EFFECTS OF INDEPENDENT CRANK ARMS AND SLOPE ON PEDALING MECHANICS

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The aim of this study was to identify the effects of independent crank arms and slope on pedaling kinetics during an anaerobic maximal-effort cycling bout. After undergoing 6 weeks of training with independent crank arms, each of 6 male cyclists completed four 30 s Wingate tests under different cycling conditions of: fixed crank arms on level surface; fixed crank arms on a slope; independent crank arms on level, and; independent crank arms on a slope. Two-dimensional pedal forces recorded using instrumented pedals were used to derive pedaling effectiveness, work distribution and power output. The effects of the crank arms and the slope were minimal, but highly effective and consistent pedaling force (90% effectiveness, 70% work and effective force of 155±6 N) was observed between 45-135˚ of the crank cycle in all experimental conditions.

KEYWORDS: cycling, efficiency, exercise, power, work

INTRODUCTION:

Road cycling has become more competitive as it has gained popularity. Specifically, ability to perform well on incline is thought to be associated with success in competition. More innovative tools have been adapted by cyclists to become successful. Independent crank arms (IND) are one of these tools that are intended to improve cycling technique. These crank arms move independently, so the rider is prohibited to rely on one leg's action to move the other. The manufacturers claim that the benefit of IND would result in promoting more active recruitment of muscles that are not typically used with the conventional crank arms (FIX) during the upstroke (PowerCranks Science, 2006). Empirical studies have provided inconclusive findings, where one study reported improved gross efficiency after a 6-week training period with IND (Luttrell & Potteiger, 2003) others reported that their effects on physiological functions and power output were minimal (Lucia et al., 2004 & Santalla et al., 2002). A comparison between two independent groups that underwent a short 5-week training period with the IND versus FIX reported no difference in power output, but a modified work distribution pattern was observed in the IND group (Bohm et al., 2008). Cyclists anecdotally report changed cycling techniques while cycling with the IND (Luttrell & Potteiger, 2003) while effects of such crank arms had not been investigated. Examining pedaling patterns while using the IND may clarify the uncertainty in their training effects reported previously. Additionally, it is beneficial to investigate pedaling techniques on incline, as hills in competitive cycling are unavoidable. In obtaining better understanding of pedaling kinetics, examining work distribution as well as the conventional index of pedaling efficiency has been suggested as it describes contributions of different pedaling phases to revolution (Bohm et al., 2008). Therefore, the purpose of the present study was, after 6 weeks of familiarization training, to investigate the effects of the IND and an incline on the pedaling power, effective force and indices of pedaling effectiveness and work distribution.

METHODS: Six male cyclists (24.7 ±3.8 years, 1.80 ±0.04 m, 73.1 ±4.5 kg) who were members of a local cycling team volunteered in the study. In accordance with the study protocol, all subjects were 18-30 years of age, and had been regularly cycling and were free of injury or illness at the time of study. For 6 weeks, each subject trained 3 times a week with a road bike equipped with a pair of IND (PowerCranks, Walnut Creek, CA, USA) that was mounted on a fluid-resisted cycle trainer (Minoura, Gifu, Japan). The subjects were instructed to gradually increase the amount of time spent riding with the IND setting during the training. Each training session lasted 60 minutes. During the 7th week, all subjects performed 4 separate Wingate tests that were 24 hours apart. The 4 testing conditions were:

1) FIX-level (FL); 2) FIX-slope (FS); 3) IND-level (IL), and; 4) IND-slope (IS). The order of tests was randomly assigned.

The load for the Wingate test was set using a front to rear cog ratio of the subject's body mass (BM kg) of BM*1.00 to 14 (actual rear cog size) for the level (0% incline), and BM*1.12 to 14 for the slope (17.6% incline). The ratio for the 0% grade was determined from pilot testing, and the ratio for the 17.6% grade was derived mathematically as the increased workload required for the increased grade equates to the product of the cyclist's body weight and tangent of the grade (Mognoni & di Prampero, 2003). The gear ratio was controlled using the virtual gear function of a stationary bike with an electro-magnetic brake (Velotron Elite, RacerMate, Inc., Seattle, WA, USA). Retro-reflective markers were placed on the pedals, crank arms, crank axis, and the cyclist's foot to track the motion of the pedal and the crank arms. After a 10-minute warm up, the subject increased the pedaling cadence to their maximum and the test was started. During the 30-second testing, positions of the crank arms and pedals were recorded using 12 high-speed cameras and Cortex software v1.0 (Motion Analysis Corp., Santa Rosa, CA, USA) at 200 Hz. A pair of custom instrumented pedals (Newmiller et al., 1988) mounted on the stationary bike were used to record the vertical and antero-posterior pedal forces at 1000 Hz. The motion and the force data were synchronized and collected simultaneously.

In the present study, only the right pedal data were included. The dependent variables derived from the collected data were: 1) the single leg power (SLP); 2) effective force (F_{Eff}) that is defined as the pedal force perpendicular to the crank; 3) the index of pedal effectiveness (IE, the ratio of the useful force to cause crank torque to the total force applied to the pedal (Coyle et al., 1991)) for the complete pedal cycle (IE_{360}) and for 4 sectors of the crank cycle (IE_{down}=45-135˚; IE_{back}=136-225˚; IE_{up}=226-315˚; IE_{fore}=316-45˚), and; 4) percent work for the 4 sectors (%W_{down}; %W_{back}; %W_{up}; %W_{fore}) for each revolution (Bohm et al., 2008). All variables were averaged over all pedal cycles performed during the 30 second trial. After the normality distribution of the variables was tested, the effects of the crank type (FIX/IND) and slope (level/slope) on each variable were examined by repeated measures ANOVA (for normally distributed data) or Friedman test (for non-normally distributed data) at $\alpha = 0.05$. The means, 95% confidence intervals, and the effect sizes of the variables were determined with Bonferroni adjustment when appropriate (SPSS, v.17, SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION: Both IND and slope were associated with lesser numbers of revolutions during the 30-second Wingate test [FIX v. IND: 40.2 - 42.2 v. 37.4 - 41.2, F = 8.00, p = 0.037, $\eta_p^2 = 0.62$; level v. slope: 39.9 – 42.8 v. 37.4 – 41.2, F = 49.71, p < 0.01, $\eta_p^2 = 0.91$]. The decreased cadence on incline has been previously reported and the reduction appears to contribute to an increase in crank torque (Caldwell et al., 1998). The greater F_{Eff}

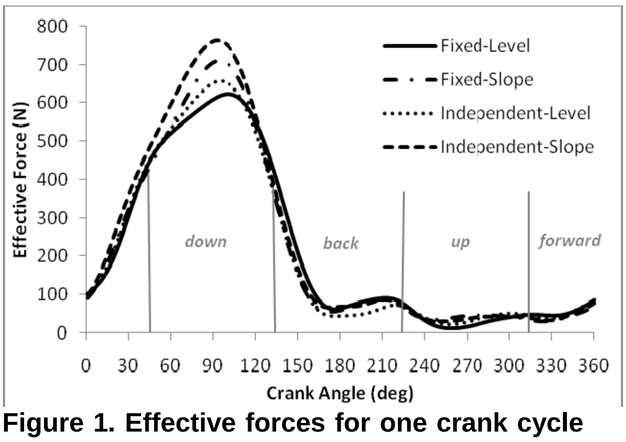

Figure 1. Effective forces for one crank cycle of a single subject during maximal effort for 4 cycling conditions

Table 1. Single leg power and effective force means (SD) during a 30-s maximal effort for 4 cycling conditions

	Single Leg Power [W]	Effective Force [N]
FL	363 (27)	215 (16)
FS	364 (20)	231 (23)
IL	336 (38)	207 (16)
IS	345 (36)	224 (17)

FL: fixed-level; FS: fixed-slope; IL independent-level; IS: independent-slope in slope conditions in the present study [$\chi^2(3) = 11.0$, $p = 0.01$] (Table 1) might indicate differences in crank torque as F_{Eff} is directly related to crank torque. Although the source of the difference was not analyzed, a typical F_{Eff} curves from one of the subjects (Figure 1) showed greater force magnitudes between about 70-110˚ for slope conditions, an implication of a raise in crank torque associated with incline. However, the average SLP did not differ across 4 experimental conditions [$\chi^2(3) = 6.20$, $p = 0.10$] (Table 1). These results suggest that the cyclist maintains power output by increasing F_{Eff} to compensate the lower pedaling cadence while cycling on an incline.

IE_{360} did not differ across conditions [crank: $F = 0.89$, $p = 0.39$, $\eta_p^2 = 0.15$; slope: $F = 0.69$, $p = 0.47$, $\eta_p^2 = 0.11$] that indicated no change in overall pedaling effectiveness while using IND on the level and incline. However, when the IE was determined separately for difference sectors of the pedal cycle, it appeared that the cyclists used different techniques to accommodate different riding conditions (Figure 2). IE_{back} was influenced by the slope indicating that the crank torque was generated more effectively between 135˚ and 225˚ on incline [level v. incline: 21.0% - 55.1% v. 32.1% - 64.8%, $F = 63.44$, $p < 0.01$, $\eta_p^2 = 0.93$]. This might be related to the position of the cranks relative to the gravitational force. Due to the offset of the angle by the incline, the gravity acted differently on the limb, pedal, and crank. Brown et al. (1996) reported that how gravity acts on the body alone affected muscle activation pattern. Therefore, it is possible that the gravitational force might have influenced muscle recruitment in this and other sectors. The line of action for the gravitational force relative to the bike could explain the difference observed in the forward sector IE across the conditions [$\chi^2(3) = 11.4$, $p < 0.01$]. IE_{up} varied greatly between subjects. With FIX, 2 of the subjects exhibited negative IE_{up} values. Though insignificant, the mean IE_{up} increased with use of IND and made between-subject variability smaller [FIX: 45.4±19.8% v. IND: 49.3±9.8%]. Unlike IEs in aforementioned sectors, IE_{down} was consistently high (average 89% - 91%) with a low deviation across all conditions. IE_{down} has been shown to be consistent at a wide range of power outputs (Bohm et al., 2008). In the present study, it was shown that a 10˚ shift in crank angle (i.e. slope) did not affect it. This consistency of IE in down phase might be because the cyclists had already learned to optimize the down phase from their cycling experience. It might also imply that the muscles function more favorably and are minimally affected by the gravity within this particular range of crank cycle. The minimally affected total and sectional IEs associated with IND might suggest that the IND do not affect the pedaling effectiveness. However, the incline appeared to improve the pedaling effectiveness during the backward section regardless of the crank arm type.

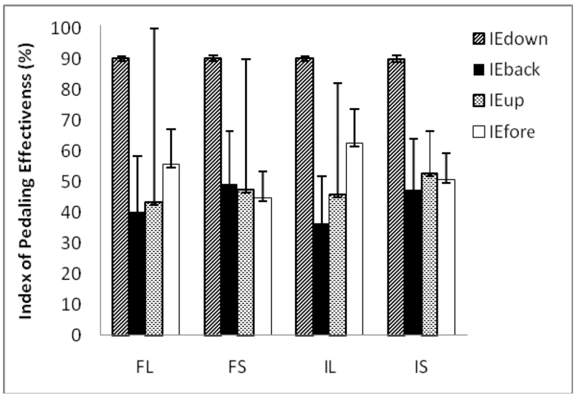

Figure 2. Index of pedaling effectiveness (mean±SD) over 30 s of maximal effort for 4 sectors for different cycling conditions
(FL: fixed-level; FS: fixed-slope; IL independent-level; IS: independent-slope)

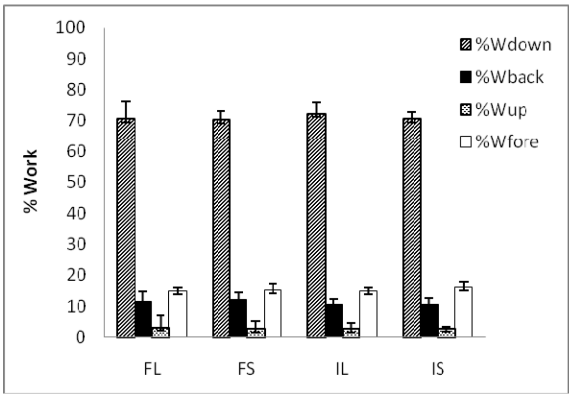

Figure 3. Work distributions (mean±SD) over 30 s of maximal effort for 4 sectors for different cycling conditions
(FL: fixed-level; FS: fixed-slope; IL independent-level; IS: independent-slope)

The work distribution in the downward phase was also consistently high and was not affected by the crank or slope conditions [$\chi^2(3) = 1.40$, $p = 0.71$] (Figure 3). The $\%W_{up}$ was not affected by the experimental conditions. Additionally, the $\%W_{up}$ was positive in all conditions. A previous study investigated pedaling work distributions observed negative work during the upward sector (Bohm et al., 2008).That observation might be as a result of different testing protocol. Since this study involved a short, all-out trial without cadence restriction, the subjects were able to actively pull up their feet quickly during the up-stroke throughout the trial. The only difference observed in the work distribution was the $\%W_{back}$. IND had reduced the amount of work contributed to this phase [FIX v. IND: 9.2% - 14.2% v. 8.6% - 12.4%, F = 17.67, p = 0.008, η_p^2 = 0.78]. This could be because the leg has no need to drive the contra-lateral leg to clear the top dead center (i.e. 0˚).

CONCLUSION: Work distribution and IE changes resulted from independent crank arms and slope during a short anaerobic cycling bout were limited to modified effectiveness in the back and forward sectors. There was no change in overall pedaling effectiveness. The power output was maintained primarily by sustaining the effectiveness during the downward sector of the pedaling cycle. Both the independent crank arms and the slope were associated with lesser number of pedal revolutions that appeared to be related to an improvement in effective force production. These minimal changes are based on a short cycling session, and the effects of independent crank may differ in a longer cycling session. Investigations including more subjects, longer training, and different cycling ability may yield different results. To obtain the comprehensive understanding of the effects of the independent crank arms, other measurements, such as joint moments and electromyography should also be considered in future investigations.

REFERENCES:

Bohm, H., Siebert S., & Walsh M. (2008). Effects of short-term training using SmartCranks on cycle work distribution and power output during cycling. *European Journal of Applied Physiology,* 103, 225-232.

Brown, D. A., Kautz, S. A., & Dairaghi, C. A., (1996). Muscle activity patterns altered during pedaling at different body orientations. *Journal of Biomechanics*, 29, 1349-1356.

Caldwell, G.E., McCole, S.D., Hagberg, J. M. & Li, L. (1998). Pedal and crank kinetics in uphill cycling. *Journal of Applied Biomechanics*, 14, 245-259.

Coyle, E.F., Feltner, M. E., Kautz, S. A., Hamilton, M. T., Montain, S. J., Baylor, A. M., Abraham, L. D., & Petrek, G. W. (1991). Physiological and biomechanical factors associated with elite endurance cycling performance. *Medicine and Science in Sports and Exercise*, 23, 93-107.

Lucia, A., Balmer, J., Davison, R.C.R., Perez, M., Santalla, A., & Smith, P.M. (2004). Effects of the rotor pedalling system on the performance of trained cyclists during incremental and constant-load cycle ergometer tests. *International Journal of Sports Medicine*, 25, 479-485.

Luttrell, M.D., & Potteiger, J.A. (2003). Effects of short-term training using powercranks on cardiovascular fitness and cycling efficiency. *Journal of Strengthening and Conditioning Research*, 17, 785-791.

Mognoni, P., & di Prampero P.E. (2003). Gear, inertial work and road slopes as determinants of biomechanics in cycling. *European Journal of Applied Physiology*, 90, 372-376.

Newmiller, J., Hull, M.L., & Zajac, F.E. (1988). A mechanically decoupled 2 force component bicycle pedal dynamometer. *Journal of Biomechanics*, 21, 375-386.

PowerCranks, (2006). Science: Some science behind PowerCranks and cycling improvements. Retreived April 10, 2009, from http://www.powercranks.com/sports/Studies/cycling%20science.htm

Santalla, A., Manzano, J.M., Perez, M., & Lucia, A. (2002). A new pedaling design: the Rotor-effects on cycling performance. *Medicine and Science in Sports and Exercise*, 34, 1854-1858.

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