Section: Original Investigation

Article Title: The Effects of a Sports Specific Maximal Strength and Conditioning Training on Critical Velocity, Anaerobic Running Distance and 5-km Race Performance

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Abstract

Purpose: To investigate the effects of a sports specific maximal 6-week strength and conditioning program on Critical Veloicty (CV), anaerobic running distance (ARD) and 5-km time trial performance (TT). **Methods**: 16 moderatly trained, recreational endurance runners were tested for CV, ARD and TT performances on three separate ocassions (baseline, mid and post study). Design: Partiticpants were randomly allocated into a strength and conditioning group (S&C; n=8) and a comparison, endurance training only group (EO; n=8). During the first phase of the study (6 weeks), the S&C group performed a concurrent maximal strenght and endurance training, whilst the EO group performed an endurance only training . After the re-test of all variables (mid study) both groups subsequently, during phase two, performed another 6 weeks of endurance only training which was followed by post study tests. **Results**: No significant change for CV was identified in either groups. The S&C group demonstrated a signficant decrease for ARD values after the first and second phase of the study. TT performances were significanly different in the S&C group after the intervention with a performance improvement of 3.62%. This performane increase returned close to baseline after the 6-week endurance only training. **Conclusion**: combining a 6-week resistance training program with endurance training significantly improves 5-km time trial performance. Removing strength training results in some loss of those performance improvements.

Key Words: time-distance relationship, exercise testing; endurance capacity, anaerobic running distance, resistance exercises

INTRODUCTION

Exercises which enhance endurance capacities are imperative in improving competitive running performance. Besides neurological and morphological changes [1,2], anaerobic factors may also play an important role in the success of endurance events [3]. A proper integration of a periodized resistance training (RT) and endurance training programme can cause such positive adaptations [4], for example changes in motor unit recruitement patterns, force development rates, anaerobic enzyme activity, stretch shortening cycle and a shift between specific fibre groups [1,2,5]. In running the combination of these changes can provide an athlete with enhanced tactical advantages, such as attacks or finals sprints, whilst potentially also affecting indices of aerobic capacity. The effects of concurrent endurance and strength and conditioning (S&C) training have shown to be an effective strategy to increase endurance performance (i.e. Ferrauti et al. [6]). Importantly, to target optimal training adaptions Jones and Bampouras [7] recommended to use a sports specific resistance training.

Another critical determinant in endurance running performances is that of a highest sustainable velocity [8]. The sustainable fastest performance intensity can be described through the power-duration relationship of the Critical Power (CP) concept. CP reflects a rate of aerobic energy reconstitution which dictates the maximal sustainable power without a progressive loss in metabolic steady-state. In running the analogous term of Critical Velocity (CV) is traditionally used, which once exceeded (i.e. under non metabolic steady-state conditions) results in the utilization of the anaerobic running distance (ARD). The depletion rate of ARD is proportional to the magnitude of velocity requirement and reflects at exhaustion the accumulation of fatigue related metabolites to a tolerable critical limit. ARD therefore reflects the maximal distance that can be performed above CV; it has however been subject to controversy about its exact nature and its reliability [9–11]. CV demarcates the boundary between the heavy and the severe exercise intensity and has been considered as a reference marker of endurance performances [12]. Marathon times for example correlate with CV. However CV generally over-predicts a mean marathon velocity, as performance intensities are located in the heavy domain, i.e. below the lactate turn point with CV being located slightly above this marker. Indeed a stronger correlation between 10-km race performances and CV intensity has been reported [13].

To date two cycling studies have investigated the effects of a strength training intervention on CP and the anaerobic work capacity (W' – the analogous of ARD). Bishop and Jenkins [14] used untrained participants who underwent a 6-week RT intervention. The researchers reported a significant increase in W' with no change in time to exhaustion (TTE) at CP and consequently proposed RT not to alter indices of endurance ability. Similar findings were described by Sawyer et al. [8] with recreational athletes who after an 8-week strength training intervention showed significant improvement of W' with no alteration of CP. In addition, TTE performed at pre-determined intensities, which are required to determine CP, were increased but did not impact on CP values. Whilst improving exercise tolerance, the researchers concluded that CP is unsuitable to track changes in endurance capacity which are elicited by strength training, whilst W' may present a better indicator of such changes. Contrarily other authors have identified CP/CV to be a valid and reliable marker of endurance capacity [15,16], which further necessitates the present study.

Whilst research has demonstrated the beneficial effects of S&C onto endurance performance, no such evidence to-date has been provided for the distance - time relationship of CV and ARD. The purpose of this study was therefore to investigate the effects of an integrated S&C program and regular endurance training in runners on CV, ARD and 5-km TT performance. As a second objective, we aimed to analyze the effects of removing the S&C training while maintaining the endurance training on CV, ARD and 5-km TT performance. Based on the findings of previous investigations we hypothesised that the addition of a S&C program results in significant changes of all measured variables. Furthermore it was hypothesized that by removing the S&C treatment, results would demonstrate a progressive loss of possible effects on all measured variables.

METHODOLOGY

Experimental Approach to the Problem

Participants

Sixteen recreational endurance runners and triathletes with a minimum of 2 years of regular training and with a frequency of 3 to 5 training sessions and a training volume of 180 – 300 min/week were randomly allocated to the experimental strength and conditioning group (S&C, n=8; 5 male and 3 female: 39 ± 5.1 yr., height 176.6 ± 8.3 cm, body mass 73.6 ± 10.6 kg, VO_2max 47.3 ± 4.8 ml/min/kg) and to an endurance training only group (EO, n=8; 6 male and 2 female: 30 ± 7.7 yr, height 174.9 ± 6.3 cm, body mass 68.7 ± 9.2 kg, VO_2max 47.0 ± 7.4 ml/min/kg)

Participants agreed to refrain from intense exercise and alcohol consumption on the day preceding any tests and not to consume a major meal or caffeine 3 hours prior to testing. In addition participants were not allowed to perform any other exercises than those required in the partaking of this investigation

All participants were notified about the study procedures, protocols, benefits and risks. A health history questionnaire was used to ensure that participants were healthy and free of any musculoskeletal injury or cardiovascular disease. The study was carried out in accordance with the guidelines contained in the Declaration of Helsinki and was approved by the institutional review board for human subjects at the University.

Design

This study utilized a two parallel-groups randomized controlled design, where two between-participant conditions S&C and EO, were tested. Participants attended the laboratory for two pre-training test sessions, where VO_2max and CV/ARD were tested. Thereafter, participants performed a 5-km TT on an outdoor track for which running time was recorded. Before the start of the study all participants performed only low intensity aerobic training (i.e. 70-85% HRmax) and they were instructed to maintain a similar training throughout the experimental period**.** Participants included in the S&C group started a 12-week experimental period that was devided into two phases: phase 1 involved a 6-week maximal S&C intervention (12 sessions) while the EO group did not perform any type of RT and continued with their normal endurance training. In phase 2, both groups only performed their regular endurance training. CV, ARD and 5-km TT performance were re-tested after phase 1 (week 8) and phase 2 (week 15). Prior to the start of the S&C program, participants of the S&C group were familiarized with the strength and conditioning exercises and the procedures of 1-RM maximum testing. Figure 1 depicts the general structure of study.

Measurements

VO_2max test

Prior to testing, resting heart rate (HR) and a blood sample from the fingertip were obtained. Samples were analysed for blood [lactate] using a Biosen C-line analyzer (EKF Diagnostics, Barleben, Germany). The incremental treadmill test (Woodway, Weil am Rhein, Germany) commenced at an initial speed of $3km{\cdot}h^{-1}$ (1% slope). After 3 minutes, the treadmill speed was increased by $1km{\cdot}h^{-1}$ every minute until participants reached volitional exhaustion. Immediately post-test, another blood sample was obtained and analysed. Throughout the test, gas was sampled continuously and analysed using a Metalyzer 3B gas analyser (Cortex, Magdeburg, Germany). Maximal aerobic consumption (VO_2max) and corresponding velocity (vVO_2max) were calculated using the highest 30-second average values over the last minute of the exercise.

Critical velocity test

Participants had to run at 90%, 100% and 105% of individual vVO2max values, using a 30 minutes recovery method between trials [11]. Following a 5-minute warm-up period at 6 km/h, the speed was rapidly increased to individual 90%, 100% or 105% vVO2max values. Subjects were strongly verbally encouraged throughout each test TTE was recorded to the nearest second. A 5-minute cool-down at a self-chosen pace was performed before passively resting for another 25 minutes. Resting HR and a fingertip capillary blood samples were obtained prior and post each TTE run. Fluid intake was permitted ad libitum. During each TTE trial, participants were cooled using an electric fan. Laboratory conditions were stable in a range of 18–22 C° with 45–55% humidity. All athletes reached their individual VO_2max value (± 1.25ml/min/kg), a post-test blood (lactate) of ≥ 8 $mmol^{-1}$ and a HR within ± 5 beats of their maximal HR values established during the VO_2max test. Linear regression was used to determine CV and ARD ($r^2 = 0.99 – 1$; SE range CV = 0.1 – $0.5 km \cdot h^{-1}$) using the distance – time relationship [(d = CV * t) + ARD], where: d = distance run and t = total running time.

5-km Time Trial

Testing was only carried out when wind speeds did not exceed 2 $m \cdot s^{-1}$ [17] and under dry conditions. To minimize biological variation [18], participants were tested at the same time of the day (± 2 h). After a 10-minute warm-up at a self-chosen pace, a 5-km run on a 400m outdoor running track was performed. Participants were instructed to perform their best effort during each 5-km TT test. Finishing times were recorded to the nearest second.

Strength and Conditioning Training (S&C)

During phase 1, the S&C group performed a 6-week RT program involving four resistance lower body exercises: romanian deadlift, parallel squat, calf raises and lunges. The programme was performed twice a week in non-consecutive days (12 sessions in total). In order to determine the training load of each of the selected exercise, participants included in S&C group performed a maximal strength test (1-RM) for all the 4 selected exercises. The 1-RM value was determined according to the methodology proposed by Baechle et al. [19]. Each S&C workout included 4 sets of 4 repetitions at 80% 1-RM per 2 min rest between sets for each exercises. Participants were instructed to perform exercises as fast as possible using a proper technique.

Statistical analysis

A descriptive analysis was performed and subsequently the Kolmogorov-Smirnov and Shapiro-Wilk test were applied to assess normality. A 2 × 3 (group × time) mixed ANOVA model was used to assess training effects (control vs. intervention) along with three repeated measures (pre vs. post vs. detraining). A 2 × 3 (group × time) mixed ANOVA model was used to test for significant differences in CV, ARD and 5- km TT performance between the two groups, along with three repeated measures (baseline, mid and post). Bonferroni-corrected post hoc analyses were performed. Generalized eta squared (η_G^2) and Cohen´s d values were reported to provide an estimate of standardized effect size (small d=0.2, η_G^2=0.01; moderate d=0.5, η_G^2=0.06; and large d=0.8, η_G^2=0.14). The significance level was set to $p<0.05$. Results are reported as mean ± SD unless stated otherwise.

RESULTS

All data were normally distributed. Table 1 shows the values measured for CV; ARD and TT for the two treatment groups.

CV showed no significant main effect of time (F(2,28)=2.14, p=0.137), η_G^2=0.003), treatment intervention (F(1,14)=0.55, p=0.47, η_G^2=0.04) or interaction between time and intervention (F(2,28)=2.22, p=0.127, η_G^2=0.003). Pairwise comparisons indicated no significant change in CV across the three testing periods for the two treatment conditions, see Figure 2. However, when comparing baseline values to those afer phases 1 and 2, S&C showed medium effect sizes (d=0.5) whereas EO showed small effect sizes (<0.2).

Statistically significant main effect of time was found (F(2,28)=10.28, p<0.001, η_G^2=0.05) for ARD values. In addition, no group (F(1,14)=2.46, p=0.139, η_G^2=0.14) or interaction (F(2,28)=1.2, p=0.315, η_G^2=0.01) resulted in statistically significant effects. However, pairwise comparisons revealed significant decreases in ARD, only for the S&C group, from baseline to post-test (t(14)=3.37, p=0.014, d=0.84) and from mid to post-test (t(14)=3.28, p=0.017, d=0.82), see Figure 3.

No significant main effect per time (F(2,28)=1.76, p=0.191, η_G^2=0.002) or treatment group (F(1,14)=0.01, p=0.931, η_G^2=0.001) was observed for 5-km TT. However, significant interaction was determined per time and treatment intervention (F(2,28)=4.18, p=0.026, η_G^2=0.005). Pairwise comparisons for the S&C group revealed a significant decrease in 5-km TT from baseline to mid-test (t(14)=4.25, p=0.002, d=1.06), followed by a significant increase from mid to post-test (t(14)=-2.74, p=0.048, d=0.68), see Figure 4. In contrast, EO group showed no statistically significant changes.

DISCUSSION

The main findings of the study were that a 6-week running specific S&C training program resulted in increased 5-km TT performances, alongside a decrease in ARD values with non-significant changes of CV. However, when CV is expressed as a percentage a meaningful increase of 2.98% after phase 1 was identified [20]. As a consequence, 5-km TT performances would theoretically decrease by a mean of 38 s. However, the 5-km TTs performed by our participants demonstrate a larger mean performance improvement of- 45 ± 24 s ($P < .05$). These findings are supported by those of Paavolainen et al. [29] who demonstrated significant 5-km TT performances changes when employing an explosive strength training program in endurance trained athletes. Such positive effects of an integrated S&C training on endurance performance have also been reported by others (i.e. Mikkola et al. [23] and Taipale et al. [24]). Mikkola et al. [23] moreover recommended heavy RT to be most effective when enhancing maximal running speed and performance. In their works, Saunders et al. [25] highlighted strength training properties which can cause an enhanced muscular ability to utilize more elastic energy, causing a reduction in energy wasted in braking force. Furthermore, in order to improve endurance performance in well trained athletes, Aargard and Anderson [26] recommended the integration of heavy RT concurrently with endurance training. Aargard and Anderson [26] demonstrated these effects by use of a 16-week concurrent strength and endurance training program in elite cyclists. Endurance capacity was enhanced by a significant 8%. Our results are furthermore supported by several other studies which have also found positive effects of combined strength and endurance training on performance [21,27,28].Rønnestad et al. [28] for example highlighted the importance of strength training integration and strength training maintenance in well-trained endurance cyclists throughout the season. However, even though both groups continued with their regular endurance training, other factors other than the implementation of the S&C training may have contributed to the increase in performance in the present study.

Different to our findings, Barnes et al. [29] cautioned male athletes to include any heavy RT during the competetive season as their results demonstrated a 0.5% 5-km TT performance decrease after a 9-week intervention. Ferranti et al. [6] despite an increase in leg strength demonstrated no aerobic performance improvement when applying a combined strength and endurance training over 8-weeks. Recently, Sawyer et al. [8] demonstrated a non-significant change in CP in untrained subjects after an 8-week strength training intervention, despite an increased exercise tolerance for all TTE trials. Similarly, Bishop and Jenkins [14] demonstrated no changes in CP and significantly enhanced values of W’ after a 6-week RT intervention. The difference in findings might be due to the choice of participants as both aforementioned studies utilized less-trained or untrained participants. Moreover, Sawyer et al. [8] applied an hypertrophy orientated resistance training program involving 3 sets at 8RM for 7 exercises (both lower and upper body) and 3 sets at 12RM for 1 other exercise (heel raises), while in our study a maximal strength resistance training was performed [19]. As identified by Mikkola et al. [23], Taipale et al. [24] and Hickson et al. [30] a RT program focused on maximal strength development appears to be most effective in enhancing indices of aerobic performance.

Rønnestad et al. [28] demonstrated attenuated performance enhancing effects when reducing a twice-weekly to a once-weekly implemented heavy resistance training during the change from preparatory to competitive season. At present our study is novel as it also investigates resulting effects when terminating the S&C program whilst continuing with an endurance training only program. Performance times for the 5-km distance within 6 weeks returned back to pre-intervention values in the S&C group with no changes in the EO group. In short, the applied S&C program caused significant performance improvements (mean difference of - 45 s, P = 0.001; fig 3), whilst when terminated resulted in a significant performance reduction towards baseline levels (mean difference + 42 s, P = .04; fig 4).

The present study identified significant changes for ARD values between baseline and phase I and between baseline and phase 2 values for the S&C but not the EO group (Fig 3). These findings are inconsistent with those of Bishop and Jenkins [14] and Sawyers et al. [8], as both studies resulted in a significant improvement in W’. Reasons for the difference in findings are likely to be multi-factorial (i.e. duration of recovery time between exhaustive trials or reliability of ARD). Researchers such Vanhatalo et al. [31] argue a more complex behavior of W’ when adapting to training. Their works suggests that enhanced values of CP result in a decrease in W’ but that the overall consequences of such changes are still beneficial to endurance performances. Dekerle et al. [9] advised prudence when interpreting values of W’ and its changes over training. Both, W’ and ARD have been demonstrated to be less reliable [10,11]. With an apparent disagreement in the literature about the true constitution and reliability of this parameter, we can only speculate about the exact cause in its decrease. Interestingly however is the continuous decrease of ARD values, whilst TT performances returned back to pre-intervention values after the termination of the S&C training. Whether reliable or valid, values of ARD decreased in the S&C group, demonstrating its independency with indices of aerobic performance.

Practical application

The study has found a meaningful endurance enhancing effect of a sports specific S&C training intervention in recreational runners. Coaches and endurance athletes are therefore advised to integrate a twice weekly heavy resistance S&C training for a minimum of 6 weeks when preparing for races. To avoid undesirable performance reduction, coaches are furthermore encouraged to maintain a lower volume resistance training thorough the competitive period. Limitations of the current study were that the volume of training was not equalized (perhaps adding another high intensity endurance training would have produced different results) and the use of recreationally trained athletes that were exercising at a low to moderate intensity. Further research should clarify if our results could be transferred to runners with different performance levels or with a more controlled and periodized training strategy.

Conclusion

A 6-week concurrent endurance and RT program using heavy load (80% 1-RM) resulted in a significant increase of the 5-km TT performances. In addition a non-significant but probably important improvement on the CV values was also observed. Future studies are recommended which investigate the optimal duration and hence an optimal performance improvement of such sports specific S&C training.

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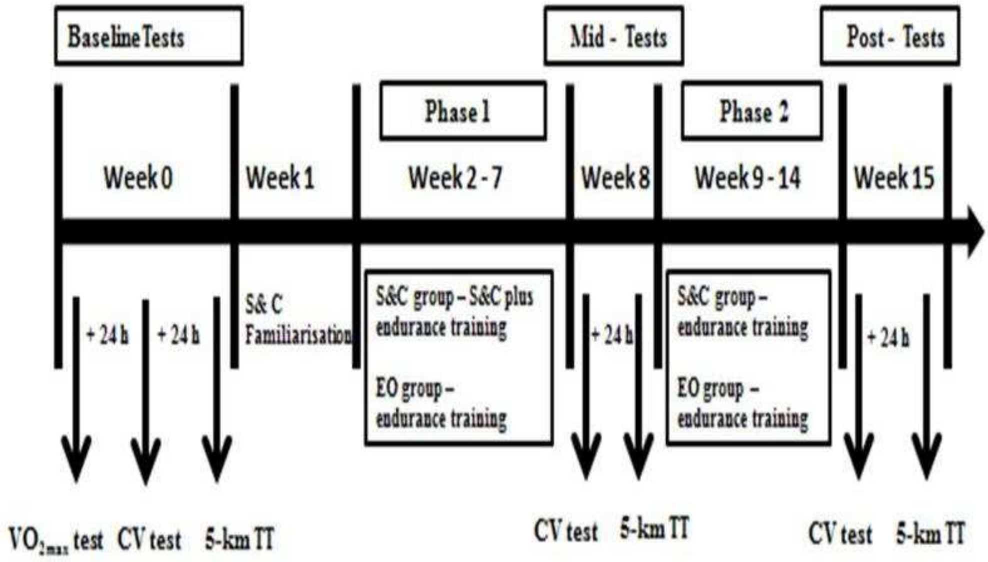

Figure 1. Testing timeline: testing period at baseline, after phase 1 and after phase 2. S&C = experimental group (performing S&C + endurance training from week 1-7 and endurance training only from week 9-14); EO = endurance-only group (endurance training from week 1-14).

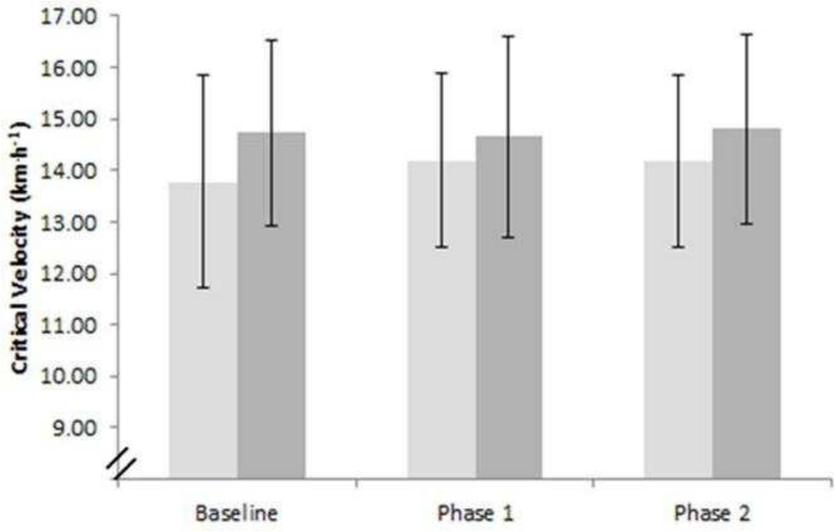

Figure 2. Values of CV (km·h^{-1}) at baseline, after phase 1 (7 weeks) and after phase 2 (14 weeks) for the S&C (light grey) and the EO (dark grey) group. (P < .05 denoted as * indicates a significant difference). After phase 1, CV increased by 2.98% and 0.14% in the S&C group while the EO group showed a -0.48% decrease and a 0.54 increase after the phase 1 and phase 2 respectively.

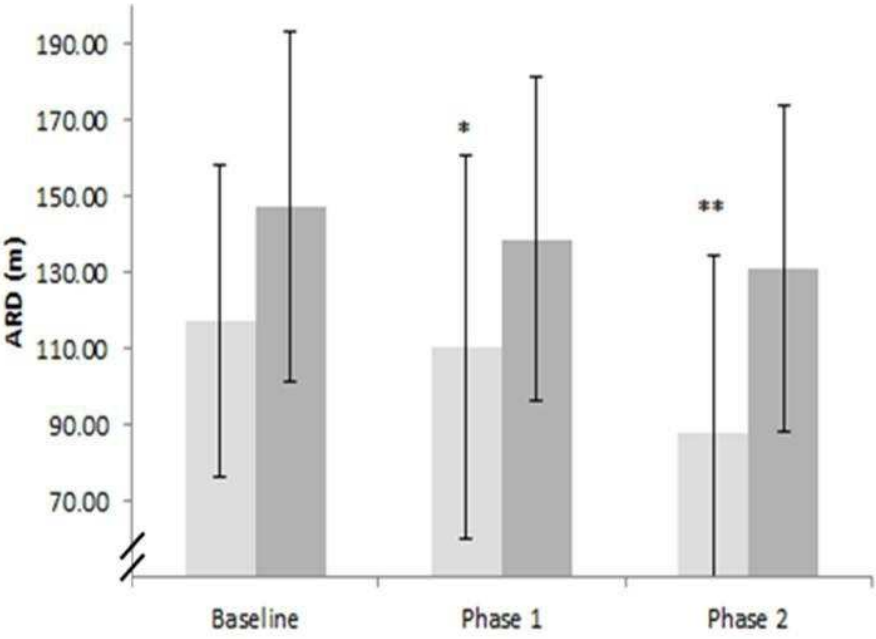

Figure 3. Values of ARD (m) at baseline, after phase 1 (7 weeks) and after phase 2 (14 weeks) for the S&C (light grey) and the EO (dark grey) group. Significant differences between ARD values for phase 1 and baseline (*) and for ARD values between phase 2 and baseline (**) for the S&C group ($P < .05$)

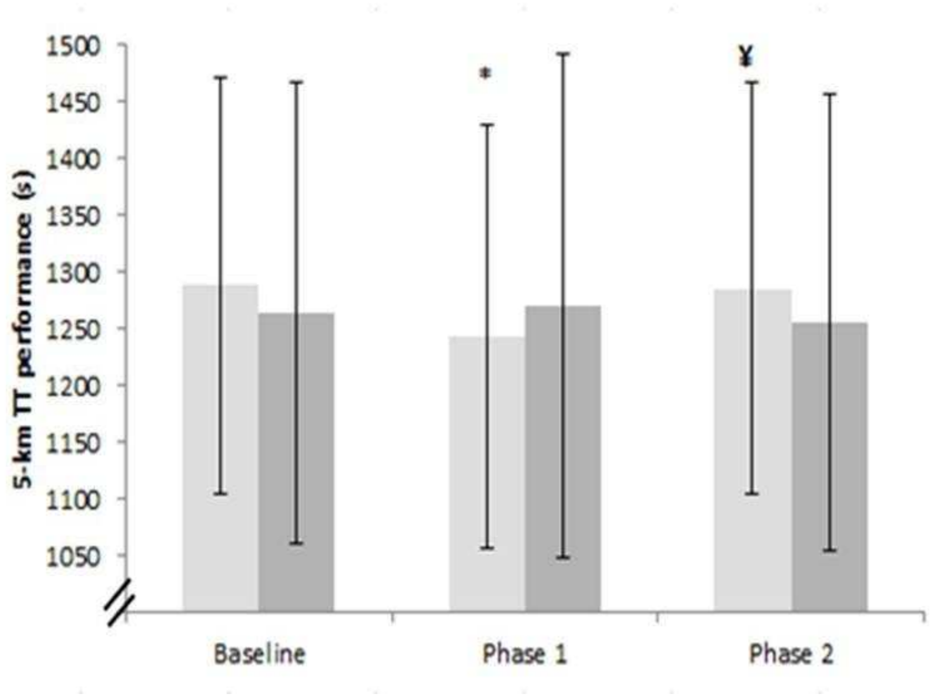

Figure 4. Illustration of the 5-km (s) time trial performance at baseline and after phase 1 and phase 2. (* significantly different from baseline value; ¥ significantly different from 7-weeks testing values).

Table 1. Baseline, Phase 1 and Phase 2 values for CV, ARD and TT for the experimental and control groups.

	Baseline		Phase 1		Phase 2	
	S&C (n=8)	EO (n=8)	S&C (n=8)	EO (n=8)	S&C (n=8)	EO (n=8)
CV ($km \cdot h^{-1}$)	13.8 ± 2.1	14.7 ± 1.8	14.2 ± 1.7	14.7 ± 1.9	14.2 ± 1.7	14.8 ± 1.8
ARD (m)	117.2 ± 41.1	147.28 ± 44.6	110.5 ± 50.3	138.88 ± 42.7	87.98 ± 46.3	130.92 ± 42.9
TT (s)	1288.3 ± 183.4	1264.4 ± 203.7	1242.9 ± 187.0	1270.3 ± 221.8	1285.1 ± 181.5	1255.8 ± 200.3