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Running Economy

The Forgotten Factor in Elite Performance

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Abstract

Running performance depends on maximal oxygen uptake ($\dot{V}O_{2max}$), the ability to sustain a high percentage of $\dot{V}O_{2max}$ for an extended period of time and running economy. Running economy has been studied relatively less than the other factors. Running economy, measured as steady state oxygen uptake ($\dot{V}O_2$) at intensities below the ventilatory threshold is the standard method. Extrapolation to a common running speed (268 m/min) or as the $\dot{V}O_2$ required to run a kilometer is the standard method of assessment. Individuals of East African origin may be systematically more economical, although a smaller body size and a thinner lower leg may be the primary factors. Strategies for improving running economy remain to be developed, although it appears that high intensity running may be a common element acting to improve economy.

Running performance, particularly in long events such as the marathon, depends on a complex interplay of factors,[1] including (i) both a high cardiac output and a high rate of oxygen delivery to working muscles, which leads to a large capacity for aerobic adenosine triphosphate regeneration (i.e. high maximal oxygen uptake [$\dot{V}O_{2max}$]);[2] (ii) the ability to sustain a high percentage of $\dot{V}O_{2max}$ for long periods of time (fractional utilisation of $\dot{V}O_{2max}$);[3] and (iii) the ability to move efficiently (running economy).[4,5] $\dot{V}O_{2max}$ and fractional utilisation of $\dot{V}O_{2max}$ have been relatively widely studied as determinants of running performance.[1,2] With a very few remarkable exceptions (who usually have remarkable running economy), it is entirely fair to state that unless $\dot{V}O_{2max}$ is >70 mL/min/kg, it is almost impossible to achieve world class running performances and that average values of 75–80 mL/min/kg are to be expected in any group of established world class runners. Similarly, the percentage of $\dot{V}O_{2max}$ that can be sustained for the slightly >2 hours required by top class marathon runners is almost always in the range of 80–90%, and for the ≈28 minutes required for the 10km is 90–95%. However, although we have been aware of the importance of running economy at least since the 1970s, this factor has been relatively ignored in the scientific literature. A recent review addresses many of the issues presented in this article in more detail,[6] but even these authors note that the state of knowledge about running economy is low compared with our understanding of other elements of running performance. Interest in running economy as an issue of real importance has increased in parallel with the emergence of runners of East African origin as the dominant runners during the last 20 years.[5,7] This has paralleled the realisation that performance differences amongst elite athletes is highly related to differences in economy (or efficiency).[8] Effectively, in a group of individuals, all of whom have a high $\dot{V}O_{2max}$ and all of whom can sustain a high percentage of $\dot{V}O_{2max}$ for a long time, the winner is usually

Table I. Reference values for the aerobic cost of running in different populations

Population	Maximal oxygen uptake	
	mL/min/kg	mL/min/kg$^{0.75}$
Reference value (ACSM) [80kg]	58	175
Elite Europeans/ North Americans (65kg)	55	156
Elite East Africans (60kg)	50	130

ACSM = American College of Sports Medicine.

the most economical or efficient athlete. This brings us to the following primary questions to be addressed here:

1. What is the range in running economy across the range of serious runners?
2. Are the differences in running economy based on anatomical differences?
3. Can running economy be improved?

1. Differences in Running Economy

A standard approach to measuring running economy has emerged over the last 30 years or more. These methods involve running at progressively increasing speeds in stages of 4–10 minutes duration (e.g. long enough to achieve a physiological steady state). The intensity of running is below the ventilatory threshold, since above this intensity, the slow component of oxygen uptake ($\dot{V}O_2$) dictates that steady state conditions are unlikely to be achieved. Depending on the laboratory, reference treadmill runs are made either on a flat treadmill or with the treadmill elevated by ≈1% (to correct for the wind resistance that would be encountered during overground running). In the ideal world, which may be possible given the availability of portable heart rate telemetry and portable metabolic systems, these runs would be accomplished outdoors to fully account for wind resistance, the characteristics of the running surface and the minor undulations present on even level outdoor terrain. Expression of running economy can be made in several ways. The two most common are to interpolate (or extrapolate) the $\dot{V}O_2$ to a common running velocity. The most commonly used reference velocity is 268 m/min (4.47 m/s), which represents 6 minutes per mile, or 3 minutes 44 seconds per km. Representative $\dot{V}O_{2max}$ values for different types of runners (assuming a 1% grade on the treadmill belt) are presented in table I and in figure 1.

The lowest reported value for $\dot{V}O_2$ at 268 m/min is 39.0 mL/min/kg in an individual East African runner, capable of running 1500m in 3:35 with a $\dot{V}O_{2max}$ of only 63 mL/min/kg. The differences in $\dot{V}O_2$ may be accentuated if the aerobic requirement of running is expressed as $\dot{V}O_2/kg^{-0.75}$, which is a conceptually attractive approach that has been used primarily in Scandinavia.[7] An alternative method of expressing running economy is in terms of the $\dot{V}O_2$ required to run 1km. Representative values, allowing for the differences in velocity amongst different groups (and assuming a 1% grade on the treadmill belt) are presented in table II and in figure 2.[2-7]

2. Anatomical Basis of Differences in Running Economy

One of the most obvious things about distance runners generally is that they are comparatively small people, and the runners from East Africa who currently dominate the highest competitive levels are small, even by the standards of distance runners.[5,7] Although there have been some relatively larger individuals who have become elite marathon

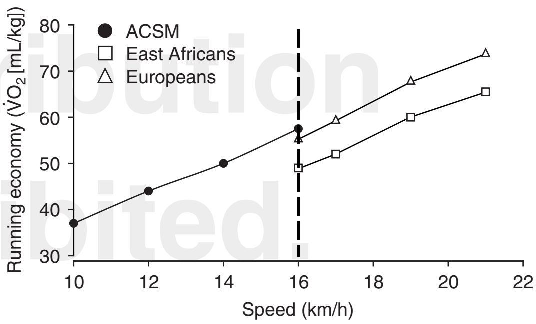

Fig. 1. Schematic values of the oxygen uptake cost of treadmill running (up a 1% gradient) in terms of normative data (from the American College of Sports Medicine [ACSM]), and based on pooled values for elite runners of European descent[1,3,6,7,9] and elite runners of East African descent.[5,7] The dashed vertical line represents a running velocity of 268 m/min, which is the most commonly used reference value. **$\dot{V}O_2$** = oxygen uptake.

Table II. Reference values for running economy in different populations

Population	Maximal oxygen uptake (mL/min/kg)
Reference value (ACSM)	218
Elite Europeans/North Americans	210
Elite East Africans	187

ACSM = American College of Sports Medicine.

runners (e.g. Derek Clayton and Jack Batchelor), these individuals are remarkable exceptions to the general pattern. On the basis of simple biomechanics, verified with experimental data,[9] the tendency for runners from East Africa to be not only small generally, but to have very thin lower legs may be expected to contribute to their excellent running economy. Recent data demonstrate a significant, inverse correlation between the maximal circumference of the calf and the $\dot{V}O_2$ at a fixed running velocity (21 km/h) in a group of high level Spanish and Eritrean runners.[5] Since this trend was obvious, even within the group of Spanish runners, it may be argued that running economy is related to body dimensions generally and does not have a uniquely 'African' element (figure 3). If these data can be confirmed, they would suggest that the primary reason that runners with East African origin are economical is because of their small size. Interestingly, runners of European origin who are particularly small (e.g. 1972 Olympic marathon champion Frank Shorter) have also been shown to have particularly good running economy,[2] comparable with East Africans.[5] Thus, extraordinary running economy may primarily be a characteristic of small people generally and small people with thin lower legs specifically. This works at a common sense level, as we know that adding weight, particularly at the end of a long lever (as in running shoes), is important to the energy cost of ambulation.

3. Can Running Economy Be Improved?

Given the importance of running economy to running performance, there are surprisingly few studies of strategies that might improve running economy. Saunders et al.[6] have reviewed interventions that might improve running economy including strength and/or plyometric training, altitude exposure and training in the heat. Plyometric training, arguably, works either by augmenting the stretch/shortening characteristics of the muscle or by increasing the stiffness of the muscle-tendon system. Studies of exposure to altitude have shown mixed results. There is some evidence that simple exposure to altitude, without any particular training, may improve running economy, although how this might be mediated is unclear. All have shown promise as strategies, although a common mechanistic link is not yet evident. Billat et al.[10] have reported improved running economy secondary to adding relatively high intensity training to baseline running. There was a significant improvement in running economy when this type of training was performed twice weekly, but this seemed to be lost when high intensity training was performed too often. In a case study, Conley et al.[4] noted that running economy improved subsequent to the addition of high intensity interval training to baseline mileage. There is no clear reason why such training should improve running economy, although it may be argued from first principles that, in an already well trained athlete with little possibility of additional adaptation of $\dot{V}O_{2max}$, the only way to make a difficult task (e.g. running 1000m at $\dot{V}O_{2max}$) easier is to improve running economy. A similar argument might be

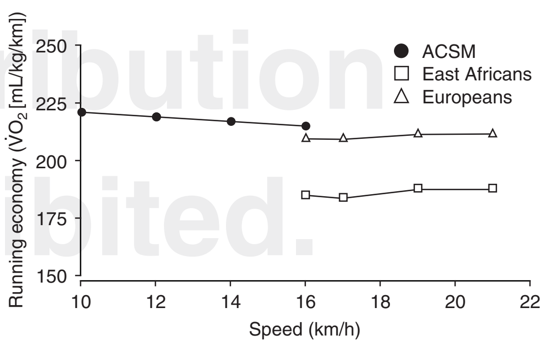

Fig. 2. Schematic values of the oxygen cost of treadmill running (up a 1% gradient) in terms of the oxygen uptake ($\dot{V}O_2$) required to run 1km, expressed in terms of normative data (from the American College of Sports Medicine [ACSM]), and pooled values for elite runners of European descent[1,3,6,7,9] and elite runners of East African descent.[5,7]

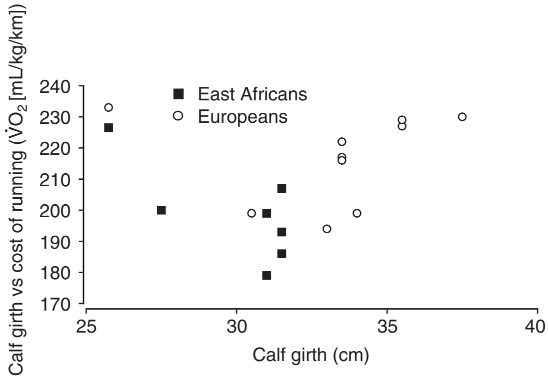

Fig. 3. Effect of calf girth on the oxygen uptake ($\dot{V}O_2$) cost of running (mL/kg/km) in elite runners of European and East African descent. Note that although the East Africans have both smaller calf girth and a generally lower cost of running, the relationship overlaps and is evident in the data from the European runners, suggesting that body dimensions, rather than area of origin, is the determinant of the cost of running.

made for the benefit of altitude training. With a limited ability to provide for the cost of running aerobically, the only way to make training easier (assuming that a particular pace is maintained) is to become more efficient. In this regard, it is of interest that early observations of East African runners noted that their training was performed at relatively high intensity.[7] Given that we know that humans find the easiest way to do any task, improving running economy is not an unreasonable response to high intensity training at altitude. This, of course, remains to be experimentally verified.

4. Conclusions

Running economy is clearly important to running performance. Even amongst well trained runners, there is a considerable range of running economy. There appears to be a tendency for runners of East African origin to be more economical; however, this may be as much a function of small size and small lower limbs as of 'African' origin, *per se*. There is some evidence that running economy improves with the addition of high intensity interval training to baseline mileage. Other factors such as plyometric training, altitude and heat exposure may also contribute to improved running economy, although how this is mediated remains unclear. Since high level athletes already have, either through training or selection, high values for $\dot{V}O_{2max}$ and the ability to sustain $\dot{V}O_{2max}$, it may be that future improvement in running performance will depend on improved economy.

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