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 (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 (VO₂peak = 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 VO₂; Ethiopians; Caucasians

Introduction

Many factors have been identified as having an influence on success in distance running. The observation of significant relationships between VO₂ max, the fraction of slow twitch fibers, the fraction of VO₂ 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; Coetzee 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 (VO₂ max) during either a simulated treadmill marathon (Bosch et al., 1990) (higher percentage of their VO₂ max-marathon) or at a 10-km race pace (Weston et al., 2000) compared with their white counterparts. VO₂ max differed in one (Weston et al., 2000) but not the other study (Bosch et al.,...
The Caucasian runners were all born and trained in Israel and had been living and training in Israel for the last 10 to 20 years. 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 VO₂ 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 VO₂ 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 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 performed on a treadmill (RAM 770 s, Germany) using a sub-maximal and maximal incremental exercise test protocol (Inbar et al., 2001). The exercise protocol consisted of 1-min stages with workload increments of 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 VO₂ peak). This work rate (speed) was kept constant for 5 minutes in order to secure steady state conditions (verified by unchanged HR and VO₂ for at least two consecutive minutes). Following the constant-sub-maximal stage, the 1-min stages protocol with speed increments of 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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ethiopian (n = 16)</th>
<th>Caucasian (n = 14)</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>27.9 ± 8.1</td>
<td>28.4 ± 6.1</td>
<td>0.875</td>
</tr>
<tr>
<td>Height, cm</td>
<td>167.4 ± 7.4</td>
<td>175.9 ± 4.5</td>
<td>0.001</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>54.3 ± 4.3</td>
<td>63.8 ± 6.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>19.4 ± 1.5</td>
<td>20.6 ± 2.0</td>
<td>0.062</td>
</tr>
<tr>
<td>Years training, yrs</td>
<td>9.6 ± 6.6</td>
<td>8.2 ± 4.3</td>
<td>0.519</td>
</tr>
<tr>
<td>Weekly distance, km</td>
<td>98.1 ± 17.6</td>
<td>94.3 ± 14.5</td>
<td>0.524</td>
</tr>
<tr>
<td>10 k time, min:sec</td>
<td>30:36 ± 00:43</td>
<td>32:24 ± 00:20</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>10 k average speed, km/h</td>
<td>19:37 ± 00:27</td>
<td>18:27 ± 00:17</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Note. *Bold numbers denote significant difference between groups.
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 10k 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 10k run time). To identify the parameters that significantly affect the 10k run time a multiple linear regression was applied, with a stepwise selection method and validation for multicolinearity. Significance level was defined as α≤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 10k time trial (see Table 1). The respective mean (±SD) 10k 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 VO2peak (l/min), peak VCO2 (l/min), peak O2 pulse (ml/sec) and Vpeak (l) were all significantly lower in the ET compared with the CA runners. Moreover, even when values were corrected for body mass (VO2peak, ml/kg/min, or peak VO2peak−0.75 kg, and peak O2 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 accurate to 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.

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

Note: Bold numbers denote significant difference between groups. FVC = Force vital capacity; FEV1 = Force expiratory volume in one second; *speed = 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.

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It is evident that maximal volitional more, when observing the selected and relevant peak values tests, as would be expected for athletes of that caliber. Further-

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ethiopian (n = 16)</th>
<th>Caucasian (n = 14)</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO_{max}, l/min</td>
<td>3.6</td>
<td>0.6</td>
<td>4.8</td>
</tr>
<tr>
<td>\dot{V}vol/peak/min</td>
<td>3.2</td>
<td>0.6</td>
<td>4.2</td>
</tr>
<tr>
<td>VO_{max}, ml/kg/min</td>
<td>59.5</td>
<td>8.5</td>
<td>65.6</td>
</tr>
<tr>
<td>VO_{max}, 0.75 kg/l/min</td>
<td>161.8</td>
<td>24.5</td>
<td>184.6</td>
</tr>
<tr>
<td>Speed@ VO_{max}, km/h</td>
<td>21.5</td>
<td>1.3</td>
<td>21.6</td>
</tr>
<tr>
<td>peakRER, l/l</td>
<td>1.1</td>
<td>0.1</td>
<td>1.2</td>
</tr>
<tr>
<td>peakHR, b/min</td>
<td>184.0</td>
<td>8.2</td>
<td>181.1</td>
</tr>
<tr>
<td>peakO2 pulse, ml/kg/beat*100</td>
<td>32.4</td>
<td>4.3</td>
<td>36.3</td>
</tr>
<tr>
<td>peakVE, l/min</td>
<td>112.3</td>
<td>11.2</td>
<td>147.0</td>
</tr>
<tr>
<td>peakBF, b/min</td>
<td>1.7</td>
<td>0.3</td>
<td>2.5</td>
</tr>
<tr>
<td>BR, l/min</td>
<td>35.2</td>
<td>18.1</td>
<td>43.5</td>
</tr>
<tr>
<td>peakVE/ VO_{max}, l/l</td>
<td>32.2</td>
<td>4.5</td>
<td>34.0</td>
</tr>
<tr>
<td>peakVE/ Vdot, l/l</td>
<td>29.1</td>
<td>3.7</td>
<td>30.1</td>
</tr>
<tr>
<td>peakPETO2, mmHg</td>
<td>118.6</td>
<td>3.5</td>
<td>119.5</td>
</tr>
<tr>
<td>endPETCO2, mmHg</td>
<td>34.0</td>
<td>3.9</td>
<td>33.4</td>
</tr>
<tr>
<td>endVd/Vt, %</td>
<td>26.3</td>
<td>2.0</td>
<td>22.3</td>
</tr>
</tbody>
</table>

Note: *Bold numbers denote significant difference between groups. VO_{max} = Rate of Oxygen uptake at maximal effort; VCO_{max} = Rate of CO$_2$ production at maximal effort; VO_{max}, ml/kg/min = Oxygen uptake at maximal effort in ml/kg-min; VO_{max}, 0.75 kg/l/min = Oxygen uptake at maximal effort in ml/kg*75 min; Speed@VO_{max} = Running speed at VO_{max}; peakHR = Heart rate at maximal effort; peak O_{2}pulse = Oxygen pulse at maximal effort; peakRER = Respiratory exchange ratio at maximal effort; peakVE = Minute ventilation at maximal effort; peakBF = Breathing frequency at maximal effort; BR = Breathing reserve at maximal effort; peakVE/VO = Respiratory equivalent for O$_2$ at maximal effort; peakVE/Vdot = Respiratory equivalent for CO$_2$ at maximal effort; peak PETO$_2$ = End tidal O$_2$ at maximal effort; end PETCO$_2$ = End tidal CO$_2$ at maximal effort; endVd/Vt = Physiological dead space at maximal effort.

PeakRER (l/l), peakHR (b/min), Speed@ VO_{peak} (km/h), peakBF (l/min), peakVE/VO$_2$ (l/l), peak Vdot (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% VO$_2$ 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, VO$_2$, l/min, VCO$_2$, l/min, VO$_2$, ml/kg/min, VO$_2$, 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/VO$_2$, l/l, VE/VCO$_2$, 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/VO$_{max}$, %) were similar in the ET and the CA runners (Table 4). However, the 10 k AvSpeed/speed@VO$_{peak}$ 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-
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).

\( \text{VO}_{2\text{sub}}, \) 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 \( \text{VO}_{2\text{sub}} \) 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) the 10 k running performance and prevent multicollinearity.

The outcome of this stepwise analysis is provided in Tables 6(a) and (b). Absolute \( \text{VO}_2 \) at sub-maximal effort (\( \text{VO}_{2\text{sub}} \)) (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 \( \text{VO}_{2\text{sub}} \), was the next most closely associated variable (multiple \( R_{\text{mult}} = 0.802; \ p < 0.016 \)). The multiple R did not rise significantly with the addition of any other measured variable/s to the combined variance of \( \text{VO}_{2\text{sub}} \) 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:

\[
10 \text{ k Run Time (min)} = 27.00 + 0.00 \cdot 53[\text{VO}_{2\text{sub}}] + 0.00 \cdot 01[\text{peakVE}]
\]

An increase of either \( \text{VO}_{2\text{sub}} \) or peakVE causes an increase in run time (slower running speed) and vice versa.

**Third step**—adjustment for weight—Since both \( \text{VO}_{2\text{sub}} \) 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 \( \text{VO}_{2\text{sub}} \), peakVE and performance in the 10 k race are graphically provided in Figure 1. It implies that the lower both the \( \text{VO}_{2\text{sub}} \) and peakVE, the better (faster) is the 10 k run time (\( R_{\text{mult}} = 0.802; \ p < 0.042 \)).

### Discussion

While there are many possible combinations that might lead to elite performance in endurance events, it appears that extremely high values for \( \text{VO}_2 \) 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 \( \text{VO}_2 \) 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
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 (VO₂peak, both in absolute terms and relative to body mass, lower peak VE and lower peak O₂ pulse. Furthermore, all VAT-related values (VAT, ml/kg/min, VAT/VO₂peak, %, and Speed@VAT, km/h) were similar in the two ethnic groups (see Table 4). Similar findings to these have been reported previously (Coetzee et al., 1993; Noakes, 2000; Noakes, 2002; Saltin et al., 1993; Larsen et al., 2003; Noakes, 2000; Saltin et al., 1993; Scott & Pitsiladis, 2007; Weston et al., 2000).

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, VO₂ (l/min), but it remained so even when body mass was accounted for (40.3 vs. 45.5, VO₂peak, ml/kg/min; or 103.5 vs. 131.8, VO₂, ml × 0.75 kg/m/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 VO₂ 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 (Coetzee 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.
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@VO_{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 O2 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 O2 uptake, both at maximal and submaximal effort, could be more efficient O2 utilization (Scott et al., 2005; Scott & Pittalis, 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 \( \text{VO}_{2peak} \) 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% \( \text{VO}_2 \) 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% \( \text{VO}_{2peak} \) 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 \( \text{VO}_{2sub} \) and peakVE one can confidently discriminate between and identify the ET (\( \leq 31:30 \) min) and the CA (\( \geq 31:30 \) 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 \( \text{VO}_{2sub} \) and peakVE (Table 6(a)). Looking at and solving Equation (1) indicates that entering both \( \text{VO}_{2sub} \) 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 O2 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 \( \text{VO}_{2sub} \) 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% \( \text{VO}_{2peak} \)) (\( \text{VO}_2 \) 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 & Pittalis, 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 (Flouri 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 la-
ter-life environmental factors (including training) at the 10 k performance level.

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