

Lower Leg Length is Associated with Running Economy in High Level Caucasian Distance Runners

by

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The aim of the present study was to investigate lower limb anthropometric and composition variables related to running economy (RE) and running performance in a homogeneous group of high level European distance runners. RE at the speeds of 14, 16 and 18 km·h⁻¹ (189 ± 12; 188 ± 11; 187 ± 11 O₂ ml·kg⁻¹·km⁻¹) and maximal oxygen uptake (VO_{2max}) (67.3 ± 2.9 ml·kg⁻¹·min⁻¹) of 13 high level distance runners were determined on a motorised treadmill. Anthropometric variables and body composition were measured. The BMI was related to RE at the speed of 14 (r² = 0.434; p = 0.014), 16 (r² = 0.436; p = 0.014) and 18 km·h⁻¹ (r² = 0.389; p = 0.023). Lower leg length was negatively related to RE at the speed of 16 and showed such a tendency at the speed of 14 and 18 km·h⁻¹. VO_{2max} indicated a moderate relationship with RE at the speeds of 14, 16 and 18 km·h⁻¹ (r² = 0.372, p = 0.030; r² = 0.350, p = 0.033; r² = 0.376, p = 0.026, respectively) which was confirmed by subsequent partial correlation analysis. While lower leg length and the BMI presented a relationship with RE, none of the calculated body composition and anthropometric proportions were related to RE or performance. The relationship between RE and VO_{2max} would confirm the notion that RE could be at least partly compensated by VO_{2max} to achieve high performance results.

Key words: *running economy, maximal oxygen uptake, running performance, anthropometric characteristics, body composition, DEXA scan.*

Introduction

In addition to different physiological parameters, several anthropometric and body composition variables are known to be associated with running performance in elite Caucasian middle- and long-distance runners (Arrese and Ostariz, 2006). For example, body height and mass (Maldonado et al., 2002), fat and fat free mass (Winter and Hamley, 1976), arm circumference (Knechtle et al., 2008), different lower limb skinfolds and circumferences (Arrese and Ostariz, 2006; Legaz and Eston, 2005; Tanaka and Matsuura, 1982) as well as the sum of three (Kong and de Heer, 2008) or six (Legaz and Eston, 2005) skinfolds have been related to distance running performance. However, there is equivocal data about how running economy (RE) is related to anthropometric and/or body composition

variables. Runners with proportionally lower body mass concentrated in the extremities, particularly in the legs, would perform less work moving their body segments during running, if all other factors are unchanged (Myers and Steudel, 1985). Therefore, leg mass and the distribution of leg mass might be important characteristics in performance and RE of distance runners (Myers and Steudel, 1985). In contrast, no difference has been shown in RE between recreational athletes with similar body mass, but different body composition (Maciejczyk et al., 2015). Recent evidence (Mooses et al., 2015a) indicates that relatively longer legs are related to better performance, however, in a homogenous group of athletes RE has shown not to be related to performance (Foster et al., 1977; Mooses et al.,

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2015a; Williams and Cavanagh, 1987). Although the body composition of runners has been examined extensively, often these studies have been conducted with relatively heterogeneous groups of runners (Arrese and Ostariz, 2006; Winter and Hamley, 1976). Furthermore, despite a number of analyses focused on different anthropometric variables in top level runners (Kong and de Heer, 2008; Lucia et al., 2006, 2008), there is a paucity of studies examining different leg proportions in relation with running performance and RE. With recent development in equipment, this has become easy and cost effective by using the Dual Energy X-ray Absorptiometry (DEXA) method.

It has been agreed that RE is not determined only by one variable, but it is rather a combination of factors to investigate especially at the highest performance level of distance running (Foster and Lucia, 2007; Mooses et al., 2015a; Saunders et al., 2004). Therefore, better understanding of the interaction between RE, $\text{VO}_{2\text{max}}$, performance, body composition and anthropometrics of different level athletes as well as intensities is needed. To date, there is no consensus which factors are responsible for superior RE and how RE is related to $\text{VO}_{2\text{max}}$. Thus, the aim of the present study was to investigate lower limb anthropometric and composition variables related to RE and running performance in a homogeneous group of high level European distance runners. It was hypothesized that relatively lighter and longer legs would be related to better RE at the speed of 14, 16 and 18 $\text{km}\cdot\text{h}^{-1}$. The findings of this study could help explain a complex interaction between anthropometric characteristics, body composition and RE in high level running performance.

Material and Methods

Participants

High level male European distance runners ($n = 15$) were initially recruited to the study, however, 2 of them were excluded after the treadmill test due to surpassing the second ventilatory threshold (VT_2) at the speed of 18 $\text{km}\cdot\text{h}^{-1}$. Therefore, the number of the subjects included into the final analysis was 13 (Table 1). The participation criteria were (i) regular training sessions during the last three years for a minimum of five times per week, (ii) average

monthly mileage during the last year of at least 240 km, (iii) inclusion in the top 10 on the National Athletics Association ranking list, and (iv) competing at international level. The best performance of the previous competition season (3-4 months before the study) of the athletes was established using the International Association of Athletics Federations (IAAF) Scoring Tables (Legaz and Eston, 2005; Lucia et al., 2008; Mooses et al., 2015a, b; Spiriev, 2011). These tables assign a definite score to each performance, enabling comparison between different events (Legaz and Eston, 2005; Mooses et al., 2015a). The participants of the present study were of a high performance level and included some of the athletes who had competed in indoor and/or outdoor European Championships.

Procedures

A cross-sectional study using a group of middle- and long-distance runners was carried out. During the first visit to the laboratory, athletes were familiarised with the treadmill and face masks that were used during the test on the second visit. On the second visit to the laboratory, the measurement of main anthropometric variables and the DEXA procedure preceded the treadmill test. Athletes were requested to abstain from high intensity training and/or competition for at least 24 h before testing and to maintain their usual dietary intake as well as to refrain from caffeine and alcohol. Study procedures and protocols were approved by the Research Ethics Committee of the University of Tartu, Estonia, and conformed to the Declaration of Helsinki. All testing procedures and related risks were described to the athletes before providing written informed consent to participate in the study.

Measures

Following the 10 min familiarisation with the treadmill (freely chosen speeds), participants performed an incremental running test on a motorized treadmill (Viasys LE 300 C 175/65, HP Cosmos Quasar Sports & Medical GmbH Nussdorf-Traunstein, Germany) until voluntary exhaustion. Ten minutes of familiarisation were considered acceptable as previously it had been reported that for healthy adults who were inexperienced on a treadmill, even 6 minutes of treadmill running in one training session were sufficient before highly reliable lower limb angular kinetic variables could be measured

(Lavcanska et al., 2005). Before commencement of the test, each athlete remained stationary on the treadmill for three minutes and cardio-respiratory data was collected. The initial running speed was set at 8 km·h⁻¹ with a gradient of 1% (Jones and Doust, 1996; Lucia et al., 2005; Mooses et al., 2013a, b, 2015a, b) and was then increased by 2 km·h⁻¹ every three minutes until 18 km·h⁻¹. Following the 3 min 18 km·h⁻¹ stage, the speed remained constant and elevation increased 1% after every one minute until voluntary exhaustion (Mooses et al., 2015a, b). The heart rate (HR) and maximum running time on the treadmill (t_{\max}) were recorded with a heart rate monitor Polar RS400 (Polar Electro Oy, Kempele, Finland). Expired gases were measured using MasterScreen CPX (Viasys Healthcare GmbH, Hoechberg, Germany), which was calibrated before each test according to instructions of the manufacturer. $\dot{V}O_{2\max}$ was defined as highest average $\dot{V}O_2$ during a 30 s period and a failure to further increase $\dot{V}O_2$ despite an increase in the work rate (Wasserman et al., 2005). If participants did not reach the $\dot{V}O_2$ plateau, it was considered to be $\dot{V}O_{2\text{peak}}$ rather than $\dot{V}O_{2\max}$. However, for an easier reading, we used the acronym $\dot{V}O_{2\max}$ for all the participants (Billat et al., 2003). RE was calculated from the last two minute submaximal $\dot{V}O_2$ of the 14, 16 and 18 km·h⁻¹ stage. RE was expressed as oxygen cost (O_2 ml·kg⁻¹·km⁻¹) and was calculated as follows:

$$RE = \frac{1000 \cdot \dot{V}O_2}{v},$$

where $\dot{V}O_2$ is steady-state oxygen uptake (ml·kg⁻¹·min⁻¹) and v is running velocity (m·min⁻¹) (Bragada et al., 2010). A steady state was defined as an increase of less than 100 ml O_2 over the final two minutes of the respective running stage (Fletcher et al., 2009). VT_2 (Table 2) was determined as the second rise in ventilation and as the intensity that accompanied the second rise in the VE - $\dot{V}O_2$ relationship with a concurrent rise in the VE - $\dot{V}CO_2$ relationship (Mooses et al., 2013a; Rabadan et al., 2011).

Body height (Altimetro, Gima Spa, Gessate, Italy) and body mass (Sartorius Combics 3, Sartorius AG, Goettingen, Germany) of the participants were measured to the nearest 0.5 cm and 0.05 kg, respectively. In total, 4 girths (thigh, mid-thigh, calf, ankle) and 2 lengths (*trochanterion* height and *tibiale laterale* height) were measured

using the Centurion Kit instrumentation (Rosscraft, Surrey, BC, Canada) according to protocols recommended by the International Society for Advancement of Kinanthropometry (Marfell-Jones et al., 2006). The series of anthropometric measurements were taken by a trained researcher who had previously shown test-retest reliability of $r > 0.95$. The following calculations were made:

$$\text{upper leg length} = \text{trochanterion (total leg length)} - \text{tibiale laterale (lower leg length)}$$

Body composition was measured by Dual Energy X-ray Absorptiometry (DXA) (Hologic QDR Discovery, Hologic Inc., Bedford, USA). The three compartments (lean, fat and bone) were measured with the participant in the supine position (Hetland et al., 1998). Total fat and lean mass were measured for the total body, upper leg (thigh) and lower leg (calf). In addition, the following anthropometric and body composition proportions were calculated:

1. leg mass to body mass: leg mass (kg)/body mass (kg) * 100
2. upper leg (thigh) mass to body mass: upper leg (kg)/body mass (kg) * 100
3. lower leg (calf) mass to body mass: calf mass (kg)/body mass (kg) * 100
4. calf mass to thigh mass: calf mass (kg)/thigh mass (kg) * 100
5. leg length to body height: leg length (m)/total body height (m) * 100
6. upper leg (thigh) length to body height: upper leg (m)/total body height (m) * 100
7. lower leg (calf) length to body height: lower leg (m)/total body height (m) * 100
8. lower leg (calf) length to upper leg (thigh) length: lower leg (m)/upper leg (m) * 100

Statistical Analysis

The normality of all variables was tested with the Shapiro-Wilk test. Pearson or Spearman, where necessary, correlation analyses were used to determine linear relationships between variables. To avoid spurious correlation between RE and $\dot{V}O_{2\max}$, additionally a partial correlation was used to assess the relationship between absolute $\dot{V}O_{2\max}$ and RE as oxygen cost (L·min⁻¹) (Shaw et al., 2015). Calculations were performed using IBM SPSS Statistics v.20 (SPSS Inc., Chicago, IL, USA). The level of significance was set at $p < 0.05$.

Results

Runners were of a high performance level (Table 1) and with good RE (Table 3). RE and VO_{2max} values for individual athletes are shown in Figure 1.

VO_{2max} showed a moderate relationship with RE at the speeds of 14, 16 and 18 $km \cdot h^{-1}$ ($r^2 = 0.372$, $p = 0.030$; $r^2 = 0.350$, $p = 0.033$; $r^2 = 0.376$, $p = 0.026$, respectively); however, the performance score was not related to RE at any of the speeds

($p > 0.05$). Partial correlation analysis controlling body mass confirmed positive relationships between submaximal VO_2 at the speed of 14, 16 and 18 $km \cdot h^{-1}$ and VO_{2max} ($r^2 = 0.426$, $p = 0.021$; $r^2 = 0.440$, $p = 0.019$; $r^2 = 0.350$, $p = 0.042$, respectively). None of the measured and calculated proportions of different body segment masses (Table 4) were related to RE (Table 5), VO_{2max} or performance ($p > 0.05$).

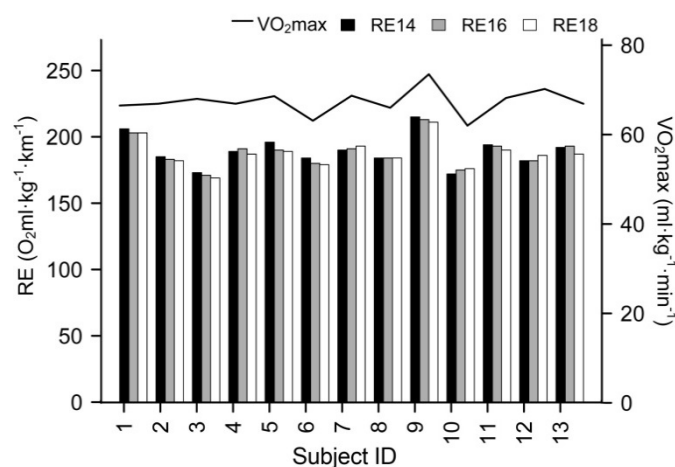


Figure 1

Running economy (RE) at the speed of 14, 16 and 18 $km \cdot h^{-1}$ (black, dark-grey and light-grey bars, respectively) and maximal oxygen uptake (VO_{2max}) of the individual runners (solid line)

Table 1

Main anthropometric characteristics and performance level of the participants (mean \pm SD)

	Runners (N = 13)
Age (years)	25.2 \pm 2.9
Body height (m)	1.83 \pm 0.07
Body mass (kg)	70.9 \pm 5.4
BMI ($kg \cdot m^{-2}$)	21.1 \pm 0.7
Body fat %	13.0 \pm 1.2
Body lean mass (kg)	57.7 \pm 4.3
Body fat mass (kg)	9.1 \pm 1.0
IAAF (p)	921 \pm 116

BMI - body mass index;

IAAF - International Amateur Athletic Federation scoring table points.

Table 2*Relative intensities from VO_{2max} and HR (mean \pm SD)*

	$\%VO_{2max}$	$\%HR_{max}$
14 (km·h ⁻¹)	66 \pm 3	81 \pm 4
16 (km·h ⁻¹)	75 \pm 4	87 \pm 3
18 (km·h ⁻¹)	83 \pm 5	91 \pm 3
VT ₂	92 \pm 3	95 \pm 2

 $\%VO_{2max}$ – percentage from maximal oxygen uptake; *$\%HR_{max}$ – percentage from the maximal heart rate;**VT₂ – second ventilatory threshold***Table 3***Variables of the incremental treadmill test (mean \pm SD)*

	Runners (N = 13)
t_{max} (s)	1618 \pm 108
VO_{2max} (ml·kg ⁻¹ ·min ⁻¹)	67.3 \pm 2.9
RE14 (O ₂ ml·kg ⁻¹ ·km ⁻¹)	189 \pm 12
RE16 (O ₂ ml·kg ⁻¹ ·km ⁻¹)	188 \pm 11
RE18 (O ₂ ml·kg ⁻¹ ·km ⁻¹)	187 \pm 11
VO_{214} (ml·kg ⁻¹ ·min ⁻¹)	44.2 \pm 2.8
VO_{216} (ml·kg ⁻¹ ·min ⁻¹)	50.2 \pm 3.0
VO_{218} (ml·kg ⁻¹ ·min ⁻¹)	56.0 \pm 3.7

 *t_{max} - maximum time on the treadmill; VO_{2max} - maximal oxygen uptake;**RE14, RE16 and RE18 - running economy at the speed of 14, 16 and 18 km·h⁻¹;* *VO_{214} , VO_{216} , VO_{218} - submaximal oxygen uptake at the speed of 14, 16 and 18 km·h⁻¹, respectively.***Table 4***Specific leg anthropometric and composition characteristics of the participants (mean \pm SD)*

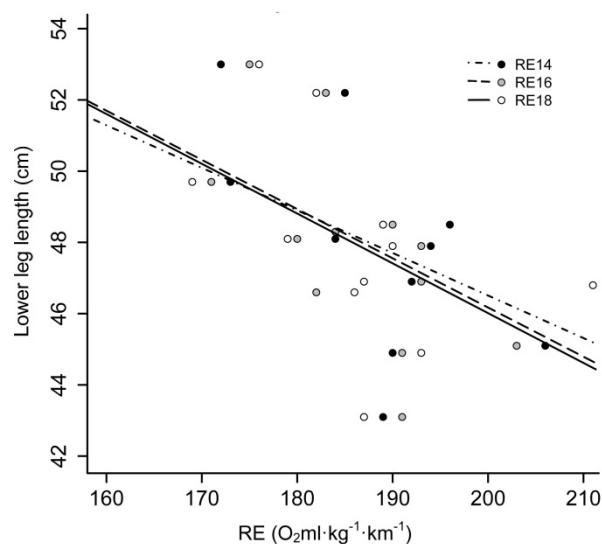
	Runners (N = 13)
Circumferences (cm)	
Thigh	52.2 \pm 1.6
Mid-thigh	49.2 \pm 1.6
Calf	36.7 \pm 1.3
Ankle	22.1 \pm 1.1
Lengths (cm)	
Total leg	91.3 \pm 4.4
Upper leg	43.5 \pm 3.1
Lower leg	47.8 \pm 2.8
Proportions of body lengths (%)	
Lower leg to upper leg length	110.2 \pm 9.3
Lower leg to body height	26.1 \pm 0.9
Upper leg to body height	23.8 \pm 1.5
Total leg to body height	49.8 \pm 1.3
Proportions of body masses (%)	
Total leg to body mass	20.2 \pm 0.5
Upper leg to body mass	14.4 \pm 0.5
Lower leg to body mass	5.9 \pm 0.3
Lower leg to upper leg mass	41.1 \pm 3.0

Table 5

Correlation coefficients between running economy (RE)
and specific leg anthropometric and composition characteristics of the participants

	RE14 (O ₂ ml·kg ⁻¹ ·km ⁻¹)	RE16 (O ₂ ml·kg ⁻¹ ·km ⁻¹)	RE18 (O ₂ ml·kg ⁻¹ ·km ⁻¹)
Circumferences (cm)			
Thigh	0.004	0.004	0.016
Mid-thigh	0.004	0.044	0.000
Calf	0.001	0.002	0.041
Ankle	0.027	0.078	0.112
Lengths (cm)			
Total leg	0.055	0.125	0.151
Upper leg	0.015	0.000	0.004
Lower leg	0.265	0.316*	0.303
Proportions of body lengths (%)			
Lower leg to upper leg length	0.225	0.162	0.118
Lower leg to body height	0.127	0.129	0.149
Upper leg to body height	0.140	0.084	0.055
Total leg to body height	0.102	0.020	0.023
Proportions of body masses (%)			
Total leg to body mass	0.006	0.002	0.012
Upper leg to body mass	0.042	0.023	0.056
Lower leg to body mass	0.038	0.081	0.075
Lower leg to upper leg mass	0.005	0.027	0.014

* - $p < 0.05$

**Figure 2**

Relationship between lower leg length and running economy
(RE) at the speed of 14 ($r^2 = 0.265$; $p = 0.072$); 16 ($r^2 = 0.316$; $p = 0.046$)
and 18 ($r^2 = -0.303$; $p = 0.051$) km·h⁻¹ (black, grey and white circles, respectively)

From anthropometric variables, the BMI was related to RE at the speeds of 14 ($r^2 = 0.434$; $p = 0.014$), 16 ($r^2 = 0.436$; $p = 0.014$) and 18 $\text{km}\cdot\text{h}^{-1}$ ($r^2 = 0.389$; $p = 0.023$). In addition, lower leg length was negatively correlated with RE at the speed of 16 $\text{km}\cdot\text{h}^{-1}$ and showed a similar tendency at the speeds of 14 and 18 $\text{km}\cdot\text{h}^{-1}$ (Figure 2).

Discussion

The purpose of this study was to investigate anthropometric and body composition variables in relation with RE at different submaximal speeds used in everyday training settings in a homogeneous group of high level European distance runners. Additionally, their performance, with particular emphasis on lower limb anthropometric and composition variables, was investigated. The important findings of this study were that in the homogeneous group of distance runners longer lower legs were associated with better RE at the speed of 16 $\text{km}\cdot\text{h}^{-1}$ and a similar trend was observed at the speeds of 14 and 18 $\text{km}\cdot\text{h}^{-1}$. Secondly RE was related to $\text{VO}_{2\text{max}}$ at the range of measured speeds (14, 16 and 18 $\text{km}\cdot\text{h}^{-1}$) and this indicates a complex and multifactorial interaction between RE, $\text{VO}_{2\text{max}}$ and performance.

Despite a number of studies describing different anthropometric variables of high level distance runners (Fudge et al., 2006; Marino et al., 2004; Prommer et al., 2010; Vernillo et al., 2013) there are only few (Lucia et al., 2008; Mooses et al., 2015a) that have paid attention to different anthropometric proportions, which in turn might be important characteristics in running performance and RE as a smaller amount of body mass in distal parts of extremities, specifically in the legs, would require less work in moving body segments during running (Myers and Steudel, 1985). Even though it is risky to compare different anthropometric (Vernillo et al., 2013) as well as body composition variables between the studies due to the variability in technique, equipment, as well as the site location, we found that lower limb circumferences and lengths in the present study were similar to those reported earlier for high level European distance runners (Lucia et al., 2006; Mooses et al., 2013a, b) and that circumferences were expectedly higher compared to elite East African runners (Kong and de Heer, 2008; Lucia et al., 2006; Mooses et al., 2015a;

Vernillo et al., 2013). A present finding that longer lower legs and a lower BMI were related to better RE at all the measured submaximal speeds (14, 16 and 18 $\text{km}\cdot\text{h}^{-1}$) are somewhat in line with a previous study with high level East African distance runners, where relatively longer legs were shown to be advantageous for running performance (Mooses et al., 2015a). Previously, it has been indicated that RE is influenced by structural and physiological variables which in contrast differ to those related to running performance in high level runners (Mooses et al., 2015a; Sano et al., 2015). Despite RE being a good predictor of running performance, it may not necessarily explain the high performance level of elite athletes (Mooses et al., 2015a; Sano et al., 2015). Considering the examples of East African runners, despite the potential contribution of several biomechanical factors influencing RE, it has been argued that the superior RE is largely attributable to the low BMI and slim limbs with low masses that allow athletes to run with minimal energy used for swinging the limbs (Lucia et al., 2006; Saltin et al., 1995). It has been also stated that the precise mechanism explaining this relationship is not clear (Lucia et al., 2006). Oscillating long legs increases the energy cost of running in proportion to the limb mass moment of inertia and reduction in distal limb mass would produce substantial metabolic savings during running (Myers and Steudel, 1985). Likewise, shorter ground contact time has been related to better RE as there is less time for the braking force to decelerate forward motion of the body (Kong and de Heer, 2008; Mooses et al., 2015a; Nummela et al., 2007; Saltin et al., 1995; Santos-Concejero et al., 2013). The present finding with the homogeneous group of distance runners where no relationship between lower leg circumference as well as leg mass ratios and RE were found is in line with an earlier study (Lucia et al., 2006), where a relationship between calf circumference and submaximal VO_2 was established when Spanish and Eritrean athletes were analysed as one group. However, such a relationship did not exist within the homogeneous group of Eritrean runners (Lucia et al., 2006). Alternatively, increasing stride length is more efficient than increasing frequency by devoting less energy to leg acceleration, longer legs favour longer stride length and therefore, allow better RE (Anderson,

1996; Rahmani et al., 2004; Sleivert and Rowlands, 1996). It has to be noted that this explanation is valid up to 90% of individual maximum speed (Nummela et al., 2007), which was also the case in the present study. It can be argued that RE is influenced by lower limb anthropometric variables, however, equivocal data exist in describing the precise mechanism behind this phenomenon. It seems that anthropometric and body composition variables are of importance when determining RE among athletes with a broad range of the performance level, but not in a homogeneous group of high level athletes.

VO_{2max} values of the participants were similar compared to previous studies with high level European and East African runners (Esteve-Lanao et al., 2007; Maldonado et al., 2002; Mooses et al., 2015a; Tam et al., 2012; Weston et al., 2000) and RE was in the same range or better than previously reported in high level distance runners (Billat et al., 2003; Lucia et al., 2006; Maldonado et al., 2006; Tam et al., 2012; Weston et al., 2000). Our current finding that running performance was not related to RE is in line with earlier studies of European and East African runners (Foster et al., 1977; Mooses et al., 2015a; Williams and Cavanagh, 1987). This result confirms that a single variable or a small subset of variables cannot explain differences in RE, as it is rather influenced by combined effect of many variables (Mooses et al., 2015a; Williams and Cavanagh, 1987). More importantly there was an inverse relationship between VO_{2max} and RE, indicating that athletes with superior economy had lower VO_{2max} . It is supported by the literature, where better RE has been found to be associated with lower VO_{2max} in a heterogeneous group of recreational male and female runners (Pate et al., 1992) as well as an elite group of 10 km and marathon runners (Billat et al., 2001; Morgan and Daniels, 1994); this relationship was also confirmed by the recent data from East African (Mooses et al., 2015a) and European (Shaw et al., 2015) high level distance runners. A latter study where a small to moderate relationship was found between RE and VO_{2max} , argued that with >85% of the variance in these variables unexplained by this relationship, it was reaffirmed that RE and VO_{2max} were primarily determined independently (Shaw et al., 2015).

In contrast, it has been discussed that higher VO_{2max} could compensate lower RE and

indeed cycling efficiency (Lucia et al., 2002; Mooses et al., 2015a; Morgan and Daniels, 1994). However, this hypothesis has been questioned as spurious correlation because of small sample sizes as well as the validity of the statistical techniques due to consideration of both variables in relation to body mass (Pate et al., 1992; Shaw et al., 2015). A recent study (Shaw et al., 2015) suggested that spurious correlations between RE and VO_{2max} could be avoided by removing the influence of body mass on partial correlations, which in turn would enable to examine the true relationship between these variables. It has to be noted that in the present study removing the influence of body mass strengthened the relationships between RE (O_2 ml·kg⁻¹·km⁻¹) and relative VO_{2max} as well as absolute submaximal VO_2 (L·min⁻¹) and VO_{2max} (L·min⁻¹) at all the measured speeds. Discussion in this area is to be continued (Atkinson et al., 2003; Lucia et al., 2002; Mooses et al., 2016; Morgan and Pate, 2004; Santos-Concejero and Tucker, 2016) especially considering that understanding the relationships between RE and VO_{2max} is necessary to tailor individualised training plans that lead to maximal performance in distance running.

The limitations of the present study should also be discussed. We had a relatively small sample size and we did not measure the Achilles tendon moment arm, that has been given a lot of attention during recent years (Mooses et al., 2015a; Raichlen et al., 2011; Sano et al., 2015; Scholz et al., 2008) and could contribute to RE. On the other hand, the strengths of this study were using the precise DEXA method for body composition analysis and the evaluation of RE at three submaximal speeds commonly used in everyday training settings.

In conclusion, while lower leg length and the BMI indicated a relationship with RE, none of the calculated body composition and anthropometric proportions were related to RE or performance in the homogenous group of competitive level European distance runners. The importance of lower leg length to RE will be most likely mediated through a more efficient running stride. Dissociation between RE and performance and, in contrast, the association between RE and VO_{2max} would suggest that RE could be at least partially compensated by VO_{2max} to achieve high performance as proposed earlier (Mooses et al., 2015a). The identification of the specific

anthropometric variables that could characterize RE of distance runners is important and could be

used for talent identification and performance prediction.

Acknowledgements

The authors wish to specially thank the subjects for their participation and cooperation.

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