THE RELATIONSHIP OF ANTHROPOMETRY AND BODY COMPOSITION WITH RUNNING ECONOMY

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The aim of this study was to investigate the relationships of anthropometry and body composition with running economy within a large heterogeneous cohort of runners. Locomotory energy cost was determined in ninety-four healthy male and female endurance runners across a range of performance standards. Various anthropometric and body composition measurements were taken manually and via DXA scans. The relationships between anthropometry and running economy were assessed using independent Pearson's correlation and stepwise multiple linear regression. Three parameters, normalised neck and calf perimeters and normalised whole body bone mass explained 30% of the variance in locomotory energy cost. Low locomotory energy cost was related solely to parameters indicating relative slenderness of the body.

KEY WORDS: moment of inertia, BMI, slenderness, Achilles tendon moment arm

INTRODUCTION: Running economy is defined as the efficiency with which metabolic energy turnover can be translated into forward movement of the centre of mass (di Prampero, Atchou, & Brückner, 1986) and has been identified as a key determinant of endurance running performance (Costill & Winrow, 1970). Many factors are thought to influence running economy, broadly, these factors can be categorised as being physiological, anthropometric, environmental, or biomechanical (Anderson, 1996). There is a great deal of overlap between these factors, with anthropometry (i.e. joint moment arms) greatly influencing running biomechanics and thus running economy (Scholz, Bobbert, & van Soest, 2008). However, the influence of anthropometry and body composition on running economy has received little attention when compared to biomechanics and physiology, and what attention it has received has typically been in groups of homogeneous male East African distance runners (Scholz et al., 2008; Mooses et al., 2014). Therefore, the aim of this study was to investigate the relationships of anthropometry and body composition with running economy within a large heterogeneous cohort of male and female runners.

METHODS: Ninety-four healthy male and female endurance runners with a wide range of performance standards were recruited (Table 1). Participants visited the lab twice: during the first session width, depth, length and perimeter measurements were taken, enabling segmental moments of inertia about a transverse axis through their mass centre to be calculated (Yeadon, 1990), photographs of the foot were taken allowing Achilles tendon moment arm to be estimated using the method of Scholz et al., (2008), and participants subsequently performed a treadmill familiarisation run; during the second session dual-energy x-ray absorptiometry (DXA) scans were taken allowing total and regional body composition and limb and segment lengths to be determined, and an incremental treadmill running test was performed. The running test started at 7 km.h^{-1} for females, and 8 km.h^{-1} for males, and consisted of 4 min stages of running at each speed, interspersed by 30-s rest periods during which a blood sample was obtained for analysis of blood lactate. Increments (+1 km.h^{-1}) were continued until blood lactate (BLa) had risen >2 mmol.L^{-1} from the previous stage, at which point the participant started a maximal running assessment and the treadmill speed was increased by 1 km.h^{-1} every 2 min until volitional exhaustion. Breath-by-breath pulmonary gas exchange data were measured continuously throughout the running assessment and the 60-s average $\dot{V}O_2$ and $\dot{V}CO_2$ data collected during the final minute of each submaximal stage were used to calculate the energy cost of running. Absolute energy expenditure was calculated as the sum of the energy derived from fat and carbohydrate at rest and during each running velocity below lactate turn point and with a respiratory exchange ratio value of <1.00, to ensure an insignificant anaerobic contribution to energy expenditure. Energy expenditure at rest during quiet standing was subtracted from running measurements to calculate the locomotory energy cost (LEc). Subsequently LEc was expressed in $kcal.kg^{-1}.km^{-1}$. Since there was no difference in LEc between males and females (0.79 ± 0.10 $kcal.kg^{-1}.km^{-1}$ vs 0.79 ± 0.09 $kcal.kg^{-1}.km^{-1}$) they were considered together in all analyses. To reduce measurement noise LEc was averaged over the three highest speeds at which all subjects remained below their lactate turn point (10-12 $km.h^{-1}$). As well as being considered in absolute terms, lengths were normalised to standing height, masses to body mass, and moments of inertia to body mass*height^2. Overall, 79 parameters were included in the analysis. Pearson's correlation was used to identify relationships between individual variables and LEc, the false discovery rate was controlled at 5% (Benjamini & Hochberg, 1995) and significance was set at 0.05. Subsequently, stepwise multiple linear regression was used to build a predictive equation of LEc using those variables which were found to be significantly related to LEc individually.

Table 1
Descriptive characteristics of the participants

	Males (n=49)	Females (n=45)
Anthropometric		
Age (y)	29 ± 7 (19 – 40)	28 ± 7 (18 – 40)
Height (m)	1.79 ± 0.06 (1.68 – 1.93)	1.66 ± 0.07 (1.46 – 1.80)
Body mass (kg)	69.1 ± 6.3 (58.0 – 83.4)	55.8 ± 6.3 (43.6 – 74.6)
Performance		
% 10 km road world record time	142 ± 24 (110 – 202)	145 ± 23 (110 – 187)
Training		
Frequency ($session.wk^{-1}$)	5 ± 3 (2 – 12)	4 ± 2 (2 – 10)
Volume ($km.wk^{-1}$)	69 ± 40 (8 – 177)	50 ± 27 (8 – 105)

RESULTS: 17 variables were significantly related to LEc (Table 2). Stepwise multiple linear regression resulted in three normalised parameters - neck and calf perimeters and whole body bone mass - predicting LEc with an adjusted r^2 of 0.304 (Figure 1).

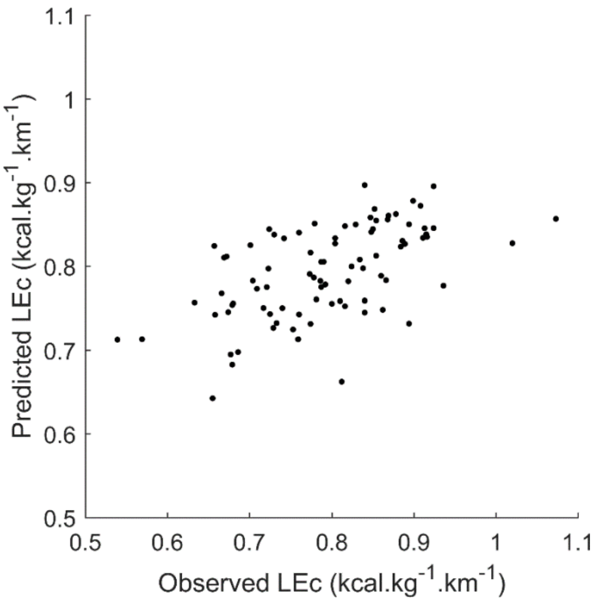

Figure 1: Observed vs predicted LEc from stepwise multiple linear regression.

Table 2
Results of Pearson's correlations between anthropometric parameters and LEc

Parameter	r	p (adjusted)
BMI (kg.m^{-2})	0.332	0.009
Normalised perimeters		
Neck (-)	0.396	0.002
Mid-upper arm (-)	0.386	0.002
Maximum forearm (-)	0.329	0.009
Waist (-)	0.327	0.009
Hip (-)	0.297	0.021
Mid-thigh (-)	0.347	0.008
Maximum calf (-)	0.392	0.002
Minimum calf (-)	0.388	0.002
Normalised moments of inertia		
Shank (-)	0.342	0.008
Normalised masses		
Whole body bone (-)	-0.345	0.009
Arm bone (-)	-0.285	0.036
Thigh bone (-)	-0.367	0.007
Shank bone (-)	-0.279	0.040
Foot bone (-)	-0.334	0.010
Foot lean (-)	-0.288	0.035
Foot total (-)	-0.290	0.035

DISCUSSION: All measurements that were significantly related to LEc individually were of relative slenderness. Neither body height, body mass, nor limb lengths were correlated with LEc, nor was any other non-normalised length, mass, or moment of inertia, indicating that absolute body size has no relationship with running economy. Locomotory energy cost is a normalised measure, expressed as a proportion of body mass (kcal.kg^{-1}.km^{-1}), therefore it was no surprise that measures normalised to body size were related to LEc. Body mass index was positively related to LEc, indicating athletes who are proportionally slim in relation to their height are more economical. Various normalised perimeters showed the same relationship; having relatively slender body segments (both trunk and limbs) was correlated with better running economy. A low moment of inertia of the shank was also related to better running economy, which is perhaps unsurprising given that this parameter was calculated partly from segment perimeters. Relative bone masses were also negatively related to LEc, indicating that the greater the proportion of the body that is made up of bone, the lower the LEc. Since skeleton mass is low and unlikely to vary substantially due to training status, a high proportion of bone mass is likely to indicate low non-bone mass, rather than exceptionally high bone mass. Aside from those of the foot, whole body and segmental overall, fat, and lean masses were not related to LEc, indicating that it does not seem to matter what the composition of the body is, so long as non-bone mass is low and it is slim relative to its length. Since it is well known that the addition of mass to the feet increases the energy cost of running (Frederick, Daniels, & Hayes, 1984) the finding that normalised foot masses were negatively related to LEc may indicate that they are simply acting as a proxy for general slenderness; since the non-bone mass of the foot is less variable than many other body segments, a proportionally high foot mass may simply indicate low non-bone mass elsewhere in the body. Achilles tendon moment arm was not related to LEc in this cohort, contrary to previous findings in homogeneous groups of male East African distance runners (Scholz et al., 2008; Mooses et al., 2014). This finding may to be due to the heterogeneous nature of our cohort, and that the proposed mechanism by which a shorter Achilles tendon moment arm benefits economy is due to higher energy storage and return; this is likely to apply more to forefoot than rearfoot strikers (of which there were a number in our cohort), since the Achilles tendon of rearfoot strikers is likely to become slack upon impact, inhibiting energy storage.

The stepwise multiple linear regression procedure chose three parameters which explained 30% of the variance in running economy: two normalised perimeters - neck and calf - and normalised whole body bone mass. It is intuitive that a low moment of inertia of the shank (represented by a low normalised calf perimeter) relates to running economy, since it is more energetically costly to swing a limb with a higher moment of inertia, and indeed this has been shown previously to relate to better running economy (Scholz et al., 2008; Mooses et al., 2014). That calf perimeter and not shank moment of inertia was chosen may be because calf perimeter captures both the effects of the moment of inertia of the segment about its mass centre, and the relative segment mass which determines the more energetically costly aspect of rotating the limb centre of mass about the knee and hip joints. It is not immediately obvious why neck perimeter would relate to LEc, other than as an indicator of general slenderness of other body segments for which low moments of inertia could reduce the energy cost of running. Equally a high proportion of whole body bone mass is also likely to be an indicator of slender body segments and hence relatively low moments of inertia.

Since it has been shown that aspects of running technique also relate to running economy (Williams & Cavanagh, 1987) it is possible that some anthropometric and body composition parameters co-vary with kinematics, and therefore it is difficult to attribute direct causality to the parameters in this study, however there is a plausible mechanistic rationale by which body segments with relatively low inertia could reduce the relative energy cost of locomotion.

CONCLUSION: Relative slenderness of the body and its constituent segments was associated with lower energy cost of locomotion across a large heterogeneous cohort of male and female distance runners. Contrary to previous studies in more homogeneous cohorts, Achilles tendon moment arm did not relate to energy cost of locomotion. Future studies could investigate whether the parameters identified in this study can also be used to predict performance outcomes.

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Acknowledgement

This study was funded by MAS Holdings, Colombo, Sri Lanka.