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Physiological Differences between Ethiopian and Caucasian Distance Runners and Their Effects on 10 km Running Performance*

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Objective: Ethiopian athletes currently dominate long distance running events in Israel. In an attempt to explain the apparently superior running ability of Israeli Ethiopian athletes at distances >5 km, we compared anatomical and physiological measurements in the fastest 21 Israeli Caucasian (CA) and 22 Israeli Ethiopian (ET) long distance runners with similar mean age, years of training, and weekly volume of training. **Methods:** Two to six months prior to or following official 10 km track race, subjects underwent an incremental maximal and sub-maximal exercise testing in an attempt to identify which of the measured anatomical and/or physiological variable/s explain best the success of the of Israeli Ethiopian long distance runners. **Results:** The ET runners were significantly shorter and lighter and possessed a lower BMI than the CA runners. Whereas mean $\dot{V}O_{2peak}$ (ml/kg/min) was 10.3% lower in the Ethiopian runners ($p = 0.007$), their mean 10,000 m run time was 6.2% faster than their Caucasian counterparts ($p < 0.001$). Although anaerobic threshold-related variables were similar in the two ethnic groups, the Ethiopians' running economy (cost) was significantly higher than that of the CA ($\dot{V}O_{2sub} = 40.3$ vs. 45.5 ml/kg/min in the ET and CA respectively) ($p > 0.001$). **Conclusion:** The results suggest that factors associated with running cost, independent of body size, play a crucial role in the performance of 10 km running. The results also suggest, though indirectly, that genetic and early life phenotypic factors are more dominant than later-life environmental factors (including training) at the 10 km performance level.

Keywords: Long Distance Running; Running Economy; Anaerobic Threshold; Peak VO_2; Ethiopians; Caucasians

Introduction

Many factors have been identified as having an influence on success in distance running. The observation of significant relationships between VO_2 max, the fraction of slow twitch fibers, the fraction of VO_2 max which can be utilized, and running economy has implicated these factors, and a number of others, as being associated with success in distance running (Costill et al., 1976; Daniels, 1974; Rusko et al., 1978).

The physiological characteristics and capabilities of the elite athlete are developed from a combination of genetic predisposition and arduous physical training (Ruiz et al., 2009; Saltin, 2003; Scott et al., 2005).

While it is our belief that these physiological factors represent some of the most important determinants of athletic success, it should be acknowledged that biomechanical, psychological, tactical, nutritional and environmental factors also have the potential to impact upon performance to a greater or lesser extent.

Running events from the middle distances (800 - 10,000 m) to long distances (half- and full-marathon) are dominated by East African black runners (Noakes, 2002; Noakes, 2000; Saltin, 1995). These populations may have a genotypic or phenotypic advantage when it comes to endurance running; several investigators have searched for phenotypic differences between black and white endurance athletes from South Africa, Kenya, and Eritrea (Bosch et al., 1990; Coetzer et al., 1993; Lucia et al., 2006; Saltin, 1995; Weston et al., 2000).

Studies comparing South and East African and Caucasian long distance runners have presented some consistent but also some inconsistent findings. Two studies indicated that black runners ran at a higher percentage of their maximum oxygen consumption (VO_2 max) during either a simulated treadmill marathon (Bosch et al., 1990) (higher percentage of their VO_2 max-marathon) or at a 10-km race pace (Weston et al., 2000) compared with their white counterparts. VO_2 max differed in one (Weston et al., 2000) but not the other study (Bosch et al.,

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1990). Similarly, one study found no difference in running economy at either 17 or 21 km/h (Coetzer et al., 1993), while another found a significant difference (Weston et al., 2000). A more consistent finding was that black endurance runners had lower blood lactate concentrations during submaximal exercise tests (Bosch et al., 1990; Coetzer et al., 1993; Weston et al., 2000).

As stated above, it has been suggested that running economy may be related to performance in long distance running, with running economy defined as the oxygen consumption (l/min and ml/kg/min) for a given standardized sub-maximal treadmill velocity. However, it has also been pointed out that the variation of all of the above mentioned parameters cannot always explain running performance, especially in subjects with a limited range of performance levels (Costill et al., 1973; Daniels, 1974; Pollock, 1997).

Studies have shown that the ability to run without accumulating lactate as a fatigue substance in active muscles is more critical than the magnitude of VO_2 max (Costill et al., 1973; Fay et al., 1989). These studies have recommended several blood lactate-related indices, such as lactate threshold (LT), maximal lactate steady-state (maxLaSS) and speed at the anaerobic threshold (speed@AT) as better predictors for endurance running performance than VO_2 max (Noakes et al., 1990).

The above findings suggest that many factors are related to success in distance running, and that runners may set a race pace which closely approximates the running velocity at which running cost is at its lowest and/or at or just below the lactate threshold.

No adequate study has so far been carried out to analyse the relationships among anatomical, pulmonary and exercise-related cardiopulmonary parameters, and 10 k running performance in Israel. The current study, therefore, it intended to examine the power of some 30 physical and physiological laboratory-based parameters (sub-maximal and maximal) in identifying the dominant factor/s that, singularly or in combination, explain and/or contribute to 10 k running performance in sub-elite competitive, though heterogeneous, Israeli long distance runners. Additionally, in an attempt to explain the apparently superior running ability of Israeli Ethiopian athletes at distances > 5 km, we compared physiological measurements in the fastest 21 Israeli Caucasian and 22 Israeli Ethiopian long distance runners with similar mean age, years of training and weekly volume of training.

Material and Methods

Subjects

Thirty of Israel's top male long distance runners (16 ethnic Ethiopians and 14 Caucasians) were recruited from local athletic clubs. Athletes were informed about all the tests and the possible risks and discomfort involved. Each athlete signed a written informed consent before testing. The Kaplan Medical Center's Helsinki Committee approved this study.

Inclusion criteria included currently competing in official long distance races, a current 10 k road race time of <32:40 min, no illness or injury in the previous 6 months, and training of >70 km/wk. The Ethiopian runners were born in Ethiopia but had been living and training in Israel for the last 10 to 20 years. The Caucasian runners were all born and trained in Israel and were of European, Arabicor North American descent, representing most Caucasians living in Israel.

Each athlete completed a detailed questionnaire reporting recent and career 10 k personal and season-best time, and his typical training volume per week specifically for the previous six months.

Six months prior to or following a formal 10 k race and after the study's procedures had been explained to them, each subject underwent a thorough medical examination, which included physical examination, full spirometric evaluation, and a cardiopulmonary exercise test (CPET). Most of the subjects had participated in several national and international level competitions in long distance running, including 10 k, and half- and full-marathon races. The subjects' selected physical characteristics and training profile, as well as their 10 k run time, are presented in **Table 1**.

Cardiopulmonary Exercise Tests (CPET)

Prior to the exercise challenge, anthropometric measurements were taken (weight, height, BMI) and a full resting pulmonary function test was performed (ZAN-600, Germany).

Runners were encouraged to be well rested and to perform very low-intensity training the day before testing. All athletes were thoroughly familiarized with the treadmill (including exposure to low- and high-speed running on the treadmill) before the running tests.

The CPET was performedon a treadmill (RAM 770 s, Germany) using a sub-maximal and maximal incremental exercise testprotocol (Inbar et al., 2001). The exercise protocol consisted of 1-min stages with workload incrementsof 1 km/h (speed) (the treadmill's elevation remained constant at 1.5% throughout the test) until the subject reached the speed of 12 or 14 km/h depending on the runner's best 10 k run time (~70% of $\dot{V}O_2$ peak). This work rate (speed) was kept constant for 5 minutes in order to secure steady state conditions (verified by unchanged HR and $\dot{V}O_2$ for at least two consecutive minutes). Following the constant-sub-maximal stage, the 1-min stages protocol with speed incrementsof 1 km/h was reinstated (keeping the slope unchanged) until the patient reached his maximum tolerable effort (typical total CPET time was 13 - 17 min). Runners were said to have attained their maximal ability when at least two of the following criteria were fulfilled:

Table 1.
Physical characteristic, training profile and 10 k run time-Ethiopian (ET) vs. Caucasian (CA) runners.

Parameter	Ethiopian (n = 16)		Caucasian (n = 14)		P^*
	Mean	SD	Mean	SD	
Age, yr	27.9	8.1	28.4	6.1	0.875
Height, cm	167.4	7.4	175.9	4.5	0.001
Mass, kg	54.3	4.3	63.8	6.4	<0.001
BMI, kg/m^2	19.4	1.5	20.6	2.0	0.062
Years training, yrs	9.6	6.6	8.2	4.3	0.519
Weekly distance, km	98.1	17.6	94.3	14.5	0.524
10 k time, min:sec	30:36	00:43	32:24	00:20	<0.001
10 k average speed, km/h	19:37	00:27	18:27	00:17	<0.001

Note: *Bold numbers denote significant difference between groups.

1) A plateau in $\dot{V}O_2$ during the last two stages of the test 2) RER ≥ 1.15; 3) $PETCO_2$ down-sloping during the last two minutes of the test; and 4) HR within 10 beats/min of age-predicted maximum heart rate (220-age). A plateau in $\dot{V}O_2$ was considered as less than one-half the expected rise in oxygen consumption for the workload compared with the linear relationship between oxygen consumption and speed during the incremental test. Whenever these criteria were not fulfilled, the athletes had to perform the same test on another visit and were encouraged verbally during the test to perform better.

Continuous 12-lead ECG was monitored throughout the test, with recordings made at baseline and at the end of each minute of exercise as well as during the recovery period.

Expired O_2 and CO_2 gases and the rate of airflow were measured breath-by-breath at rest and throughout the exercise period using the ZAN-600 (Germany) automated metabolic and respiratory diagnostic system (metabolic cart). The system was calibrated before each test using standard reference gases with known concentrations.

The following parameters were determined for each test on a breath-by-breath basis, and used for the interpretation of the results: Oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), heart rate (HR), oxygen pulse (O_2 pulse), ventilatory anaerobic threshold (VAT), minute ventilation (V_E), tidal volume (Vt), breathing frequency (Bf), end-tidal PO_2 (P_{ETO2}), and end-tidal PCO_2 (P_{ETCO2}).

The VAT was determined visually by two experienced reviewers and expressed as $\dot{V}O_2$ (ml/kg/min) and speed (km/h), using previously established criteria (Beaver et al., 1986).

Maximal volitional effort was attempted in each test unless there were overt limiting symptoms such as fatigue, shortness of breath, leg pain, chest pain, BP abnormalities, arrhythmias or marked ST segment displacement (>3 mm).

Running economy (running cost) was determined by using the mean $\dot{V}O_2$ of the last three min during the steady-state phase of the CPET.

Statistical Treatment

All measured parameters (physical, anthropometric, maximal, sub-maximal and pulmonary) were compared between the Ethiopian (ET) and the Caucasian (CA) groups, using an independent t-test. Pairwise Pearson correlation was used to calculate the level of association between all measured parameters and 10 k running time.

To identify the factors that can discriminate between groups Ethiopian/Caucasian), a logistic regression model was applied (the parameters that were included in the model were those that demonstrated significant correlation with 10 k run time).

To identify the parameters that significantly affect the 10 k run time a multiple linear regression was applied, with a stepwise selection method and validation for multicolinearity. Significance level was defined as $\alpha \leq 0.05$. All analyses were carried out using SPSS version 20.0.01.

Results

The physical and performance characteristics, as well as the groups' training profile, are presented in **Table 1**.

Each of the Ethiopian runners outperformed his Caucasian counterpart in the study's 10 k time trial (see **Table 1**). The respective mean (±SD) 10 k run time of the ET and the CA groups were 30:36 (±00:43) and 32:24 (±00:20) min, respectively ($p > 0.001$).

There were no significant differences in age, weekly training volume, and years of training between the CA and the ET athletes. However, the ET runners were significantly shorter and lighter ($P < 0.001$) and possessed a lower BMI ($P < 0.05$) than the CA runners.

Table 2 presents and compares selected pulmonary functions of the ET and the CA runners. It was noted that for absolute VC, FVC, FEV1, and FEV1/FVC, the ET runners had values significantly lower than those of the CA runners. However, the relative DLCO (to VA-DLCO/VA) was significantly higher in the ET than in the CA runners, suggesting relatively (to VA) more efficient pulmonary gas diffusion in the former. FEV1/ FVC % of pred, DLCO and TGV/TLC were similar in the two running groups (**Table 2**).

Responses during Maximal Treadmill Testing (CPET)

Table 3 compares the peak cardiopulmonary responses (reached during the CPET) between the ET and the CA runners.

Absolute $\dot{V}O_{2peak}$ (l/min), peak $\dot{V}_{CO2}$ (l/min), peak O_2 pulse (ml^{-beat}) and Vtpeak (l) were all significantly lower in the ET compared with the CA runners. Moreover, even when values were corrected for body mass ($\dot{V}O_{2peak}$, ml/kg/min, or peak $\dot{V}O_{2peak}{}^{-0.75\ kg}$, and peak O_2 pulse, ml/kg/beat*100), significant differences between the two groups were still apparent, with the ET group presenting significantly lower values (see **Table 3**). It should be pointed out that when comparing populations differing in body stature, it is more accurateto express oxygen uptake as milliliters per minute per kilogram$^{0.75}$ than milliliters per minute per kilogram (Svedenhag, 1995).

Only peakBf (b/min) and peakVd/Vt (%) showed significantly higher values in the ET than in the CA runners (**Table 3**).

Table 2.
Resting pulmonary function-Ethiopian (ET) vs. Caucasian (CA) runners.

Parameter	Ethiopian (n = 16)		Caucasian (n = 14)		P*
	Mean	SD	Mean	SD	
FVC, l	3.8	0.5	5.1	0.5	<0.001
FVC % pred	86.1	11.1	102.1	9.0	<0.001
FEV1, l/sec	3.3	0.5	4.3	0.5	<0.001
FEV1, % pred	85.6	9.9	102.5	11.7	<0.001
FEV1/FVC, %	86.4	6.4	79.2	22.0	0.239
FEV1/FVC, % pred	106.3	6.8	102.3	10.5	0.234
DLCO, (mL/min/mmHg)	35.2	4.6	35.5	10.0	0.999
DLCO/VA, (mL/min/mmHg)/l	6.6	1.2	5.5	0.6	0.010
TGV/TLC, l/l	59.5	7.3	54.7	6.3	0.088

Note: *Bold numbers denote significant difference between groups. FVC = Force vital capacity; FEV1 = Force expiratory volume in one second; %pred. = Percent of predicted value; DLCO = Diffusing capacity of lung for carbon monoxide; DLCO/VA = The ratio of the DLCO to alveolar volume; TGV/TLC = The ratio of thoracic gas volume to total lung capacity.

Table 3.
Peak physiological data measured during maximal treadmill test.

Parameter	Ethiopian (n = 16)		Caucasian (n = 14)		P^*
	Mean	SD	Mean	SD	
$\dot{V}O_{2peak}$, l/min	3.6	0.6	4.8	0.5	<0.001
$\dot{V}_{CO2}$ peakl/min	3.2	0.6	4.2	0.5	<0.001
$\dot{V}O_{2peak}$, ml/kg/min	59.5	8.5	65.6	6.2	0.007
$\dot{V}O_{2peak}{}^{-0.75\ kg}$, ml/$^{-0.75\ kg}$/min	161.8	24.5	184.6	17.4	0.007
Speed@ $\dot{V}O_{2peak}$, km/h	21.5	1.3	21.6	0.9	0.777
peakRER, l/l	1.1	0.1	1.2	0.1	0.388
peakHR, b/min	184.0	8.2	181.1	9.0	0.367
peakO_2pulse, ml/kg/beat*100	32.4	4.3	36.3	2.6	0.006
peakVE, l/min	112.3	11.2	147.0	18.8	<0.001
peakVt, l	1.7	0.3	2.5	0.3	<0.001
peakBf, b/min	65.9	7.7	60.0	11.0	<0.001
BR, l/min	35.2	18.1	43.5	16.9	0.210
peakVE/ $\dot{V}O_2$, l/l	32.2	4.5	34.0	5.8	0.330
peakVE/ $\dot{V}_{CO2}$, l/l	29.1	3.7	30.1	5.6	0.580
peakPETO_2, mmHg	118.6	3.5	119.5	4.8	0.569
endPETCO_2, mmHg	34.0	3.9	33.4	5.9	0.729
endVd/Vt, %	26.3	2.0	22.3	2.2	<0.001

Note: *Bold numbers denote significant difference between groups. $\dot{V}O_{2peak}$ = Rate of Oxygen uptake at maximal effort; $\dot{V}CO_{2peak}$ = Rate of CO_2 production at maximal effort; $\dot{V}O_{2peak}$, ml/kg/min = Oxygen uptake at maximal effort in ml/kg$_*$min; $\dot{V}O_{2peak}{}^{-0.75\ kg}$ = Oxygen uptake at maximal effort in ml/kg^{75}*min; Speed@$\dot{V}O_{2peak}$ = Running speed at $\dot{V}O_{2peak}$; peakHR = Heart rate at maximal effort; peak O_{2pulse} = Oxygen pulse at maximal effort; peakRER = Respiratory exchange ratio at maximal effort; peakVE = Minute ventilation at maximal effort; peakVt = Tidal volume at maximal effort; peakBf = Breathing frequency at maximal effort; BR = Breathing reserve at maximal effort; peakVE/$\dot{V}O_2$ = Respiratory equivalent for O_2 at maximal effort; peakVE/$\dot{V}_{CO2}$ = Respiratory equivalent for CO_2 at maximal effort; peakP_{ETO2} = End tidalO_2 at maximal effort; end P_{ETCO2} = End tidal CO_2 at maximal effort; endVd/Vt = Physiological dead space at maximal effort.

PeakRER (l/l), peakHR (b/min), Speed@ $\dot{V}O_{2peak}$ (km/h), peakBR (l/min), peakVE/ $\dot{V}O_2$ (l/l), peak $\dot{V}_{CO_2}$ (l/l), peakPETO_2 (mmHg), and peakPETCO_2 (mmHg) demonstrated similar values in the two groups (see **Table 3**).

It is apparent that both groups reached similarly high peak CPET values as well as treadmill speeds at maximal treadmill tests, as would be expected for athletes of that caliber. Furthermore, when observing the selected and relevant peak values (RER, HR and PETCO_2) it is evident that maximal volitional efforts were reached in both groups (see **Table 3**).

Responses during Sub-Maximal (Steady-State) Effort:

At sub-maximal workload (12 or 14 km/h and approx. 70% $\dot{V}O_2$ peak), no differences were observed between the two runners' groups for RER, HR or O_2 pulse/kg, confirming similar relative exercise intensity for both groups (**Table 4**). In addition, during the sub-maximal effort, $\dot{V}O_2$, l/min, $\dot{V}_{CO2}$, l/min, $\dot{V}O_2$, ml/kg/min, $\dot{V}O_2$ ml$^{-0.75\ kg}$/min and Vt, l, demonstrated significantly lower values in the ET compared with the CA group, while Bf, br/min, VE/ $\dot{V}O_2$, l/l, VE/ $\dot{V}_{CO2}$, l/l, PETO_2, mmHg, and Vd/Vt, %, showed higher values in the ET than in the CA runners (**Table 4**).

As seen in **Table 4**, both VE and PETCO_2 were also appreciably lower in the ET than in the CA group, though the difference in these two variables did not reach a significant level (p = 0.07).

Variables associated with the runners' ventilatory anaerobic threshold (VAT, ml/kg/min, Speed@VAT, km/h, and VAT/ $\dot{V}O_{2peak}$, %) were similar in the ET and the CA runners (**Table 4**). However, the 10 k AvSpeed/speed@ $\dot{V}O_{2peak}$ was significantly faster in the ET compared with that of the CA (92 vs. 86%; $p > 0.001$) (**Table 4**). It is also evident that, on the aver-

Table 4.
Physiological data obtained during sub-maximal treadmill test (~70% VO_{2peak}).

Parameter**	Ethiopian (n = 16)		Caucasian (n = 14)		P^*
	Mean	SD	Mean	SD	
$\dot{V}O_2$, l/min	2.1	0.4	3.0	0.3	<0.000
$\dot{V}CO_2$, l/min	2.1	0.4	2.8	0.3	<0.000
$\dot{V}O_2$, ml/kg/min	40.3	4.1	45.5	2.8	0.000
$\dot{V}O_2{}^{-0.75\ kg}$, ml$^{-0.75\ kg}$/min	103.5	16.8	131.8	17.9	<0.001
RER, l/l	1.0	0.1	0.9	0.0	0.099
HR, b/min	148.7	9.0	153.6	9.7	0.120
O_2 pulse, ml/kg/beat*100	27.5	2.8	29.1	2.6	0.122
VE, l/min	64.7	10.4	74.4	7.7	0.077
Vt, l	1.3	0.2	2.0	0.3	<0.001
Bf, br/min	49.4	8.4	40.4	5.1	0.001
VE/ $\dot{V}O_2$, l/l	27.9	2.5	25.5	2.2	0.001
VE/ $\dot{V}CO_2$, l/l	27.8	2.6	25.8	1.8	0.019
PETO_2, mmHg	112.4	3.2	109.4	3.6	0.018
PETCO_2, mmHg	35.3	3.3	37.4	2.5	0.072
Vd/Vt, %	29.3	2.3	25.7	3.1	0.001
VAT, ml/kg/min	51.6	8.5	54.5	5.9	0.304
Speed@VAT, km/h	18.4	1.6	17.8	1.3	0.310
VAT/peakVO_2, %	86.6	6.1	84.4	4.5	0.276
10 k Avspeed/speed@$\dot{V}O_2$peak, %	0.92	0.05	0.86	0.04	0.001

Note: *Bold numbers denote significant difference between groups. **Respective abriviations as in **Table 3** but for submaximal steady-state effort ($_{sub}$). VAT = Ventilatory anaerobic threshold; Speed@VAT = Running speed at VAT; 10 k AvSpeed/speed@ $\dot{V}O_{2peak\ 2}$ = % of 10 k average speed of the speed at $\dot{V}O_{2peak}$.

age, runners in both groups ran the 10 k time-trial at an average pace faster than their respective speed at the VAT (see **Tables 1** and **4**).

$\dot{V}O_{2sub}$, and peakVE demonstrated, using this model, the highest association with 10 k run time (**Table 5**).

As can be seen in **Table 5**, by knowing the runner's $\dot{V}O_{2sub}$ and peakVE one can discriminate between and identify the ET (<31:30 min) and the CA (≥31:30 min) runners with 93.3% confidence. This analysis, however, will not facilitate prediction of the runner's 10 k run time. For that, a multiple regression analysis was performed on the entire study's sample disregarding the ethnic origin (N = 30), using a 10 k run time as the dependent variable with all other measured parameters (physical, spirometric and exercise cardiopulmonary) as independent variables. The selection of the optimal model was conducted in steps:

First step—For all measurements (physical, spirometric and exercise cardiopulmonary) a pair-wise correlation was calculated. The parameters, which demonstrated a significant association with 10 k run time, were included in the multiple linear regression models.

Second step—A combined model was applied, using the stepwise elimination method, to identify the combined parameters that best explain (affect??? Why is this here?) 10 k running performance and prevent multicolinearity.

The outcome of this stepwise analysis is provided in **Tables 6(a)** and **(b)**. Absolute $\dot{V}O_2$ at sub-maximal effort ($\dot{V}O_{2sub}$) (running cost) was most closely related to 10 k run time (r = 0.730; $p < 0.004$), thus accounting for the largest amount of variance (53%) in the 10 k performance ($R^2 = 0.533$) (**Table 6(b)**). Minute ventilation at peak exercise level (peakVE), when grouped with $\dot{V}O_{2sub}$, was the next most closely associated variable (multiple $R_{mult} = 0.802$; $p < 0.016$). The multiple R did not rise significantly with the addition of any other measured variable/s to the combined variance of $\dot{V}O_{2sub}$ and peakVE, in the 10 k run time.

The following is the predictive equation modelled by the discriminant analysis, quantifying the relationship between the 10 k run-time and the selected variables:

$$\begin{aligned}&10\text{ k Run Time (min)}\\&=27:00+00:53\left|\dot{V}O_{2sub}\right.+00:01\left|\text{peakVE}\right.\end{aligned} \quad (1)$$

An increase of either $\dot{V}O_2$ sub or peakVE causes an increase in run time (slower running speed) and vice versa.

Third step: adjustment for weight—Since both $\dot{V}O_{2sub}$ and peakVE are size-related, a combined model was applied adjusting for weight and applying a stepwise elimination method that forced weight to be included in the model. It is evident that forcing body weight into the model did not increase (significantly) the aggregate variance of the 10 k run-time beyond that observed without it (**Table 7**).

This supports our previous findings (**Table 5**) that of all the measured variables, these two physiologic exercise-related responses are the most distinctive physiognomies of top Israeli Caucasian and Ethiopian 10 k runners (combined variance = 64.4%).

The relationships among $\dot{V}O_{2sub}$, peakVE and performance in the 10 k race are graphically provided in **Figure 1**. It implies that the lower both the $\dot{V}O_{2sub}$ and peakVE, the better (faster) is the 10 k run time (Rmult. = 0.802; $p < 0.042$).

Table 5.
Cross-classification of 10 k run-time predicted by the selected variables usingbinary logistic regression.

Parameter*	Observed	Predicted		
		Ethiopians	Caucasians	Correct Prediction (%)
		(<31:30 min)	(>31:30 min)	
$\dot{V}O_{2sub}$, l/min	Ethiopians (<31:30 min)	14	2	87.5
	Caucasians (≥31:30 min)	2	12	85.7
	Overall Percentage			86.7
$\dot{V}O_{2sub}$, l/min peakVE, l/min	Ethiopians (<31:30 min)	15	1	93.8
	Caucasian (≥31:30 min)	1	13	92.9
	Overall Percentage			93.3

Note: *Respective abbriviations as in **Table 3**.

Table 6.
Multiple regression analysis for selected variables and the 10 k run time.

(a)

Significant parameters*	R	R^2
$\dot{V}O_{2sub}$	0.730	0.533
$\dot{V}O_{2sub}$ &peakVE	0.802	0.644

(b)

Significant parameters**	Estimate	P*
$\dot{V}O_{2sub}$	53.49	0.004
peakVE	1.079	0.016

Note: *Bold numbers denote significant difference between groups. *Respective abbreviations as in **Table 3**.

Discussion

While there are many possible combinations that might lead to elite performance in endurance events, it appears that extremely high values for VO_2 max and outstanding running economy are rarely seen in the same person (Daniels, 1974; Saltin, 2003; Joyner & Coyle, 2007).

East African runners do not have exceptional high values for VO_2 max or lactate threshold, but generally have outstanding running economy (Billat et al., 2003; Larsen, 2003; Noakes, 2002; Saltin et al., 1955).

Although the subjects in the current study were sub-elite (>29:00 - 32:40 min) rather than elite (<28:00) 10 k runners, any differences between groups (ET and CA) should also be apparent in this study, as even at this level of performance, as shown in the present study, black East African runners also dominate over white Caucasian runners (Lucia et al., 2006; Weston et al., 2000).

The first important finding to emerge from this study is that

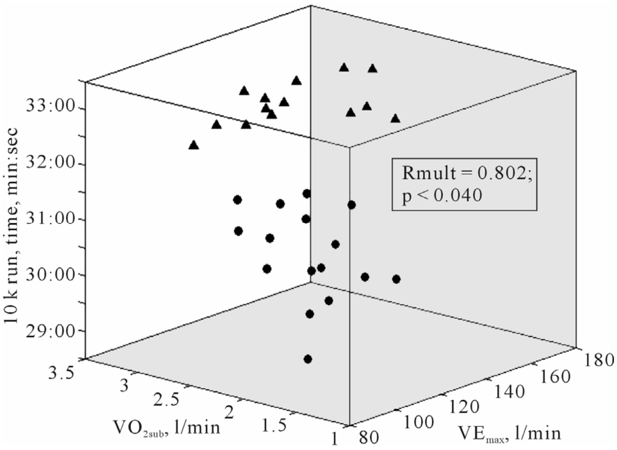

Figure 1.
Relationships among $\dot{V}O_{2sub}$, peakVE and 10 K run time in both the ET (●) and the CA (▲). *R_{mult} = Multiple linear regression coefficience.

Table 7.
Stepwise elimination method forcing weight to be included in the model.

Significant parameters**	R	R^2	Estimate	P*
$\dot{V}O_{2sub}$	0.730	0.533	49.29	0.022
peakVE; $\dot{V}O_{2sub}$	0.802	0.644	1.001	0.042
Weight	0.804	0.647	0.686	0.688

Note: *Bold numbers denote significant difference between groups. **Respective abbbreviations as in **Table 3**.

each of the ET runners was able to achieve better performance than the CA runners in the 10 k race, despite having a considerably lower peak oxygen uptake ($\dot{V}O_{2peak}$), both in absolute terms and relative to body mass, lowerpeakVE and lower-peakO_2 pulse. Furthermore, all VAT-related values (VAT, ml/kg/min, VAT/$\dot{V}O_{2peak}$, %, and Speed@VAT, km/h) were similar in the two ethnic groups (see **Table 4**). Similar findings to these have been reported previously (Coetzer et al., 1993; Noakes, 2000; Noakes, 2002; Saltin et al., 1995).

Physiological factors that might contribute to such findings are: 1) better running economy (Saltin et al., 1955; Weston et al., 2000), or 2) the ability to sustain a higher percentage of their $\dot{V}O_2$ peak throughout the race, or a combination of both (Billat et al., 2003; Costill et al., 1973; Larsen, 2003).

What, then, makes the ET runners run the 10 k faster than the CA runners? Analyzing the study's data and statistical outcomes points to several possible alternatives: 1) As a group, the ET runners' average speed during the measured 10 k, relative to their maximal speed in the laboratory treadmill test (10 k AvSpeed/speed@ $\dot{V}O_{2peak}$), was significantly faster than that of the CA runners (92 vs. 86%; $p > 0.001$) (**Table 4**); 2) The ET's absolute as well as relative (to body mass) oxygen uptake during the sub-maximal steady-state phase of the CPET ($\dot{V}O_{2sub}$) was significantly lower than the respective values of the CA runners (see **Table 4**). If we consider both variables as reflecting running cost and/or running economy, then the ET runners were metabolically and/or mechanically more efficient and energy conserving, which could explain, at least partially, their better performance in the 10 k race.

What makes the ET runners more efficient and energy conserving than the CA runners? Above all it is their smaller, lighter and leaner body stature (see **Table 1**) (Jensen et al., 2001; Kyröläinen et al., 2001). Nonetheless, the ET's running cost was lower not only when absolute values were compared (2.1 vs. 2.8, $\dot{V}O_2$ l/min), but it remained so even when body mass was accounted for (40.3 vs. 45.5, $\dot{V}O_{2sub}$, ml/kg/min; or 103.5 vs. 131.8, $\dot{V}O_2$, $ml^{-0.75\ kg}$/min) (see **Table 4**).

Studies on East and South African black runners all reported that black athletes are shorter and lighter than their Caucasian counterparts (Jensen et al., 2001; Joyner & Coyle, 2007; Kyröläinen et al., 2001; Weston et al., 2000).

Body size does play a significant role in absolute $\dot{V}O_2$ max and in lung volumes, which differ extensively between population groups (Saltin, 2003; Saltin et al., 1955; Wyndham et al., 1969). However, the present study's results point to the possibility that factors other than body size and which are associated with and influence metabolic and/or mechanical efficiency (physical, mitochondrial, enzymes, cell blood supply, etc.) play a major role in the success and dominance of the East African long distance runners in general and of Israeli ET runners in particular. Indeed, such factors have been implicated in many studies as playing possible role in the success and dominance of the elite East and South African long distance runners (Coetzer et al., 1993; Larsen et al., 2003; Noakes, 2000; Saltin et al., 1995; Scott & Pitsiladis, 2007; Weston et al., 2000).

However, none of these studies could supply convincing evidence supporting specific factor/s, genotypic or phenotypic, as responsible for the East and South African dominance in long distance running.

In running, biomechanical factors can contribute to success in performance in terms of improving running economy and preventing injury (Scott & Pitsiladis, 2007; Williams, 2007). Running economy has been shown to correlate with certain gait characteristics such as stride length (Morgan & Daniels, 1994), ground contact time (Nummela et al., 2007), vertical oscillation and lower extremity angles (Williams & Cavanagh, 1987). It is possible that Kenyan runners, as well as our ET runners, run in a form that positively contributes to their superior performance. To our knowledge, the only two biomechanical studies on Kenyan runners available in English are an abstract by Enomoto and Ae (2005) and that of Kong and de Heer (2008). The former reported kinematic differences between elite Kenyan and Japanese runners and concluded that the Kenyan runners were able to swing their legs forward faster and through a greater range. In the latter study it was shown that the slim limbs of Kenyan distance runners may positively contribute to performance by having a low moment of inertia and thus requiring less muscular effort in leg swing. The short ground contact time observed in Kong and de Heer study (2008) may also be related to good running economy since there is less time for the braking force to decelerate the forward motion of the body. Although limited data were presented in these studies, their findings highlight the notion that biomechanical factors may play a significant role in the success of East African distance runners.

Yet another conceivable route for our ET runners' low running cost could be greater reliance on glycolytic anaerobic energy pathways. Although blood lactate concentration was not measured in the present study, the latter alternative is rather remote. It is widely accepted that East African long distance runners' blood and muscle lactate levels are lower than those of Caucasian runners at both maximal and sub-maximal exercise levels (Larsen, 2003; Saltin, 2003; Saltin et al., 1995).

The findings reported above (low blood and muscle lactate levels) could partially elucidate the present study's observation that the ET runners' average speed during the measured 10 k race, relative to their maximal speed in the laboratory treadmill test (10 k AvSpeed/speed@ $\dot{V}O_{2peak}$), was significantly faster than that of the CA runners.

The observed lower VEsub and peakVE in our ET runners could be an additional contributing factor to the ET runners' lower O_2 uptake at both sub-maximal and maximal exertion, and consequently to their lower running cost. The ET runners' significantly higher relative (to VA) pulmonary gas diffusion, as implicated by their significantly higher DLCO/VA (6.6 vs. 5.5, mL/min/mmHg/L; $p < 0.010$) (see **Table 2**) could be related to their lower VEsub and peakVE and, though indirectly, to their better running economy and faster 10k run time. Other compensations for a slower rate of O_2 uptake, both at maximal and submaximal effort, could be more efficient O_2 utilization (Scott et al., 2005; Scott & Pitsiladis, 2007) or a specific leg muscle morphology (Saltin, 2003; Saltin et al., 1995).

Although all the VAT-related variables were statistically similar in the study's two ethnic groups, it is clear that runners in both groups possessed the ability to utilize a relatively large fraction of their $\dot{V}O_{2peak}$ during the 10 k race. Costill et al. (1973) found that a similar group of runners utilized an estimated 51.1 mllkg/min and 86% VO_2 max while running a ten mile race. These values are in close agreement with the 51.6 - 54.5 ml/kg/min and 86.6% - 84.4% $\dot{V}O_{2peak}$ values found in the present study.

To further explore the differences between the ET and the CA 10k runners and to identify those responses/features that best discriminate between the "fast" (ET) and the "slow" (CA) runners, three additional steps/procedures were carried out.

1) A logistic regression model, signifying that by knowing the runner's $\dot{V}O_{2sub}$ and peakVE one can confidently discriminate between and identify the ET (<31:30 min) and the CA (≥31:30 min) runners with 93.3% confidence.

2) A multiple regression analysis on the entire study's sample, disregarding the ethnic origin (N = 30), using a 10 k run time as the dependent variable, with all other measured parameters (physical, spirometric and exercise cardiopulmonary) as independent variables. Here again, the most closely related responses/variables to the 10 k run time were $\dot{V}O_{2sub}$ and peakVE (**Table 6(a)**). Looking at and solving Equation (1) indicates that entering both $\dot{V}O_{2sub}$ and peakVE to the regression equation explains 64.4% of the total variance in 10 k run time (**Table 6(a)**). The remaining variance in 10 k running performance (35.6%) could not be explained by any single variable or a combination of the variables measured in the present study. Further, the above equation (Equation (1)) suggests that reducing O_2 consumption during a 10 k run by 1 l/min will improve the 10 k run time by approximately 1 min (53.5 sec). Reducing peakVE at the end of an all-out running task by 1 l/min will enhance 10 k running performance by only 1 sec (**Table 6(b)** and Equation (1)).

3) Since both $\dot{V}O_{2sub}$ and peakVE are size-related, a combined model was applied, adjusting for weight and applying a stepwise elimination method that forced weight to be included in the model (**Table 7**). It is apparent that forcing body weight into the model did not (significantly) increase the aggregate variation in the 10 k run time beyond that observed without it (**Table 7**).

This model confirms that both mechanical and/or metabolic efficiency, defined in this study as the oxygen consumption during running at a treadmill velocity of 12 - 14 km/h (~70% $\dot{V}O_{2peak}$) ($\dot{V}O_2$ sub), and, though to a smaller extent, minute ventilation at maximal effort during a treadmill test, play major roles in 10 k run-time.

Several questions has arisen concerning our ET runners' lower running cost and lower peakVE in the face of their faster 10 k run-time. Is this mostly genetic, environmental, or a combination of both? A growing body of evidence suggests that genetic variation does influence athletic performance, yet despite the speculation that East African athletes have a genetic advantage for endurance performance, there is no genetic evidence to suggest that this is indeed the case (Scott et al., 2005; Scott & Pitsiladis, 2007).

There are just three relevant studies in the scientific literature that have examined physiological differences between Africans and non-Africans, and none of the three looked specifically at gene quality. That is no surprise since scientists don't actually know which genes code for endurance performance; they can't possibly determine whether Africans have a lock-hold on superior genetic material.

The malleability of mammalian biology during early life carries considerable weight throughout the course of the lifespan (Scott et al., 2005). Factors such as socioeconomic status (Flouris et al., 2009) and early mental stimulation are associated with life cognitive as well as metabolic and physiologic adjustments that could translate into enhanced physical performance in later life (Buchowicz et al., 2010; Julian et al., 2009). Potential candidates include, but are not limited to, training at high altitude, increased level (intensity) of daily physical activity, fatigue resistance, differences in running economy and genetics (Holden, 2004).

The present study's ET runners are somewhat unique in that their birth, childhood and adolescence took place in Ethiopia while most of their adult life, and thus training, was spent in Israel. With such a unique background our ET runners possess both Ethiopian genotypic and phenotypic characteristics blended with Israeli phenotypic/environmental features.

The Ethiopian runner's unconditional dominance in endurance running events, both globally and in Israel, implies a more dominant influence of Ethiopian-associated genetic and early life phenotypic factors than of later life factors (adulthood environmental and training), on their performance of long distance running in general, and that of the 10 k in particular.

Conclusion

Elite sporting performance results from the combination of innumerable factors, which interact with one another in a poorly understood but complex manner to mould a talented athlete into a champion. Within the field of sports science, elite performance is understood to be the result of both genotypic and phenotypic factors. However, the extent to which champions are born or made is a question yet unsolved. The present study describes the contributions made by selected physical, training and physiological (spirometric and exercise-related) parameters to the attainment of a high level 10 k performance. The results suggest that factors associated with running cost, independent of body size, play a crucial role in the performance of 10 k running. The results also suggest, though indirectly, that genetic and early life phenotypic factors are more dominant than later-life environmental factors (including training) at the 10 k performance level.

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