

## **Cycling Efficiency and Performance Following Short-Term Training Using Uncoupled Cranks**

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**Objectives:** Uncoupled cycling cranks are designed to remove the ability of one leg to assist the other during the cycling action. It has been suggested that training with this type of crank can increase mechanical efficiency. However, whether these improvements can confer performance enhancement in already well-trained cyclists has not been reported. **Method:** Fourteen well-trained cyclists (13 males, 1 female;  $32.4 \pm 8.8$  y;  $74.5 \pm 10.3$  kg;  $\text{VO}_{2\text{max}}$   $60.6 \pm 5.5$  mL·kg<sup>-1</sup>·min<sup>-1</sup>; mean  $\pm$  SD) participated in this study. Participants were randomized to training on a stationary bicycle using either an uncoupled ( $n = 7$ ) or traditional crank ( $n = 7$ ) system. Training involved 1-h sessions, 3 days per week for 6 weeks, and at a heart rate equivalent to 70% of peak power output (PPO) substituted into the training schedule in place of other training.  $\text{VO}_{2\text{max}}$ , lactate threshold, gross efficiency, and cycling performance were measured before and following the training intervention. Pre- and posttesting was conducted using traditional cranks. **Results:** No differences were observed between the groups for changes in  $\text{VO}_{2\text{max}}$ , lactate threshold, gross efficiency, or average power maintained during a 30-minute time trial. **Conclusion:** Our results indicate that 6 weeks (18 sessions) of training using an uncoupled crank system does not result in changes in any physiological or performance measures in well-trained cyclists.

**Keywords:** cyclists, training modality, PowerCranks, SmartCranks

Endurance performance in sports such as cycling can be influenced by three major physiological variables. These are the maximal aerobic power ( $\text{VO}_{2\text{max}}$ ) of an individual, the proportion of  $\text{VO}_{2\text{max}}$  that can be sustained (lactate threshold), and the economy or efficiency with which muscular work is performed.<sup>1</sup> For the committed athlete, the ultimate goal of training is to improve one or more of these variables in an attempt to enhance overall performance. Given that ongoing improvements in  $\text{VO}_{2\text{max}}$  and lactate threshold may become progressively more

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difficult to achieve with increased training status,<sup>2,3</sup> many athletes search for alternative methods to improve their performance.

Recent research has investigated potential ways by which cycling efficiency may be improved.<sup>4-8</sup> Some literature suggests that using cycle crank systems that are not fixed at 180°<sup>8</sup> or training with cranks that are independent of each other (uncoupled)<sup>6</sup> will improve efficiency in moderately trained individuals. PowerCranks (PowerCranks, CA, USA) and SmartCranks (SmartCranks GmbH, Zug, Switzerland) are uncoupled cycling crank systems that make it necessary for each leg to apply force on the crank over the entire crank cycle. Thus both legs have to apply force by both pushing down and pulling up. According to the manufacturers, these systems will train the cyclist to eliminate negative torque during the upstroke of the crank cycle, thus providing greater propulsive force for the same energy expenditure.

To date, two papers have investigated the effect of training with uncoupled cranks with mixed results.<sup>6,7</sup> Luttrell and Potteiger<sup>6</sup> reported significant improvements in gross efficiency in a group of recreational cyclists after 6 weeks of training using PowerCranks with no change in maximal aerobic power ( $\text{VO}_{2\text{max}}$ ). In the more recent study, by Bohm et al,<sup>7</sup> five weeks of training with SmartCrank was reported to modestly alter the distribution of power output over the crank cycle by significantly reducing the work performed in the downward sector of the pedal revolution. This reduction in work was compensated for by increases in work performed during the other phases of the pedal action so as to have no impact on power output at either maximum or the individual anaerobic threshold compared with the control group. Thus, while some evidence suggests that using this type of training aid may alter cycling mechanics and gross efficiency, the data are inconclusive and there is no evidence at this stage for any changes being linked to improved cycling performance.

Therefore, the aim of this study was to determine whether training with an uncoupled crank (in this case, PowerCranks) could significantly improve cycling time-trial performance in well-trained cyclists.

## Methods

### Participants

Fourteen trained, competitive cyclists (13 males, 1 female;  $31.4 \pm 8.5$  y;  $74.5 \pm 10.3$  kg;  $\text{VO}_{2\text{max}}$   $60.6 \pm 5.5$  mL·kg<sup>-1</sup>·min<sup>-1</sup>; mean  $\pm$  SD) volunteered to participate in this randomized controlled study. Written informed consent was obtained from all participants. The study was approved by the local ethics committee and complied with the principles outlined in the Declaration of Helsinki. The inclusion criteria required participants to be actively competing and maintaining a minimum of 6 hours or 200 km of cycling each week for a minimum of 12 weeks before the start of the study. Participants were excluded if they were identified during preliminary health screening as having any clinically relevant disease that precluded them from participating in vigorous exercise or if their baseline aerobic fitness was not representative of a well-trained endurance athlete ( $\text{VO}_{2\text{max}} < 50$  mL·kg<sup>-1</sup>·min<sup>-1</sup>). Except for training history, all participants were classified as well trained according to the criteria outlined by Jeukendrup et al.<sup>9</sup>

## Study Design

Participants were randomly allocated to either 6 weeks of  $3 \times 1$ -hour training sessions per week on an ergometer fitted with the independently clutched Power-Cranks system or 6 weeks of  $3 \times 1$ -hour training sessions per week on an ergometer fitted with traditional cranks. The training sessions were implemented to take the place of existing training sessions rather than altering the weekly training load in any way. Aerobic fitness, lactate threshold, and cycling efficiency and performance were determined before and following the 6-week intervention.

## Exercise Testing

Participants were requested not to perform any vigorous exercise for 24 hours before any exercise test session. Maximum oxygen uptake ( $VO_{2max}$ ), peak power output (PPO), and lactate threshold were determined from a graded cycle exercise test (GXT) to volitional exhaustion using an electronically braked bicycle ergometer (Lode, Groningen, Netherlands). Throughout the test, the participants' gas-exchange data were collected *breath-by-breath* using a metabolic cart (Vista Mini CPX Gold). Data were then averaged over 30-second time periods. The test protocols used were the senior or junior men's, or women's, lactate transition threshold test protocol, which have been described previously.<sup>10</sup> Briefly, in the junior and senior men's protocol, the work rate increased by 50 W every 5 minutes, with a starting work rate of 100 W or 150 W respectively. Male participants were assigned to the senior men's protocol if they weighed more than 75 kg and had an extensive (>5 years) training history. All other male participants were assigned to the junior men's protocol. The women's protocol consisted of an initial work rate of 125 W, with the work rate increasing by 25 W every 3 minutes. Each participant performed the same protocol at baseline and end-point testing. Capillary blood was taken via finger prick samples and tested for lactate concentration using an automated blood lactate analyzer (Lactate Pro, Arkray, Japan) during the last 30 seconds of each incremental stage. The total volume of blood taken via this method during each exercise test was less than 2 mL. Rating of perceived exertion (RPE) using Borg's scale<sup>11</sup> and heart rate using a heart rate monitor (Polar Electro Oy, Kempele, Finland) were also recorded during the last 30 seconds of each incremental stage. Participants chose a cadence that was comfortable and attempted to maintain it throughout the test. The test ended when the participant stopped pedaling or if the cadence dropped below 70 revolutions per minute ( $rev \cdot min^{-1}$ ) for a duration exceeding 15 seconds. The technical error of measurement (TEM) of this test for determination of  $VO_{2max}$  in our laboratory is 0.7% and for calculation of power output at the lactate threshold (LT) is 1.2%. Gross efficiency (GE) was calculated using the gas exchange data and workload at a nominal power output of 200 W and at a power output corresponding to 70% of  $VO_{2max}$  to account for the potential effects of the intervention on  $VO_{2max}$ . Power output at the LT was calculated from the relationship between work rate and blood lactate concentration using the D-max method.<sup>12</sup> Peak power was determined according to the equation described by Kuipers et al<sup>13</sup>:

$$W_{max} = W_{com} + (t/INT \times FI)$$

where  $W_{\text{com}}$  is the power output for the last full stage completed,  $t$  is the time in seconds that the final uncompleted work rate was sustained, INT is the target number of seconds in each stage, and  $FI$  is the final work rate increment in watts.

Following the baseline GXT, participants performed a time trial familiarization session on a separate day. In this session, participants were asked to maintain as high an average power as possible over 30 minutes. This trial was carried out on a wind-braked ergometer (Hayes, Adelaide, Australia). This was done to familiarize the participants to the time trial to account for initial performance improvements,<sup>14</sup> as some participants had not previously performed a laboratory time trial.

The recorded time trial session was carried out on the same ergometer as the familiarization trial. This was conducted on a separate day and was preceded by a 30-minute constant load ride at a power output corresponding to 70%  $VO_{2\text{max}}$ , which aimed to avoid participants' beginning the time trial too aggressively (and potentially altering cadence drastically) and thus running the risk of premature fatigue. Immediately after the 30-minute constant load segment, participants attempted to maintain the highest power output possible for a 30-minute period. The participants were allowed to adjust the gears and choose the cadence to suit their riding style so as to simulate a competitive time trial. Power and cadence were measured continuously using the SRM Training System (SRM, Schoberer GmbH, Germany) professional-grade road model ergometer.

## Training

The experimental group trained on a wind-braked cycling ergometer (Hayes Wind-braked ergometer) fitted with the PowerCranks system, whereas the control group trained on a road bicycle (Trek, Sydney, Australia) that was mounted on a stationary trainer (Pro Trainer, Kurt Kinetic, Jordan, MN, USA). Both training protocols involved participants substituting three 1-hour sessions per week for 6 weeks in place of some of their regular training. During training, participants were fitted with heart rate (HR) monitors (Polar 610i) and instructed to maintain a heart rate equal to that attained at 70% of the PPO determined during the baseline GXT. There was a researcher present at each training session to assist with heart rate monitoring and, if heart rate varied by more than 5% from the prescribed value, the researcher advised the participant and gave them instruction on raising or reducing work rate to bring heart rate back in line with the prescribed value.

## Statistical Analysis

Preliminary power calculations for the exercise testing subgroup were determined for a statistical power of 0.80 and two-tailed alpha level of 0.05. From these calculations, it was determined that six participants per group were required to demonstrate improvements in GE based on the data of Luttrell and Potteiger.<sup>6</sup> Test-retest reliability was quantified using the TEM.

Baseline data were analyzed via unpaired  $t$  tests. Training data were analyzed via two-factor (group, time) ANOVA with repeated measures on time using general linear modeling (SPSS v15.0; Chicago, IL). When statistically significant

differences were identified, post hoc testing was performed using *t* tests to locate the means that were significantly different. Data are expressed as means  $\pm$  standard error of measurement (SEM) unless otherwise indicated. Statistical significance was set at *P* less than 0.05.

## Results

### Descriptive Characteristics

Descriptive characteristics for the participants are presented in Table 1. There were no significant differences (*P* > .05) between the two groups for any of the descriptive variables at the start of the study.

### Vo<sub>2max</sub>, PPO, and LT

There were no differences (*P* > .05) between the groups in Vo<sub>2max</sub> (L·min<sup>-1</sup>; *P* = .66), relative Vo<sub>2max</sub> (mL·kg<sup>-1</sup>·min<sup>-1</sup>; *P* = .157), PPO (*P* = .458), or LT (*P* = .280) at baseline (Table 1). Individual participant changes in PPO and LT are presented in Figure 1. In response to the 6 weeks of training, there were no statistically significant time (training) effects in absolute Vo<sub>2max</sub> (L·min<sup>-1</sup>; *P* = .764). The partial eta-squared value ( $\eta^2$ ) for this nonsignificant effect was 0.008, indicating a small effect.<sup>15</sup> Similarly, no statistically significant time (training) effects were observed for relative Vo<sub>2max</sub> (mL·kg<sup>-1</sup>·min<sup>-1</sup>; *P* = .854,  $\eta^2$  = 0.003), PPO (*P* = .085,  $\eta^2$  = 0.23), or LT (*P* = .391,  $\eta^2$  = 0.62). No significant interaction effect (time  $\times$  training intervention) was observed in Vo<sub>2max</sub> (L·min<sup>-1</sup>; *P* = .420,  $\eta^2$  = 0.055), Vo<sub>2max</sub> (mL·kg<sup>-1</sup>·min<sup>-1</sup>; *P* = .347,  $\eta^2$  = 0.074), PPO (*P* = .571,  $\eta^2$  = 0.027) or LT (*P* = .669,  $\eta^2$  = 0.016) (Table 2).

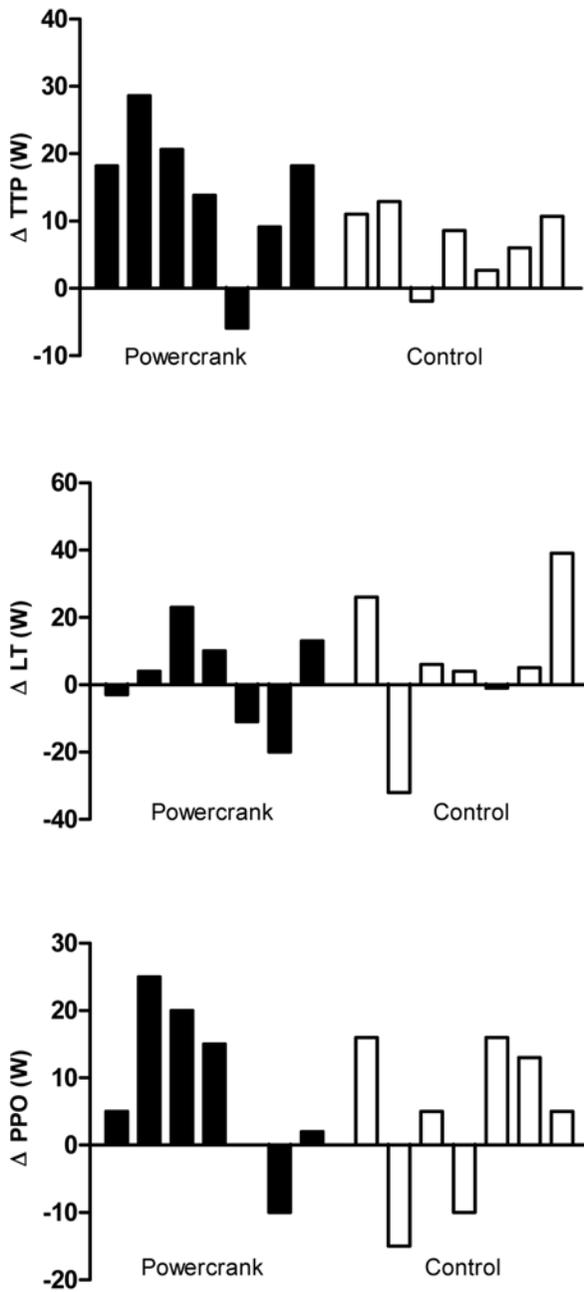
### Cycling Efficiency

The GE at which the participants cycled was similar between treatment groups at baseline (GE at 70% Vo<sub>2max</sub>, *P* = .962; GE at 200 W; *P* = .183). There was a statistically significant effect of time (training) on efficiency at a work rate corre-

**Table 1 Descriptive Data of the Participants**

	Uncoupled Crankers (n = 7)	Traditional Crankers (n = 7)	Significance, <i>P</i>
Age (years)	36.1 (9.0)	28.7 (7.4)	0.117
Gender (M/F)	7/0	6/1	N/A
Height (cm)	181.0 (8.3)	177.1 (6.4)	0.340
Weight (kg)	78.5 (12.0)	70.6 (7.2)	0.159
Vo <sub>2max</sub> (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	58.5 (4.3)	62.7 (6.0)	0.157
LT (W)	286 (33)	265 (38)	0.280
GE at 70% Vo <sub>2max</sub> (%)	19.7 (1.1)	19.8 (1.1)	0.961

Data presented as mean (SD). GE = gross efficiency, LT = lactate threshold.



**Figure 1** — Changes in performance variables for intervention and control participants. TTP = time trial performance, LT = lactate threshold, and PPO = peak power output.

**Table 2 Changes in Exercise Variables Following the 6-Week Training Protocol**

	Uncoupled Cranks		Traditional Cranks		Group × Time	P
	Baseline	End Point	Baseline	End Point		
$\dot{V}O_{2max}$ (L·min <sup>-1</sup> )	4.56 (0.19)	4.65 (0.27)	4.41 (0.26)	4.37 (0.27)		0.420
$\dot{V}O_{2max}$ (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	58.5 (1.6)	59.3 (2.2)	62.7 (2.3)	61.4 (2.5)		0.347
LT (W)	286 (12)	288 (12)	265 (14)	271 (9)		0.699
PPO (W)	362 (15)	370 (16)	345 (16)	349 (14)		0.571
GE at 70% (%)	19.7 (0.4)	20.9 (0.4)	19.8 (0.4)	20.3 (0.4)		0.250
Cadence at 70% (RPM)	91 (2)	87 (4)	90 (2)	89 (3)		0.057
GE at 200 W (%)	20.8 (0.4)	20.4 (0.4)	20.0 (0.4)	20.8 (0.4)		0.260
Cadence at 200 W <sup>#</sup> (RPM)	91 (2)	87 (2)*	91 (3)	90 (3)		0.025
Time Trial Power (W)	284 (17)	298 (17)	274 (14)	281 (13)		0.125
Cadence during Time Trial (RPM)	90 (2)	88 (1)	92 (1)	91 (2)		0.477

Data are presented as mean and (SEM). GE = gross efficiency; PPO = peak power output, and LT = lactate threshold during the graded exercise test. P values are for group × time effect from repeated-measures ANOVA. \*Denotes P < .05 compared with baseline value. #Denotes n = 6 in uncoupled Cranks group and n = 4 in traditional cranks group.

sponding to 70%  $\dot{V}O_{2\max}$  ( $P = .011$ ,  $\eta^2 = 0.431$ ) but not at 200 W ( $P = .671$ ,  $\eta^2 = 0.016$ ). However, there were no between-group changes in cycling efficiency at either 70%  $\dot{V}O_{2\max}$  ( $P = .250$ ,  $\eta^2 = 0.109$ ) or at 200 W ( $P = .260$ ,  $\eta^2 = 0.104$ ) following the 6-week intervention (Table 2). There was a trend toward a statistically significant interaction effect on self-selected cadence at a cycling efficiency of 70% ( $P = .057$ ,  $\eta^2 = 0.270$ ) and a significant interaction effect on self-selected cadence at 200 W ( $P = .025$ ,  $\eta^2 = 0.486$ ) (Table 2). Post hoc testing using paired samples *t* tests revealed a significant decrease in self-selected cadence at 200 W in the group randomized to the PowerCranks training ( $P = .002$ ) but no statistically significant change in the group randomized to the control condition ( $P = .141$ ).

### Time Trial Performance

There were no differences in time trial performance between the groups at baseline ( $P = .655$ ). The average power attained during the 30-minute time trial significantly improved following the training intervention ( $P = .0005$ ,  $\eta^2 = 0.655$ ). However, there were no statistically significant between-treatment changes observed in time trial performance ( $P = .125$ ,  $\eta^2 = 0.185$ ) following the training intervention. There was no treatment-specific change in average cadence maintained during the time trial ( $P = .477$ ,  $\eta^2 = 0.043$ ) over the course of the study.

## Discussion

The major findings of this study were that training with an uncoupled crank system did not impart any additional benefits to time trial performance,  $\dot{V}O_{2\max}$ , PPO, LT, or GE compared with training with a traditional crank system. It has been argued that the effective measurement of performance should be considered as the most valid means of evaluating a training intervention.<sup>16</sup> Consequently, the most important finding from the current study is that training with uncoupled cranks did not improve time trial performance in well-trained cyclists.

Overall, time trial performance improved in both groups during the study with no significant between group differences. Cycling performance is dependent on many variables, including GE,  $\dot{V}O_{2\max}$ , LT, and motivation. Previous research has speculated whether training with uncoupled cranks might enhance cycling performance by positively influencing one or several of these parameters.<sup>6,7</sup> Luttrell and Potteiger<sup>6</sup> reported improvements in GE following 6 weeks of training with an uncoupled crank system but unfortunately did not include any measure of performance. A more recent study<sup>7</sup> found small changes in the work distribution through various phases of the crank cycle following uncoupled crank training, and suggested this as a potential mechanism for improved efficiency. However, these changes did not translate to improvements in PPO or work rate at LT, while GE and performance were not actually measured. We found no statistically significant improvements in  $\dot{V}O_{2\max}$ , LT, or GE in either treatment group, indicating no apparent physiological benefit from training with such a device. This makes the improvement in time trial performance observed for both groups in the current study somewhat difficult to explain but may be attributable to improved motivation as a consequence of participating in the study (the Hawthorne effect), or a

result of improved pacing strategies in response to the 18 constant intensity training rides on a stationary ergometer.

The lack of effect of training using uncoupled cranks on GE is in contrast to that of Luttrell and Potteiger.<sup>6</sup> A potential reason for these disparate results may be related to the participant recruitment criteria. There was a wide variation in baseline fitness levels in the group randomized to training with the uncoupled crank system in the study by Luttrell and Potteiger ( $\text{Vo}_{2\text{max}} = 56.0 \pm 11.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), suggesting a fairly heterogeneous group. Consequently, there may have been several participants in this group that had been performing only 2 days of cycling training before the commencement of the training study. It is therefore possible that some participants increased cycling volume during the uncoupled crank training intervention. As increased training will increase GE,<sup>17</sup> this could potentially account for the significant improvements in GE reported previously. In contrast, the current study recruited participants who performed a substantial cycling training load each week (at least 6 hours or 200 km); thus, it is unlikely that inclusion in the study led to any increase in training volume.

Our belief that training volume did not increase during our study is also supported by the results for  $\text{Vo}_{2\text{max}}$ . Neither training protocol produced improvements in  $\text{Vo}_{2\text{max}}$  expressed in absolute ( $\text{L}\cdot\text{min}^{-1}$ ) or relative ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) terms. There was also no effect on the power output at the LT. The substitution of the three hourly sessions each week into their training schedule was at an intensity that was intended not to significantly improve aerobic fitness. The absence of any changes in these physiological variables suggests that the participants were sufficiently well trained and that training load did not increase over the intervention period.

Our finding that PPO and LT were not improved as a result of uncoupled crank training is in agreement with the work of Bohm et al.<sup>7</sup> These authors reported an increase in work performed during the backward and upward sectors but also a reduction in work completed during the forward and downward sectors after training with uncoupled cranks. These changes did not appear to improve the overall torque production as they did not translate to any benefit with respect to power output achieved at LT or PPO. Bohm et al did not measure GE, but the lack of any improvement in LT or PPO provides little support for a possible improvement in GE in light of the results of the current study. Furthermore, a recent study<sup>4</sup> has reported that consciously increasing the effort provided during the upstroke phase of the cycling action causes a decrease in GE when riding at a fixed power output (200 W). The only group  $\times$  time interaction in the current study was for cycling cadence at 200 W. Given that GE can be influenced by cadence,<sup>18</sup> it is possible that we found no change in GE as cadence was reduced in response to alterations in pedaling technique. Consequently, while cyclists were instructed to self-select their cadence, as this is what would occur in the "real world," it must be acknowledged as a potential reason for not finding any change in cycling efficiency.

Two other limitations of the study were that we did not control all other training undertaken by the cyclists and that it was impossible to blind the participants to their training intervention. Even though the cyclists were instructed to maintain their normal training but substitute three sessions per week with either the experimental or control condition, it is possible that one group may have on average increased or decreased their overall training volume. However, although the sig-

nificant increases in time trial performance in both treatment groups may support this theory, there were no changes in either  $\text{VO}_{2\text{max}}$  or LT, which may also have been expected to be altered in response to changes in training volume. Further, it is likely that any placebo effect due to an inability to blind participants to their training intervention would more likely result in a treatment effect with greater improvements in the experimental group. However, this was not the case in the current study for any of the physiological or performance variables.

## Practical Applications

The results of this study indicate that the use of an uncoupled crank system as a supplement to training does not result in improvements in cycling performance or in any of the major physiological variables that influence performance. However, our findings do not discount the possibility that immersion training (completing all training with uncoupled cranks for a period of time) may still elicit improvements due to an associated increased physiological demand.

## Conclusion

In conclusion, short-term training (6 weeks) with an uncoupled crank system did not improve  $\text{VO}_{2\text{max}}$ , LT, GE, or cycling performance in a group of well-trained cyclists. Although more research is needed using longer and more intense training protocols, the results from the current study do not support the use of the uncoupled cranks to benefit cycling performance in this population.

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