RESEARCH ARTICLE

Addition of strength training to off-road cyclists training. A pilot study

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Abstract

This study investigated the effects of adding a traditional strength training approach (endurance-strength = ES) during the pre-season versus a non-traditional approach where strength training is further maintained throughout the season (maximal-strength = MS), on aerobic and anaerobic parameters of off-road cyclists. Eleven off-road cyclists were divided into two groups. The ES group (n=6) performed during the first 8 weeks endurance-strength training, while the MS group (n=5) performed maximal-strength training, both together with their usual endurance training. During the following 8 weeks, only MS group maintained 1 session of strength training per week. 1RM, VO2max, Maximal aerobic power (Wmax), Power at 4-mmol·L-1 (LT4.0), Peak Power (PP), Mean Power (MP), Power best 5s (PB5), Power last 5s (PL5) and Fatigue Index (FI) were assessed. Results showed that there were significant (P < 0.05) increases for MS group in PP (+ 4.8%) from PRE to MID, in 1RM (+ 15.8%) from PRE to POST, while in the ES group there was a decrease in 1RM (- 16.1%), PL5 (-4.3%) with an increase in FI (+ 9.5) from MID to POST. Effect size calculations showed small and moderate improvements in PP (+ 3.6%), MP (+ 2.8%), PB5 (+ 4.3%) from PRE to POST for MS group, while ES group showed a small improvement in VO2max (+ 4.1%), LT4.0 (+ 4.3%) and PB5 (+ 2.7%) from PRE to MID, and a small decrease between MID to POST in Wmax (- 4.1%) and MP (- 2.6%). These results suggest that by including a non-traditional strength training approach it is possible to maintain aerobic levels and possibly increase anaerobic parameters throughout the off-road cycling season.

Keywords: concurrent training, endurance, strength, cycling, maximal strength

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Introduction

Endurance performance is mainly explained by physiological parameters such as maximal oxygen uptake (VO2max), lactate threshold and efficiency (Joyner and Coyle, 2008). However, there is growing evidence suggesting that neuromuscular and anaerobic characteristics (i.e; peak power) might have the potential of improving endurance performance during the final minutes of a race (Paavolainen et al., 1999b; Aagaard and Andersen, 2010). Therefore, it has become increasingly popular that training programs utilized by endurance athletes include resistance training in efforts to improve the neuromuscular and anaerobic characteristics (i.e., concurrent training).

The effect of concurrent training has been reported mostly in untrained or moderately trained subjects, showing a greater improvement in cardiovascular and neuromuscular parameters (Häkkinen et al., 2003; Mikkola et al., 2012), or similar improvements compared with strength or endurance training alone (Izquierdo et al., 2005). However, especially during the

last decades the effect of concurrent training in well-trained and highly-trained endurance athletes, such as runners, has been reported and indicated no trivial effect on VO2max (Sedano et al., 2013; Paavolainen et al., 1999a), a possible improvement in running economy (Paavolainen et al., 1999a; Millet, Jaouen et al., 2002; Storen et al., 2002), improvements in velocity at the lactate threshold (Mikkola et al., 2007; Taipale et al., 2013) and in the actual endurance running performance (Paavolainen et al., 1999a). However, the influence of strength training in cycling remains somewhat unclear, with some studies showing an improvement in maximal aerobic power (Wmax) (Rønnestad et al., 2010a, 2010b; Sunde et al., 2010) or no beneficial effects of the added strength training (Bishop et al., 1999; Jackson et al., 2007; Levin et al., 2009). Some authors have found beneficial effects on endurance performance as an improvement in time trial performance (Rønnestad et al., 2010b; Aagaard et al., 2011), or improvement in power output at a certain blood lactate concentrations (Rønnestad et al., 2010a, 2010b). Furthermore, there are equivocal findings about improvements in cycling efficiency, found only in the study of Sunde et al. (2010) and in the study of Rønnestad et al. (2010a) during the final 60 min of a 185 min cycle test. Importantly, adding strength training to the usual endurance training did not compromise the development of speed at lactate

threshold, efficiency and VO2max in cyclists (Rønnestad and Mujika, 2014).

Within the different cycling disciplines, Olympic Cross-Country (XCO) mountain biking is a sport in which races are performed in an off-road circuit of about 6-9km long, with an average total climb of about 1500m and a significant amount of climbing and descending, with a usual winning time below 2h. These races are performed at an average heart rate close to 90% of the maximum, and more than 80% of race time is spent above the lactate threshold (Impellizzeri and Marcora, 2007; Impellizzeri et al., 2005). An important performance component in XCO is the ability to generate a relatively high power output of short duration at key points during the race, such as the mass start, steep climbs, when sprinting to pass slower riders or in the final sprint of a race (Baron, 2001). Based on previous research, it appears that the effects of anaerobic power on competitive performance should be further investigated, as it may have implications for training and testing of XCO cyclists (Impellizzeri and Marcora, 2007; Inoue et al., 2012; Davidson et al., 2000; Machado et al., 2002).

Cyclists have traditionally included some 'sport specific' type of strength training (Jackson et al., 2007) during the preparatory period but refrained from it during the competitive season due to the potential negative impact of muscle hypertrophy on endurance performance (Rønnestad and Mujika, 2014). The traditional strength training found in both road and off-road cyclists is characterised by a high number of repetitions with low loads, which has been traditionally considered to be more 'sport specific', and thus, more beneficial for the cycling performance (Jackson et al., 2007), this together with a total absence of any strength training once the competitive season has started. On the other hand, a non-traditional strength training approach, suggests that including maximal efforts (high loads) with a low number of repetitions and to further maintain part of these sessions during the season (Rønnestad et al., 2010b) may be more beneficial for the cyclist. However, empiric data confirming that

adding strength training would enhance the neuromuscular and anaerobic characteristics of XCO cyclists are lacking.

To the best of our knowledge, previous studies have focused on the effects of concurrent training in road cycling, while off-road cycling has received no or limited scientific attention. Thus, the purpose of this study was to examine the effect of supplementing endurance training with two different strength training periodizations and its effect on aerobic and anaerobic parameters during the preparatory and competitive period of off-road cyclists.

Materials and methods
Participants
Fourteen well-trained XCO cyclists volunteered to participate in the present study. Because of injuries and illnesses unrelated to the study protocol, 3 participants withdrew before completion of the study. The remaining 11 participants (mean ± SD; age 31.4 ± 6.5 yr; stature 177.7 ± 7.2 cm; body mass 71.1 ± 9.6 kg; and VO2max 61.6 ± 6.9 mL·kg-1·min-1) were divided according to initial values of VO2max into a maximal strength training group (MS, n = 5) and an endurance strength group (ES, n = 6). Participation was limited to individuals who had at least 5 years of consistent cycling training and had not performed lower-body resistance training for at least 6 months before the study. All participants were competing at a regional and national level in their corresponding age category. The study was approved by the University Ethics Committee and written informed consent was obtained from all the participants.

Study Design
The randomized controlled study spanned over the preparatory period and during the first two months of the competitive season of well-trained off-road cyclists. The study was designed to compare the effects of two different strength training approaches, one traditional approach (endurance strength = ES) where cyclists only perform strength training twice a week in the off-

Table 1. Overall training guidelines for both groups during the preparatory period (A) and during the competitive period (B)

A (weeks 1-8)

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Rest	*Strength Training* 1h Road Bike	2h-2:30h MTB with 4-6 x 30" 90% HRmax	*Strength Training* 1h Road Bike	2h-2:30h Road bike with 2x5-10km at low cadence	3-4h MTB	3-5h Road Bike

B (weeks 9-16)

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Rest	*Strength Training** 1:30h Road Bike	2h-2:30h MTB with 4-6 x 30" 90% HRmax	2h Road Bike	Rest	1:30h MTB	XCO Race

*Only for the MS group. MTB = Mountain Bike; HRmax = Maximal Heart Rate; XCO = Cross Country.

season (weeks 0-8) in a low-load/high-rep fashion, and one non-traditional approach (maximal strength = MS) where strength training was done twice a week in

Table 2. The strength training program for the ES and the MS groups over the entire 16-week period.

Group	Week 0	Week 1	Week 2	Week 3-4	Week 5-6	Week 7-8	Week 9-16
ES	3x20RM	3x20RM	3x20RM	3x18RM	3x16RM	3x14RM	None
MS	3x20RM	3x8RM	3x7RM	3x6RM	3x5RM	3x4RM	2x5 (85%RM) & 1x6RM

the off-season (weeks 0-8) and further maintained once a week throughout the competitive season (weeks 8-16) in a high-load/low-rep fashion. Since it was conducted throughout 16 weeks and only well-trained off-road cyclists were within the scope of this research, only a very small number of subjects could be recruited, thus, the current study is considered as a pilot. The measurements were conducted at three time points: the first ones were conducted at the beginning of a 8-week preparatory period (PRE); the second ones were performed at the end of the preparatory period and beginning of the competitive period (MID); and the final testing was done 8-weeks after the start of the competitive period (POST). All the subjects were required to attend 2 testing sessions at each time-point: On the first day, the anthropometric profile was determined and the maximal cycle ergometer test was carried out. At least 48 h later, maximal strength performance was assessed and the Wingate test performed. Subjects were instructed to refrain from intense exercise on the day preceding a test. The measurements were then repeated after 8 and 16 weeks and performed at the same time of the day (± 2 h).

Training
The endurance training was similar in both groups and is described in Table 1. Subjects were requested to report the distance, duration, as well as mean and maximal heart rate of each training session. Training load was then quantified using the TRIMP method (Banister, 1991).Before the first intervention period, cyclists carried out two sessions of strength training to allow the subjects an adaptation period to become familiar with proper lifting technique and to limit muscle soreness after the first official training sessions. During the first intervention period, two sessions per week were performed, with three sets of each of the exercises (Half-Squat in Multipower, Leg Curl, and single-leg Leg Press) with a resting time between sets of 3min. The MS group followed a similar strength training program described elsewhere (Rønnestad et al., 2010a), while the ES group followed a high-rep/low-load program similar to Jackson et al. (2007) protocol used with road cyclists, and which reflected the current strength training programs found within off-road cyclists. Description of the training can be seen in Table 2. The same researcher supervised all strength training sessions, and loads and technique were strictly monitored. Weights were determined based on NSCA's 1RM estimation table (Baechle and Earle, 2008) and

further adjusted to the individual capabilities if the subjects were able or unable to lift the weight for the prescribed number of repetitions. The time period between strength sessions was at least 48 h during the preparatory period. During the competitive period, the maintenance session was only done once a week by the MS group 48-72 h after the competition. Subjects were encouraged to lift the weight with the emphasis on maximal mobilization in the concentric phase as far as the technique was not compromised, while the eccentric phase was controlled. The strength training exercises focused on the muscles involved in the primarily power generating phase. Additionally, one-legged Leg Press was chosen for the present study since cyclists work each leg alternately when cycling, and a force deficit has been observed during bilateral exercises (Cresswell and Ovendal, 2002),. Because the protocol was designed to improve cycling performance and the peak force during pedalling occurs at approximately a 100º knee angle (Coyle et al., 1991), strength exercises were performed with a knee angle between 90º and almost full extension.

Anthropometric profile
Anthropometric profile was assessed with the skinfold technique. The same ISAK level I anthropometrist obtained all the measurements in standardized order. Skinfold thickness was obtained with an AW610 Holtain (British Indicators Ltd., Pembrokeshire, UK) limiting caliper (0-48 mm, accurate to 0.2 mm). Seven skinfolds were measured (triceps, subscapular, suprailial, chest, abdomen, front thigh and medial calf), and the subsequent fat mass percentage was calculated using the method proposed by Withers et al. (Withers et al., 1987). The mean of two readings taken at each site was used for the data analysis.

Aerobic power and VO$_2$max
All cycling tests were performed on the same electromagnetically braked cycle ergometer (Monark 839 Ergomedic; Monark, Vansbro, Sweden), which was adjusted according to each cyclist preferences for seat height, handlebar distance and pedal clips. Before each test session, the Spiroergometer (K4b2; COSMED s.r.l, Rome, Italy) was calibrated, and oxygen consumption was measured breath by breath throughout the test, together with heart rate (HR) (Polar, Kempele, Finland). Blood lactate (Lactate Scout, EKF Diagnostics GmbH, Magdeburg, Germany) was obtained from the ear lobe during the last thirty seconds of each stage and at the end of the test. The test

started with a 5 min step at 100 W, after which it increased to 150 W, and from then on, it increased 25 W every two minutes until exhaustion. The subjects were instructed to maintain a comfortable cadence between 80-90 rpm throughout the test. The test was used to determine Wmax, VO2max and lactate threshold. Wmax was calculated as the mean power output during the last two minutes of the test, as described elsewhere (Rønnestad et al., 2010a). VO2max was defined as the maximal average value over 30 s, and was considered as maximum if RER was higher than 1.1, attainment of 10 b·min-1 within predicted HRmax was achieved or VO2 reached a plateau. The power output at 4 mmol·L-1 (LT4.0) was calculated from the relationship between [la-] and power output using linear regression between data points (Newell et al., 2007).

Maximal Strength Test

Maximal strength was measured in each of the three exercises with the following order: half squat, leg curl and unilateral leg press. Only unilateral leg press was tested in the POST testing because of possible injury risks associated with performing maximum leg curl and squat testing in the middle of the season in the ES group. Participants performed a standardized protocol consisting of 10 min warm-up on a cycle ergometer followed with 3 warm up sets with gradually increasing load (50% body mass - 12 reps; 70%- 8 reps; 85%- 6 reps). Then subjects started their first attempt, if they were able to lift the weight more than 6 times, they were requested to stop and rest for 3 min before the next attempt. If the 1RM was not achieved in 3 sets, and a value of 2-6 RM was recorded, the latter value was used to estimate the 1RM (Baechle and Earle, 2008). The depth of the half squat, leg curl and leg press was set to a knee angle of 90º.

Wingate test

The 30-s Wingate test was performed on the same cycle ergometer as the VO2max test (Monark

839 Ergomedic; Monark, Vansbro, Sweden). Braking resistance was set to 0.75 Nm·kg-1 (Bar-Or, 1987). The test was performed 30 min after the RM strength test, and participants had a 10 min warm-up before the start of the test. Participants were told to stop pedalling after the warm-up and after a 30 s rest, cyclists started from the stopped condition by the order of the investigator. Cyclists were instructed to go as hard as possible from the start until the end of the test, and to remain seated throughout the test. Verbal encouragement was constantly provided from the test personnel. Cyclists received feedback at the 10 s and 20 s of the test. Sampling rate was 1 Hz. The variables obtained from this test were: Peak Power (PP) as the highest single power value; Mean Power (MP) as the average power over the test; Highest Mean Power over 5 s (PB5) as the best 5 s value registered; Mean Power over the last 5 s (PL5) as the last 5 s of the test; and Fatigue Index

Table 3. Changes in 1RM leg press in the left and right leg over the entire 16-week period.

	PRE	%	MID	%	POST
MS					
Left leg	98.8 ± 28.7	+12.7 (0.44)	111.4 ± 27.0	+4.3 (0.17)	116.2 ± 26.7*
Right leg	99.0 ± 26.3	+16.5 (0.62)	115.3 ± 24.9†	+0.8 (0.04)	116.2 ± 26.5*
ES					
Left leg	102.8 ± 24.8	+4.7 (0.19)	107.6 ± 16.7	-16.4 (-1.05)	90.0 ± 12.9§
Right leg	106.1 ± 20.7	+7.8 (0.40)	114.4 ± 19.7	-15.4 (-0.89)	96.8 ± 15.2§

Effect sizes are shown in brackets
*p< 0.05, significant difference pre and post test
†p<0.05, significant difference between pre and middle test
§p<0.05, significant difference between middle and post test

Table 4. Changes in aerobic parameters over the entire 16-week period.

	PRE	Effect Size	MID	Effect Size	POST
MS group					
VO$_2$max(ml·kg^{-1}·min^{-1})	60.9 ± 7.2	-0.15	59.8 ± 7.3	0.01	59.9 ± 3.6
Wmax (W)	329.4 ± 22.2	-0.11	326.9 ± 33.4	-0.07	324.4 ± 36.1
Wmax BM (W·kg^{-1})	4.47 ± 0.4	-0.05	4.45 ± 0.3	-0.27	4.38 ± 0.3
LT$_{4.0}$ (W)	272.0 ± 24.5	-0.16	268.2 ± 32.5	-0.04	266.7 ± 24.6
HRmax	188.2 ± 8.9	-0.09	187.4 ± 8.3	-0.79	180.8 ± 8.7
La Max (mmol·L^{-1})	9.1 ± 1.4	0.60	9.9 ± 1.6	0.08	10.0 ± 3.3
ES group					
VO$_2$max(ml·kg^{-1}·min^{-1})	62.0 ± 7.4	0.34	65.0 ± 10.9	-0.18	63.9 ± 8.5
Wmax (W)	333.1 ± 37.9	0	333.1 ± 43.9	-0.31	319.4 ± 38.4
Wmax BM (W·kg^{-1})	4.91 ± 0.5	-0.05	4.89 ± 0.6	-0.29	4.72 ± 0.6
LT$_{4.0}$ (W)	251.9 ± 37.2	0.29	262.9 ± 33.9	0.19	269.2 ± 34.8
HRmax	187.0 ± 12.1	-0.20	184.6 ± 11.0	-0.33	181.0 ± 13.9
La Max (mmol·L^{-1})	10.4 ± 2.9	0.14	11.4 ± 2.8	-0.58	9.0 ± 3.5

Effect size calculated within groups between PRE-MID and MID-POST as [(Posttest mean – Pretest mean)/ Pretest SD]. The magnitude of the effect is determined based on Rhea37 scale: <0.25 Trivial, 0.25-0.5 Small, 0.5-1.0 Moderate, and >1.0 Large.

BM = Variable adjusted to body mass

(FI) as the percentage of difference between PB5 and PL5. All parameters were expressed in absolute values and relative to the body mass.

Statistical analysis

The data was analyzed using SPSS 19 (SPSS Inc, Chicago, USA). All data are presented as mean ± SD. Data normality was examined using the Kolmogorov-Smirnov statistic with a Lilliefors correction. A mixed-design ANOVA was carried out for each dependent variable, with the within-subject factor "training effect" (3 levels: PRE, MID, POST) and the between-subject factors

Table 5. Changes in anaerobic parameters over the entire 16-week period.

	PRE	Effect Size	MID	Effect Size	POST
MS group					
Peak Power (W)	820.2 ± 69.8	**0.46**	852.0 ± 106.9	**-0.05**	846.8 ± 92.4
Peak Power BM (W·kg^{-1})	11.12 ± 0.9	**0.58**	11.65 ± 0.8†	**-0.18**	11.52 ± 0.8
Mean Power (W)	585.1 ± 55.3	**0.37**	605.4 ± 102.0	**-0.03**	601.9 ± 59.9
Mean Power BM (W·kg^{-1})	7.92 ± 0.6	**0.44**	8.21 ± 0.6	**-0.10**	8.14 ± 0.6
Power Best 5s (W)	770.6 ± 43.9	**0.22**	780.1 ± 92.2	**0.31**	808.3 ± 87.0
Power Best 5s BM (W·kg^{-1})	10.47 ± 1.0	**0.15**	10.61 ± 0.4	**0.70**	10.92 ± 0.6
Power Last 5s (W)	520.4 ± 74.0	**0.05**	523.8 ± 75.9	**-0.03**	521.7 ± 69.0
Power Last 5s BM (W·kg^{-1})	7.02 ± 0.5	**0.17**	7.11 ± 0.4	**-0.20**	7.03 ± 0.3
Fatigue Index (%)	32.7 ± 6.0	**-0.05**	33.0 ± 3.2	**-0.80**	35.6 ± 2.4
ES group					
Peak Power (W)	720.2 ± 120.1	**0.05**	725.8 ± 105.1	**0.01**	726.5 ± 125.3
Peak Power BM (W·kg^{-1})	10.52 ± 1.2	**0.13**	10.66 ± 1.0	**0.22**	10.88 ± 1.1
Mean Power (W)	529.1 ± 73.5	**0.02**	530.9 ± 58.2	**-0.26**	515.6 ± 66.9
Mean Power BM (W·kg^{-1})	7.74 ± 0.6	**0.14**	7.82 ± 0.5	**-0.37**	7.62 ± 0.5
Power Best 5s (W)	688.1 ± 112.3	**0.18**	708.0 ± 99.8	**0.04**	704.4 ± 115.9
Power Best 5s BM (W·kg^{-1})	10.05 ± 1.0	**0.27**	10.32 ± 0.9	**0.09**	10.39 ± 1.0
Power Last 5s (W)	488.1 ± 53.2	**-0.21**	477.2 ± 35.2	**-0.68**	453.2 ± 40.7*
Power Last 5s BM (W·kg^{-1})	7.15 ± 0.4	**-0.26**	7.05 ± 0.6	**-0.58**	6.73 ± 0.5
Fatigue Index (%)	28.3 ± 6.7	**-0.52**	31.8 ± 7.4	**-0.39**	34.7 ± 7.8*§

Effect size calculated within groups between PRE-MID and MID-POST as [(Posttest mean – Pretest mean)/ Pretest SD]. The magnitude of the effect is determined based on Rhea37 scale: <0.25 Trivial, 0.25-0.5 Small, 0.5-1.0 Moderate, and >1.0 Large.
BM = Variable adjusted to body mass
*p< 0.05, significant difference pre and post test
†p<0.05, significant difference between pre and middle test
§p<0.05, significant difference between middle and post test

"group" (2 levels: MS and ES). This was followed by a Bonferroni post hoc test. The level of significance was set at p < 0.05. Effect sizes (ES) were used to examine the magnitude of change over the intervention period (Cohen, 1988), with inferences made using the proposed criteria for highly trained athletes (Rhea, 2004).

Results

Body mass remained unchanged in both groups after the treatment (MS: 74.4 ± 11.0 kg vs 74.3 ± 9.8 kg; ES: 68.4 ± 8.2 kg vs 67.7 ± 9.2 kg). No statistical differences were observed in lean body mass after the training in any group. Body fat percentage was significantly decreased in both groups after the intervention (MS: 10.3 ± 2.0 % vs 8.7 ± 0.9 %; ES: 10.5 ± 1.7 % vs 9.1 ± 1.2 %). Weekly TRIMP values were not statistically different between groups (694 ±

109 vs 746 ± 93 AU, P > 0.05), neither were weekly training volume (542 ± 72 vs 631 ± 72 min, P > 0.05) between MS and ES group.

The values for 1RM leg press are presented in table 3. Leg Press 1RM in MS group increased significantly from PRE to MID for the right leg (P = 0.004) and from PRE to POST in left and right leg respectively (P = 0.039; P = 0.011), while in the ES group it did not increase significantly from PRE to MID and decreased from MID to POST in both left and right leg (P = 0.02; P = 0.001). When both legs were analysed together, the MS group increased the 1RM significantly from PRE to MID (P = 0.006; +15.8%) and from PRE to POST (P = 0.01; + 19%), while the ES group only decreased significantly between MID and POST (P = 0.003; -16.1%)

Changes in endurance parameters obtained from the aerobic test are shown in table 4. No significant differences were obtained in any endurance parameter

throughout the 16 weeks. However, the effect size analysis showed a small effect in VO2max and LT4.0 for the ES group between PRE and MID (+ 4.1%, + 4.3% effect size = 0.34, 0.29). Additionally, the effect size analysis of Wmax showed no differences between PRE and MID for both the MS and the ES group, but there was a small negative effect in Wmax for the ES group between MID and POST (- 4.1%; effect size = - 0.31).

Data obtained from the Wingate test are presented in table 5. PP adjusted to body mass showed a significant increase for the MS group between PRE and MID test (P = 0.019; + 4.8%; effect size = 0.58), while there were no significant difference in the ES group in any time period. There was no statistical change in MP or PB5 for the MS or the ES group in neither MID or POST. However, the effect size analysis showed a moderate increase in PB5 adjusted to body mass for the MS group between MID and POST (+ 2.9%; effect size = 0.70). There was a significant decrease in PL5 adjusted to body mass for the ES group between MID and POST (P = 0.043; - 4.3%; effect size = -0.68) and a large effect size from PRE to POST (- 5.3%; effect size = -1.12). Fatigue index also showed a significant increase in ES group from MID to POST (P = 0.026) and between PRE and POST (P = 0.006), while there is a moderate increase (effect size = 0.80) in the MS group from MID to POST, with no statistically significance.

Discussion

To the best of our knowledge, this is the first study to investigate the effects of adding a traditional versus a non-traditional strength training approach throughout a regular season in off-road cyclists. The major findings of this study were: (I) all anaerobic characteristics were maintained throughout the competitive season following a non-traditional strength approach, while PL5 decreased and FI was increased following a traditional approach; (II) the differences in the strength training approach did not affect significantly any aerobic parameter throughout the 16 weeks; (III) leg strength, measured as 1RM, was significantly increased after 8 weeks of maximal strength training and maintained during the competitive period by having only one maintenance session per week, while no changes were observed when endurance-strength training was added.

According to our results, the MS group showed a significant improvement in PP from PRE to MID, and effect size analysis show a moderate increase in PB5 from PRE to POST, that would enhance the athlete performance over the continuous intermittent uphill climbs usually found in XCO competitions (Davison et al., 2000). Our data also suggest that the inclusion of 1 session of maximal strength per week during the competitive session is a potential way of maintaining the benefits obtained from strength training during the pre-season and, thus, preventing a drop in anaerobic parameters, such as those found in the ES group (FI, PL5). We suggest that in XCO -where the anaerobic contribution is higher than in more steady competitions as road cycling, running or triathlon- the importance of improving and maintaining the anaerobic characteristics throughout the season would be of great importance for maximising performance, thus being strength training an interesting addition to the usual training of these cyclists. The adaptive mechanisms responsible of improving endurance performance by adding strength training to the usual endurance training program may have different neuromuscular sources (i.e. changes in voluntary activation or selective hypertrophy of type IIa fibers) (Aagaard et al., 2011; Eklund et al., 2014). These potential mechanisms may have been responsible for the improvements in the different anaerobic markers found in the study such as PP and PB5, and we suggest that this could be reflected in improved performance over short distances as shown in previous studies (Inoue et al., 2012; Davison et al., 2000; Machado et al., 2002).

In our study there was no advantage of maximal strength training over a more traditional endurance strength training on endurance performance parameters like Wmax or VO2max, which is in line with previous investigations (Levin et al., 2009). However, we suggest that cyclists started the intervention period with a moderate to high level, so there was no much room left for further development in maximal aerobic performance over the intervention. Furthermore, when looking at effect sizes, during the first 8 weeks the ES group had a small improvement in the relative VO2max (+ 4.1%; Effect Size = 0.34), but the MS group was able to maintain the same level over the 16 weeks, while the ES group returned to PRE values, suggesting that 1 session of maximal strength training to the normal endurance training would not compromise their performance, and can potentially help maintain the endurance parameters over the season. On the other hand, as the ES group did not perform endurance strength over the season, it remains to be investigated whether endurance strength would have helped to further develop the aerobic and anaerobic parameters when maintaining one session over the season.

Our findings showed a significant gain in maximal strength only in the MS group following the present resistance training protocol during the first 8 weeks, and by maintaining only 1 maximal strength training session per week, these subjects were able to maintain the benefits of strength training over the second 8-week period. However, the ES group showed a significant decrease in strength during the latter 8-week period. Previous data suggest that a specific muscle atrophy stimulus may take place following regimens of intensive endurance training (Kraemer et al., 1995), and this may be prevented by the maintenance of maximal strength training during the season, indicating the importance of strength training even during the competitive period. Furthermore, one of the main reasons why endurance athletes refrain of doing resistance training is the fear of gaining weight. Our results are in concordance with previous studies (Rønnestad and Mujika, 2014), showing that endurance

athletes involved concurrently in resistance training do not significantly gain weight and, thus, no effects on the relative values of endurance performance like VO2max or Wmax are to be expected.

When interpreting the present findings one should bear in mind that the total number of subjects was low and, thus, the study design is considered as a pilot. Thus, the findings of the present study should be evaluated with great caution, and future studies should focus on investigating the adaptations following a non-traditional strength approach with larger sample sizes, and how this might impact both aerobic and anaerobic performance over the off-road cycling season.

Practical applications

The results of the present study suggest the importance of adding non-traditional strength training for maintaining or possibly improving anaerobic characteristics that may be crucial in the final performance of endurance events such as off-road cycling. In MTB XC, the start of the race and successive attacks require the ability to produce a really high power output. Furthermore, with the recent inclusion of Cross-country Eliminator -where the distance of the event is 500m to 1000 m, with an ending time of 1:30-2:00 min- we reinforce the importance of methodologies, such as strength training, aiming at improving the anaerobic characteristics.

Conflict of interest
None declared

References

1. Aagaard P, Andersen JL. (2010) Effects of strength training on endurance capacity in top-level endurance athletes. Scand J Med Sci Sports. 20(s2): 39-47.
2. Aagaard P, Andersen J, Bennekou M, Larsson B, Olesen JL, Crameri R, Magnusson SP, Kjaer M. (2011) Effects of resistance training on endurance capacity and muscle fiber composition in young top-level cyclists. Scand J Med Sci Sports. 21(6): e298-307.
3. Baechle TR, Earle RW. (2008) Essentials of strength training and conditioning: National strength and conditioning association. Third edition. Champaign, IL: Human Kinetics. pp. 382-412.
4. Banister E.W. (1991) Modeling elite athletic performance. In: MacDougall, J. D., Wenger, H. A., & Green, H. J. Physiological testing of the high-performance athlete. Champaign, Ill.: Human Kinetics. pp. 403-425.
5. Baron R. (2001) Aerobic and anaerobic power characteristics of off-road cyclists. Med Sci Sports Exerc. Aug; 33(8): 1387-93.
6. Bar-Or O. (1987) The Wingate anaerobic test an update on methodology, reliability and validity. Sports Medicine. 4(6): 381-94.
7. Bieuzen F, Lepers R, Vercruyssen F, Hausswirth C, Brisswalter J. (2007) Muscle activation during cycling at different cadences: effect of maximal strength capacity. Journal of Electromyography and Kinesiology. 17(6): 731-8.
8. Bishop D, Jenkins DG, Mackinnon LT, McEniery M, Carey MF. (1999) The effects of strength training on endurance performance and muscle characteristics. Med Sci Sports Exerc. Jun; 31(6): 886-91.
9. Cohen J. (2013) Statistical power analysis for the behavioral sciences. Academic press.
10. Coyle EF, Feltner ME, Kautz SA, Hamilton MT, Montain SJ, Baylor AM, Abraham LD, Petrek GW. (1991) Physiological and biomechanical factors associated with elite endurance cycling performance. Med Sci Sports Exerc. Jan; 23(1): 93-107.
11. Cresswell AG, Ovendal AH. (2002) Muscle activation and torque development during maximal unilateral and bilateral isokinetic knee extensions. J Sports Med Phys Fitness. Mar; 42(1): 19-25.
12. Eklund D, Pulverenti T, Bankers S, Avela J, Newton R, Schumann M, Häkkinen K. (2015) Neuromuscular adaptations to different modes of combined strength and endurance training. Int J Sports Med. Feb; 36(2): 120-9.
13. Häkkinen K, Alen M, Kraemer W, Gorostiaga E, Izquierdo M, Rusko H, Mikkola J, Häkkinen A, Valkeinen H, Kaarakainen E, Romu S, Erola V, Ahtiainen J, Paavolainen L. (2003) Neuromuscular adaptations during concurrent strength and endurance training versus strength training. Eur J Appl Physiol. 89(1): 42-52.
14. Impellizzeri FM, Marcora SM. (2007) The physiology of mountain biking. Sports medicine. 37(1): 59-71.
15. Impellizzeri FM, Marcora SM, Rampinini E, Mognoni P, Sassi A. (2005) Correlations between physiological variables and performance in high level cross country off road cyclists. Br J Sports Med. Oct; 39(10): 747-51.
16. Inoue A, Sa Filho AS, Mello FC, Santos TM. (2012) Relationship between anaerobic cycling tests and mountain bike cross-country performance. J Strength Cond Res. Jun; 26(6): 1589-93.
17. Izquierdo M, Häkkinen K, Ibanez J, Kraemer WJ, Gorostiaga EM. (2005) Effects of combined resistance and cardiovascular training on strength, power, muscle cross-sectional area, and endurance markers in middle-aged men. Eur J Appl Physiol. 94(1-2): 70-5.
18. Jackson NP, Hickey MS, Reiser RF. (2007) High resistance/low repetition vs. low resistance/high repetition training: effects on performance of trained cyclists. J Strength Cond Res. Feb; 21(1): 289-95.
19. Joyner MJ, Coyle EF. (2008) Endurance exercise performance: the physiology of champions. J Physiol. 586(1): 35-44.
20. Kraemer WJ, Patton JF, Gordon SE, Harman EA, Deschenes MR, Reynolds K, Newton RU, Triplett NT, Dziados JE. (1995) Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. J Appl Physiol. Mar; 78(3): 976-89.
21. Levin GT, Mcguigan MR, Laursen PB. (2009) Effect of concurrent resistance and endurance training on physiologic and performance parameters of well-trained endurance cyclists. J Strength Cond Res. Nov; 23(8): 2280-6.
22. Machado C, Caputo F, Lucas R, Denadai B. (2002) Physiological and anthropometrical factors associated with uphill off-road cycling performance. Braz J Sci Mov. 10(4): 35-40.
23. Mikkola J, Rusko H, Izquierdo M, Gorostiaga EM, Hakkinen K. (2012) Neuromuscular and cardiovascular adaptations during concurrent strength and endurance training in untrained men. Int J Sports Med. Sep; 33(9): 702-10.
24. Mikkola JS, Rusko HK, Nummela AT, Paavolainen LM, Hakkinen K. (2007) Concurrent endurance and explosive type strength training increases activation and fast force production of leg extensor muscles in endurance athletes. J Strength Cond Res. May; 21(2): 613-20.
25. Millet GP, Jaouen B, Borrani F, Candau R. (2002) Effects of concurrent endurance and strength training on running economy and VO~ 2 kinetics. Med Sci Sports Exerc. 34(8): 1351-9.
26. Newell J, Higgins D, Madden N, Cruickshank J, Einbeck J, McMillan K, McDonald R. (2007) Software for calculating blood lactate endurance markers. J Sports Sci. 25(12): 1403-9.
27. Paavolainen L, Hakkinen K, Hamalainen I, Nummela A, Rusko H. (1999a) Explosive-strength training improves 5-km running time by improving running economy and muscle power. J Appl Physiol. May; 86(5): 1527-33.
28. Paavolainen LM, Nummela AT, Rusko HK. (1999b) Neuromuscular characteristics and muscle power as determinants of 5-km running performance. Med Sci Sports Exerc. Jan; 31(1): 124-30.
29. Rhea MR. Synthesizing strength and conditioning research: the meta-analysis. (2004) J Strength Cond Res. Nov; 18(4): 921-3.

30. Davison R, Swan D, Coleman D, Bird S. (2000) Correlates of simulated hill climb cycling performance. J Sports Sci. 18(2): 105-10.

31. Rønnestad BR, Hansen EA, Raastad T. (2010a) Effect of heavy strength training on thigh muscle cross-sectional area, performance determinants, and performance in well-trained cyclists. Eur J Appl Physiol. 108(5): 965-75.

32. Rønnestad BR, Hansen EA, Raastad T. (2010b) In-season strength maintenance training increases well-trained cyclists' performance. Eur J Appl Physiol. 110(6): 1269-82.

33. Rønnestad BR, Hansen J, Hollan I, Ellefsen S. (2015) Strength training improves performance and pedaling characteristics in elite cyclists. Scand J Med Sci Sports. Feb; 25(1): e89-98

34. Rønnestad BR, Mujika I. (2014) Optimizing strength training for running and cycling endurance performance: A review. Scand J Med Sci Sports. 24(4): 603-12.

35. Sedano S, Marin PJ, Cuadrado G, Redondo JC. (2013) Concurrent training in elite male runners: the influence of strength versus muscular endurance training on performance outcomes. J Strength Cond Res. Sep; 27(9): 2433-43.

36. Storen O, Helgerud J, Stoa EM, Hoff J. (2008) Maximal strength training improves running economy in distance runners. Med Sci Sports Exerc. 40(6): 1087.

37. Sunde A, Storen O, Bjerkaas M, Larsen MH, Hoff J, Helgerud J. (2010) Maximal strength training improves cycling economy in competitive cyclists. J Strength Cond Res. Aug; 24(8): 2157-65.

38. Taipale R, Mikkola J, Vesterinen V, Nummela A, Häkkinen K. (2013) Neuromuscular adaptations during combined strength and endurance training in endurance runners: maximal versus explosive strength training or a mix of both. Eur J Appl Physiol. 113(2): 325-35.

39. Withers R, Craig N, Bourdon P, Norton K. (1987) Relative body fat and anthropometric prediction of body density of male athletes. Eur J Appl Physiol Occup Physiol. 56(2): 191-200