Running Economy (Articles Review)

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ABSTRACTS

Running economy (RE) is typically defined as the energy demand for a given velocity of submaximal running, and is determined by measuring the steady-state consumption of oxygen (VO2) and the respiratory exchange ratio. Running economy (RE), particularly for distance runners, is regarded as a crucial physiological indicator for endurance athletes. In this review, the definition and measurement of RE are examined, as well as the physiological and biomechanical variables that affect or determine RE. Maximum oxygen uptake (VO 2max), the capacity to maintain a high percentage of VO 2max for a sustained length of time, and running economy all contribute to running performance. Comparatively less research has been done on running economy than on the other parameters. The typical method is to assess running economy as steady state oxygen uptake (VO 2) at intensities below the ventilator threshold. The traditional technique of evaluation is an extrapolation to a typical running speed (268 m/min) or as the VO 2 needed to run a kilometer. Though a smaller frame size and a thinner lower leg may be the main contributing variables, people of East African descent may generally be more economically successful. Though high-intensity running may be a prevalent factor working to enhance the economy, strategies for doing so have yet to be developed. Of the numerous metabolic, cardiopulmonary, biomechanical, and neuromuscular characteristics contributing to RE, many of these are able to adapt through training or other interventions resulting in improved RE.

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1. Introduction

Running is a performance activity, where run as fast as possible is required to cover a given distance in a minimum of time (Hoogkamer. 2017b; Sousa. 2018). The physiological variables that are associated with aerobic system are used to determine running performance (Grivas,2020).To improve the level of performance in distance running events, the training must have a positive effect on one or more of the main physiological factors that underlie success in these distances (Andrew, 2016). These are: maximal oxygen uptake (VO2max), running economy (RE), running velocity at VO max (vVO max), and time limit at vVOmax (tlimit), running velocity at lactate threshold (vLT), and maximal speed (Vmax). Aerobic fitness, as well as running performance, can be measured by physiological variables (Claudio, 2013).

Running performance depends on (i) both a high cardiac output and a high rate of oxygen delivery to working, (ii) the ability to sustain a high percentage of VO2max for long periods of time, and (iii) the ability to move efficiently running economy (Foster and Alejandro, 2007). Among the factors running economy (RE) is the one that may predict middle and long-distance running performance, commonly defined as the steady-state VO2 required at a given submaximal speed (Balsalobre, Santos, Grivas. 2016).

The relationship between RE and performance was studied by different scholars. As an example, a case study of American mile record holder Steve Scott-, reported that during a 6-month period of training Scott improved his VO2 max by 3.8% (74.4 to 77.2 mL/kg/min). During the same period, there was a 6.6% improvement in RE (48.5 to 45.3 mL/kg/min) at a running velocity of 16 km/h. In the last decades, researchers have focused on measuring RE in distance runners and many studies have found a strong association between RE and race performance. And also recent researcher addresses many of the issues presented in this article in more detail but even these authors note that the state of knowledge about the running economy is low compared with our understanding of other elements of running performance.

Interest in the 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 (Lucia et al., 2006). This has paralleled the realization that performance differences amongst elite athletes are highly related to differences in the economy (or efficiency). Effectively, in a group of individuals, all of whom have a high VO2 max and all of whom can sustain a high percentage of VO2 max for a long time, the winner is usually the most economical or efficient athlete. This brings us to review articles related to running the economy and performance, examine research relating to physiological and biomechanical factors which influence RE, describe interventions that have attempted to improve RE and discuss potential areas for future research directions in this field.

2. What is Running Economy (RE)?

Barnes and Kilding (2015) stated that running economy is a measurement of or a given task which is both a conceptually clear and practical evaluation of endurance activities and it is the physiological criterion for efficient performance.

Running economy is a common phonological variable used to study running performance (Claudio, 2013) and it represents the sum of various metabolic, cardiorespiratory, biomechanical and neuromuscular characteristics during sub-maximal running (Barnes and Kilding, 2015). And also Barnes and Kilding (2015) explained that RE is represented by the energy demand for a given velocity of submaximal running and expressed as the submaximal VO2 at a given running velocity.

J. Daniels and N. Daniels defined running economy (RE), is the energy demand for a given velocity of submaximal running, is an important predictor of aerobic running performance, particularly in elite runners who have a similar aerobic power (i.e., maximal oxygen uptake, VO2max).

Fletcher (2009) defined running economy is usually as the steady-state oxygen uptake (VO2) required at a given submaximal speed or as the energy requirement per unit of distance run. Running economy (RE) is the determent of distance running performance to sustained, predominantly aerobic energy production and the conversion of this energy into forward movement (Folland, Allen, Black, Handsaker, and Forrester (2017).

*Shaw, Ingham &Folland, (2014) stated that r*unning economy is the metabolic cost required to cover a given distance. RE is a strong predictor for performance because a runner with a greater economy will tend to work at lower percentages of VO2max for various speeds than a runner who requires more oxygen and has a poor economy.

It is useful predictor of endurance running performance especially in athletes who are homogenous with respect to VO_2max (Barnes and Kilding, 2015).

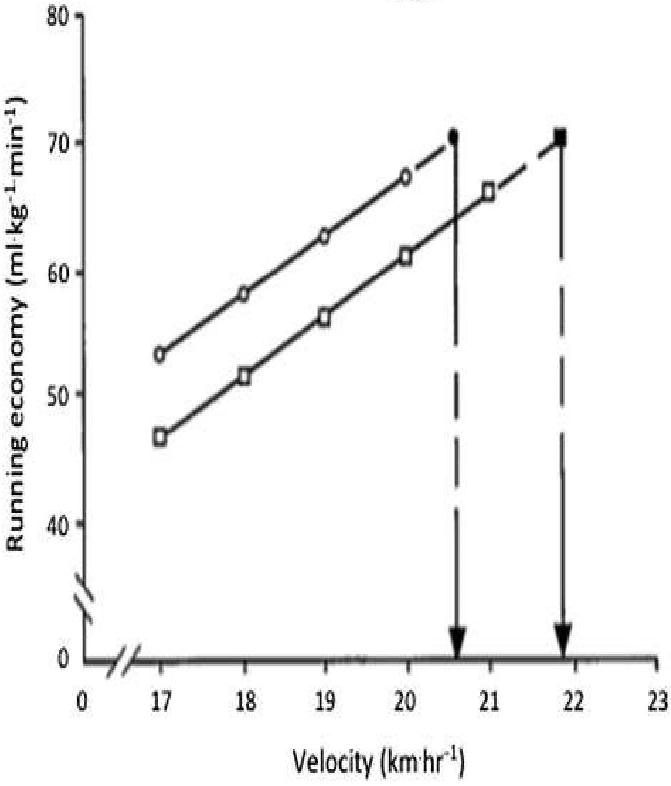

Fig.1. Running economy profiles of two runners of equal VO_2max (Barnes & Kilding, 2015).

Generally running economy (RE) is the energy demand for a given velocity of submaximal running, and is determined by measuring the steady-state consumption of oxygen (VO_2) and the respiratory exchange ratio.

3. Measuring and Expressing Running Economy (RE)

According to Barnes and Kilding (2015) the measure of RE is determined by multiple variables that based on oxygen consumption. They also describe the VO2 related to a particular velocity of running provides a useful way of comparing individuals, or any individual with him or herself under various conditions, and this VO2 gives a measure of running economy. RE can be expressed as a ratio of a runners' VO2 (L/min) divided by their body mass (BM) in kilo grams (Saunders, 2004).

Running economy was typically measured as the oxygen cost of running, which is defined as the oxygen required to cover a given distance (***Foster & Lucia, 2007***). Silva (2018) **stated the measurement assumes that the oxygen cost is an index of adenosine triphosphate turnover during submaximal exercise and thus reflects the metabolic cost of running.**

Measures of RE have typically been determined **in** the laboratory by having the athlete run on a **motorized** treadmill (Saunders, 2004). 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 over ground running) **(Foster and Alejandro 2007)**. Saunders stated that air and wind resistance are effectively eliminated during indoor running; however, transferring treadmill data to over ground running requires caution.

Another study estimated the amount of energy required to overcome air resistance was 4% for middle-distance runners and 2% for marathon runners (Davies,1980).When a tailwind velocity is equal to running velocity, over ground VO2 was equivalent to treadmill VO2(Daniels 1986). Differences between over ground running and treadmill running are more likely to be observed as speed increases and the effect of air resistance becomes more pronounced (Daniels, 1985).Hagerman reported lower submaximal VO2 values at an altitude where the air is less dense than at sea-level. Expression of running economy can be made in several ways. The most commonly used reference velocity is 268 m/min (4.47m/s), which represents 6 minutes per mile, or 3 minutes 44 seconds per km. The lowest reported value for VO2 at 268 m/minis 39.0 mL/min/kg in an individual East African runner, capable of running 1500m in 3:35 with a VO 2max of only 63 mL/min/kg (Foster and Alejandro, 2007). The literature stated the terms that are describing the relationship between oxygen consumption (VO2) and running velocity such as *"*cost, *"*oxygen cost,*" "*energy cost,*"* and *"*requirement*"*. The energy cost of running reflects the sum of both aerobic and anaerobic metabolism, and the aerobic demand, measured by the VO2 in L.min-1 at a given speed does not necessarily account for the energy cost of running, which is measured in joules, kilojoules, calories or kilocalories of work done (Barnes and Kilding, 2015).

4. The Effects of RE in Runners' Performance

Running economy (RE) is a key factor that influences long-distance running performance (Carranza, Mohíno, Concejero and Ravé, 2020). Grivas (2020) stated that when comparing two runners with similar VO2maxvalues the runner with better RE will achieve better performance time. A Griva's observation of the Kenyan and Ethiopian runners have dominated middle- and long-distance running events compared to European runners. The runners from Africa do not have a higher VO2 max compared to European runners, but they have better performance.

The explanation is that African runners are typically smaller even compared to other elite runners, and studies have shown that smaller runners and runners with thinner and shorter lower limbs have better RE.

Numerous studies have examined the effects of RE in distance runners' performance and found a strong association between RE and race performance. For instance, Prampero reported that a 5% increase of RE induced a 3.8% increase in distance running performance.

(Weston, 2000) investigated the RE and 10 km performance in African and Caucasian distance runners. African and Caucasian runners had similar race times in 10 km, but the African runners had a 13% lower VO2 max, but 5% better RE than Caucasians. This study indicates a greater RE and higher fractional utilization of VO2peak in African distance runners.

The study of Conley and Krahenbuhl determined the relationship between RE and distance running performance in highly trained and experienced distance runners. All runners had similar VO2max and within this elite cluster of finishers, 65.4% of the variation observed in race performance time on the 10 km run could be explained by variation in RE

Grivas definite when comparing two runners with similar VO2max values the runner with better RE will achieve better performance time. On the other hand, only a few studies suggested that RE was not associated with running performance in competitive distance runners.

Mooses (2015) suggested that in the homogenous group of Kenyan distance runners, RE can be compensated for by other factors (such as VO2max) to maintain high-performance levels. Similar results are found in the study of Grant, who reported that neither VO2max nor RE was strongly correlated with the performance of 3 km.

RE is influenced by many physiological and biomechanical variables; however, little research exists with regard to improving RE and endurance performance by manipulation of these factors. As Claudio (2013) reviewed, several factors have been proposed to influence RE in trained subjects. These include oxidative muscle capacity and muscle stiffness.

RE is influenced by multiple factors, including metabolic, cardiorespiratory, neuromuscular, a number of biomechanical (e.g., gait patterns, kinematics, and the kinetics of running) and physiological factors(e.g., oxidative muscle capacity) seem to influence RE in trained athletes (Anderson, 1996).

5. The Factors that Influence Running Economy

Many factors are modifiable through various training modalities (Figure below) (Barnes and Kilding, 2015).

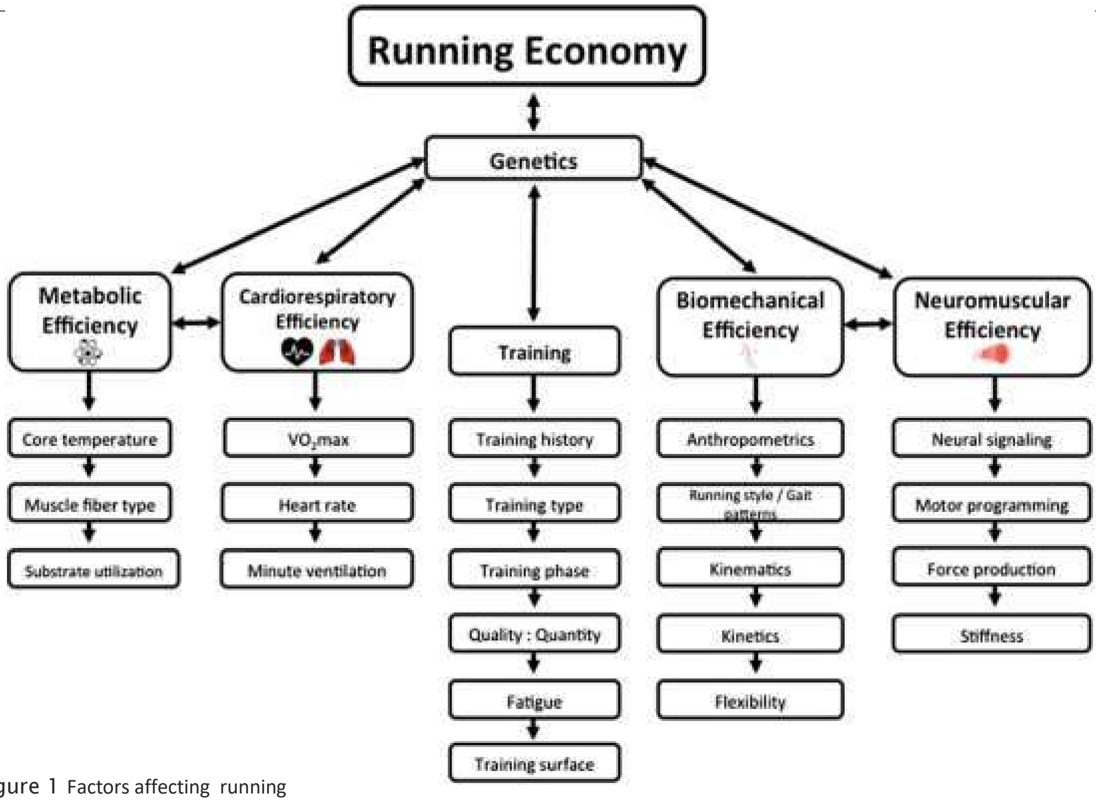

Figure 1 Factors affecting running

Claudio stated plyometric and resistance trainings lead to neuromuscular adaptations such as increased neural drive to the muscles and changes in muscle stiffness and muscle fiber composition, which might reduce the energetic cost during submaximal exercise. Saunders (2004) also stated in his study, RE is influenced by multiple factors, including metabolic, cardiorespiratory, neuromuscular, biomechanical, training and environmental factors. Hoogkamer, Kipp, Barry and Spiering confirmed that adding shoe mass degrades RE, and they showed, for the first time, that adding shoe mass slows 3000-m time-trial performance proportionally (0.78% per 100g per shoe). Their data demonstrate that laboratory-based RE measurements can accurately predict changes in distance running race performance due to shoe modifications. And also Barnes and Kilding (2015) stated some of these factors can be changed chronically through training whereas others can be modified acutely through interventions, for instance changes in footwear (Hoogkamer, 2018). Folland, Allen, Black, Handsaker, and Forrester, (2017) studies showed, running technique also influence performance via RE. The study provides that running techniques such as stride parameters (lower duty factor, shorter ground contact time, and shorter stride length) and lower limb angles (more vertical shank and plantar flexed foot at touchdown, and a smaller range of motion of the knee and hip during stance) in part to optimize pelvis movement (minimal braking, vertical oscillation, and transverse rotation), and ultimately enhance performance (Folland, Allen, Black, Handsaker, and Forrester, 2017).

5.1. Physiological Factors Affecting RE

Thomas sited in Saunders, (2004) investigated the effect of a simulated 5km race on RE, Ventilation, Core temperature, Lactate and Heart rate. Thomas determined RE by using a constant treadmill speed eliciting 80–85% of the athletes VO2max. From the beginning to the end of the 5km run, RE decreased significantly and Ventilation, Core Temp, Lactate and Heart Rate all increased significantly. From those the increased VE was the only factor that correlated the moderately with the decrease in RE ($r = 0.64$; $p <0.05$), indicating a greater oxygen cost was associated with the increase in VE. A higher Core Temp increases VO2 at a given speed. The major factors that increase submaximal VO2 and decrease RE are increases in the metabolic cost from augmented circulation, VE and sweating (Saunders, 2004).Rowell also stated that the mechanical efficiency of muscle increases when Core Temp is mildly elevated, reducing VO2 by an amount equal to or greater than the increase caused by changes in the cost of circulation, VE and sweating. The composition of muscle fibers also seems to influence RE. It has been suggested that a higher percentage of slow-twitch muscle fibers is associated with better RE (Saunders, 2004).

5.2. Biomechanical factors affecting running economy

The biomechanical factors potentially influencing RE include kinematics, kinetics, flexibility, and elastic energy storage in the stretch–shortening cycle (Moore, Jones and Dixon, 2012). Silva (2018) verify the relationships of isokinetic hip strength, muscular strength balance ratios, total body mass and fat free mass with RE. The main outcome was that the hip functional balance ratio was strongly associated with RE at 11 (1% gradient) and 12 km h-1 (at 3% gradient) in male runners. *And also* Silva *obtained,* hip muscle strength values were not related to RE. Hoogkamer, Kram& Arellano (2017*) argued that a reduction in body mass was a good strategy to improve RE. The results from Silva (2018) study showed that the percentage of fat-free mass and absolute values and total body mass was not associated with RE in either male or female runners.*

5.3. Training strategies to improve RE

A variety of training strategies have been adopted in an attempt to improve RE. Saunders (2004) reviewed the most studies demonstrating improvements in RE as a result of training have used untrained or moderately trained subjects, and improvement in fitness is a natural adaptation from endurance training. Some interventions such as training, environment, and muscle damage can modify the oxygen cost over a range of running speeds [Saunders, 2004]

Claudio indicated, RE can be improved (2-3%) after relative short periods (~15–20 days) of altitude exposure (~2.000–4.500 m). Altitude exposure during daily activities, sleeping, or training can enhance RE at sea level altitude through hematological and muscle changes in favor of oxygen transport. Moreover, heat exposure during training sessions can also improve RE by enhancing the thermoregulatory process, thus reducing the cardiovascular and muscle work for a given exercise intensity (Svedenhag, 2000). Grivas found the most common training factors for improving RE are strength training (plyometric), tapering, hill, and pace-specific training.

Balsalobre, Santos and Grivas. (2016) studied the effects of Strength Training on Running Economy. *They show the average RE change was -2.32 ± 2.07 and 0.57 ±2.48mlkg^{-1}min^{-1} for the intervention group and control group, respectively. The meta-analysis demonstrated an overall, significant, large beneficial effect of the strength training interventions on RE when compared with the control group (SMD [95% CI] = -1.43 [-2.23 to -0.64], Z =3.53, p, 0.001).* The meta-analysis shows an overall large beneficial effect of the strength training interventions on RE in highly trained middle- and long-distance runners when compared with the control group (Balsalobre, 2016). Muscular strength and endurance also seem to be critical components of the running economy (Silva, 2018).

5.4. Relationship between Running Economy andVO2max

Running economy (RE) and maximal oxygen uptake (VO2max) are two of the primary determinants of endurance running performance (Prampero, 2003). Shaw AJ, Ingham SA, Atkinson G, Folland (2015) stated that, the combination of RE and VO2max, defined as the velocity at VO2max (vVO2max), has been found to account for ~94% of the inter-individual variance in running performance over 16.1 km. Hopker, Coleman, Jobson, Pass field, (2012) reported an association between individual changes in cycling efficiency and VO2max in response to endurance training and across a competitive season; despite no change in mean group VO2max. These preliminary findings highlight the significance of this relationship for elite endurance athletes, as enhancements in either RE or VO2maxmight only be achievable at the expense of the other variable. Shaw, Ingham, Atkinson, Folland (2015) demonstrates that only a small to moderate relationship exists between running economy and VO2max in highly trained distance runners. With >85% of the variance in these parameters unexplained by this relationship, these findings reaffirm that running economy and VO2max are primarily determined independently.

6. CONCLUSION

In summary, running is a performance activity, when run as fast as possible is required to cover a given distance in a minimum of time. Running economy is the energy demand for a given velocity of submaximal running, is an important predictor of aerobic running performance, particularly in elite runners who have a similar aerobic power. Running economy was typically measured as the oxygen cost of running. Measures of RE have typically been determined in the laboratory by having the athlete run on motorized treadmill. A greater RE and higher fractional utilization of VO_2 peak in African distance runners. When comparing two runners with similar VO_2max values the runner with better RE will achieve better performance time. Strength training has beneficial effect on RE in highly trained middle and long-distance runners. RE in trained subjects is influenced by oxidative muscle capacity and muscle stiffness. Some interventions such as training, environment, and muscle damage can modify the oxygen cost over a range of running speeds. Three areas that have potential to improve RE are strength training, altitude exposure and training in a warm to hot environment. The most common training factors for improving RE are strength training (plyometric), tapering, hill, and pace-specific training. But further research into this area is still required. More precision in measuring the contribution of both metabolic and mechanical aspects of RE are required before we are able to gain better insight into how we can improve RE. Current work aimed at developing better over ground measurements of metabolic and mechanical work offers potential in improving our understanding of physiological and training factors that affect RE in elite runners.

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