Overview of Factors Affecting Running Economy in Distance Running

Yang, Chia-I
Department of Physical Education, National Pingtung University of Education

ABSTRACT

Running economy is an important determinant of affecting distance running performance. Purpose: Supplying the factors affecting running economy for athletes and coaches how to facilitate and improve distance running performance. Methods: Inducing, analyzing, and integrating documents and then describing the meaning of running economy as well as narrating the different factors influencing running economy. Conclusion: Running economy is one of physiological factors, but the interactional effects of anthropometrical, psychological, biomechanical, physiological, and environmental factors as well as the interventions of training will influence changes in running economy and performance.

Key Words: Running Economy, Running Performance, Maximal Oxygen Uptake

Correspondence: Yang, Chia-I, 4-18, Minsheng Rd., Pingtung 90003, Taiwan (Department of Physical Education, National Pingtung University of Education)
E - MAIL: yang3262@yahoo.com.tw
Introduction

Aerobic metabolism plays an important role in endurance performance. It has been well documented that a high maximal ability to metabolize energy aerobically is a prerequisite for success in distance running events. In competitive distance running, better running performance has been correlated to an athlete’s maximal oxygen uptake ($\text{VO}_2\text{max}$).

Whether distance running performance is great, it is directly influenced by changes in utilizing oxygen, carbohydrate and fat, and the density of muscle mitochondria. Factors of affecting $\text{VO}_2\text{max}$ include muscle capillary density, hemoglobin mass ($\text{Hb}_{\text{mass}}$), stroke volume, aerobic enzyme activity, muscle fiber type composition, and so on (Coyle, 1999).

Although a high $\text{VO}_2\text{max}$ is required for distance running, other physiological factors are also important in determining endurance capacity. These factors depend on the race distance and include the percentage of lactic acid, the ability to utilize fat as a fuel at high work rates, spare carbohydrate, running at race pace with relatively low energy expenditure (i.e. good running economy), and so on (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999). Since running economy is one of critical determinants of distance running performance, it is important that how to improve running economy facilitates distance running performance.

Running Economy and Performance

Running economy (RE) refers to the energy demand for a given running velocity, and is determined by measuring the steady-state consumption of oxygen ($\text{VO}_2$) and the respiratory exchange ratio (RER). Taking body mass (BM) into consideration, better RE is typically thought of as running a greater distance for a given volume of oxygen consumption or consuming less oxygen while running a given distance. Therefore, runners with good RE use less energy and less oxygen than runners with poor RE at the same velocity.

RE is one determinant of successful performance in distance running. The relationship between RE and performance has been well established, with many independent reports demonstrating a strong relationship between RE and distance running performance. Thus, RE is a better indicator of performance than $\text{VO}_2\text{max}$ in elite runners who have a similar $\text{VO}_2\text{max}$.

Conley and Krahenbuhl (1980) indicated the relationship between running performance and RE as well as $\text{VO}_2\text{max}$ is different on the 10-km run at three running paces. The relationship between $\text{VO}_2\text{max}$ and distance running performance was $r = -0.12$. The relationships between steady-state $\text{VO}_2$ at 241, 268 and 295 m/min and 10-km time were $r = 0.83, 0.82,$ and $0.79.$
respectively. 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. It concluded that among highly trained and experienced runners of comparable ability and similar VO₂max, RE accounted for a large and significant amount of the variation observed in performance on a 10-km race.

Factors Affecting Running Economy

Anthropometrical factors

Anthropometric characteristics such as height, limb mass and its distribution, as well as BM, have been addressed as potential effects on RE.

Myers and Steudel (1985) indicated that the cost of adding a given mass to the limbs was much greater than adding it to the center of mass and that this effect became more marked as the limb loads were moved distally. It demonstrated that a clear influence of limb mass and its distribution on the cost of locomotion.

Maldonado, Mujika, and Padilla (2002) investigated that the influence of BM and height on the energy cost of running (Cr) in 38 highly trained male runners and possible differences in body dimensions in different running events. The researchers found that the long middle-distance group had a lot higher on Cr and VO₂max and that only in the short middle-distance group, the relationship between Cr and height (r = -0.86) as well as BM (r = -0.77) was marked. It concluded that highly trained distance runners tended to show offsetting profiles of RE and VO₂max (the higher Cr, the higher VO₂max and vice versa), and that anthropometric characteristics related with great performance were different in long-distance and middle-distance events.

Psychological factors

Although RE is an important physiological characteristics related to superior distance running performance, little is known about the potential psychological link of RE.

Martin, Craib, and Mitchell (1995) found that there was no relationship between anxiety and RE, while self-attention and RE were related (r = 0.50) in the 18 competitive male distance runners at the 10-km race time (mean 34.17 min). It showed that runners who habitually directed attention inwards were the most economical because they were sensitive to muscle tension interfering with running performance and used relaxation techniques to reduce tension.

Schücker, Hagemann, Strauss, and Völker (2009) addressed an increased RE in the external
focus condition and indicated that in line with research on motor control, endurance sport also showed that an external focus of attention was better than an internal focus in terms of the physiological performance measure of VO$_2$. It certified that the psychophysiological intervention caused the improvements in RE.

Caird, McKenzie, and Sleivert (1999) investigated that 7 long distance runners learned and practiced relaxation techniques for a 6-wk control phase. The researchers addressed that the subjects were able to lower their VO$_2$, heart rate (HR), and ventilation (V$_E$) at lactate threshold by 7.3%, 2.5%, and 9.2% ($P < 0.05$), respectively. Post-tests of lactate threshold, VO$_{2\text{peak}}$, peak running velocity, and stretch-shortening cycle efficiency showed that no changes occurred as a result of a training effect. Crews (1992) also indicated that increased tension was highly correlated ($r = 0.81$) with increased oxygen cost and that reductions in tension, using stress management techniques, improved RE.

**Biomechanical factors**

Running involves the conversion of muscular forces translocated through complex movement patterns that utilize all the major muscle joints in the body. High running performance is reliant on skill and precise timing in which all movements have purpose and function.

Støren, Helgerud, and Hoff (2011) found that the sum of horizontal and vertical peak forces showed a noticeable inverse correlation ($p < 0.05$) both with 3000-m performance ($r = 0.71$) and RE ($r = 0.66$) in 11 male elite endurance athletes. Hence, avoiding vertical movements and high horizontal braking force was crucial for a positive development of RE.

Unnithan and Eston (1990) investigated the oxygen demand in 10 aerobically fit prepubescent boys (9-10 years old) and 10 fit young men (18-25 years old) and found that the oxygen demand was higher at all running speeds in the boys' group as well as that to compensate for a shorter stride span, the boys employed higher stride frequency at all speeds to maintain similar running speeds. Tseh, Caputo, and Morgan (2008) examined 9 female distance runners under 4 randomly-selected conditions and indicated that running with exaggerated vertical oscillation ($51.0 \pm 2.5$ ml/kg/min) and hands on head ($46.1 \pm 2.0$ ml/kg/min) resulted in significantly ($p < 0.05$) elevated VO$_2$ values compared to hands behind back ($43.9 \pm 2.4$ ml/kg/min) and normal running ($43.4 \pm 2.6$ ml/kg/min). Specific gait manipulations could produce marked decrements in RE among trained female distance runners.

During the eccentric phase of contact, mechanical energy is stored in the muscles, tendons and ligaments acting across joints and recovery during the concentric phase of the stored elastic energy reduces the energy expenditure. The studies demonstrated that stiffer muscles reduced the
aerobic demand by facilitating variation in the storage and reutilization of elastic energy and improved RE (Arampatzis et al., 2006; Craib et al., 1996; Jones, 2002; Scholz, Bobbert, van Soest, Clark, & van Heerden, 2008). Also, Spurrs, Murphy, and Watsford (2003) examined that 17 male runners completed 6 weeks of plyometric training related to alterations in lower leg musculotendinous stiffness. After the training, the group significantly improved 3-km performance (2.7%) and RE at each of the tested velocities, while there was no change in VO$_{2\text{max}}$ or lactate threshold. Turner, Owings, and Schwane (2003) also indicated that even the VO$_{2\text{max}}$ did not change with training for the period of 6 weeks, plyometric training improved RE. Following the plyometric training, the improvement in RE was small (2–3%), but small differences in RE could be important in competitive distance running.

What is more, wind resistance and surface stiffness also affect mechanics of human running as well as RE. Davies (1980) indicated that at high wind velocities, the subjects (3 healthy male) altered their posture and "leaned" into the wind, and that the possible converting potential drag into body lift and the energy cost of overcoming air resistance on a calm day outdoor were calculated to be 7.8% for sprinting (10 m/s), 4% middle-distance (6 m/s), and 2% marathon (5 m/s) running. Kerdok, Biewener, McMahon, Weyand, and Herr (2002) assessed the effect of 5 different surface stiffnesses on energetics and mechanics of human running in 8 male subjects and found that the 12.5-fold decrease in surface stiffness resulted in a 12% decrease in the runner's metabolic rate and a 29% increase in their leg stiffness. The study indicated that surface stiffness affected RE without affecting running support mechanics. It might be that an increased energy rebound from the compliant surfaces contributed to the improved RE.

**Physiological factors**

Fluctuations in physiological factors, such as gender, age, HR, $V_E$, lactate, may be associated with changes in RE during distance running competition.

At absolute running velocities, men were more economical than women. When men and women had equal VO$_{2\text{max}}$, the men showed a better aerobic profile (Daniels & Daniels, 1992). RE also improved steadily with age in normally active children and adolescents. Compared with adults, children were less economical than adults because children exhibited higher resting metabolic rates, greater ventilatory equivalents for oxygen, and disadvantageous stride rates as well as stride lengths (Krahenbuhl & Williams, 1992).

Weston, Mbambo, and Myburgh (2000) investigated RE of African and Caucasian distance runners. The African runners had 13% lower mean VO$_2$peak and 5% more economical. This difference increased to 8% ($P < 0.01$) when standardized per kg. At race pace, the Africans utilized a higher %VO$_2$peak and had higher HR.
Saltin et al. (1995) found that the best Scandinavian runners were similar to the Kenyans in VO\textsubscript{2}\text{max}, but blood lactate concentration was in general lower in the Kenyan than in the Scandinavian runners, and the Kenyans also had extremely low ammonia accumulation in the blood even at very high exercise intensities. Their high aerobic capacity and good RE made them such superior runners.

Most studies have demonstrated improvements in RE as a result of training for untrained or moderately trained subjects. However, in highly trained runners who already possess a well developed RE, the superior runners also improve RE through different training methods. That is, the specific trainings, such as strength training (Støren, Helgerud, Støa, & Hoff, 2008), simultaneous explosive-strength and endurance training (Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999), simulated moderate-altitude training (Saunders et al., 2004), bring about the adaptations occurring across the various physiological systems that ultimately lead to improvements in RE and performance.

In addition, environment also influences one’s physiological adaptations. Smith (1980) indicated that acute exposure to altitude was one of decreased partial pressure of oxygen which decreases the aerobic power of the individual. With acute exposure, to compensate for this hypoxia, one must increase his pulmonary ventilation from 40 to 100%. When one did not fully compensate for the decreased partial pressure of oxygen, VO\textsubscript{2}\text{max} would reduce and then influenced RE.

Conclusions

RE and VO\textsubscript{2}\text{max} have been researched extensively over the past decades and are thought of as a critical factor in performance of distance runners. However, factors that influence RE include ventilation, muscle metabolism, muscle fiber type, body composition, running technique, ground reaction forces, muscle stiffness, and storage and return of elastic energy, altitude, relaxation technique, and so forth. In a limited VO\textsubscript{2}\text{max} situation, training intervention indeed improves running economy and performance. In addition to employing psychological approach, to improve and facilitate their running economy and distance running performance, distance runners are supposed to adopt the different interventions of training according to the individual characteristics.
References


在長距離跑步中影響跑步經濟性因素之概觀

楊佳益
國立屏東教育大學

摘要

跑步經濟性是影響長距離跑步表現的重要因素。本文研究目的：提供影響跑步經濟性因素給運動選手和教練如何促進及改善長距離跑步表現。方法：歸納、分析以及整合文獻並描述跑步經濟性且叙述影響跑步經濟性之不同因素。結論：跑步經濟性雖是生理因素之一，但是人體型態、心理、生理和環境因素之交互作用的影響以及運動介入將會影響跑步經濟性和表現之變化。

關鍵詞：跑步經濟性、跑步表現、最大攝氧量

通訊作者：楊佳益 屏東市民生路 4-18 號 國立屏東教育大學體育研究所
E - MAIL：yang3262@yahoo.com.tw