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DEVELOPMENT IN ADOLESCENT MIDDLE DISTANCE ATHLETES: A STUDY OF TRAINING LOADINGS, PHYSICAL QUALITIES AND COMPETITION PERFORMANCE

ABSTRACT

The purpose of this study was to examine changes in running performance and physical qualities related to middle distance performance over a training season. The study also examined relationships between training loading and changes in physical qualities as assessed by laboratory and field measures. Relationships between laboratory and field measures were also analyzed. This was a 9-month observational study of 10 highly trained adolescent middle distance athletes. Training intensity distribution was similar over the observational period, whereas accumulated and mean distance and training time and accumulated load varied monthly. Statistically significant ($P < 0.05$) and large effect sizes (Cohen's d) (> 0.80) were observed for improvements in: body mass (5.6%), 600 m (4.6%), 1200 m (8.7%) and 1800 m (6.1%) m time trial performance, critical speed (7.1%), $\dot{V}O_{2\max}$ (5.5%), running economy (10.1%), vertical stiffness (2.6%), reactive index (3.8%) and countermovement jump power output relative to body mass (7.9%). Improvements in 1800 m TT performance were correlated with increases in $\dot{V}O_{2\max}$ ($r = 0.810$, $p = 0.015$) and critical speed ($r = 0.918$, $p = 0.001$). Increases in $\dot{V}O_{2\max}$ and critical speed were also correlated ($r = 0.895$, $p = 0.003$). Data presented here indicate that improvements in critical speed may be reflective of changes in aerobic capacity in adolescent middle distance athletes.

KEY WORDS:

Endurance, Physiology, Loading, Critical speed, $\dot{V}O_{2\max}$

INTRODUCTION

Performance in middle distance running (800 m and 1500 m) is dependent on a range of physical qualities including: aerobic capacity ($\dot{V}O_{2\mathrm{max}}$), maximal speed, running economy and anaerobic capacity (4,23). Training programs include a variety of activities that are designed to develop these qualities.

Studies employing short-term training interventions (4 to 8 weeks) in trained runners reported effects on $\dot{V}O_{2\mathrm{max}}$ ranging from no improvements (6,27) to increases of ˜5% (5,28) indicating that longer training periods may be required to maximize endurance capacity in trained cohorts. Previous work has detailed the longitudinal training loads and associated responses in senior endurance athletes (15,17,29). However, few studies examine how training loads and strategies may influence changes in physical qualities and/or competition performance. Galbraith et al (13) examined highly trained runners over a one year period, combined with laboratory and field assessments, and reported small yet significant improvements in $\dot{V}O_{2\mathrm{max}}$ (~6.3%) and critical speed (~2.0). It was also reported that increases in critical speed were correlated with distances covered in training and time spent above lactate threshold speed. In contrast, Esteve-Lanao et al (9) reported that over a 6-month period total training time at intensities lower than ventilatory threshold was associated with improved performance during intense endurance events.

While previous work has quantified the long term training loads of senior endurance athletes (1,9,13,15,17,24,29) the training quantified consists solely of running based training. There is a growing body of evidence that strength training may improve running performance in both senior and junior endurance athletes (2,3,16,21,22) via improvements in economy. It is now typical for runners to engage in planned/structured strength and conditioning plans aimed at reducing the injury risks as well as contribute to the performance enhancements sought with running specific programs (7). Therefore, any study aimed at describing/analyzing training loads in cohorts of competitive runners' should also report and consider the contribution of any structured strength training program.

While longitudinal studies are now appearing in the literature on mature athletic cohorts there is a lack of information pertaining to adolescent athletes and how they respond to training loadings in endurance events. As such, it presently remains unclear how longitudinal loads can influence performance and associated physical qualities in adolescent populations. As a result, practitioners supporting highly trained adolescent middle distance athletes have a limited evidence-base with which to guide their programming have to rely on data on adults and/or scaled down training interventions or incomplete records.

It is not only important that training stimulus is correctly prescribed and quantified, it is also imperative that rigorous testing is conducted. The purpose of this being to ensure the training prescribed improves the physical qualities which are being targeted. Both laboratory and field testing protocols are commonplace in athletic events such as middle distance running. For comprehensive information on: $\dot{V}O_{2\max}$, metabolic responses and muscle contractile characteristics, laboratory based protocols are necessary. However, laboratory testing can be time consuming and detract from training, particularly if the testing in question must be performed on an individual basis. Furthermore, specific and costly equipment is required. As such, field testing protocols with high ecological validity are often employed as a proxy for laboratory testing. However, it is not known whether positive relationships exist between the aforementioned laboratory and field measures.

Considering the lack of information about the training content of young runners the aim of this observational study was, first, to quantify all training content of adolescent middle distance athletes over a training season. A secondary aim was to examine and report typical changes in running performance and physical qualities as assessed by laboratory and field based measures and identify the relationship with training variables. The study also sought to assess the relationships between changes in physical qualities as assessed by laboratory and field testing protocols.

METHODS

Experimental Approach to the Problem

This was an 9-month (September – May) observational study of highly trained adolescent middle distance athletes, examining training loads and corresponding changes in field and laboratory tests and competition performance. Two blocks of training were identified according to their coach's plan; block 1 consisted of training activities performed between September and January and block 2 consisted of training activities performed between February and May. Laboratory and field tests took place in September (start of season), January (end of block 1) and May (end of block 2). Competition performance was assessed when the competitive season began. Competition performance data used for analysis was recorded within a week of laboratory and field assessments conducted in January and May.

Field assessments consisted of time trials over 600 m, 1200 m and 1800 m, and laboratory tests assessed the following physical qualities: $\dot{V}O_{2\text{max}}$, lactate threshold, running economy (RE), lower body power and vertical stiffness. Data collection commenced at the start of the Sports Academy's academic year, before which participants had performed minimal structured training of any kind for ≥4 wk. Athletes were not prescribed any training by the head coach, however it is possible that some athletes performed some unmonitored training within this “off season” period.

Middle distance training was prescribed by the group’s Head Coach. Throughout training sessions participant’s heart rate (HR) was recorded using Polar RS800CX monitors (Polar Electro, Kempele, Finland) for the purposes of quantifying training load using the Edwards approach (8). Distances covered and peak achieved were also quantified via Polar RS800CX global positioning satellite (GPS) systems (Polar Electro, Kempele, Finland). HR and GPS derived variables were converted in to mean (per athlete per session) and accumulated loads for analysis.

Alongside the middle distance specific training, the athletes were prescribed a structured strength training intervention by an accredited strength and conditioning coach (one of the authors). Strength training was a combination of strength training exercises with a focus on lower body development alongside plyometric activity. The training session data was recorded via software (VisualCoaching® Pro, Visual Coaching Pty, Melbourne, Australia, V. 2.0.45.0) and each training session was supervised by at least one coach. All data are reported as exercise volume load (load per set x number of repetitions), mean exercise load (mean load per exercise) and mean repetitions completed per training set. Plyometric exercises were differentiated as either: slow or fast stretch-shortening-cycle, based on the ground contact/movement time of above/below 250 ms (Slow = Vertical box jumps, broad jumps, squat jumps; Fast = pogo jumps, depth rebound jumps) (11). All plyometric training data are reported as total contacts per type of exercise.

Subjects

Ten highly trained adolescent male middle distance athletes (mean ± standard deviation, age 16 ± 2 years (range 14 – 18 years), stature 1.73 ± 0.09 m, body mass 55.7 ± 10.1 kg, ∑7 skinfolds 42.4 ± 6.0 mm, $\dot{V}O_{2\max}$ 60.0 ± 5.4 ml·kg·min^{-1}, peak height velocity (PHV) status 1.3 ± 1.4 years, years of training 4 ± 1) from a full-time sports academy participated.

All procedures were part of the routine sports science support and were approved by the Anti-Doping Laboratory Qatar ethics committee as part of a wider growth and maturation study on young athletes [E20140000012]. Informed consent and verbal ascent was provided by a parent or guardian before enrolling in the academy.

Procedures

Aerobic capacity, lactate threshold and economy assessments

All assessments of aerobic capacity and lactate threshold were conducted via running on a motorized treadmill (Woodway ELG, Woodway Inc., WI, USA) with online breath by breath analysis (Oxycon Pro, Jaeger, CareFusion, Hoechberg, Germany). All assessments were conducted in line with standardized procedures developed in the laboratory. Briefly, initially participants completed a standardized warm up. Participants then completed 3 min incremental stages with running speed increasing 1 km·h^{-1} upon completion of each stage, starting speed was individual to each athlete and based on historical data. The submaximal protocol (3 min incremental stages as detailed above) ended when participants blood lactate concentrations (BLA) reached above 4 mmol·L^{-1}. Lactate threshold was established as the running speed at which BLA concentrations reached above 4 mmol·L^{-1}. RE was calculated in the last minute of each 3-min stage of the submaximal lactate threshold protocol as gross oxygen cost: $VO2$ (ml·kg·min^{-1}) / (workload (km·h^{-1}) / 60). For analysis purposes RE was reported as the mean RE of all stages of the individual athlete's submaximal test. Following a 10-min rest period participants began the $\dot{V}O_{2\max}$ assessment. Participants ran at the speed of their individual lactate threshold; treadmill incline was increased 1%·min^{-1} until participants reached volitional exhaustion. The athlete's effort was considered maximal if any of the following criteria were met: respiratory exchange ratio (RER) of >1.15, ≥30 s or ≥8 breath plateau in $\dot{V}O_2$ or HR within 5% of participants maximum HR for 1 min prior to the cessation of the effort. Full details of the produces are presented in Jones et al (16).

Time trials (TT)

Participants completed 3 time trials on an indoor 200-m athletics track certified by the International Association of Athletics Federations (IAAF) for international competitions. The 3 trials were over set distances of 1800 m, 1200 m and 600 m (9, 6 and 3 laps) and were kept in the same order for all observations. All 3 trials were conducted on the same day with a 20-min relief period between efforts. Participants were instructed to complete each trial in the fastest time possible. Participants were not provided with the elapsed time during the track runs. All trials were conducted at the same time of day (± 1 h) and athletes ran individually. A linear distance–time model was used to calculate critical speed (CV) and critical distance (D') from these trials (r^2 range .99–1.00, SE range CS 0.00–0.11 m/s, D′ 0–64 m). The linear distance–time model is represented by d = (CV Å~ t) + D′, where d = distance run and t = running time. This protocol is the adapted from described by Galbraith et al. (12)

Countermovement jump assessment

Participants completed 3 maximal effort jumps with the hands-on hips with ≥ 3 min recovery between efforts. The jumps were completed with each foot on series linked force plates (Kistler, type 9281CA, Winterthur, Switzerland). Kinetic data collection was managed through Bioware software (version 5.2.1.3). Only the jump with the greatest height was reported. Jump height was derived from impulse-momentum method and relative power was calculated using body mass measured on the force plate and peak power.

Vertical stiffness assessments

To assess vertical stiffness of the lower limb, a repeated jumping test was performed on dual force plates. Before the test, all participants were instructed to place their hands placed on their hips, keep their knees straight and land in a similar position to that of take-off from the force plates and minimize ground contact times. Participants performed a series of 30-40 consecutive bilateral jumps for the 2.2 Hz sub-maximal test. Jumping frequency was provided with a digital metronome (Seiko DM-50, Seiko sports life Co., Ltd, Tokyo, Japan) in visual and auditory signals. For the maximal jumping test, participant performed a series of 10-15 maximal height jumps. Details of the calculations of vertical stiffness (k_{vert}) are presented in Jones et al. (16).

Skinfold assessments

All assessments were performed in accordance with those set by the International Society for Advancement of Kinanthropometry (ISAK). Sum of the following 7 sites (mm) were used for analysis: triceps, biceps, subscapular, abdomen, suprailliac, iliac crest and mid-thigh.

Statistical analysis

Data are presented as mean ± standard deviation. Before analysis, dependent variables were assessed for normal distribution via the Kolmogorov Smirnov test. The alpha level of 0.05 was set before data analysis to identify significant changes. The time achieved in 800 m and 1500 m competitions and training loadings between blocks 1 and 2 were analyzed using a Student's dependent T-test (SPSS, version 24, Chicago, IL). Changes in outcome measures over the 3 assessment points during the experimental period and monthly variations in training loadings were assessed using repeated-measures analysis of variances (ANOVA). Assumptions of sphericity were assessed using Mauchly's test of sphericity, if the assumption of sphericity was violated Greenhouse Gessier correction was employed. If significant effects over time were observed *post-hoc* differences were analyzed with the use of Bonferroni correction. Furthermore, standardized effect size (Cohen's d) analyses were used to interpret the magnitude of any differences, thresholds were set at: d = 0.2 small effect, d = 0.5 medium effect and d = 0.8 large effect. Effect size values are reported as eta squared.

Pearson's correlation (*r*) analysis was employed to evaluate any relationships between changes in physical performance indices. Correlation analysis was also employed to analyze any relationships between middle distance training and strength type training loads and any changes in outcome measures.

RESULTS

Training content, loads and distribution

Examples of training weeks prescribed in blocks 1 and 2 are presented in Table 1. Middle distance training volume and intensity distribution was similar between training blocks 1 and 2, other than mean distance covered per session (Table 2). Large effect sizes were observed ($\eta \geq 0.80$) for increases from block 1 to 2 in accumulated distance covered and mean distance covered per session. Information pertaining to training intensity distributions is presented in Figure 1. Monthly accumulated Edwards training load changed over the observational period ($F_{(7, 63)} = 10.540$, $p < 0.001$, Figure 2, Panel A), however, mean Edwards training load was not different between training months ($F_{(7, 63)} = 0.824$, $p = 0.477$). Mean and accumulated distance covered varied monthly over the observational period (Mean; $F_{(7, 63)} = 17.024$, $p < 0.001$, Accumulated; $F_{(7, 63)} = 14.643$, $p < 0.001$, Figure 2, Panel B). Both mean and accumulated training time also differed monthly (Mean; $F_{(7, 63)} = 3.429$, $p = 0.004$, Accumulated; $F_{(7, 63)} = 12.581$, $p < 0.001$, Figure 2, Panel C). Strength and plyometric training volume was greater in block 2 than block 1 for all variables analyzed lower body and core volume load (Table 3).

Table 1 about here

Table 2 about here

Figure 1 about here

Table 3 about here

Figure 2 about here

Competition performance

No differences nor large effect sizes were observed for changes in competition performance over the experimental period. Details of percentage change (%Δ), 90% CI and effect sizes are presented in Table 4.

Table 4 about here

Growth, maturation and anthropometry

Body mass increased over the experimental period ($F_{(2, 18)} = 43.003$, $p < 0.001$), as did PHV status ($F_{(2, 18)} = 32.735$, $p < 0.001$). Sum of 7 skinfolds did not change over the observation period ($F_{(2, 18)} = 1.086$, $p = 0.334$). Details of %Δ, 90% CI and effect sizes are presented in Table 4.

Field measures

Performance in 600 m ($F_{(2, 4)} = 1.605$, $p = 0.308$) and 1200 ($F_{(2, 4)} = 4.217$, $p = 0.176$) time trials did not change significantly. Performance in 1800 m time trials was however significantly improved from the start of the experimental period ($F_{(2, 4)} = 10.720$, $p = 0.025$). Critical speed significantly increased over the observation period ($F_{(2, 4)} = 14.220$, $p = 0.015$), no such changes were observed for critical distance ($F_{(2, 4)} = 1.150$, $p = 0.403$). Details of %Δ, 90% CI and effect sizes are presented in Table 4.

Laboratory measures

Significant increases in peak lactate ($F_{(2, 12)} = 13.208$, $p = 0.001$) and economy ($F_{(2, 12)} = 12.635$, $p = 0.001$) were identified, without concomitant increases in $\dot{V}O_{2\max}$ ($F_{(2, 10)} = 2.117$, $p = 0.163$) or lactate threshold ($F_{(2, 10)} = 2.499$, $p = 0.132$). Both vertical stiffness ($F_{(2, 10)} = 4.406$, $p = 0.042$) and reactive index ($F_{(2, 8)} = 13.823$, $p = 0.003$) significantly improved during the observation period. No such significant improvements were observed for CMJ (m) ($F_{(2, 6)} = 2.358$, $p = 0.176$) nor CMJ ($\text{W}\cdot\text{kg}^{-1}$) ($F_{(2, 6)} = 3.476$, $p = 0.099$). Details of %Δ, 90% CI and effect sizes are presented in Table 4.

Relationships between outcome measures

Improvements in 1800 m TT performance were correlated with increases in both $\dot{V}O_{2\max}$ ($r = 0.810$, $p = 0.015$) and critical speed ($r = 0.918$, $p = 0.001$), increases in $\dot{V}O_{2\max}$ and critical speed were also significantly correlated ($r = 0.895$, $p = 0.003$). Any relationships between improvements in outcome measures are only reported if statistically significant changes and/or large effect sizes (> 0.80) were observed.

Relationships between outcome measures and training loads

Any relationships between loads and improvements in outcome measures are only reported if statistically significant changes and/or large effect sizes (> 0.80) were observed for outcome measures in question. Percentage time spent in HR zone 5 was correlated with improvements in running economy ($r = 0.720$, $p = 0.044$) and upper body strength training volume load was correlated with improvements in 800 m competition performance ($r = 0.778$, $p = 0.040$).

DISCUSSION

This is the first study to present longitudinal endurance and strength training loads in highly trained adolescent middle distance athletes. Over the 9-month observational period, athletes achieved significant improvements in: body mass, 1800 m TT performance, critical speed, peak lactate and RE. In addition, large effect sizes were observed for improvements in the following variables: 600 m, 1200 m, 1800 m TT performance, critical speed, $\dot{V}O_{2\text{max}}$, peak lactate, RE and CMJ ($W \cdot kg^{-1}$). Improvements in 1800 m TT performance were correlated with increases in $\dot{V}O_{2\text{max}}$ and critical speed. Increases in $\dot{V}O_{2\text{max}}$ and critical speed were highly correlated.

Training intensity distributions were similar over the observational period, both between training blocks 1 and 2 and monthly. Furthermore mean Edwards training load was similar between months. This is consistent with previous work on adults, indicating that endurance athletes training intensity distribution remains similar throughout the course of the training year (13,25). As many physical performance parameters were improved it is reasonable to suggest that this similar monthly training intensity distribution is an effective means of improving physical qualities in a group of trained adolescent athletes. Conversely, it may also be speculated that greater improvements may have been observed if a more polarized approach was employed. This involves the majority of training (~80%) being performed at low intensities corresponding to blood lactate concentrations of ~2 mmol·L^{-1}, and the remaining ~20% primarily consisting of interval training at intensities equivalent to ~90% $\dot{V}O_{2\max}$ (26). However, this suggestion remains speculative and requires further investigation in this cohort. It should also be noted that the 10 athletes trained as a group and generally performed the same sessions at the same relative intensities. If more individual athlete training prescriptions were implemented it is possible that intensity distribution may have differed monthly and between training blocks.

The strength training load was increased from training block 1 to 2. This was due to fact that before the observational period many athletes had minimal or no prior exposure to strength training, as such, the coaching team designed a progressive plan with gradual increase in volume load as recommended by recent positions statements (10). The focus of the initial phase of the strength training plan was evidently directed to improve the strength of trunk muscles. As athletes' movement competencies improved and external load in upper and lower body exercise could be prescribed, the coaching plan showed an increase and upper and lower body training volumes and intensities.

Previous work has also indicated concurrent endurance and explosive type of strength training has been shown to improve running performance and economy in young and senior runners (3,16,20,21). As such, coaches and practitioners supporting adolescent middle distance athletes should consider gradually incorporating strength training strategies in to their periodized plans. This suggestion is in part supported by the large improvements (ES = 1.57, 10.1%) in running economy observed in the present study. These improvements are notably greater than those reported by Svedenhag and Sjodin (29) who reported 3.4% improvements in running economy over a 12 month period in adult runners, also Galbraith et al. (13) reported no improvements in running economy over a 12 month training period in adults. Therefore, it may be suggested that the large improvements in running economy observed in our study in this adolescent cohort could be attributable to the strength and plyometric training combined with the athletes' middle distance training prescriptions.

The limited improvements in 800 m performance and no improvements in 1500 m performance observed might be explained by the fact these measures were recorded in "real world" competition environments and therefore were likely affected by competition strategies. Recent work has indicated that in high performing middle distance athletes competitive environments can bring about ego orientated behavior (14). Furthermore, it was also reported that eventual medalists ran slower in qualification rounds than the final. Although competition performance was not improved athletes' experienced large improvements (4.6 – 8.7%) in 600 m, 1200 m and 1800 m time trial performance. These assessments were conducted independently, on an indoor and temperature controlled track at the same time of the day and indicated that performance potential was indeed increased during the observed training period. Although somewhat speculative, it is reasonable to suggest that the athletes were unable to convert this improved performance potential to improved competition performance due to lack of experience in competition environments and underdevelopment emotional regulation and pacing strategies. This may indicate that if coaches are able to improve the adolescent athlete's ability to regulate the emotional response to competitive environments and improve pacing strategies, the athlete may be better able to convert any improvements in physicality to improved competition performance.

Only trivial changes in lactate threshold were observed here with similar findings reported in highly trained adult endurance athletes (13). Previous work has suggested improvements in lactate threshold require regular training exposes at intensities greater than lactate threshold (19). In the case of the training group analyzed here, athletes' speed at lactate threshold was not used typically to guide training intensity until the start of block 2. This may explain the lack of increase in speed at lactate threshold. Therefore, if coaches are seeking to improve the lactate threshold of the adolescent athletes, threshold should be used to guide training intensity to ensure sufficient exposes to intensities greater than lactate threshold.

Critical speed increased by 7.1% over the observational period, this is notably larger than the 1.9% increase in critical speed noted over a 1 year period by Galbraith et al. (13) in an adult well trained cohort. This discrepancy in findings is likely due to the differing maturation and training status of the athletes assessed. Galbraith et al. (13) assessed highly trained adults with 8 years high volume training history and mean $\dot{V}O_{2\max}$ of 70 ml·kg·min^{-1}, whereas here athletes were adolescents (PHV status 1.3 ± 1.4 years') with varied training histories and mean $\dot{V}O_{2\max}$ of 60 ml·kg·min^{-1}. Is it is reasonable to suggest that the higher training status of the adult athletes contributed to lesser improvements in time trial performance and critical speed. Contrary to previous work, no relationships were observed between training loads and improvements in athlete's critical speed. Galbraith et al (13) reported increases in training loads resulted in concomitant increases in critical speed. In the present study, critical speed was only assessed 3 times over an 9-month period, Galbraith et al. (13) assessed critical speed on 9 occasions over a 12-month period.

The aforementioned increases in critical speed were correlated with large (ES = 0.88) increases in $\dot{V}O_{2\max}$. This robust correlation (r = 0.895, p = 0.003) is similar to that reported by

Kranenburg and Smith (18). Whilst, Galbraith et al (13) also reported significant correlations between critical speed and $\dot{V}O_{2\max}$, the relationships were notably weaker ($r = 0.48$). The 5.5% increases in $\dot{V}O_{2\max}$ observed in this cohort are consistent with previous work involving adult athletes following 12 months of training (13). These data may indicate that assessments of critical speed via TT are reflective of changes in $\dot{V}O_{2\max}$ in adolescent athletes. Therefore, if coaches and practitioners do not have access to laboratory facilities, critical speed assessments may be a viable option for not only tracking changes in TT performance but also $\dot{V}O_{2\max}$.

PRACTICAL APPLICATIONS

This is the first study to present longitudinal training loadings encompassing all modalities of training performed in trained adolescent middle distance athletes. Based on the analysis of training load metrics, physical performance parameters and competition performance practical applications for coaches and practitioners can be made.

In terms of training intensity distribution, similar monthly training intensity distribution is an effective means of improving physical qualities in a group of trained adolescent athletes. Although further work is needed to determine if a threshold or polarized approach is favorable in this population. Strength training strategies should be gradually implemented in to a young athletes training program, when the athlete has built sufficient robustness and movement competency plyometric activities should be performed. Coaches should attempt to improve the adolescent athlete's ability to regulate the emotional response to competitive environments and be mindful of pacing strategies. This may enable the athlete to better covert performance potential to improved competition performance.

Changes in critical speed obtained via TT are reflective of changes in $\dot{V}O_{2\mathrm{max}}$ in adolescent middle distance athletes. Many practitioners supporting adolescent training groups may not have access to laboratory facilities required to determine $\dot{V}O_{2\mathrm{max}}$. As such, it appears that critical speed assessments may be used as a proxy for assessing changes in an adolescent's $\dot{V}O_{2\mathrm{max}}$ in the absence of laboratory facilities.

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FIGURE LEGENDS

Figure 1. Distribution of middle distance training intensity over the experimental period. Zone 1 = 50 – 59% HRmax, zone 2 = 60 – 69% HRmax, zone 3 = 70 – 79% HRmax, zone 4 = 80 – 89 HRmax and zone 5 = ≥90% HRmax.

Figure 2. Monthly accumulated and mean Edwards TRIMP (Panel A), distance covered (Panel B) and training time (Panel C). Data are reported as mean per athlete. AU = Arbitrary units, Edwards TRIMP = Edwards training impulse. * accumulated Edwards > September; # accumulated Edwards and training time < November; @ accumulated Edwards < October; ^ accumulated Edwards, distance and training time > April; + accumulated Edwards, distance and training time > February; † mean distance > October; $ mean distance > November, all $P < 0.05$.

TABLES

Table 1. Summary of a training weeks in block 1 and 2. For block 1 week 9 (of 18) is presented, for block 2 week 8 of 16 is presented.

Training day	**Session Type**		**Session content**	
		Block 1 – September to January		
	AM	PM	AM	PM
Sunday	S&C	“Fartlek”	Compound movements & core	5 x 3'
Monday	Long run	Hills	50' & strides	12 x 150 m moderate incline
Tuesday	Rest	Track	-	2 x 4 x 400 m & 4 x 200 m
Wednesday	S&C	Long run	Unilateral LB strength & core	40’ & ABCs
Thursday	Rest	Track	-	2 x 1200 m|500 m|300 m|200 m
Friday	Recovery run	Rest	40'	-
Saturday	Rest			
		Block 2 – February to May		
Sunday	S&C	Track	Compound movements & plyometrics	3 x 3 x 400 m
Monday	Long run	“Fartlek”	40’ & ABCs	2 x 3', 2', 1' & 4 x 150 m
Tuesday	Rest	Track	-	1200 m & 4 x 200 m
Wednesday	S&C	Tempo run	Unilateral LB, upper body and core strength	3000 k
Thursday	Rest	Track	-	Competition WU & 4 x 400
Friday	Recovery run	Rest	40’	-
Saturday	Rest			

' = min, ABCs = running mechanics focused drills, LB = lower body S&C = strength and conditioning, WU = warm up

Table 2. Summary of middle distance type training performed over the experimental period. Data are reported as mean ± SD per athlete unless otherwise specified.

	Block 1 September – January	**Block 2 February – May**	**% Δ**	***P* value (90% CI)**	**Cohen's d**
Mean training time (h:min:s)	0:51:41 ± 0:04:58	0:52:46 ± 0:05:34	2.1	0.438 (-0.002 - 0.001)	0.29
Sum training time (h:min:s)	50:0:14 ± 14:22:43	44:46:02 ± 12:55:14	-10.5	0.209 (-0.077 - 0.513)	0.54
Mean distance covered (km)	6.5 ± 1.2	7.3 ± 0.9	11.4	0.002 (-1.071 - - 0.418)	1.0
Sum distance covered (km)	300.4 ± 123.4	360.7 ± 101.8	20.1	0.095 (-119.446 - -1.134)	0.75
% time spent in HR zone 5	6.1 ± 4.3	4.9 ± 3.2	-19.4	0.094 (0.024 - 2.335)	0.44
% time spent in HR zone 4	16.1 ± 5.1	15.6 ± 4.4	-2.9	0.618 (-1.200 - 2.140)	0.14
% time spent in HR zone 3	29.2 ± 6.1	29.6 ± 3.4	1.2	0.812 (-3.025 - 2.311)	0.10
% time spent in HR zone 2	27.1 ± 6.0	27.6 ± 5.4	1.9	0.504 (-1.852 - 0.832)	0.13
% time spent in HR zone 1	21.5 ± 4.5	22.3 ± 3.5	3.6	0.354 (-2.251 - 0.685)	0.28
Mean Edwards TRIMP (AU)	133.0 ± 18.8	135.1 ± 15.7	1.6	0.525 (-7.992 - 3.752)	0.17
Sum Edwards TRIMP (AU)	7742.6 ± 2454.7	6847.9 ± 1936.3	-11.6	0.171 (-207.518 - 1996.918)	0.57

AU = arbitrary units, mean = mean per session, CI = confidence interval (lower - upper bound), Edwards TRIMP = Edwards training impulse, HR zone 5 = ≥90% HRmax, HR zone 4 = 80 - 89% HRmax, HR zone 3 = 70 - 79% HRmax, HR zone 2 = 60 - 69% HRmax, HR zone 1 = 50 - 59% HRmax

Table 3. Summary of strength and plyometric type training performed over the experimental period. Data are reported as mean ± SD per athlete unless otherwise specified.

	Block 1 September – January	**Block 2 January – May**	**% Δ**	***P* value (90% CI)**	**Cohen's d**
Total mean volume load (reps*load kg)	41596 ± 10031	53747 ± 19846	29.2	0.107 (-24599.018 - 296.718)	1.09
Lower body mean volume load (reps*load kg)	40758 ± 9580	45226 ± 17326	11.0	0.498 (-16074.313 – 7137.013)	0.45
Lower body bilateral mean volume load (reps*load kg)	28610 ± 6125	38172 ± 15703	33.4	0.095 (-18950.869 - -173.030)	1.13
Lower body unilateral mean volume load (reps*load kg)	7677 ± 3317	1115 ± 789	-85.5	<0.001 (4913.617 - 8211.382)	3.85
Upper body mean volume load (reps*load kg)	1531 ± 2293	8367 ± 4903	446.5	0.002 (-11073.030 - -4810.477)	2.53
Fast SSC[1] Plyometric contacts	1003 ± 321	2689 ± 1041	168.0	<0.001 (-2230.568 - -1140.831)	3.09
Slow SSC[2] Plyometric contacts	932 ± 436	6380 ± 2867	584.6	<0.001 (-7033.6647 - - 3862.1353)	3.76

CI = confidence interval (lower - upper bound), [1]Fast SSC = Stretch shortening cycle (ground contact under 250 m·s^{-1}), [2]Slow SSC = Stretch shortening cycle (ground contact over 250 m·s^{-1}).

Table 4. Summary of any changes in outcome measure.

Variable	September	January	May	% Δ†	*P* value (90% CI) †	Cohen's d†
Competition performance						
800 m (min:s)	-	02:03.03 ± 0:06.60	02:02.51 ± 0:07.06	-0.5	0.283 (-42.383 - 10.113)	0.12
1500 m (min:s)	-	04:16.53 ± 0:10.92	04:17.04 ± 0:11.43	0.2	0.172 (-3.648 - 0.398)	0.05
Growth, maturation and anthropometry						
PHV status (years)	1.3 ± 1.4	1.6 ± 1.3*	1.8 ± 1.3*	4.5	<0.001 (-0.722 - -7.258)	0.60
Body mass (kg)	55.7 ± 10.1	57.8 ± 9.9*	58.8 ± 9.8*	5.6	<0.001 (-3.787 - -2.412)	0.44
∑7 skinfolds (mm)	42.4 ± 6.0	41.0 ± 6.3	40.7 ± 7.1	-4.1	0.334 (-1.366 – 4.806)	0.37
Field measures						
600 m TT (min:s)	01:42.64 ± 0:08.22	01:40.01 ± 0:08:70	01:37.94 ± 0:06.61	-4.6	0.053 (0.926 – 9.046)	0.89
1200 m TT (min:s)	3:54.12 ± 0:14.03	3:41.82 ± 0:11.74	3:33.82 ± 0:08.52	-8.7	0.001 (15.055 – 29.539)	2.48
1800 m TT (min:s)	5:59.23 ± 0:24.50	5:44.21 ± 0:13.82*	5:37.23 ± 0:13.84*	-6.1	0.011 (9.134 – 31.985)	1.56
Critical speed (m·s^{-1})	4.7 ± 0.3	4.9 ± 0.2*	5.0 ± 0.3*	7.1	0.041 (-0.522 - -0.072)	1.53
Critical distance (m)	117.1 ± 25.7	112.0 ± 26.1	115.5 ± 41.6	-1.4	0.720 (-40.284 – 27.009)	0.06
Laboratory measures						
$\dot{V}O_{2\max}$ (ml·kg·min^{-1})	60.0 ± 5.4	58.6 ± 4.1	63.4 ± 5.2	5.5	0.059 (-7.081 - -0.603)	0.88
Lactate threshold (km·h^{-1})	14.9 ± 2.0	15.6 ± 1.4	15.6 ± 1.8	4.4	0.009 (-1.593 - -0.521)	0.49
Peak lactate (mmol·L^{-1})	6.5 ± 1.6	5.6 ± 1.1	10.0 ± 3.1*	54.3	0.005 (-5.085 - -1.869)	2.01
Running Economy (ml·kg·km^{-1})	227.1 ± 21.2	217.6 ± 12.4*	204.3 ± 19.9*	-10.1	<0.001 (15.720 – 29.779)	1.57
Reactive index (AU)	2.14 ± 0.47	2.09 ± 0.43*	2.06 ± 0.36	-3.8	0.283 (-0.310 - 0.075)	0.27

Stiffness 2.2 Hz (AU)	38.2 ± 5.9	45.4 ± 7.4*	39.2 ± 2.8	2.6	0.457 (-6.211 – 2.566)	0.30
CMJ (m)	.31 ± .05	.33 ± .03	.33 ± .05	6.4	0.077 (-0.063 - -0.003)	0.55
CMJ (W·kg^{-1})	47.1 ± 6.3	49.5 ± 3.7	50.8 ± 7.1	7.9	0.063 (-8.357 - -0.762)	0.78

AU = arbitrary units, CI = confidence interval (lower - upper bound), CMJ = countermovement jump, HRmax = maximum heart rate, PHV = peak height velocity, TT = time trial, v$\dot{V}O_{2max}$ = speed at $\dot{V}O_{2max}$. †Between first and final observation, *Significant change from start of season ($p < 0.05$),