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Enhancing cycling performance using an eccentric chainring

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ABSTRACT

HUE, O., O. GALY, C. HERTOIGH, J. F. CASTIES, and C. PREFAUT. Enhancing cycling performance using an eccentric chainring. *Med. Sci. Sports Exerc.*, Vol. 33, No. 6, 2001, pp. 000–000. **Purpose and Methods:** This study was designed to compare the physiological responses and performance of well trained cyclists riding with two different chainring designs, round or eccentric, during a brief and intense cycling exercise: an “all-out” 1-km laboratory test. The eccentrically designed chainring was made of two crank arms sliding into each other, with the inside arm fixed on the center of the arm of a circular chainring and the outside arm sliding along the inside and revolving around an elliptical cam. This design increases crank arm length at the downstroke and decreases it during the upstroke, thus increasing and decreasing the torque. In terms of the chainring's revolution, the crank arm length at 0° and 180° is similar to the arm length of circular chainrings (175 mm). However, during the downstroke (0–180°), it increases to its maximum length of 200 mm at 90° and then returns to its original length of 175 mm at 180°. During the upstroke, it decreases to a minimum length of 150 mm at 270° and then increases to 175 mm at 360°. Eleven cyclists performed an all-out 1-km laboratory test using each chainring. The study was conducted over two consecutive weeks with the order of chainring use randomized. During all trials, ventilatory data were collected every minute using an automated breath-by-breath system. Heart rate was measured using a telemetry system. **Results:** None of the cardiorespiratory variables showed significant differences between chainring trials. Performance, however, was significantly improved using the eccentric design (64.25 ± 1.05 vs 69.08 ± 1.38 s, $P < 0.004$, with the eccentric and the round design, respectively). **Conclusion:** We concluded that the eccentric chainring significantly improved the cycling performance during an all-out 1-km test. Further testing with indoor cycling specialists performing on a velodrome would be helpful to define the maximal possibilities of such a chainring. **Key Words:** PHYSIOLOGY, HEART RATE, SPRINT EXERCISE, BIOMECHANICS

Cycling performance can be optimized by two different approaches: physiological and biomechanical. Physiological variables such as high maximal oxygen uptake, peak power output, and fractional utilization of $\text{VO}_{2\text{max}}$ at the lactate threshold and high second ventilatory threshold have been demonstrated to be positively related to successful cycling performance (3,5,16,22). A similar relationship has also been shown between performance and biomechanical factors, especially those linked to aerodynamics, such as frontal area, seat height, and seat tube angle (6,11).

Today's training programs seem to focus on enhancing the physiological variables, but research has indicated that biomechanical adaptations would also improve performance, as demonstrated by Gnehm et al. (6). Concerning the physiological variables, Lucia et al. (16) demonstrated that professional cyclists have a significantly higher second ventilatory threshold than elite cyclists. From a biomechanical point of view, Coyle et al. (3) showed that the most important difference between “elite national class” and “good

state class” cyclists is a combination of higher power output and higher peak torque about the center of the crank. This last may result from the greater vertical force application to the crank arm during the cycling downstroke. From a mechanical point of view, however, higher peak torque can be induced by either greater vertical forces or a longer crank arm (5).

Earlier research concerning the motion cycle of the legs focused on noncircular chainrings, though no positive improvement was demonstrated (4,9,12,14). Recently, however, an experimental chainring with variable crank arm length was developed and certified by the International Cyclists Union (ICU). To our knowledge, no study has yet determined its effect on cycling performance. The aim of the present study was therefore to investigate the effect of this experimental eccentric chainring on the cycling performance of competitive triathletes and cyclists.

MATERIALS AND METHODS

Subjects. Eleven male competitive triathletes and cyclists participated in this study. All were students at the School of Physical Education at the University of Montpellier, France. Average competitive experience in the triathlon or cycling was 8.3 ± 1.8 yr, and subjects were in the competitive period (from April to August) at the time of the

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TABLE 1. Subject characteristics.

| Subject | Age (yr) | Weight (kg) | Height (cm) | Cyclist Type | Maximal Workrate (W) | $\dot{V}O_{2\max}$ (mL·kg ⁻¹ ·min ⁻¹) |
|---------|----------|-------------|-------------|--------------|----------------------|--|
| 1 | 26 | 70 | 176 | Triathlon | 430 | 73.9 |
| 2 | 19 | 71 | 180 | Triathlon | 430 | 72.0 |
| 3 | 22 | 82 | 190 | Triathlon | 450 | 67.2 |
| 4 | 19 | 61 | 174 | Triathlon | 370 | 69.3 |
| 5 | 18 | 65 | 168 | Triathlon | 430 | 71.8 |
| 6 | 25 | 64 | 170 | Triathlon | 370 | 66.2 |
| 7 | 20 | 71 | 181 | Road racing | 410 | 59.9 |
| 8 | 21 | 77 | 184 | Road racing | 450 | 74.5 |
| 9 | 21 | 75 | 183 | Road racing | 400 | 69.0 |
| 10 | 19 | 62 | 182 | Mtn. bike | 360 | 64.0 |
| 11 | 18 | 53 | 168 | Mtn. bike | 300 | 74.0 |
| Mean | 20.7 | 68.3 | 177.8 | | 400 | 69.2 |
| SEM | 0.8 | 2.5 | 2.2 | | 13.9 | 1.4 |

study. Anthropometric and physiological data are reported in Table 1. All subjects were informed of the purpose of the study and gave written consent in accordance with the regional ethics committee before participating.

Testing protocol. Each subject was tested in a two-trial protocol that took place over two consecutive weeks. The tests were conducted at the same time of day and during the same day of the week to minimize the effects of personal training on results. The subjects were asked to maintain their training schedule for the duration of the study but were not allowed to compete in a triathlon or cycle race during the testing period. All subjects were familiarized with the use of both the cycle ergometer and the home-trainer before testing. The subjects were asked to refrain from training on experimental days. Trial 1 consisted of an incremental cycle test; trial 2 consisted of an all-out 1-km cycling sprint with either a circular and eccentric chainring with 1-h rest between. The incremental cycle test was performed on an electromagnetic cycle ergometer (Monark 864, Monark-Crescent AB, Varberg, Sweden). After a 3-min warm-up at 30 W, the power was then increased by 30 W every minute up to exhaustion.

Wind-load simulator. In trial 2, the cycling test was performed with each athlete using his own cycle. This was set on a wind-load home trainer (Cateye CS 1000, Cateye, Osaka, Japan) that was fixed to the floor to prevent accidents due to the high power generated during such a test (8). The tubular wire was inflated to a pressure of 8 atmospheres (117.6 psi). The bicycle's rear wheel was in contact with a freely rotating axle with two fans. This roller with fan pressed automatically against the tubular tire in such a way as to eliminate variations in the rolling resistance between individuals. The rotating fans impelled air and created wind resistance. The speed/power output relationship documented using this type of wind-load simulator has been noted to be similar to that described for velodrome cycling (17,21) and has been used by others (7,13). Distance was automatically started and stopped with an odometer (Cateye CS 1000, Cateye, Osaka, Japan) fixed on the rotating axle. The gear ratios were free in order to optimize performance.

Eccentric chainring. An explanation of the eccentric chainring can be found in Figures 1 and 2. In terms of the chainring's revolution, the crank arm length at 0° and 180°

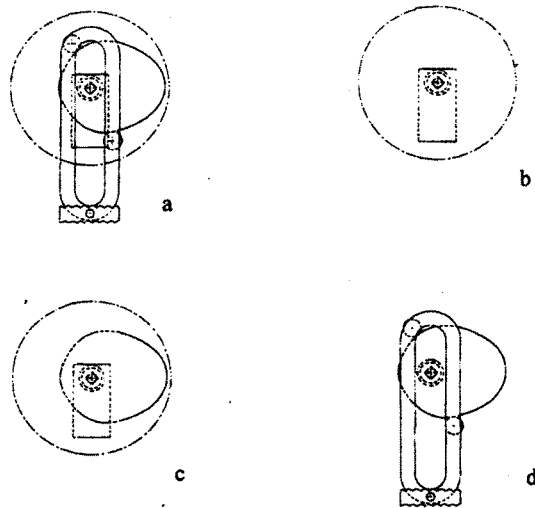


FIGURE 1—The eccentric chainring (a) is made of two crank arms sliding into each other, with the inside one fixed on the center of the arm of the circular chainring (b) and the outside one (d) sliding on the inside and revolving around an elliptical cam (c).

is similar to the arm length of circular chainrings (175 mm). However, as the figures show, it increases to its maximum length of 200 mm at 90° during the downstroke (0–180°) and decreases to a minimum length of 150 mm at 270° during the upstroke. The center of the pedal's revolution is 25 mm in front of the crank arm center (which explains the term "eccentric"). Because of its design, this eccentric chainring permits higher torque during the downstroke and lower torque during the upstroke.

Gas exchange measurements. Cardiorespiratory pulmonary data were continuously monitored and measured every 10 s using a mass spectrometer breath-by-breath automated system (MGA-1100, Marquette, NY): minute ventilation (\dot{V}_E), oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory equivalents for O_2 ($\dot{V}_E/\dot{V}O_2$) and CO_2 ($\dot{V}_E/\dot{V}CO_2$), respiratory quotient (R), breathing frequency (f), and tidal volume (V_T). Heart rate (HR) was measured every 15 s using a telemetry system (Polar Racer, Polar Electro, Kempele, Finland).

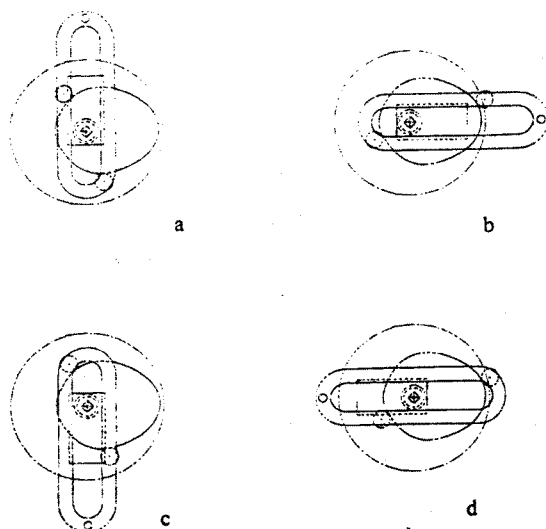


FIGURE 2—The chainring's revolution: the crank arm length at 0° and 180° (a, c) is similar to the arm length of circular chainrings (175 mm), during the downstroke (0–180°), it increases to its maximum length of 200 mm at 90° (b), and then returns to its original length of 175 mm at 180° (c). During the upstroke, it decreases to a minimum length of 150 mm at 270° (d), and then increases to 175 at 360°.

Statistical analysis. The results are expressed as means \pm SEM. After the verification of a normal distribution (Gaussian graphical distribution), cardiorespiratory data such as $\dot{V}O_2$, \dot{V}_E , $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, R, V_T , f, and HR were compared using a two-way analysis of variance (ANOVA) with repeated measures (time, chainring). Statistical significance was accepted at the $P < 0.05$ level.

RESULTS

None of the cardiorespiratory variables ($\dot{V}O_2$, \dot{V}_E , $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, R, f, V_T , HR) showed significant differences between chainring trials in terms of average values or kinematics (Figs. 3–5).

The performance was significantly greater using the eccentric chainring (64.25 ± 1.05 vs 69.08 ± 1.38 s, $P < 0.004$, with the eccentric and the round design, respectively).

DISCUSSION

The most important finding of the present study was that the eccentric chainring significantly improved performance during an all-out 1-km cycle test without any change in metabolic variables.

To ensure precision and reliability in the measurement of physiological responses, each athlete used his own bicycle for both cycling tests. The order of use of circular and eccentric chainrings was randomized. Testing was scheduled to avoid conflicts with both race schedules and periods of intense training. Adaptation to the eccentric chainring

PERFORMANCE USING AN ECCENTRIC CHAINRING

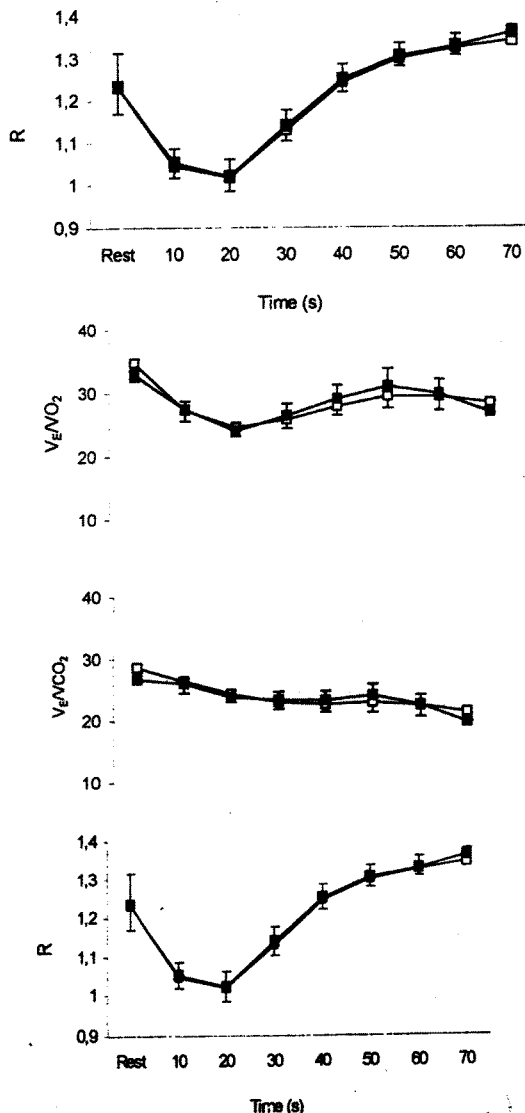


FIGURE 3—Metabolic variables during the “all-out” 1-km laboratory test with both the eccentric (■) and circular chainring (□). No significant difference. Oxygen uptake, $\dot{V}O_{2max}$; respiratory equivalents for O_2 , $\dot{V}_E/\dot{V}O_2$, and CO_2 , $\dot{V}_E/\dot{V}CO_2$; respiratory quotient, R.

design presented one potential obstacle to the validity of this study. None of the athletes had ridden using the eccentric design before the study. To familiarize them with the velocity pattern offered by this particular design, each test began with a 20-min warm-up ride using the scheduled chainring, a protocol that has been shown to be effective in learning a new motor task (24).

Studies that have tested the theoretical benefits of non-circular chainrings have used either a maximal and exhaustive test ($\dot{V}O_{2max}$ test) or a rectangular, long-duration test. Both tests have indicated that noncircular chainrings are no

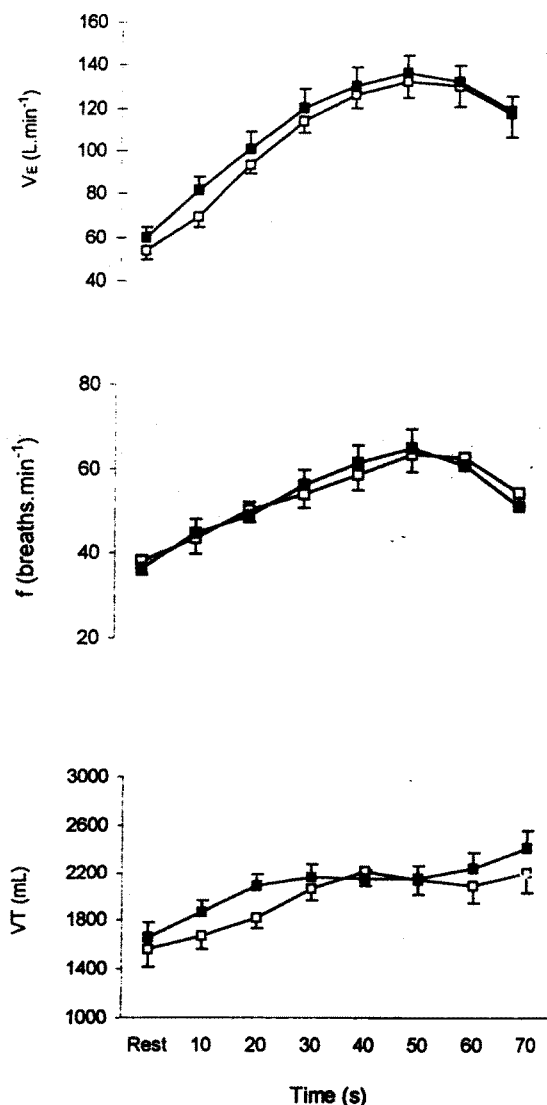


FIGURE 4—Ventilatory rate during the “all-out” 1-km laboratory test with both the eccentric (■) and circular chainring (□). No significant difference. Minute ventilation, V_E ; breathing frequency, f ; and tidal volume, V_T .

more efficient than standard chainrings (4,9,12,14). The authors of these studies had hypothesized that the noncircular chainrings would increase cycling efficiency by decreasing the internal work, which was defined as the sum of absolute changes in total mechanical energy—thus the work to move the limbs (23,25). In unpublished studies, our group investigated the effect of an eccentric chainring during similar tests ($\dot{V}O_{2\max}$ test and long-duration rectangular test) with both eccentric chainring users and nonusers. The eccentric users had been training with the eccentric chainring for at least 1 month. The results showed greater oxygen uptake—thus lower efficiency—for the eccentric chainring

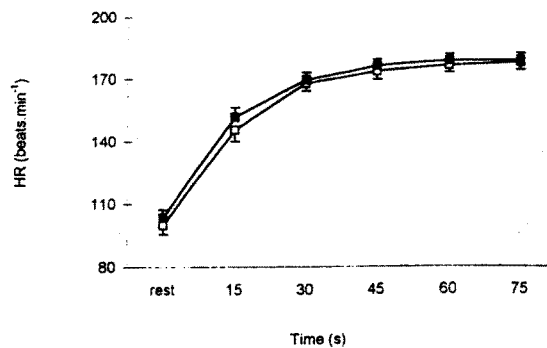


FIGURE 5—Heart rate during the “all-out” 1-km laboratory test with both the eccentric (■) and circular chainring (□). No significant difference.

users in every test, even for long-term users. We hypothesized that the eccentric chainring induced changes in the biomechanical patterns, which increased the metabolic cost and thus masked the expected mechanical advantages. Indeed, the revolution described by the pedal is a perfect circle with a fictitious center 25 mm ahead of the center of the crank arm. However, if considered from the point of the applied forces (the center of the crank), the pedal describes an elliptical circle that changes at the moment the cyclist applies maximal vertical force during the downstroke and upstroke. This thus changes the usual pattern of force application. It has been well documented that changes in optimal biomechanical pattern increase the energy cost of motion (2, 18), most likely in relation with the recruitment of different muscle fibers.

We therefore hypothesized that the theoretical advantage of the eccentric chainring would be best observed during short and intense cycling exercise where the aim is not to minimize oxygen consumption but to cycle as fast as possible. The test chosen was the all-out 1-km sprint because it is a classic indoor cycling event and is both brief and intense. The significant improvement in test performance showed that the mechanical advantage (increasing crank arm length during the downstroke and decreasing length during the upstroke) was greater than the supposed muscular disadvantage (change in biomechanical pattern), at least for short distances performed in laboratory. This may be explained by the higher torque during the downstroke resulting from the greater crank length during this cycling phase. Indeed, as stated earlier, Coyle et al. (3) demonstrated that the difference between “elite national class” and “good state class” cyclists is the combination of higher power output and higher peak torque about the center of the crank. They proposed that this last is caused by the application of higher vertical forces to the crank arm during the cycling downstroke.

Each cyclist used his own bicycle rather than the laboratory cycle-ergometer to more closely simulate road conditions. However, this condition did not offer the same inertia and freedom of movement as real road or velodrome conditions, and it thus may have influenced the crank torque

pattern (19). Moreover, we did not measure the change in the cycling position induced by the eccentric chainring. Instead, each cyclist verbally informed us on leaving that he had been comfortable riding but that his cycling position had changed a little using this design. Changes in cycling position are known to induce changes in aerodynamic resistance (1). Air drag increases with the square of the speed such that, at bicycling speeds of 60 km·h⁻¹, wind resistance is responsible for more than 90% of the total energy cost (15, 20). We therefore need to be cautious in suggesting that this eccentric chainring could enhance performance during indoor and outdoor velodrome tests. Differences have also been demonstrated between preferred and optimal positioning during cycle ergometry (10). Because the cycling position was freely chosen in our study, we may assume that the subjects used less than optimal positions during both tests.

Our subjects were road and off-road cyclists and triathletes, representing a partial selection of the different sports populations that might benefit from use of the eccentric

chainring. Because none of them were indoor cycling specialists, however, we did not study the population that would seem to benefit most from this design. Because of its variable crank arm length, the eccentric chainring seems to be particularly adapted for velodrome cycling events, whatever the gradient of the track.

The findings of the present study demonstrate that the eccentric chainring significantly improved the cycling performance during an all-out 1-km test. However, further studies with indoor cycling specialists using tests on a velodrome would be helpful to define the maximal possibilities of such a chainring.

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