (2022b), the bi-ellipse sprocket produced significantly less peak and downstroke power than the circular sprocket when the maximum sprocket radius was positioned in the first pedaling quadrant (45° to the crank). This position causes the leg to exert more torque when the crank is at 45°. As the crank moves past this position, the torque applied to the pedal decreases with the decreasing sprocket radius, resulting in a lower peak power compared to when the maximum radius is placed around 90°. This is because the area around 90° is where the leg generates maximum torque. According to Bisi et al. (2010), placing the bigger sprocket radius at the first quadrant of the pedaling (at 12 o'clock – 3 o'clock) can minimize the leg joint load. We believe this installation position of the sprocket-crank has an influence on both mechanical and physiological performance.

CONCLUSIONS

The main contribution of this study lies in providing insights into the use of asymmetric noncircular sprockets, known as bi-ellipse sprockets, which represent a novel approach in chainring design that has yet to be thoroughly explored by other studies. The study found that the 33-tooth bi-ellipse sprocket resulted in higher output speed with significantly less peak and downstroke power compared to the 32-tooth circular sprocket. Additionally, the peak and downstroke power generated by the 33-tooth bi-ellipse sprocket were significantly lower than those generated by the other bi-ellipse sprockets. No significant differences in peak and downstroke power between the 32-tooth circular sprocket and the 34 or 35-tooth bi-ellipse sprocket were also reported. Moreover, the physiological parameter comparison also supports these results, as there were no differences in any parameters when using sprockets with 32, 33, and 35 teeth. The speed produced with the bi-ellipse sprockets increased significantly with the increasing number of teeth at all pedaling cadences. These findings have implications for professional cyclists aiming for faster cycling and improved stamina. However, while our study provides valuable insights, limitations exist in sample size and scope, suggesting the need for larger studies with diverse participant profiles to validate and extend our findings. Further studies involving professional cyclists, comparing sprocket types with more teeth, and comprehensive investigations from various perspectives are needed to fully explore the potential benefits of bi-ellipse sprockets in cycling performance.

ACKNOWLEDGMENT

The authors received financial support from the Ministry of Science and Technology of the ROC – Taiwan under Grant No. MOST 110-2221-E-150-029 and MOST 111-2221-E-150-025. The authors would like to express their gratitude to SAMOX company-Taiwan for manufacturing the sprockets.

REFERENCES

Bini, R.R., and Dagnese, F., "Noncircular chainrings and pedal to crank interface in cycling: A literature review," *Brazilian J Kinanthropometry Hum Perform*., Vol. 14, No. 4, pp. 470–482 (2012).

Bisi, M.C., Stagni, R., Gnudi, G., and Cappello, A., "Non-circular chain ring allows a reduction of joint loading in cycling," *J Mech Med Biol.*, Vol. 10, No. 1, pp. 113–122 (2010).

Bunsawat, K., Ranadive, S.M., Lane-Cordova, A.D., Yan, H., Kappus, R.M., Fernhall, B., and Baynard, T., "The effect of acute maximal exercise on postexercise hemodynamics and central arterial stiffness in obese and normal-weight individuals," *Physiol Rep*., Vol. 5, No. 7, pp. e13226 (2017).

Carpes, F.P., Mota, C.B., and Faria, I.E., "On the bilateral asymmetry during running and cycling – A review considering leg preference," *Phys Ther Sport*, Vol. 11, No. 4, pp. 136–142 (2010).

Cordova, A., Latasa, I., Seco, J., Villa, G., and Rodriguez-Falces, J., "Physiological responses during cycling with oval chainrings (Q-ring) and circular chainrings," *J Sport Sci Med.*, Vol. 13, No. 2, pp. 410–416 (2014).

Elvira, J.L.L., Mateo-March, M., Zabala, M., and Blasco-Lafarga, C., "The use of accelerometry to evaluate the BMX cycling starting hill. Effect of the Q-Ring^{TM} on the acceleration profile," *Sports Biomech*, Vol. 00, No. 00, pp. 1–15 (2020).

Fattorini, L., and Rodio, A., "Acoustic and visual pacesetter influence on the energy expenditure in a cycling exercise," *The Journal of Sports Medicine and Physical Fitness*, Vol. 59, No. 7, pp. 1126–1132 (2019).

Foss, O., and Hallen, J., "The most economical cadence increases with increasing workload, " *European Journal of Applied Physiology*, Vol 92, No.4, pp. 443–451 (2004).

Hansen, E.A., Jensen, K., Hallén, J., Rasmussen, J., and Pedersen, P.K., "Effect of chain wheel shape on crank torque, freely chosen pedal rate, and physiological responses during submaximal cycling," *J Physiol Anthropol.*, Vol. 28, No. 6, pp. 261–267 (2009).

Hintzy, F., Grappe, F., and Belli, A., "Effects of a Non-Circular Chainring on Sprint Performance During a Cycle Ergometer Test," *J Sports Sci Med*, Vol. 15, No. 2, pp. 223–228 (2016).

Leong, C.-H., Elmer, S.J., and Martin, J.C., "Noncircular Chainrings Do Not Influence Physiological Responses During Submaximal Cycling," *Int J Sports Physiol Perform*, Vol. 17, No. 3, pp. 407–414 (2021).

Lesmawanto, A., Hsu, K.-K., and Chang, S.-L., "Generation method of asymmetric chainring design from pedaling torque experimental data," *J Mech Sci Technol.*, Vol. 36, No. 12, pp. 6115–6122 (2022a).

Lesmawanto, A., Hsu, K.K., Chang, S.L., and Daryono, "Computer-aided design of bi-ellipse bicycle sprocket," *J Adv Mech Des Syst Manuf.*, Vol. 16, No. 1, pp. 2022jamdsm0008 (2022b).

Lucía, A., Hoyos, J., Pérez, M., and Chicharro, J.L., "Heart rate and performance parameters in elite cyclists: a longitudinal study," *Med Sci Sport Exerc.*, Vol. 32, No. 10, pp. 1777–1782 (2000).

Mateo-March, M., Zabala, M., and González-Badillo, J.J., "Effects of the orientation of the maximum torque point with a Q-Ring^{TM} non-circular chainring system on the BMX cycling sprint performance," *Sci Sports.*, Vol. 27, No. 3, pp. e15–e19 (2012).

Mateo-March, Manuel, Bertucci, W., Chiementin, X., Lopez-Elvira, J.L., Javaloyes, A., and Zabala, M., "The effect of chain-ring systems on the performance and pedalling technique in BMX elite and cadet riders," Isokinet Exerc Sci., Vol. 29, No. 2, pp. 123–130 (2021).

Mateo-March, Manuel, Fernández-Peña, E., Blasco-Lafarga, C., Morente-Sánchez, J., and Zabala, M., "Does a non-circular chainring improve performance in the bicycle motocross cycling start sprint?," *J Sport Sci Med.*, Vol. 13, No. 1, pp. 97–104 (2014).

McCrary, J. M., and Gould, M., "Rhythm in sport: Adapted rhythmic training to optimize timing and enhance performance in athletes," *Journal of Science and Medicine in Sport*, Vol. 26, No. 11, pp. 636–638 (2023).

O'Hara, C.R., Clark, R.D., Hagobian, T., and Mcgaughey, K., "Effects of Chainring Type (Circular vs . Rotor Q-Ring) on 1km Time Trial Performance Over Six Weeks in Competitive Cyclists and Triathletes," *Int J Sport Sci Eng*, Vol. 6, No. 1, pp. 025–040 (2012).

Purdue, A.I., Forrester, A.I.J., Taylor, M., Stokes, M.J., Hansen, E.A., and Rasmussen, J., "Efficient human force transmission tailored for the individual cyclist," *Procedia Eng.*, Vol. 2, No. 2, pp. 2543–2548 (2010).

Rylands, L.P., Roberts, S.J., and Hurst, H.T., "Effect of gear ratio on peak power and time to peak power in BMX cyclists," *Eur J Sport Sci.*, Vol. 17, No. 2, pp. 127–131 (2017).

Sors, F., Murgia, M., Santoro, I., and Agostini, T., "Audio-Based Interventions in Sport," *The Open Psychology Journal*, Vol. 8, No. 1, pp. 212–219 (2015).

Strutzenberger, G., Wunsch, T., Kroell, J., Dastl, J., and Schwameder, H., "Effect of chainring ovality on joint power during cycling at different workloads and cadences," *Sport Biomech.*, Vol. 13, No. 2, pp. 97–108 (2014).

自行車騎行雙橢圓形齒輪的機械性能和生理參數：一項跨領域研究

黎安迪
國立虎尾科技大學動力機械工程學系

王順正
國立中正大學運動與休閒教育研究所

張信良
國立虎尾科技大學動力機械工程學系

摘 要

本研究旨在比較一個32齒圓形齒盤與四個具有不同齒數（齒數範圍從33到36齒）的雙橢圓形齒盤之踩踏表現，其中雙橢圓形齒輪的最大半徑位於與左曲柄成45度角的位置，並且通過評估機械與生理參數進行此比較。九名業餘自行車手參與了此研究，他們慣用右腿並且每天至少騎自行車一小時，已持續兩年以上。本研究進行了室內測試，固定踏頻分別為70、80與90轉/分，以評估機械性能。除此之外，亦進行了增量極限測試，透過每2分鐘增加30瓦特，直至騎手精疲力竭，以測量生理參數。這些生理參數用於確認觀察到的機械性能。結果顯示，隨著齒數增加，後輪速度顯著增加。33齒之齒盤表現出最低的峰值與下踏行功率，32齒齒盤與34和35齒齒盤在機械參數比較中沒有顯著差異。生理參數的比較證實了這一點，因為在測試的齒盤中它們沒有顯著差異。本研究提供了有關齒盤齒數如何影響踩踏表現的寶貴見解，這對於希望優化自身表現的自行車手至關重要。此外，該研究有助於了解使用雙橢圓形齒盤相對於圓形齒盤在增強後輪速度與減少踩踏峰值以及下踏行功率方面的潛在益處。