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TRAINING WITH INDEPENDENT CRANKS ALTERS MUSCLE COORDINATION PATTERN IN CYCLISTS

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ABSTRACT

Fernández-Peña, E, Lucertini, F, and Ditroilo, M. Traning with independent cranks alters muscle coordination pattern in cyclists. *J Strength Cond Res* 23(x): 000–000, 2009—In cycling, a circular pedaling action makes the most useful contribution to forward propulsion. Training with independent cranks (IC) has been proposed to improve the pedaling action. The aims of this study were, first, to assess whether the intermuscular coordination pattern of the pedaling action with normal cranks (NC) is modified after a training period with IC and, second, to determine if the new coordination pattern is maintained after a washing-out period. Eighteen cyclists, divided into a control (CG) and an experimental (EG) group, underwent 2 test sessions (T1 and T2) separated by 2 weeks of training (18 hours). The electromyographic (EMG) activity of 4 lower limbs' muscles was recorded while the athletes pedaled at 80 rpm for 60 seconds at 30 and 50% of the maximal power output determined during a maximal pedaling test. The tasks were performed with IC (EG) and NC (EG and CG). The EG underwent a retention test session (T3) after another 18-hour training with NC. EG showed a significant (45.8 ± 8.8 vs. 36.0 ± 6.1%, $p < 0.01$ at 30% intensity) and a quasi-significant (62.7 ± 10.3 vs. 54.2 ± 8.7%, $p = 0.09$ at 50% intensity) decrease in vastus lateralis EMG activity and a quasi-significant (36.4 ± 13.4 vs. 43.5 ± 10.9%, $p = 0.09$ at 30% intensity) and a significant (54.5 ± 12.1 vs. 65.5 ± 16.1%, $p < 0.05$ at 50% intensity) increase in biceps femoris EMG activity between T1-NC and T2-NC. By T3, EMG activity returned to initial levels (T1). On the contrary, CG did not reveal any significant variation. The results provide scientific support for muscle coordination pattern alteration from the use of IC, potentially achieving a more effective pedaling action. IC training reduces quadriceps exertion, thus preserving it for important moments during competition.

KEY WORDS powercranks, electromyography, pedaling action

INTRODUCTION

Cycling performance is strongly influenced by a proper pedaling technique. From a mechanical standpoint, a torque as constant as possible should be applied to the bottom bracket to improve efficiency (10). However, because of the circularity of the movement and the biomechanics of the human lower limbs, the forces applied to the pedal are not constant over the pedaling cycle (23), instead producing a fluctuating crank torque (3). Accordingly, several authors have divided the pedal cycle into different phases (8,17,18,26,29). Roughly, the pedal cycle can be partitioned into a downward pushing phase (downstroke or pushing phase) and an upward pulling phase (upstroke or recovery phase). Classical studies show that when the cranks are perpendicular to the ground, forces tend to be very small or even null, whereas maximal forces are produced when the crank is approximately horizontal to the ground in the pushing phase (10,23). As the 2 cranks are connected to each other with a phase of 180 degrees, the downward force, generated by the pushing leg, automatically lifts the contralateral pedal (10). This implies that if the recovery phase is passively accomplished, a negative force, reducing the effectiveness of the pedal stroke, is produced (19). The magnitude of this negative force is augmented when the cyclist becomes fatigued (27) and when the cadence increases (23,28) and can be up to the 25% of the force applied by the pushing leg at 100 and 120 rpm (23). This pattern is still evident when toe clips or clipless pedals were used (10) or even when the cyclists are asked to pedal in circles (20), thus showing that volitional effort in itself may not be enough to improve cycling mechanics. However, negative forces are reduced in the recovery phase as power output increases (28).

For years coaches and researchers have been concerned about the best training strategy for improving propulsive effectiveness of the pedaling action. Coyle (5) and Coyle et al. (6) claimed that performance improvement in cycling is achieved provided that a larger torque is applied during the pushing phase. In contrast, it was maintained that elite cyclists have a reduced negative force during the upstroke compared to recreational cyclists (3) or even that the upstroke phase, if

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actively conducted, could be essential because it is possible to measure positive forces as high as 100 N (30).

Although studies on this issue seem to be controversial, it is a common practice among cyclists and coaches to train the intermuscular coordination of the lower limbs to produce propulsive torque during the entire revolution, reducing ineffective forces and developing a more circular pedaling action. Probably the 2 most frequently proposed methods for improving circular movement are training with a fixed gear (14) and single-leg pedaling (3,15). Other advised exercises, although less popular among cyclists, are pedaling drills performed at high and low cadence.

Recently, a special independent crank system called PowerCranks (PowerCranks, Walnut Creek, California) has been developed to improve pedaling circularity. The 2 cranks are completely independent of each other, so that the cyclist is forced to actively push down and pull up each crank during 1 revolution of the pedal cranks. Moreover, the cyclist must synchronize the phasing of the 2 cranks at approximately 180 degrees to produce a smooth circular pedal stroke. As claimed by the manufacturer, PowerCranks should improve coordination and reduce injury rates in cycling (7). The independent cranks (IC) functioning mechanism does not clash with cycling rules of the International Cycling Union; therefore, they could be used even during competitions (for safety reasons, preferably during individual races), although they were developed for training purposes.

To the best of our knowledge, only a few studies have been conducted for the validation of training with independent cranks and they showed an improvement on physiological variables (21) or mechanical efficiency (1) as a consequence of IC training. Other researchers (31) utilized a strength cycle ergometer, an apparatus shifting between an engaged or disengaged mode, which allows normal or independent crank pedaling. They did not find significant improvements in power at 85% of maximum heart rate compared to standard Monark ergometer training, despite the subjects training on 3 days per week for a total of 9 weeks.

However, the cited studies do not answer the question as to whether the use of IC alters muscular activity and intermuscular coordination of the pedaling action. A study by Ichino et al. (16) found no significant differences in muscle activity before and after a 4-week training program with the strength cycle ergometer. This latter study, however, involved 40- to 60-year-old women trained for approximately 7 hours, probably not enough time for allowing neuromuscular adaptations to occur. Given the paucity of literature and because of the previously mentioned theoretical considerations, the hypothesis formulated was that training with IC could induce a modification in muscular recruitment pattern, with the main objective being the attainment of a more circular and effective pedaling action.

Accordingly, the main aim of this study was to assess whether the intermuscular coordination pattern of the pedaling action, with normal cranks (NC), was modified after an intensive training period with IC. If changes were detected, then the second objective was to assess if the new coordination pattern was maintained after a washing-out period, when the cyclists trained only with NC.

METHODS

Experimental Approach to the Problem

A 2-group pre-post1-post2 design was used in this study to determine whether an 18-hour period of training with IC would result in a coordination pattern variation of lower limbs' muscles, as determined by means of surface electromyography (EMG) (9,13,24,26).

An interesting approach for specifically determining muscular intervention in cycling came from Neptune et al. (22), who proposed splitting the pedaling action into 4 phases. Considering 0 and 360 degrees to be the highest position of the pedal (with the crank perpendicular to the ground), they considered the following regions: Top (defined from 241 to 35 degrees), bottom (72 to 228), extension (337 to 134), and flexion (149 to 324). Briefly, the extension is mostly sustained by the vastus lateralis (VL), the bottom by the biceps femoris (BF) and the gastrocnemius lateralis (GL), and the top by the tibialis anterior (TA). An increase in BF and GL activity during the bottom phase is expected when using independent cranks. This occurs because the pushing down of an independent crank does not cause a corresponding upward motion of the opposite crank; rather, the cyclist is forced to actively pull back and up. Consequently, a reduction in VL activity in the extension phase is also expected. Another consequence should be the increase in TA activity during the top phase because dorsal flexion of the foot during the upward pulling phase stabilizes the ankle, thereby facilitating the pulling action.

Two groups, a control group (CG) and an experimental group (EG), underwent a first testing session (T1) for determining the baseline muscular activity. The same training volume was performed by both groups (CG with NC, EG with IC), and a second testing session (T2) was administered. Only the EG underwent a third testing session (T3) after a washing-out period. Independent variables were group (CG and EG), exercise intensity (30 and 50% of maximal intensity), testing session (T1, T2, T3), and crank (IC and NC). Dependent variables were the muscular activity levels of the VL, BF, TA, and GL.

Subjects

Eighteen healthy cyclists were recruited and gave their written informed consent for participating in the study, which was previously approved by the Human Ethics Committee of the University of Urbino "Carlo Bo" in Italy. All cyclists competed at the Masters level. They, on average, train for 15 hours per week, had a cycling experience of about 10 years, participated in 20 to 40 competitions per year, and had covered 15,000 km during the last season. All cyclists had been continuously training for at least 3 months before participating in the study and all tests were carried-out during the competitive period, which is between April and October. None had previous experience pedaling with IC, and they were asked to refrain from exhaustive exercise 24 hours before testing.

Procedures

Subjects were randomly assigned to the EG ($n = 9$, age 35.5 ± 5.0 years, height 181.6 ± 8.0 cm, weight 75.5 ± 11.0 kg) and CG ($n = 9$, age 34.0 ± 8.9 years, height 175.4 ± 11.5 cm, weight 73.6 ± 12.4 kg).

Both groups underwent T1 followed by 2 weeks of intensive training (18 hours), then T2. All cyclists exercised with their own bicycles; however, bicycles of the EG were equipped with IC. Whereas the CG performed the training sessions at approximately 80 rpm, the first training session of the EG was performed in the laboratory for 10 minutes at low cadence (65–70 rpm) to allow a safer and more confident transition into cycling with IC. The second and third training sessions lasted 30 and 45 minutes, respectively. On completion of the 3 familiarization training sessions of reduced duration, the cyclists began the 2-week training program at approximately 80 rpm. The EG underwent T3 after completing an additional 2 weeks of intensive training (18 hours) on their own bicycles equipped with NC. Duration of the training was chosen based on previous IC literature (1,16,21). Two cyclists dropped out after T2; therefore, only 7 cyclists completed T3. The experimental design is depicted in Figure 1.

Testing Protocol

After a 10-minute warm-up period at a workrate of 150 W and 80 rpm on an SRM ergometer (Shoberer Rad Meβtechnik SRM GmbH, Jülich, Germany), a maximal pedaling test was administered to determine the maximal power output and EMG activation. It consisted of pedaling as forcefully as possible for 6 seconds while a vigorous verbal encouragement was given. The pedaling frequency was set at 80 rpm in the isokinetic mode; therefore, the resistance was automatically and proportionally increased when the subject tried to overcome it. This protocol produced a maximal dynamic contraction of the muscles involved in the pedaling action for the purpose of EMG normalization. This protocol has demonstrated good logical validity and reliability in cyclists (11). The athletes were asked to perform 2 to 3 bouts interspersed by 3 minutes of active rest periods. The crankset of the SRM ergometer was equipped with strain gauges allowing direct measurement of the torque produced by the force applied to the pedals perpendicularly to the crank length. Torque applied to the crankset was recorded at 200 Hz. Power output of each maximal trial was calculated as the product of the average torque (N m) and average cadence (rad/seconds) over the 6 seconds. The trial with the highest power output was considered for subsequent analyses.

After a 10-minute rest period, cyclists underwent 2 submaximal pedaling tests on a Monark cycle ergometer (Monark 894 E Peak Bike, Vansbro, Sweden), interspersed by 3 minutes of active rest. Each trial was performed at 80 rpm for 60 seconds at a randomly assigned workrate of 30 or 50% of the maximal power output determined during the maximal test. The 2 chosen workrates allowed the participants to produce a moderate and strong effort, respectively. The Monark was provided with adjustable dual-mode PowerCranks (Figure 2), which could be locked out, converting them to normal fixed cranks.

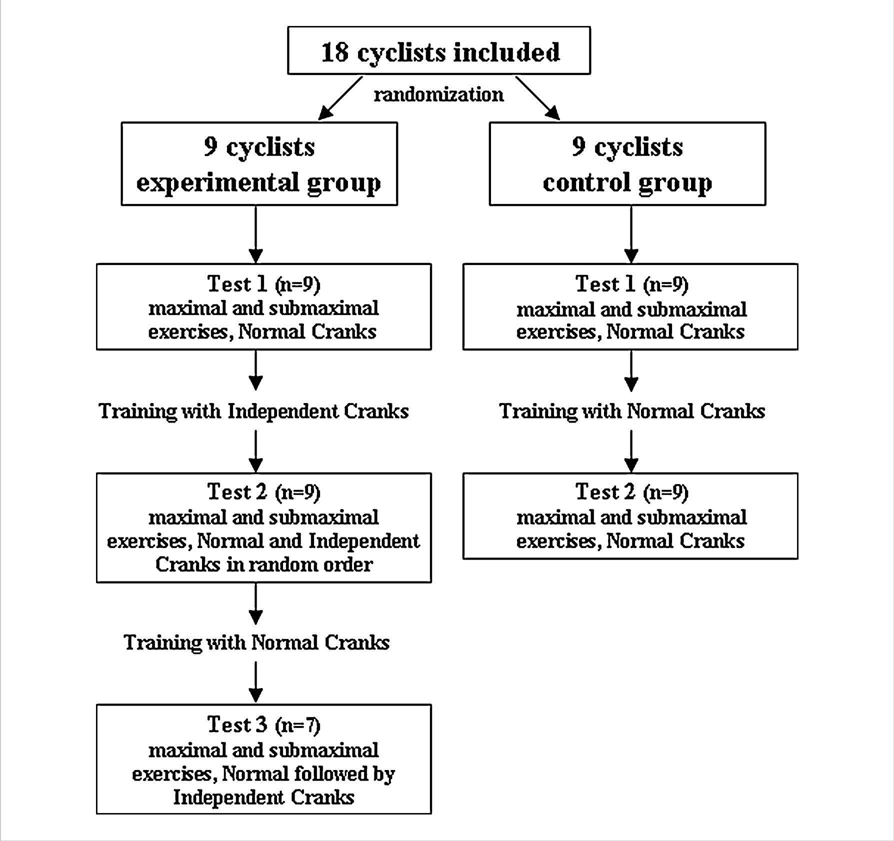

Figure 1. Flowchart outlining the experimental design.

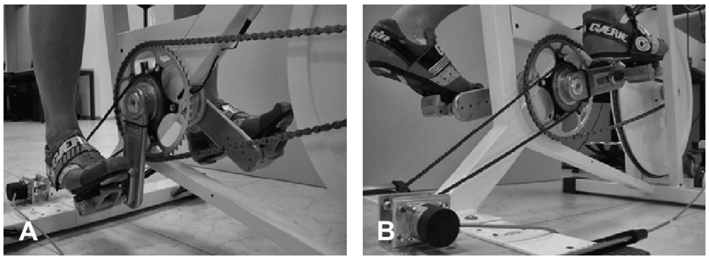

Figure 2. Independent crank device applied on Monark ergometer. The locking option allows the conversion of the independent cranks (A) into normal fixed cranks (B). The rotational encoder for recording angular crank position is also shown.

Both ergometers were adapted to match the measures of the riders' own bicycles as closely as possible, including crank lengths. Power output and EMG data collected during maximal and submaximal tests have been shown to be highly reliable (intraclass correlation coefficient [ICC] >0.90) (11).

Both EG and CG performed 2 submaximal tests each using NC on T1. The CG once again performed 2 submaximal tests using NC on T2. The EG performed a total of 4 submaximal tests (2 with NC and 2 with IC) on both T2 (in random order) and T3 (NC followed by IC).

Recording of EMG and Crank Angular Position

The EMG activity of VL, BF, TA, and GL of the right leg was recorded in all test sessions. Electrodes were placed on the selected muscles following the SENIAM (Surface EMG for Non-Invasive Assessment of Muscles) recommendations (12): Skin was shaved, slightly abraded with sandpaper, and cleaned with alcohol, then Ag/AgCl bipolar electrodes (Blue Sensor N-00-S, Ambu Medicotest A/S, Ølstykke, Denmark) were placed over the muscle belly at an inter-electrode distance of 20 mm. To avoid artifacts from lower limb movements, the wires connecting electrodes were well secured with tape. The surface EMG signal was amplified with a gain of 600. Common mode rejection rate and input impedance were, respectively, 95 dB and 10 GΩ.

To reproduce the electrode positions across the different test sessions, a simple and smart method recommended by Professor F. Felici (personal communication) was used: In T1 a tracing paper was drawn with the placing points of the electrodes and any other permanent reference points (such as moles, birthmarks, scars, etc.), and in T2 and T3 this kind of "skin map" was used to quickly locate the exact placement adopted in T1.

Instantaneous angular position of the crank was measured using a rotational encoder (EL40B, Eltra, Vicenza, Italy), with a resolution of 2,000 pulses per turn, coupled to the left (SRM) and right (Monark) crank of the ergometers by a chain drive. Angular position of the crank and EMG signals were synchronized, sampled at 1,000 Hz, and stored on a PC using a 16-bit A/D converter data acquisition system (APLab-DAQ, APLab, Rome, Italy).

Data Processing

Raw electromyographic data were band-pass filtered using a fourth-order Butterworth filter, with cut-off frequencies of 10 and 350 Hz and then full wave rectified. The highest power output achieved during the maximal test was chosen for EMG normalization purposes. The integrated EMG of each of 6 pedal revolutions was calculated and then averaged for each muscle and each subject. For the submaximal test, the last 30 seconds were analyzed, which represented 40 pedal cycles. The EMG of each pedal cycle and each different pedaling portion suggested by Neptune et al. (22) were calculated, then averaged and normalized to the maximal test to obtain a representative activation level. Figure 3 depicts an individual example of the EMG profiles vs. crank angle collected while pedaling with NC, obtained integrating the full wave rectified data over a moving window length of 100 ms.

Statistical Analyses

EMG activity of the 4 analyzed muscles and power output obtained during the maximal test were expressed as mean ± SD. For the purpose of statistical analysis, the EMG activity variables were log-transformed because they were expressed as a percentage and then were checked for normality (Kolmogorow-Smirnov test). Four (4 muscles) separate 2 (group) × 2 (exercise intensity) × 2 (test session 1 and 2) multifactorial analysis of variance (ANOVA) with repeated measures on the last factor were used to analyze the variables. When a significant F value was achieved, a Tukey post hoc was used to examine where significant differences occurred.

To evaluate the effect of the washing-out training period, when a significant interaction (group × test session) was found, an additional 2 (exercise intensity) × 3 (test session) ANOVA with repeated measures on the last factor was used with the EG only, followed by a Tukey post hoc analysis.

All statistical analyses were conducted by means of the Statistica software (Statsoft Italia, Vigonza, Italy, release 6.1). An alpha level of $p < 0.05$ was considered statistically significant for all comparisons. An alpha level between 0.05 and 0.1 was considered quasi-significant.

Statistical power is a limitation in pilot work when there are no existing mean and SD data to calculate effect size a priori. It is important to realize that cyclists are not easily enrolled in such demanding protocols, especially during the competitive period. Our sample size, based on the availability of 18 cyclists, provided a statistical power varying between 0.10

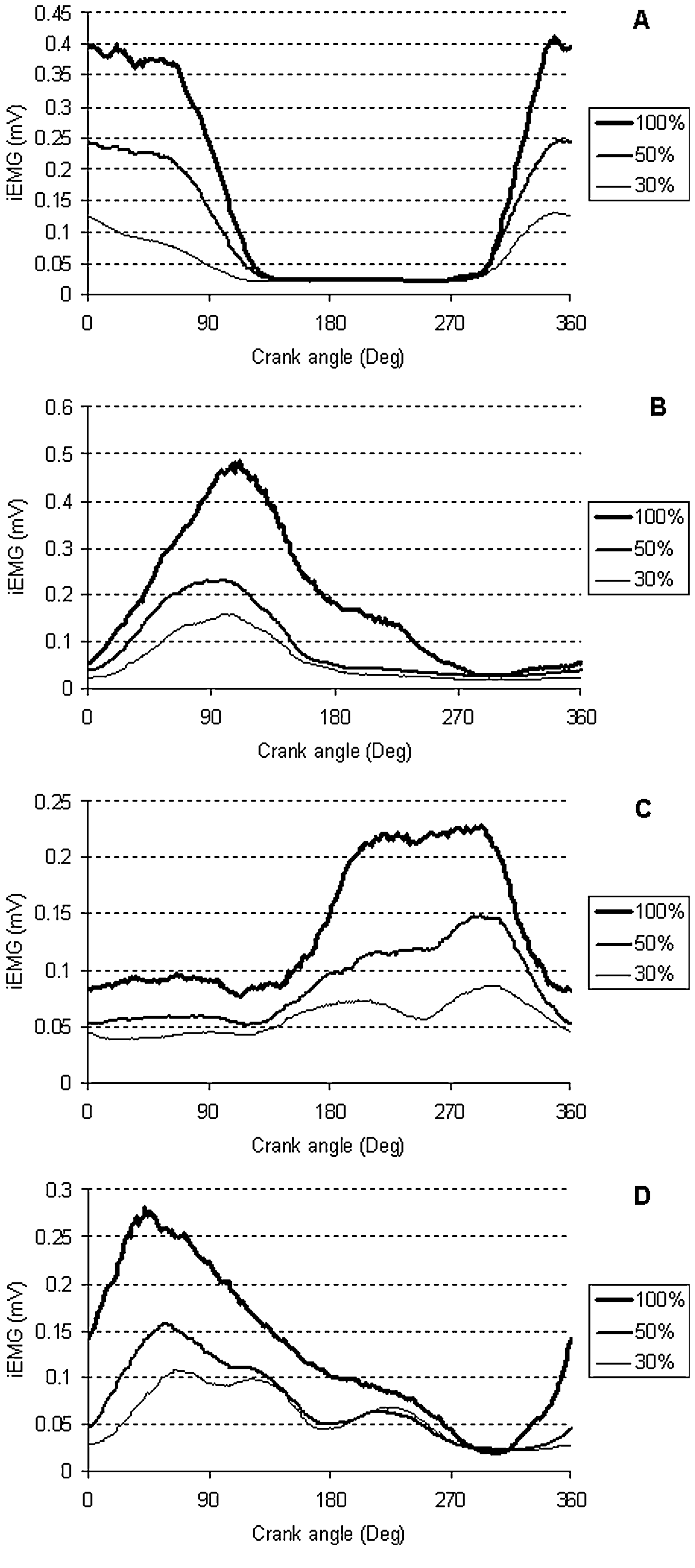

Figure 3. Example of individual muscle activity (integrated EMG), as a function of crank angle, obtained at 3 different pedaling intensities (30, 50, and 100% of the maximal power output) for the vastus lateralis (A), biceps femoris (B), tibialis anterior (C), and gastrocnemius lateralis (D).

(GL) and 1.00 (VL) for detecting effect sizes of 2.30 (VL), 1.05 (BF), 0.45 (TA), and 0.15 (GL).

RESULTS

The maximal power output was 907.5 ± 105.3 W on T1 and 920 ± 107.3 W on T2 for the CG and 829.0 ± 142.7 W on T1, 836.9 ± 140.2 W on T2, and 825.5 ± 122.4 W on T3 for the EG (data not shown). No significant differences were detected between groups and across test sessions.

F4 – F7

The EMG activity of VL, BF, TA, and GL, respectively, is illustrated in Figures 4 to 7. EG and CG were compared, on T1 and T2, when pedaling with NC at 30 and 50% of maximal intensity. For EG, the EMG activity when pedaling with NC on T3 and when pedaling with IC on T2 and T3 is also represented for both intensities. However, no statistical analysis was applied to IC sessions.

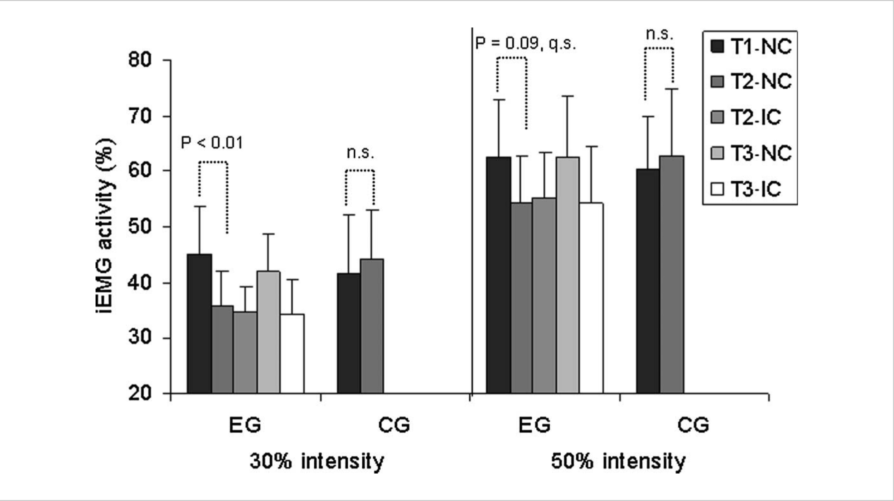

Figure 4. Vastus lateralis activity (integrated EMG, mean ± SD) corresponding to 30 and 50% of the maximal power output achieved during the maximal pedaling test. A difference was evidenced between T1-NC and T2-NC at 30% ($p < 0.01$, significant) and 50% ($p = 0.09$, quasi-significant) intensity. T1 = test session 1, T2 = test session 2, T3 = test session 3, 2-week training (18 hours) between test sessions; NC = normal cranks; IC = independent cranks; EG = experimental group ($n = 9$); CG = control group ($n = 9$); n.s. = not significantly different; q.s. = quasi significant.

Figure 4 shows the EMG activity of VL. A significant main (intensity) and interaction (test session x group) effect was observed ($F = 38.73$; $p < 0.01$ and $F = 19.17$; $p < 0.01$). The post hoc analysis revealed a significant ($p < 0.01$ at 30% intensity) and a quasi-significant ($p = 0.09$ at 50% intensity) decrease in EMG activity between T1-NC and T2-NC in EG (45.8 ± 8.8 vs. 36.0 ± 6.1% at 30%; 62.7 ± 10.3 vs. 54.2 ± 8.7% at 50% intensity), whereas the CG showed no significant differences (41.7 ± 10.3 vs. 44.0 ± 8.9% at 30%; 60.4 ± 9.7 vs. 62.9 ± 11.7% at 50% intensity). On T3-NC the EMG activity level was restored to the starting level because no significant difference was evident between T1-NC and T3-NC.

The BF activity is represented in Figure 5. A significant main (intensity) and interaction (test session × group) effect was observed ($F = 17.76$; $p < 0.01$ and $F = 7.95$; $p < 0.01$). Training with IC resulted in a quasi-significant ($p = 0.09$ at 30% intensity) and a significant ($p < 0.05$ at 50% intensity) increase between T1-NC and T2-NC in EG (36.4 ± 13.4 vs. 43.5 ± 10.9% at 30%; 54.5 ± 12.1 vs. 65.5 ± 16.1% at 50% intensity), whereas the CG showed no significant differences (38.9 ± 13.5 vs. 36.2 ± 10.9% at 30%; 58.5 ± 14.2 vs. 58.3 ± 12.6% at 50% intensity). On T3-NC the EMG activity level was restored to the

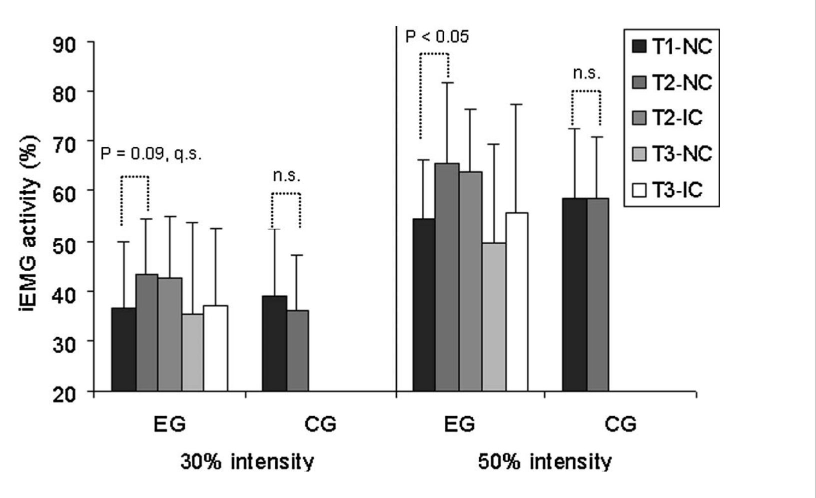

Figure 5. Biceps femoris activity (integrated EMG, mean ± SD) corresponding to 30 and 50% of the maximal power output achieved during the maximal pedaling test. A difference was evidenced between T1-NC and T2-NC at 30% ($p = 0.09$, quasi-significant) and 50% ($p < 0.05$, significant) intensity. T1 = test session 1, T2 = test session 2, T3 = test session 3, 2-week training (18 hours) between test sessions; NC = normal cranks; IC = independent cranks; EG = experimental group ($n = 9$); CG = control group ($n = 9$); n.s. = not significantly different; q.s. = quasi significant.

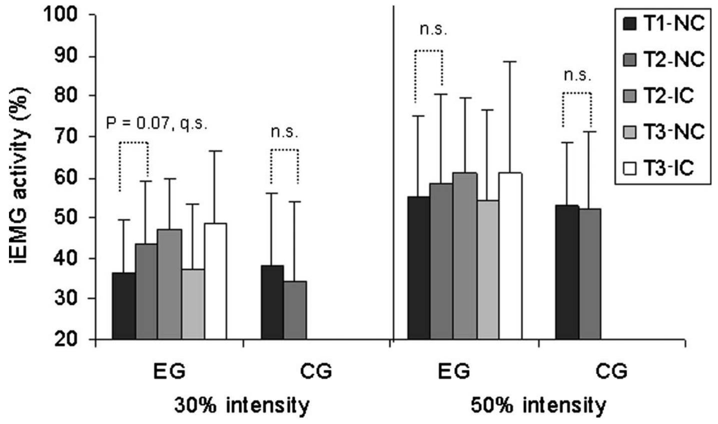

Figure 6. Tibialis anterior activity (integrated EMG, mean ± SD) corresponding to 30 and 50% of the maximal power output achieved during the maximal pedaling test. A quasi-significant difference ($P = 0.07$) was evidenced between T1-NC and T2-NC. T1 = test session 1, T2 = test session 2, T3 = test session 3, 2-week training (18 hours) between test sessions; NC = normal cranks; IC = independent cranks; EG = experimental group ($n = 9$); CG = control group ($n = 9$); n.s. = not significantly different; q.s. = quasi significant.

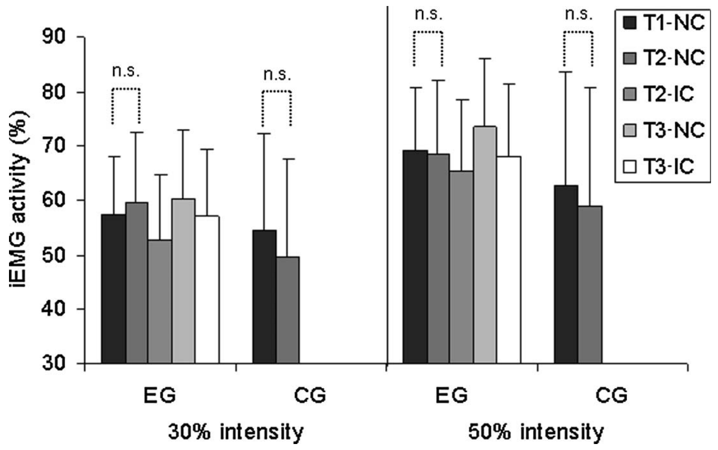

Figure 7. Gastrocnemius lateralis activity (integrated EMG, mean ± SD) corresponding to 30 and 50% of the maximal power output achieved during the maximal pedaling test. T1 = test session 1, T2 = test session 2, T3 = test session 3, 2-week training (18 hours) between test sessions; NC = normal cranks; IC = independent cranks; EG = experimental group ($n = 9$); CG = control group ($n = 9$); n.s. = not significantly different.

starting level because no significant difference was evident between T1-NC and T3-NC.

Figure 6 illustrates the EMG activity of TA. Again, a significant main (intensity) and interaction (test session × group) effect was observed ($F = 7.21$; $p < 0.05$ and $F = 11.10$; $p < 0.01$). Although a growing trend across the first 3 test sessions was noticeable, especially at 30% intensity, the post hoc analysis revealed only 1 quasi-significant increase ($p = 0.07$) in EMG activity between T1-NC and T2-NC in EG (36.4 ± 13.0 vs. 43.5 ± 15.5% at 30% intensity).

In GL EMG activity (Figure 7) no significant differences across test sessions and between intensities and groups were detected.

DISCUSSION

The main purpose of this study was to detect whether the use of IC could alter the muscular intervention during the circular movement of the pedaling action. To the best of our knowledge, this is the first time that a study has been conducted on the effect of IC training on muscular recruitment during cycling.

Consistent with the hypothesis, cyclists in the EG increased the BF activity in the 72 to 228-degree functional region and decreased the VL activity in the 337 to 134-degree region after a training period with IC. A higher activation of BF in the bottom region indicates, as expected, that the cyclist is forced to actively pull back the pedal. Linked to this, the lower activation of VL in the extension region suggests that this muscle is partly relieved of the work it usually performs when pedaling with NC. These results are similar to other research comparing different types of pedals. In fact, clipless and toe-clip–type pedals allow the cyclist to actively pull the pedals up. Ericson et al. (9) demonstrated that toe clips significantly reduced the vastus medialis activation and increased the BF and rectus femoris activation when compared to normal pedals.

A more detailed analysis of the data presented shows an interesting observation. The reduction of VL EMG activity is significant at 30% but only quasi-significant at 50% intensity. The increase of BF activity is the opposite: Quasi-significant at 30% and significant at 50% intensity.

A possible explanation for this observation may relate to the larger muscular recruitment as the result of an increase in exercise intensity. Several authors consider VL the prime mover for cycling propulsion (e.g., 25) and it seems that at 30% of maximal intensity, a minimal increase in BF is sufficient for significant VL activity reduction. Instead, at higher intensity (50% of maximal power output), although the BF activity is significantly increased, the reduction in VL activity is less pronounced because of its essential role in a more vigorous pedaling action. As a consequence, it could even be expected that if a higher intensity was performed, VL activity would be nearly unchanged despite a BF activity increase. In general it could be said that the biomechanical condition responsible for allowing a more circular pedaling action at low-intensity power outputs (30% of max) is an increase in BF activity (as a result of a more vigorous backward pulling phase) counterbalanced by a VL decrease during the downstroke. However, as cycling intensity becomes harder (50% of max), the contribution of both muscles is essential.

Partly opposing the hypothesis, TA did not show a clearly visible increase in EMG activity after training with IC. Only a quasi-significant increase of TA occurred at 30% intensity and there were no changes in GL activation. This could be result from a number of different reasons. First, the intersubject variability of EMG activity of these muscles is higher than VL and other knee extensors, as also documented elsewhere (26). As a result, significant differences across test sessions may not occur, especially when the number of subjects is not large. However, the individual changes detected could have practical relevance for certain athletes. Second, the muscles of the anterior tibial compartment and the calf muscles have roles in dorsiflexing and plantarflexing the ankle, respectively. Their activity is strongly dependent on the pedaling technique chosen by the cyclist. This issue has been addressed recently by Cannon et al. (4), who demonstrated that gastrocnemius EMG activity was significantly higher with the dorsiflexion technique compared to natural pedal stroke. Furthermore, although no statistical differences were detected, the same authors found that the highest and lowest TA activity was reached, respectively, during the dorsiflexion and plantarflexion trials. The talocrural joint position during the pedaling action was not controlled in the present study and this is a recognized limitation. Third, an extra-activation of other potentially important muscles such as the iliopsoas, which are situated deep inside the body, could contribute to alter muscle coordination patterns during the pedaling action induced by training with IC. However, deep muscles cannot be analyzed by means of surface electromyography. During and after the first IC training sessions, cyclists reported feeling pain on the upper thigh. Although this cannot objectively confirm the hypothesis, it is an indicator to take into account.

The retention test (T3) restored the EMG activity level of all muscles analyzed to the initial level (T1) for both chosen intensities. This indicates that when ICs are discarded for 2 consecutive weeks in favor of training using NC, the pattern of muscular recruitment acquired using IC is lost. Several interesting and unanswered questions can be raised at this point. Because no retention was observed, it could be argued that regardless of the length of the training period with IC, the new muscle coordination pattern is lost when the training is stopped, or that a 2-week training period with IC is not enough for the consolidation of the new skill. Practice allows motor memory to progress functionally from a short-lived fragile form to a long-lasting stable form (2), but changing a consolidated motor skill, such as riding a bike with NC, could be harder. Considering that the cyclists evaluated had a training experience of 10 years, we deem they achieved a considerable modification in intermuscular coordination. Of course, the time during which the new skill becomes consolidated could vary depending on different factors, such as cyclist technical skill, previous experience, and so on. Moreover, it is expected that an early initiation of IC training in a cyclist's career could lead to more marked results.

Future investigations are necessary to gain a better insight into the ability to retain the new muscle coordination pattern during cycling and to develop training protocols to achieve this adaptation. The authors recognize that such studies are not easy to conduct because they would require multiple testing and training sessions, thus being very laborious.

In summary, the results of the present study are the first to provide scientific support for a muscle coordination pattern alteration, at least for VL and BF, when cyclists perform IC training. It seems, however, that the new coordination pattern is easily lost if IC training is not continued. Further research is required to gain insight regarding this last issue.

PRACTICAL APPLICATIONS

Within the limitations of this research, which was conducted on 18 trained male master cyclists, the findings suggest that a short period of intensive training with IC alters muscle recruitment pattern. A reduction in VL and an increase in BF activity were attained, providing the basis for achieving a more circular pedaling action. In this regard, the reduction in VL activity, mainly detectable for pedaling exercises at lower intensity, could have the practical significance of reducing quadriceps effort and preserving it for important moments during a competition, such as steep slopes or the final sprint. For lasting coordination changes, based on the data presented, it is suggested that IC training needs to be continued even after the new coordination muscular pattern is acquired. As for training protocols, at present only the manufacturer company's advice on how to use IC is available (7).

There is a need to combine the experiences of coaches and athletes, together with researchers, to (a) develop rational IC training protocols for the purpose of achieving a more circular and effective pedaling action, (b) preserve the acquired skill forward in time, and (c) apply the acquired skill in competition.

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