Effect of Independent Cycle Crank Training on Running Economy and VO₂ Max in Distance Runners

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ABSTRACT

Wagner DR, Heath EM, Smith AW. Effect of Independent Cycle Crank Training on Running Economy and VO₂ Max in Distance Runners. JEPonline 2013;16(1):1-9. The purpose of this study was to examine the changes in running economy and maximal oxygen consumption (VO₂ max) of cross-country runners with cross-training on the PowerCranks™. Seven men and 6 women completed 6 wks of stationary cycle ergometer training using either the PowerCranks™ or the standard cranks (control group). The subjects trained 3 d·wk⁻¹ at 60 rev·min⁻¹ at 3 to 3.5 kg for 30 min, which increased to 40 min after the 3rd wk and 50 min after the 4th wk, with a 48-h minimum between training sessions. Pre- and post-running economy and VO₂ max were measured. There were no significant differences in running economy or VO₂ max after training in either the control or the PowerCranks™ group. Further, the difference in change scores for running economy between the PowerCranks™ (0.102 ± 0.101 L·min⁻¹) and the control (0.010 ± 0.108 L·min⁻¹) groups was not significant (P=0.15). Cross-training for 6 wks with independent cycle cranks 3 d·wk⁻¹ had no effect on the running economy or VO₂ max of highly-trained collegiate distance runners.

Key Words: Oxygen Consumption, Collegiate Athletes, Cycle Ergometer, Cross-training
INTRODUCTION

Distance running performance in large part depends on maximal oxygen consumption (VO₂ max), the ability to sustain a high percentage of VO₂ max, and an individual's running economy (12). Running economy is typically defined as VO₂ at steady-state. It is the least studied of the variables affecting performance (12,20). Runners with good running economy expend less energy, which is reflected in a lower VO₂ than runners with poor running economy at the same steady-state speed (23). In runners with similar VO₂ max values, running economy can vary as much as 30% (9). It is believed that in elite runners it may be a better predictor of aerobic performance than VO₂ max (7,19). Most studies that demonstrate substantial improvement in running economy use untrained or moderately-trained runners. It is difficult to demonstrate changes in running economy in experienced endurance runners. However, several literature reviews suggest that several strategies for improving running economy in highly-trained runners appear effective. These strategies include strength, plyometric, and high-intensity interval training, altitude exposure, and training in the heat (12,16,20,25).

Yamamoto et al. (25) claim that resistance training improves the running economy in the range of 3-8% in highly trained runners. The hip and knee extensors are the primary muscle groups for propelling runners and cyclists. However, the hip flexors may be more influential in increasing speed of gait and running performance due to their role in bringing the thigh forward and upward during the swing phase of running (15,22). Yet, the hip flexors are often neglected in strength training programs (10). Thus, it is logical to hypothesize that dynamic strength training of the neglected hip flexors may improve running economy in experienced runners. One way to increase the muscular loading of the hip and knee flexors is by cycling a bike with an independent crank such that the individual must pull up with each leg on every pedal stroke. With the increased training of these underutilized muscles, pedaling efficiency may improve, resulting in a decrease in VO₂ and energy expenditure for a given workload.

Cycling with independent cranks should encourage a smoother pedaling stroke by altering normal recruitment patterns, thereby stimulating the adaptive process in muscles that are not typically highly active in the cycle stroke (14). Indeed, after cyclists trained on independent cranks for 6 wks, Luttrell and Potteiger (14) observed a lower heart rate and VO₂ responses with increased gross efficiency at the conclusion of a 1-h submaximal ride for the treatment group relative to the control group that trained with traditional cranks. The improvements in cycling economy demonstrated by the dynamic strength training from using the independent cranks may have some crossover application to running economy in highly trained runners. Equally important is that other researchers (3,5,21,24) have not found independent cranks to improve cycling economy or performance. Perhaps the training of the hip flexors is of little advantage to cyclists because the down stroke is where almost all of the power is produced in cycling (6). However, this type of training may prove advantageous in running where the hip flexors are used to a greater extent (1,18).

For highly trained runners, improving running economy is one of the keys to improving performance. Investigating alternative training methods for runners, such as the recruitment of previously untrained muscles may improve the economy of motion by decreasing the workload of the hip extensors and knee extensors of the lower limbs (8). No studies have yet investigated the influence of cycle training with independent cranks on running economy and VO₂ max. The purpose of this study was to determine if 6 wks of independent crank cycle training result in improvements in the running economy and VO₂ max of highly trained collegiate distance runners.
METHODS

This was a controlled training study with treatment and control groups matched by sex. To examine the efficacy of using independent crank cycling to train experienced runners, this study comprised: (a) pre-training testing to determine treadmill running economy at 12.87 km·h⁻¹ (8 mi·h⁻¹) for women and 14.48 km·h⁻¹ (9 mi·h⁻¹) for men and VO₂ max; (b) 6 wks of cycle training using independent cranks or normal cranks for 30 min (which was increased to 40 min and 50 min after 3 and 4 wks, respectively) for 3 d·wk⁻¹; and (c) post-training for running economy and VO₂ max. This study took place during February and March, thus coinciding with the end of the indoor track season and the beginning of the spring track season.

Subjects

Eighteen athletes, 9 males and 9 females, of the Utah State University cross-country team consented to participate in this study. All subjects read and signed an informed consent document approved by the Utah State University Institutional Review Board. Half of the subjects were assigned to the experimental group and half to the control group. The runners were highly-trained and competitive as evidenced by winning the men’s and women’s cross-country team conference championships at the National Collegiate Athletic Association (NCAA) Division-I level. The VO₂ max values for the men and women were 71.1 ± 7.0 mL·kg⁻¹·min⁻¹ and 57.5 ± 5.0 mL·kg⁻¹·min⁻¹, respectively.

Procedures

The independent cycle cranks used for the experimental group training were the PowerCranks™ (PowerCranks, Walnut Creek, CA) that use a patented clutch design to power the cycle with simultaneous one-legged cycling. MonarkErgoMedic 824E cycle ergometers with toe stirrups (MonarkErgoMedic, Vansbro, Sweden) were used with both the PowerCranks™ and the control groups. To promote a uniform standard of training for the subjects, a metronome, set at 60 rev·min⁻¹, was used for both groups throughout the duration of training with the resistance set at 3.0 kg and then increased to 3.5 kg for the last 3 wks.

Oxygen consumption measurements were determined using a ParvoMedicsTrueMax 2400 Metabolic Measurement Cart (ParvoMedics, Sandy, UT). The pneumotach was calibrated with a known volume of air, and the gas analyzers were calibrated with known gas concentrations prior to each testing session. A NordicTrack 600 (ICON Health & Fitness, Logan, UT) treadmill was used for both running economy and VO₂ max testing. A Polar T31 (Polar Electro, Lake Success, NY) heart rate monitor was worn by each subject. Ratings of perceived exertion (RPE) were also recorded using Borg’s 15-point scale (4).

The subjects were randomly assigned to either the experimental group or the control group with sex being the only sorted factor for equal distribution. Demographic data to include sex, age, weight, and height were collected. Then, the subjects were asked to perform an initial VO₂ max test with the protocol individualized for each subject. After collecting 2 min of resting data, each subject began running at a pace that was equal to his or her 5 km pace. Each stage was 2 min with an increase in speed by 1.61 km·h⁻¹ (1 mi·h⁻¹) for the first 3 stages at 0% grade. Subsequently, the speed remained constant and the grade increased 2% each stage until exhaustion. Most of the athletes achieved a plateau in VO₂ max in about 10 min with this protocol; a test duration that is thought to produce optimal results (2). Heart rate, respiratory exchange ratio (RER), and RPE were recorded at the completion of each 2-min interval, which were used as secondary criteria to verify the attainment of VO₂ max.
Baseline running economy tests were performed ~48 hrs after the VO₂ max tests. The subjects were asked to run on a treadmill at 0% grade at 12.87 km·h⁻¹ (8 mi·h⁻¹) for females and 14.48 km·h⁻¹ (9 mi·h⁻¹) for males. The exercise intensity corresponded to ~65-75% of VO₂ max for most subjects, and the RER stayed below 1.0. The metabolic cart averaged data every 20 sec. The test duration was 6 min with the average of the last 2 min used to determine running economy in L·min⁻¹. A second running economy test was performed following 10 to 30 min of rest between tests to determine the test-retest reliability of the measure.

The cycle training sessions commenced 24 to 48 hrs after the baseline running economy test. The subjects’ first exercise session consisted of 10-15 min of familiarization with the assigned crank system. Subsequent training sessions were for 30 min at a cadence of 60 rev·min⁻¹ with the subjects’ respective bicycle crank system. Both groups understood that the training would take place in the laboratory for cycle workouts 3 d·wk⁻¹, ideally with 48 h between sessions. Due to the unnatural pedaling motion of the PowerCranks™, the athletes in the experimental group were not able to initially cycle for 30 min continuously. Short breaks (≤40 sec) were permitted, but the total cycling time had to be 30 min. Initially, this adjustment resulted in longer training sessions. Once accustomed to the independent cranks, subjects in the experimental group were able to cycle without breaks. After the first 3 wks of training, exercise time was increased to 40 min and then to 50 min after 4 wks of training. The workload was 3.0 kg for the first 3 wks, which increased to 3.5 kg for the last 3 wks. All subjects maintained their normal run training throughout the study with both the experimental and control groups doing the same monitored run workouts. After 6 wks, post-training running economy and VO₂ max tests were performed following the same procedures used during the baseline tests.

Statistical Analyses
Descriptive data included the subjects’ means and standard deviations of age, height, and weight. Mean differences between pre- and post-running economy and VO₂ max were analyzed with paired t tests. The change scores (post-training minus pre-training) for these variables were calculated, and the mean differences between the PowerCranks™ experimental group and normal cranks control group were evaluated with independent t tests. Intra-class correlation (ICC) was used to determine pre-training test-retest reliability of running economy. All analyses were conducted with the Statistical Package for Social Sciences (SPSS version 20, IBM, Armonk, NY), and significance was established as P<0.05.

RESULTS
Thirteen of the initial 18 subjects completed the 6 wks of training and post-tests. One subject dropped out due to injury while 4 subjects did not complete the study due to time commitment. Although the groups were initially balanced by sex, testing was completed with 6 subjects (2 females and 4 males) in the PowerCranks™ group and 7 subjects (5 females and 2 males) in the control group. In total, the subjects completed 231 of the 234 practice sessions with one subject missing 2 practice sessions. Demographic and experimental data are presented in Table 1. There was no significant difference between the control group and experimental group for any of the pre-test comparisons. Neither the PowerCranks™ nor standard cranks groups significantly changed running economy or VO₂ max after the 6 wks of training (P>0.05). Further, independent t tests showed no significant (P>0.14) differences in change scores between groups for running economy and VO₂ max. The test-retest reliability of the running economy data (2.81 ± 0.55 vs. 2.83 ± 0.58 L·min⁻¹) was excellent with an ICC of 0.99.
Table 1. Demographic and Experimental Data (n = 13).

<table>
<thead>
<tr>
<th></th>
<th>PowerCranking™ (n = 6)</th>
<th>Std Cranks (n = 7)</th>
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<td></td>
<td>Within</td>
<td>Between</td>
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<tr>
<td><strong>Age (yrs)</strong></td>
<td>20.7 ± 1.4</td>
<td>20.1 ± 1.9</td>
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<td>-0.06</td>
<td>.58</td>
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<td><strong>Sex (M/F)</strong></td>
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<td>2/5</td>
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<tr>
<td><strong>Height (cm)</strong></td>
<td>174 ± 10.3</td>
<td>168.4 ± 9.4</td>
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<td>-1.02</td>
<td>.33</td>
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<tr>
<td><strong>Weight (kg)</strong></td>
<td>63.2 ± 8.4</td>
<td>60.0 ± 8.3</td>
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<td>-0.69</td>
<td>.50</td>
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<td><strong>VO₂ max (L·min⁻¹)</strong></td>
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<td>Pre</td>
<td>4.10 ± 0.72</td>
<td>3.83 ± 1.10</td>
<td></td>
<td>-0.51</td>
<td>.62</td>
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<tr>
<td>Post</td>
<td>4.18 ± 0.75</td>
<td>-1.37 .23</td>
<td>-1.29</td>
<td>.25</td>
<td>-0.11</td>
<td>.91</td>
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<tr>
<td>∆</td>
<td>0.08 ± 0.14</td>
<td>0.09 ± 0.18</td>
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<tr>
<td><strong>Economy (L·min⁻¹)</strong></td>
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<tr>
<td>Pre</td>
<td>3.00 ± 0.60</td>
<td>2.68 ± 0.51</td>
<td></td>
<td>-0.98</td>
<td>.35</td>
<td></td>
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<tr>
<td>Post</td>
<td>3.08 ± 0.59</td>
<td>-2.46 .06</td>
<td>-2.45</td>
<td>.82</td>
<td>-1.57</td>
<td>.15</td>
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<tr>
<td>∆</td>
<td>0.12 ± 0.10</td>
<td>0.01 ± 0.11</td>
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Δ = post-training minus pre-training

**DISCUSSION**

This is the first study to examine the cross-training effects of independent leg cycling on parameters of running performance, namely running economy and VO₂ max. Previous researchers studied the effects of training with uncoupled cranks on performance measures of cycling (3,5,14,21,24). Luttrell and Potteiger (14) found an improved gross efficiency for cyclists following 6 wks of PowerCranking™ training, 1 h·day⁻¹, 3 d·wk⁻¹. In contrast, other researchers found no improvements in either gross efficiency or cycling economy (5,24), VO₂ max (5,21,24), or peak and anaerobic threshold power outputs (3,21,24) for training studies of 10-30 sessions. Thus, training with uncoupled cranks was beneficial in only 1 of 5 cycling studies.

Independent cycle cranks force the cyclist to “pull up” with the hip flexors and the knee flexors after the down stroke in order to complete the pedal cycle. Pulling the pedal up with PowerCrank™ opposed to only pushing the pedal down with standard cranks helps in the development of the hip and knee flexors. Theoretically, the greater involvement and increased strength of the hip and knee flexors during the upward (“recovery”) phase of cycling may contribute to improved efficiency with less oxygen needed for the same workload (3). However, as indicated earlier, only 1 of 5 studies, that of Luttrell and Potteiger (14), observed a benefit from training with uncoupled cranks. Perhaps the hip
and knee flexors are not involved as much in cycling as they are in running. Cavanagh and Sanderson (6) showed that nearly all of the power in cycling comes from the down stroke, so training of the hip and knee flexors may make little difference in cycling performance. The authors stated that hardly any upward force was evident in the 360° of cycling. In agreement, Korff et al. (13) concluded that the extensors are more efficient at producing power during cycling than the flexor muscles (i.e., pulling up on the pedals during the up stroke actually decreased cycling efficiency).

In contrast to cycling, hip and knee flexors have an important role during running, and increased effectiveness of these muscles may increase turnover rate in running. The hip flexors are activated just before and during early leg swing. The leg swing accounts for approximately 20% of the metabolic cost of running (1,18). Additionally, Modica and Kram (18) suggested the knee flexors are active during and at the end of the swing phase.

Greater mechanical efficiency, resulting from increased muscle strength and improved motor unit recruitment patterns, are possible explanations for improved running economy (16). Thus, it is logical to conclude that an improvement in running economy results from training of the underutilized leg flexors. In fact, there is some evidence that training the hip flexors can improve running performance. Deane and colleagues (10) reported a 3.8% and 9.0% decrease in 40- yd and shuttle run times, respectively, for physically active college subjects following 8 wks of hip flexion exercises with resistance bands.

In our study, the PowerCranks™ were clearly providing a sufficient stimulus to alter motor unit recruitment patterns to overload the hip flexors. Independent crank cycling decreases vastus lateralis electromyography activity while increasing biceps femoris activity (11), and alters the work distribution pattern of a pedal revolution (3). Actively pulling up on the pedals is an unnatural action, and our highly trained runners were challenged after only a few pedal revolutions of uncoupled cycling during the initial training sessions. Some had to take breaks (19, 10-40 sec breaks in 107 training sessions) in order to accumulate 30 min of cycling exercise until they developed the new muscle coordination pattern.

Despite a logical rationale, training the hip and knee flexors with PowerCranks™ failed to improve the subjects’ running economy or VO₂ max. One possible explanation is the high training and fitness status of the subjects. Luttrell and Potteiger (14), the only researchers to report a performance benefit from independent cycle crank training, described their subjects as physically active, cycling at least 2 d·wk⁻¹ with a mean VO₂ max value of 56.0 ± 11.5 mL·kg⁻¹·min⁻¹. The cyclists in the other studies (21,24) were described as competitive and trained, riding >6 h or 200 km·wk⁻¹ with a mean VO₂ max value >60.6 mL·kg⁻¹·min⁻¹. Similarly, the highly trained competitive distance runners in the present study had a mean VO₂ max value of 63.8 ± 9.0 mL·kg⁻¹·min⁻¹. Further, the lower VO₂ max values and the wider variability of fitness in Luttrell and Potteiger’s (14) subjects suggest that the training program may have had a bigger effect compared to the more active and better trained subjects of the other studies. Also, it could be possible that for the more active and higher trained endurance athletes, the intervention was not long enough to produce changes in performance measures. It is more difficult to improve economy of motion in highly skilled athletes than novices (20).

Another possible factor that may help explain the results of Luttrell and Potteiger (14) with the present study and the other cycling studies that did not show improvements in performance measures was the difference in the testing procedures. Luttrell and Potteiger (14) investigated a measure of economy throughout a 60-min submaximal ride at 69% of VO₂ max. The PowerCrank™ group did not show significantly higher economy than the normal crank group until the 45-min and the 60-min data collections. It is possible that the independent cycle crank group responded better to fatigue than the
control group. It is well known that running economy deteriorates and the energy cost of running increases over the duration of a long run (23) or if the athlete is fatigued (17). Therefore, if uncoupled cycling improves muscular endurance of the hip flexors and knee flexors, then, the improvement in running economy might be more obvious if evaluated at the end of a long or fatiguing run.

Strengths of the present study included highly trained athletes as subjects with a built-in control for training done outside the confines of the investigation. It is more difficult to improve the running economy of advanced runners than novice runners, and runners concerned enough about their running economy to train with PowerCranks™ would most likely be advanced. Our sample of collegiate cross-country conference champions fit this profile. Also, since all of the subjects were members of the same team, the run training outside of the research laboratory was identical for both experimental and control groups. Unfortunately, a high percentage of participants (27.8%) failed to complete the study. Those who stayed in the study completed 98.7% of the cycle training sessions.

A major limitation of the study was the short 6-wk duration of training. For highly-trained runners, it is likely that more time training with the PowerCranks™ is required to realize an improvement. However, as the subjects (i.e., athletes) progressed with their track and field season, they and their coaches were unwilling to extend the study. Also, the testing of running economy was limited to when the subjects were well rested. The post-training effect from PowerCranks™ on running economy when athletes are fatigued is unknown and, therefore, is an area for future research.

CONCLUSIONS

It is important for coaches and athletes to get the maximum benefit from their training time. We hypothesized that strengthening the hip flexors and knee flexors of collegiate distance runners with independent crank cycling sessions 3 d·wk⁻¹ for 6 wks would improve their running economy. This strategy failed. Based on previously published research it might be a better use of time to have well-trainer runners participate in power lifting, plyometrics, or high-intensity interval training to improve running economy (12,16,20,25).

ACKNOWLEDGMENTS

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