Article Title: A One-Year Study of Endurance Runners: Training, Laboratory and Field Tests

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Abstract:

Purpose: This longitudinal study examined the training and concomitant changes in laboratory and field-test performance of highly trained endurance runners. **Methods**: Fourteen highly trained male endurance runners (mean ± SD: VO_{2max} 69.8 ± 6.3mL·kg^{-1}·min^{-1}) completed this 1-year training study commencing in April. During the study the runners undertook 5 laboratory tests of VO_{2max}, lactate threshold (LT) and running economy, and 9 field tests to determine critical speed (CS) and the modelled maximum distance performed above CS (D′). The data for different periods of the year were compared using repeated measures ANOVA. The influence of training on laboratory and field test changes was analysed by multiple regression. **Results**: Total training distance varied during the year, and was lower in May-July (333km [SD: ± 206km], *P*=0.01) and July-August (339km [SD: ± 206km], *P*=0.02) than in the subsequent January-February period (474km [SD: ± 188km]). VO_{2max} increased from the April baseline (4.7L·min^{-1} [SD: ± 0.4L·min^{-1}]) in October and January periods (5.0L·min^{-1} [SD: ± 0.4L·min^{-1}], $P \leq 0.01$). Other laboratory measures did not change. Runners' CS was lowest in August (4.90m·s^{-1} [SD: ± 0.32m·s^{-1}]) and highest in February (4.99m·s^{-1} [SD: ± 0.30m·s^{-1}], *P*=0.02). Total training distance and the percentage of training time spent above LT velocity explained 33% of the variation in CS. **Conclusion**: Highly trained endurance runners achieve small but significant changes in VO_{2max} and CS in a year. Increases in training distance and time above LT velocity were related to increases in CS.

Keywords: VO_{2max}, critical speed, distance running, endurance, performance changes

Introduction:

Endurance runners may complete high volumes of training over many years to produce elite performance.[1] However, surprisingly little has been documented about the training completed or the corresponding changes elicited in laboratory and field performance tests of highly trained runners, especially in longitudinal studies. A small number of studies have examined the acute effect of 4-8 weeks of training on the $\dot{V}O_{2\,max}$ of trained runners. Results of these studies are contradictory, with some reporting no change in $\dot{V}O_{2\,max}$,[2-4] whilst others report increases of up to ~5%.[5,6] The extent to which seasonal changes in fitness occur in highly trained runners is unknown. Accordingly, the contradictory findings may be a consequence of variation in the seasonal timing of these relatively short-term studies. An increase in running performance without concomitant increases in $\dot{V}O_{2\,max}$ was highlighted in a 5-year case study of an elite female runner.[1] Longitudinal cohort studies of trained runners are sparse. Two studies involving groups of trained runners have previously been published where performance changes were reported however runners' training was not examined.[7,8] Svedenhag and Sjodin monitored elite runners over the course of a year[9] and compared increases in $\dot{V}O_{2\,max}$ and economy with training. Training was not recorded directly however, but with diary records.

Tests to assess changes in endurance fitness have traditionally been conducted in the exercise laboratory, although some field-based approaches have been developed.[10] The distance-time relationship can be used to calculate a two parameter model of critical speed (CS) and D′. A runner's CS has been suggested to reflect the highest sustainable running speed that can be maintained without a continual rise in $\dot{V}O_2$ to $\dot{V}O_{2\,max}$, whilst D′ is notionally the maximum distance that can be achieved at speeds above CS.[11] The determination of the distance-time relationship is based on actual performances times (either to exhaustion, or to complete a set distance). Accordingly measuring changes in this relationship could be more valuable to athletes and coaches than laboratory measures of $\dot{V}O_{2\,max}$ and lactate threshold (LT).[11]

In contrast to running, several studies have examined the effects of a training period on the cycling power output-time relationship. This research has demonstrated that improvements ranging from 10-31% in critical power are possible following a period of training.[12-14] Again, all of these studies have featured either untrained or moderately trained subjects (mean $\dot{V}O_{2\,max}$ values ranging from 48.5 to 55.0 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$), and utilized only a 6-8 week training period. To our knowledge previous studies have not examined the effect of prolonged endurance training on highly trained participants' CS and D′.

The aims of this study were to firstly to measure the training of endurance runners for one year. A second aim was to examine and compare the effects of this training on both laboratory and field performance tests. We hypothesized that performance in the laboratory and field tests would change during the course of the study and that there would be a relationship between these changes. Finally we hypothesised that changes in laboratory and field tests would be related to the volume and intensity of training conducted.

Methods:

Participants: Fourteen male distance runners (800m-marathon) were recruited from local athletics clubs. Participants were competitive club and national-level runners, with at least an 8-year history of running training and competition (average 11 years). At the start of the study participants displayed the following characteristics (mean ± SD): Age 28±8 yr, weight 67.0±6.3 kg, $\dot{V}O_{2\,max}$ 69.8±6.3 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$. Mean (± SD) performance times over a range of distances during the study duration are shown in table 1. All participants provided written informed consent for this study that had been approved by the University's ethics committee.

Study Design: This was a 1-year observational study of highly trained runners, examining their training and corresponding changes in both field and laboratory fitness tests. The participants' training was set by their coach and was not manipulated or directly influenced as part of this study. Participants completed five laboratory tests and nine field tests over the course of 1-year (see Figure 1).

All participants completed a familiarization session for each test prior to commencing the study. During the study participants were asked to maintain their normal diet, but no dietary analysis or data collection was performed. Throughout the study all test sessions were conducted at the same time of day (±2hr), to reduce any possible effect of circadian rhythms.[15] Participants were instructed to arrive for testing in a rested and fully hydrated state, at least 3 hours post-prandial and having avoided strenuous exercise in the preceding 24 hours. Prior to each test session participants completed a standardized warm-up consisting of 5 minutes self-paced jogging, followed by 5 minutes of their usual stretching exercises.[16]

Laboratory-test protocol: Prior to the test, participants' body mass and stature was measured (Seca Beam Scale and Stadiometer, Birmingham, UK). Immediately preceding the warm-up, a 10μL fingertip capillary blood sample was collected to determine resting blood lactate concentration (Biosen C-line, EKF diagnostic, Barleben, Germany). The laboratory test was conducted in two parts; the first part was a submaximal treadmill test[17] (Pulsar 3P, H/P/Cosmos, Nussdorf-Traunstein, Germany) using a treadmill gradient of 1%.[18] The initial treadmill belt speed was decided individually for each athlete to ensure that 5-9 stages were completed during the submaximal phase of the test.[17] Each stage of the test was 4 minutes in duration at which point the treadmill belt speed was increased by 1.0 $km \cdot h^{-1}$.[19] Throughout the test participants' expired gases were measured on a breath-by-breath basis (MetaLyzer, Cortex Biophysik, Leipzig, Germany). In the last 30 seconds of each stage average heart rate (310XT, Garmin International Inc. Kansas, USA), and rating of perceived exertion (RPE) using the Borg 6-20 scale[20] were recorded. At the end of each 4-minute stage a 10µL fingertip capillary blood sample was collected before the treadmill belt speed was increased by 1.0 $km \cdot h^{-1}$. The LT was identified as the exercise intensity that produced a 1 mmol·L increase in blood lactate concentration above baseline.[21] This phase of the test was terminated when the participants' blood lactate concentration exceeded 4.0 $mmol \cdot L^{-1}$. Running economy was calculated over this range of submaximal velocities by recording the average $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) for the last minute of each stage.[17] The energy cost of running ($kcal \cdot kg^{-1} \cdot km^{-1}$) at the highest individual speed with a RER <1.0 was also calculated for each athlete.[22]

The second phase of the test was used to determine $\dot{V}O_{2\,max}$ and the velocity at $\dot{V}O_{2\,max}$ (v-$\dot{V}O_{2\,max}$). The test started at a 1% gradient and a velocity 2.0$km \cdot h^{-1}$ below the velocity at which the participant finished the first phase of the test. The treadmill velocity remained constant whilst the gradient was increased by 1% every minute until the participant reached volitional exhaustion. Subsequently, $\dot{V}O_{2\,max}$ was calculated as the highest $\dot{V}O_2$ achieved during the test, using a rolling 1-minute average. The v-$\dot{V}O_{2\,max}$ was calculated by solving the regression equation describing the relationship between $\dot{V}O_2$ at sub-maximal intensity and $\dot{V}O_{2\,max}$.[1] To assess the exercise cortisol response, participants provided a 2 mL saliva sample by passively drooling into a plastic test tube. Saliva samples were provided upon arrival and immediately after the maximal test. Measures of salivary cortisol were determined by enzyme immunoassay (Salimetrics, State College, PA, USA). Previous research has reported high correlations between serum and salivary cortisol (r=0.94, P<0.01).[23]

Throughout these testing sessions laboratory conditions were maintained within a temperature range of 17.5-19.5°C and 35-65% relative humidity.

Field-test protocol: Each participant completed three trials on an outdoor 400-meter athletics track. The 3 trials were over set distances of 3600, 2400 and 1200 meters (9, 6 and 3 laps) and were kept in the same order for all sessions. These distances were chosen to result in completion times of approximately 12, 7 and 3 minutes.[24] Laursen et al[25] previously compared "set distance" and "time to exhaustion" approaches on a treadmill and reported lower levels of reliability for time-to-exhaustion tests compared with time-trial running tests. Participants were instructed to complete each trial in the fastest time possible, and runs were hand-timed to the nearest second. Participants were not provided with the elapsed time during the track runs. A linear distance-time model was used to calculate CS and D′ from these trials (r^2 range=0.99-1.00; SE range CS=0.00-0.11m.s^{-1}, D′=0-64m). The linear distance-time model is represented by:

$$d = (CS.t\,) + \mathrm{D}'$$

Where: d = distance run and t = running time.

All three runs were conducted on the same day with a 30-minute rest between each run. In a previous study we compared the single-visit (30-minute recovery) protocol to a multiple-visit (24^+ hour recovery) time to exhaustion treadmill protocol and found close agreement (r=0.89; 95% limits of agreement = 0.25m·s^{-1}) between methods (unpublished data). We have also previously demonstrated that the single visit (30-minute recovery) field-test of the distance-time relationship produces reliable values for CS & D′ (CV 1.7 and 14% respectively).[26] Testing was not conducted if conditions fell outside of acceptable limits (temperature <0°C or wind speed >2.0 m·s^{-1}). Mean environmental conditions during the field tests, across the study were: Temperature 13.8 °C (range 0-24 °C), Humidity 64 %

(range 38-94 %), Pressure 766 mmHg (range 756-772 mmHg) and Wind Speed 1.8 $m \cdot s^{-1}$ (range 0.0-2.0 $m \cdot s^{-1}$).

Training data collection: Throughout the study participants recorded every training session and race with a wrist worn GPS and heart rate monitor (310XT, Garmin International Inc. Kansas, USA). Data were recorded using the watches smart-recording function.

Statistical Analysis: Data were checked for normality of distribution using the Shapiro-Wilk statistic, log transformation was used where the assumption of normality was violated. Repeated-measures ANOVA were used to identify differences in the laboratory and field-test variables across the testing sessions. Participants' training data was analysed for the 42-day period immediately preceding each testing session giving a total of 8 separate periods of training data analysis (Figure 1). A multiple linear regression was conducted to assess the amount of variance in CS that could be explained by the training. Pearson correlation coefficients were used to assess the relationship between the pooled laboratory and field-test variables, and between the pooled training and laboratory-test variables. Analysis was conducted using SPSS statistics software (IBM SPSS statistics, Rel.20.0, 2011. SPSS Inc. Chicago, USA). Statistical significance was accepted at $P<0.05$.

Results:

Changes in laboratory-test variables during the season: The physiological variables measured during the five laboratory-testing sessions are shown in Table 2. Absolute $\dot{V}O_{2\,max}$ ($L \cdot min^{-1}$) improved significantly during the season ($F_{4,52}=7.97$, $P<0.01$, $\eta^2 p=0.38$), and was higher in October ($P<0.01$) and January ($P=0.01$), than in the April baseline test. The same response was apparent for relative $\dot{V}O_{2\,max}$ ($F_{4,52}=6.90$, $P<0.01$, $\eta^2 p=0.35$). There were no statistically significant changes in the other laboratory measures during the study. When the group was split by running discipline the 800m runners displayed a significantly higher $\dot{V}O_2$

$_{max}$ and a significantly lower LT, on average across the study, than the marathon runners (5.03 ± 0.46L·min^{-1}and 14.9 ± 0.99km.h^{-1} vs. 4.72 ± 0.49L·min^{-1} and 16.2 ± 1.07km.h^{-1}, P=0.01).

Changes in the field-test variables during the season: Differences in CS and D′ across the testing sessions are shown in Figure 2. The overall group CS changed significantly during the season ($F_{8,104}$=2.42, P=0.02, η^2p=0.16) being at its lowest during August and reaching a peak in February. In contrast, D′ did not change throughout the study ($F_{3.97,51.67}$=1.94,P=0.11, η^2p=0.13). On average across the study the marathon runners displayed a significantly higher CS and a significantly lower D′ than the 800m runners (5.07 ± 0.31m.s^{-1} and 94 ± 49m vs. 4.76 ± 0.22m.s^{-1} and 162 ± 44m, P<0.01).

Relationships between laboratory and field-test variables: The relationships between the pooled laboratory and field-test variables throughout the study were assessed. The strongest relationship was between CS and speed at LT (r=0.89, P<0.01). This relationship was slightly stronger in the marathon runners compared with the 800m runners (r=0.90 and r=0.77, P<0.01 respectively). Relationships were also seen between CS and $\dot{V}O_{2\,max}$ and CS and v-$\dot{V}O_{2\,max}$ (r=0.40, P<0.01 and r=0.48, P<0.01 respectively). There was no significant relationship between CS and running economy throughout the study (r=-0.06, P=0.62).

Changes in training patterns during the season: The total distance run changed during the study ($F_{7,91}$=2.94, P=0.01, η^2p=0.18). Between January-February (Figure 3) total distance run by the overall group was significantly further than between May-July (P=0.01) and July-August (P=0.02).

The total time athletes trained changed during the season ($F_{7,91}$=3.04, P=0.01, η^2p=0.19). Total training time during January-February was greater than during May-July (P=0.01) and July-August (P=0.01). The percentage of total time athletes spent above threshold velocity did not change during the study ($F_{3.49,45.42}$=2.06, P=0.11, η^2p=0.14).

Participants spent 31 ± 19% of their total training time above threshold velocity (Figure 4). The marathon runners trained for a significantly longer time than the 800m runners (P<0.01), however the percentage of training time spent in the different intensity zones was not significantly different between the groups.

Relationship between training and laboratory-test variables: The total distance and total time athletes covered in a training period correlated with the subsequent LT, running economy and v-$\dot{V}O_{2\,max}$ (r=0.55, P<0.01; r=-0.33, P=0.01; r=0.37, P=0.01 respectively for total distance and r=0.46, P<0.01;

r=-0.32, P=0.02; r=0.27, P=0.04 respectively for total time). Training volume and $\dot{V}O_{2\,max}$ were not correlated (r=0.02). The percentage of total time that athletes spent training above threshold velocity in a training period was significantly correlated with the subsequent relative $\dot{V}O_{2\,max}$ (r=0.31, P=0.02).

Relationship between training and field-test variables: Multiple linear regression was used to model the relationship between training and CS. Distance covered (km) in the 42-day period prior to the field test for CS and time spent above threshold velocity during the same period were found to determine changes in CS (explaining 33% of the variation in CS). Total distance was the strongest single predictor (R^2*=0.282,* P<0.01) of CS, although by including the time spent above threshold velocity the strength of the regression was increased (R^2_{Change}=0.043, P=0.01), with beta coefficients of 0.532, P<0.01 and 0.206, P=0.01 respectively.

The final model was:

$$CS = 4.52 + (0.001*TD) + (0.004*V)$$

Where CS=critical speed ($m \cdot s^{-1}$); TD=total distance (km) and V=percentage time above threshold velocity.

3-day training loads: The training loads that each athlete undertook in the 3-days leading into the laboratory and field-tests were analysed. Total distance and total time correlated with the subsequent LT, CS and D′ (r=0.46, r=0.46, r=-0.43, P<0.01 respectively for total distance and r=0.35, r=-0.34, r=-0.37, P=0.01 respectively for total time). There were no significant correlations between training volume and $\dot{V}O_{2\,max}$. Furthermore there were no correlations between training intensity (time or distance above threshold velocity) and any of the test variables.

Discussion:

This longitudinal study of endurance runners training has demonstrated that $\dot{V}O_{2\,max}$ and CS vary in relation to the total training distance and the time spent training above LT.

The effect of training

The current study found no changes in running economy, LT running speed or the velocity at $\dot{V}O_{2\,max}$. These results contrast with Svedenhag and Sjodin[9] who report a 3.4% improvement in running economy in a group of highly trained runners following one year's training. Short-term training studies have reported improvements in running economy of ~6% in trained runners after 4 weeks of training at or around the v-$\dot{V}O_{2\,max}$.[2,4] The reason for these divergent findings may relate to the training intensity of participants in the present study. Only ~14% of the time training was spent at intensities exceeding OBLA (Figure 4). This may also explain why no change in LT was observed. It has been suggested that athletes need to train at intensities above OBLA to bring about changes in lactate metabolism.[27] Notably, the time athletes spent above and below LT velocity did not change during the course of the season and was not different between the 800m and marathon runners. Previous studies have also suggested that the intensity distribution of endurance athletes' training remains similar throughout the course of a year.[28, 29] These observations may indicate that higher intensity training is important to gain improvements in LT and running economy.

During the study $\dot{V}O_{2\,max}$ was ~6% higher in October and January compared with the April baseline test. This is in contrast to Svedenhag and Sjodin who found a significantly higher $\dot{V}O_{2\,max}$ in trained runners during July-September compared with January.[9] The magnitude of the increase in $\dot{V}O_{2\,max}$ in the current study is similar to that reported by Tanaka et al.[7] who found a 5.8% increase following 9 months of training. Significant correlations between total training volume (miles per week) and $\dot{V}O_{2\,max}$ have previously been shown in a study of 78 well-trained runners (r=0.55 for 1-mile specialists to r=0.76 for marathon runners),[30] however a similar relationship was not apparent in the present study. Perhaps this may be due to differences in group homogeneity (47-81 $mL \cdot kg^{-1} \cdot min^{-1}$ [30] vs. 61-82 $mL \cdot kg^{-1} \cdot min^{-1}$ for the current study).

A link between CS, training volume and intensity has not previously been reported in the literature. In the current study, participants' CS was lowest during August (4.90 $m \cdot s^{-1}$), and peaked in February (4.99 $m \cdot s^{-1}$), equating to a 1.9% improvement in CS. This change in CS was greater than the CV previously reported for repeat testing with this protocol.[26] The increase in critical speed was related to an increase in training volume. Training time and distance were both significantly higher in January-February than in July-August. In July-August participants trained on average for 1549 (±803) minutes and covered a total distance of 339 (±206) km, where as in January-February this increased on average to 2184 (±883) minutes and 474 (±188) km. It might be expected that CS would be higher in August when training and race distances are typically shorter, and completed at a high average velocity. However, the results of the current study demonstrate the opposite. This seems counterintuitive, although the training and CS data provide some explanations as to why this might occur. The current study failed to find a significant change in training intensity across the season. Additionally, total training distance was significantly lower in July-August. Therefore it seems that a decrease in training volume with no corresponding increase in training intensity results in a drop in CS.

The 1.9% increase in CS from the lowest to highest values of the season appears to be a small change given the volume of training the athletes were completing. Although, it is important to remember that the athletes involved in this study were already highly trained endurance athletes (mean $\dot{V}O_{2\,max}$ of ~70 mL·kg^{-1}·min^{-1}) who had been training for an average of 5 days per week in the 8 years prior to the study. Nevertheless it seems apparent that the CS of well-trained runners shows only a small increase during the course of a training year. In contrast untrained subjects have achieved far larger increases in critical power (10-31%) following a 6-8 week period of continuous and/or interval cycle training.[12-14]

Although relatively small, the 0.09 m·s (1.9%) change in CS found during the season still implies a meaningful change in performance for a distance runner. Using the distance-time relationship, the shortest time an athlete could complete a race distance can be predicted.[11] Thus, an increase in CS from 4.90 m·s to 4.99 m·s corresponds to a 36 second improvement in 10'000m race time (based on a stable D′ of 130 m). Using the methods of Hopkins,[31] the likelihood of this being a true change in CS is 73%.

Unlike CS, D′ did not change significantly during the season. Research examining longitudinal changes in D′ in highly trained distance runners is lacking. In untrained cyclists a 49% increase in W' (the power-time equivalent of D′) following 8 weeks of high-intensity all-out cycling interval training has been shown.[32] The use of untrained participants and their focus on very short-term high-intensity all-out training might explain their different findings. Specifically, the trained participants in the present study predominantly performed continuous training or longer interval type training (interval duration >1min) which has previously been shown to produce no significant changes in W'.[12,14] D′ has been shown to have a lower level of reliability than CS,[26] and this may have reduced our ability to measure any changes.

Comparisons of highly trained endurance athletes from different running disciplines across a training year are sparse in the literature. Although only a small sample this data suggests that 800m runners have a higher $\dot{V}O_{2\,max}$ and D', whilst marathon runners have a higher CS and LT. In terms of training differences between these groups, the marathon runners typically trained for longer durations and covered greater distance in training than the 800m runners, although no differences were observed in the percentage of time spent above threshold velocity.

To assess the effect of residual fatigue on the performance outcomes the training load that each athlete undertook in the 3-days leading into each test was analysed. Significant positive correlations were seen between training volume and the subsequent LT and CS. These 3-day correlations are similar to those seen across the whole training period, so are unlikely to be reflective of fatigue. Significant negative correlations were seen between training volume and the subsequent D′, however this is likely to be a consequence of the inverse relationship seen between CS and D′ across the study (r = -0.71, P<0.01). Overall the results of these analyses suggest that residual fatigue did not affect the performance outcomes across the study.

It is acknowledged that training impulse (TRIMP) scores provide a useful method of analyzing training load. Unfortunately due to incomplete heart rate data from some participants TRIMP scores could not be calculated in the traditional way. TRIMP scores were calculated using the GPS data, however this analysis did not change the reported findings.

Relationship between laboratory and field-test measures.

CS and the speed at LT were significantly correlated (r=0.89, P<0.01), similarly strong correlations between track-based CS and the speed at ventilatory threshold (*r*=0.96, *P*<0.01) have previously been reported.[10] Weak relationships were seen in the current study between CS and $\dot{V}O_{2\,max}$ and CS and v-$\dot{V}O_{2\,max}$ (*r*=0.40, *P*<0.01 and *r*=0.48, *P*<0.01 respectively). These correlations are weaker than previously reported correlations (*r*=0.88 and *r*=0.89) between track CS with $\dot{V}O_{2\,max}$ and v-$\dot{V}O_{2\,max}$ respectively.[10] In contrast to the current study, previous research only compared CS at one particular point in the training year.[10] The results of the current study may question how indicative laboratory tests are of performance in the field. Furthermore it is interesting to note that it was only the field test that appeared sensitive enough to track small changes in fitness over the course of the year.

Practical Applications:

The practical applications of this study are:

- Athletes should focus on the total distance covered in training and train at higher intensities in order to improve CS.
- Higher intensity training may also improve LT and economy.
- A field test of CS is sensitive to small changes in performance occurring over the course of a year.

Conclusions:

The conclusion from this study is that $\dot{V}O_2$max and CS increase over the course of a training year in a group of highly trained runners. The improvements in CS were related to an increase in training distance and the percentage of total training time at a velocity above threshold-velocity.

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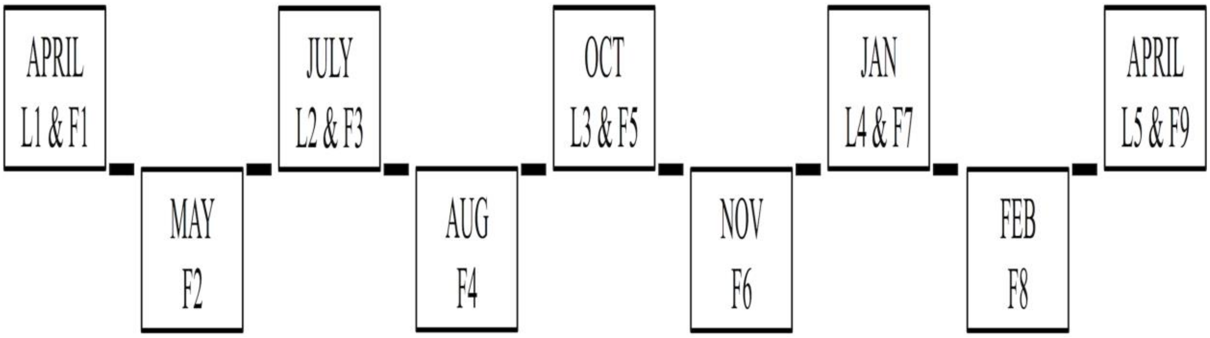

Figure 1: Schematic diagram illustrating the testing schedule.

Key: L = Laboratory test; F – field test; - = 42-day training period (8 in total)

6xx17mm (300 x 300 DPI)

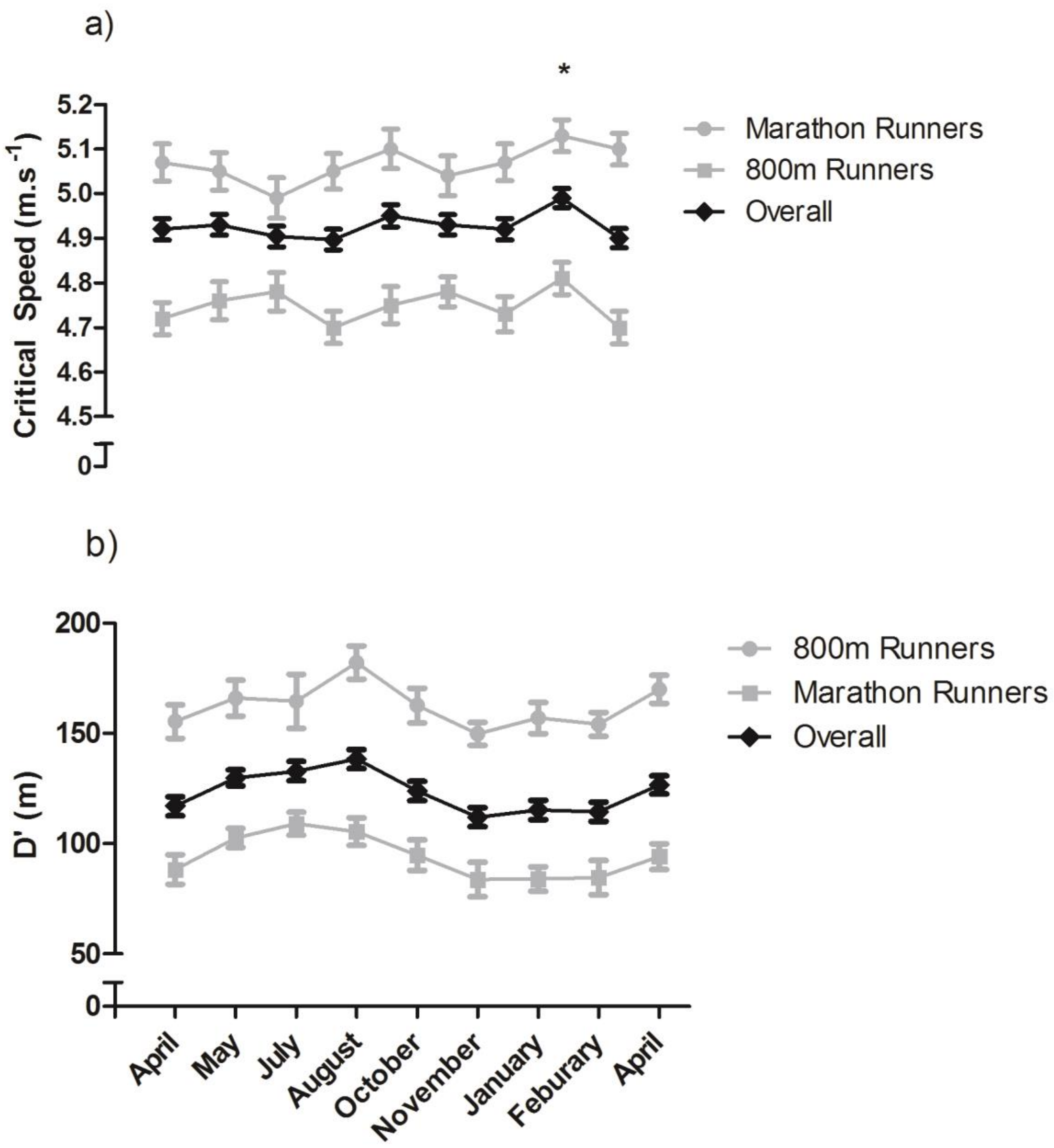

Figure 2. Changes in CS (1) and D' (b) cross the 9 field-testing sessions. Data are presented as mean ± SEM. The field-test points are representative of the points in Figure 1 and span across a whole training year.

* Significantly higher than August, $P = 0.01$ (overall group data)

161x169mm (300 x 300 DPI)

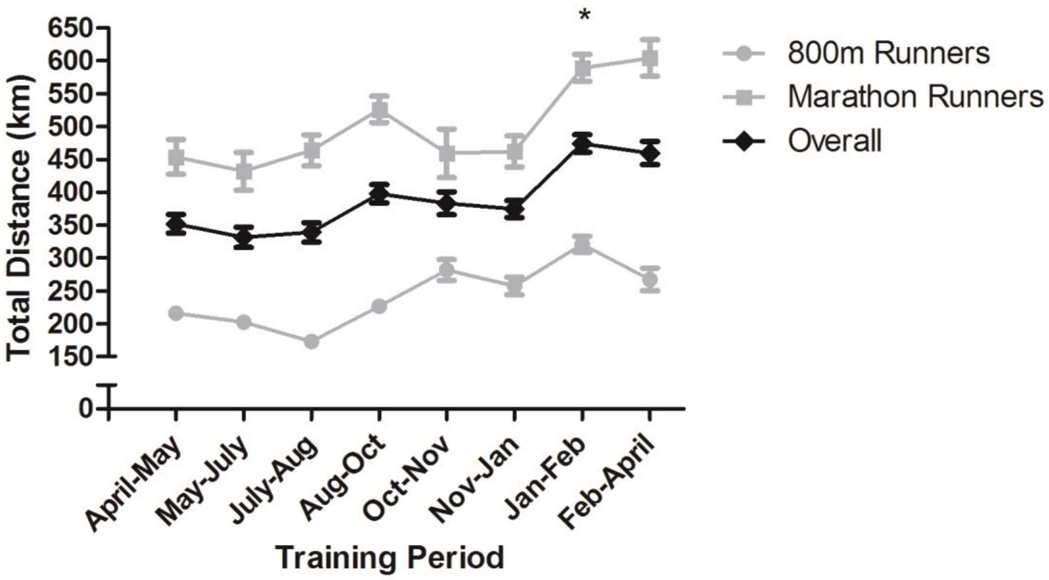

Figure 3. Distance run in different periods across the training year. Data are presented as mean ± SEM. The *x*-axis markers are representative of the 42-day training periods shown in Figure 1.

*Significantly higher than May-July and July-August, $P < 0.05$ (overall group data)

145x83mm (300 x 300 DPI)

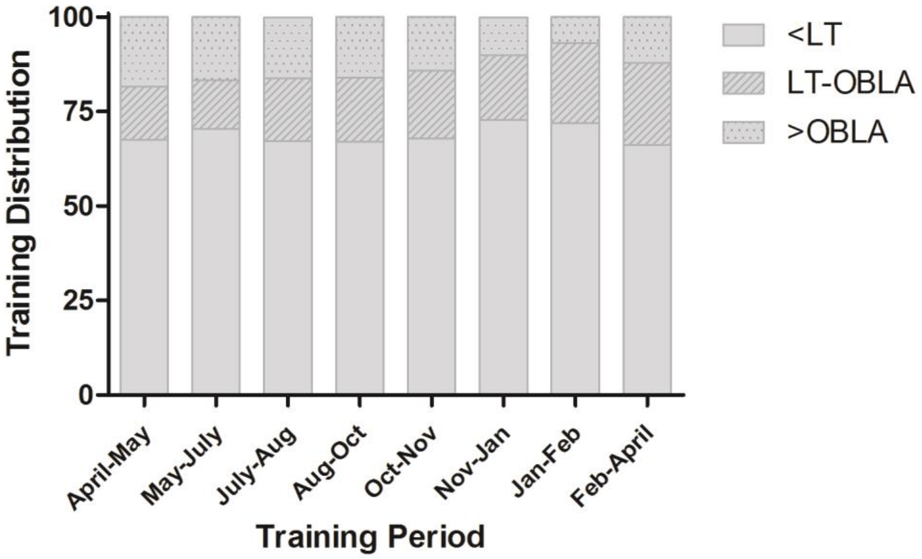

Figure 4. Training intensity distribution as a percentage of total training time. Data are presented as mean values. The *x*-axis markers are representative of the 42-day training periods shown in Figure 1. OBLA = 4mmol·L blood lactate point

128x87mm (300 x 300 DPI)

Table 1: An overview of the participants' performance level during the season

	Seasons best performance time (min:sec)		(hr.min)	
	800m	1500m	½ Marathon	Marathon
Middle-distance runners (n=6)	1:56.2 ± 3.0 sec	3:58.2 ± 4.9 sec		
Long-distance runners (n=8)			1:10:02 ± 3:48	2:28:50 ± 12:27

Data are presented as mean ± SD

Table 2: The physiological variables measured across the 5 laboratory-testing sessions.

	April	July	October	January	April
Mass (kg)	67.0±6.3	67.3±6.4	67.3±6.9	67.0±6.4	67.0±6.7
LT ($km \cdot h^{-1}$)	15.7±1.2	15.5±1.3	15.8±1.4	15.7±1.1	15.6±1.2
RE at $16 km \cdot h^{-1}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	222.6±14.5	228.0±12.2	224.5±13.4	229.6±12.6	223.2±12.0
Energy cost of running ($kcal \cdot kg^{-1} \cdot km^{-1}$)	1.13±0.07	1.16±0.06	1.16±0.07	1.17±0.06	1.14±0.07
$\dot{V}O_{2\,max}$ ($L \cdot min^{-1}$)	4.7±0.4	4.8±0.5	5.0±0.4*	5.0±0.4*	4.9±0.5
$\dot{V}O_{2\,max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	69.8±6.3	71.0±6.7	74.0±4.4*	74.2±5.5*	73.5±6.2
v-$\dot{V}O_{2\,max}$ ($km \cdot h^{-1}$)	19.1±1.7	19.2±1.6	20.0±1.4	19.7±1.3	20.1±1.4
Relative change in Cortisol (post-pre stress test)	2.0±1.4	1.5±0.9	1.3±0.9	1.7±1.6	1.4±1.5

Data are presented as mean ±SD ; * Significantly higher than April baseline test, $P \leq 0.01$; RE = Running economy