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Original Article

Physiological Factors of Long-Distance Runners Performance

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Abstract:

Athletics, is a universal sport that comprises races between 5 km and 42 km, which have increased their popularity in the last decade. It has generated a need for information by coaches and athletes. The factors that affect performance are some of the most frequently studied in the literature, particularly the psychological factors: maximum oxygen consumption, running economy, types of muscle fibers, age, sex, fatigue, and genetics. The aim of this review is to describe the physiological factors that affect sports performance in long-distance runners.

Keywords: Long-distance runners, physiological factors, sports performance

Introduction

According to the International Association of the Athletics Federations (IAAF), long distance races are a type of athletics event that comprise races on foot between 5 000 meters to 42 km in the marathon.

Long distance races usually take place in urban settings through the main avenues of cities or towns where they are organized (Salguero *et al*., 2011); (García & Llopis, 2010).

A significant growth in the number of participants has been observed, so they have a commercial component, which include several different marathon programs that promote the participation of runners of different categories, sex, regions, and world.

Today, there is a high production of scientific papers related to sports performance, which deal with the factors that affect it, depending on psychological, physiological, biochemical, and anthropometric criteria (Urdampilleta *et al*., 2012).

Sports performance has a multifactorial character, in individual sports the influence of physiological factors is significant. Hence, coaches and researchers have focused on the prediction of sports performance, cardiovascular factors, lactate, maximum consumption of oxygen (VO_{2max}), (Saw *et al*., 2016), ventilatory threshold, running economy (RE), age, gender, muscular fiber, and the race of the long-distance runner (Orgueta-Alday & García-lopez, 2016), working speed in the VO_{2max}, time limit in VO_{2max}, race speed in the threshold of lactate (Grivas, 2020).

Research done in the genetics associated with sports performance of runners indicate that one of the aspects that determine the chances of becoming a champion is genetics, in which inheritance is fundamental for the potential of physical performance in interaction with other factors, such as environmental, the setting, training, and nutritional (Medellín, 2012).

The research of physiological indicators that affect performance in long distance runners is predominant; they are dealt with independently, like the process of biological maturation of young athletes (Verdugo, 2015), the analysis of the influence of anthropometric, physiological, and biomechanical factors (Ogueta-Alday *et al*., 2013), assessment of gender differences that affect the participation in popular long distance events (Salguero *et al*., 2011).

From a multidisciplinary perspective, there are various factors that affect sports performance, thus creating interest in the scientific community in relation to the study of these factors, especially the physiological aspects (Ortigosa, 2016). In sight of this situation, What are the physiological factors that affect sports performance in long distance runners most? Accordingly, the aim of this review is to describe the physiological factors that affect sports performance in long-distance runners.

Materials and Methods

The review consisted in the narrative type. The databases of GOOGLE, PUBMED, REDALYC, LATINDEX, and Dialnet were consulted, using a search strategy designed to retrieve the results associated with the physiological aspects that affect performance in long distance runners.

A total of 50 documents related to the physiological factors that affect performance in long distance runners were selected. The search was completed with reading and tracking the referenced bibliography in the documents selected during the 2015-2021 period. The information search relied on the following descriptors: *Long distance runners and maximum oxygen consumption*, *long distance runners and running economy*, *long distance runners and muscle fiber*, *long distance runners and fatigue*, *long distance runners and genetics*.

Results and Discussion

Among the physiological factors associated with sports performance of long distance runners, the VO_{2max},, running economy/effectiveness, age, gender, muscle fiber, stand out.

Maximum oxygen consumption

Performance in endurance sports is closely related to VO_{2max} in such a way that this physiological indicator is associated with a drop in performance during the Dial net endurance events.

The VO_{2max} is an indicator of aerobic potential; however, there are factors that limit or can limit it, including the energy demand of respiratory muscles, respiratory muscular fatigue, limitation of pulmonary diffusion. The typical values range between 35-45ml/kg/min, whereas endurance athletes may reach 60-80ml/kg/min. **Table 1.**

Table 1. Values of maximum oxygen consumption of long distance runners

Author (year)	Study (title)	Values VO_{2max}
Torres Navarro, V. (2017)	Consumo de oxígeno, velocidad y economía de carrera en jóvenes atletas y triatletas.triathletes.	62.7ml/kg/min
Ruiz Griman, D. J. (2014)	Consumo máximo de oxígeno, composición corporal y clasificación según el rendimiento en 10 km de corredores aficionados.	49ml/kg/min (men) 46ml/kg/min (women)
Niño Hernández, C. A (2012)	Estimación del consumo máximo de oxígeno mediante Pruebas de ejercicios maximales y submaximales	36.68 ml/kg/min (men), 29.07 ml/kg/min (women)
Rivera *et al*., (2012)	El modelo paralelo de procesamiento y la percepción de esfuerzo en corredores de fondo.	53.90ml/kg/min
Tucker *et al*., (2009)	The runners´s body. How the latest exercise science can help run stronger, longer, and faster.	65 and 85 ml/kg/min
Caldas Zárate, R., Marino Isaza, F., & Valbuena Ruiz, L. H. (1991)	Validación de un test de carrera sobre 3200 m. Para la determinación del consumo máximo de oxígeno y de las fracciones aeróbica-anaeróbicas a concentraciones definidas de lactato plasmático en corredores de fondo	66.3ml/kg/min
Padilla *et al*., (1991)	Capacidad aerobia y anaerobia en corredores de medio fondo.	66ml/kg/min

Running economy/effectiveness

The term running economy describes the stable state of oxygen consumption to a particular intensity. The changes of ER are directly reflected on changes in sport benefit;

that is, the weight increase of sports shoes and alterations in the ER for sports performance. It means that and changes that cause or influence the running economy may appear in the final result of a competition (González-Mohíno Mayoralas *et al*., 2018).

ER is a critically important indicator of performance, being VO_2 necessary to maintain certain rhythm in the race, which will be a percentage of VO_{2max}. The anaerobic threshold and the running economy are the factors to be improved in experienced runners. ER gains more importance the longer the distance to run is, so proper ER is essential for long distance runners.

Improvements in ER demands more efficiency; that is, consuming the least possible energy when running, along with a better biomechanics of the race. Well executed training of the race technique leads to higher biomechanical efficiency and favors the elimination of unnecessary movements that increase energy consumption. Besides, strength training delays the occurrence of fatigue, which contributes to maintaining a better ER.

Today, the true role of ER in performance is being discussed; possibly the two variables (VO_{2max} and ER) are inversely related, and athletes with a lower VO_{2max} can compensate it with better ER (Orgueta-Alday & García-lopez, 2016).

Age

It is a component to be considered to achieve optimum benefit in sports. Generally, the greatest achievements in long distance races are observed in the 30-40 year-old group. In this age group, there is an optimum balance of variables VO_{2max}, muscle strength, and ER. It has been defined that VO_{2max}, gradually increases to approximately 20 years of age, and then decreases less than 1% a year, unusually in the same way as muscle strength, which achieves optimum development between 20 and 30 years of age, diminishing inmost muscle groups due to a reduction in the muscle mass (McArdle *et al*., 2015). However, it has been observed that ER increases with age. Accordingly, one of the training objectives in the advanced age subjects is to influence on the capacities that will be affected in time.

Proper strength work and high intensity endurance slow down deterioration in such a way that it can be kept until 70 or older, very acceptable for long distance races.

Gender

It has a clear influence on the performance of long distance races. For instance, in the Olympic Games, London 2012, the winner of the marathon (men) was Stephen Kiprotich, UGA, who recorded 2 h:08 min:01seg, whereas in the women's event, the winner, Tiki Gelana made it in 2 h:23 min:07seg. In the 10 km, the winner was Mohamed Farah, GBR, with 27 min:30seg, and the winner among the women was Tirunesh Dibaba, in 30 min:20seg, setting a three-minute difference. (Olympic Games Committees, 2021). There is a 10% difference, which also corresponds to the 12% difference observed among the best 10 qualified men and women for the New York marathon, between 2006-2010 (Hunter & Stevens, 2013). One possible explanation could be the lower values of strength and VO_{2max} shown by women in relation to men, with 20-25% VO_{2max} greater than that of women at any age. It was attributed to greater muscle mass and other genetic and hormonal conditions, and to even less hemoglobin in women caused by the blood loss during menstruation.

The influence of gender in ER is still argued. Meanwhile, some authors claim that men are more economical than women, others have not found significant differences to similar relative intensities (Daniels & Daniels, 1992). On the contrary, some papers indicate that women are more economical (Helgerud *et al*., 2009) with a normally lower index of body mass and less need of energy to run at the same speed.

Muscle fiber

Physical training can change the distribution of the types of muscle fiber. The differences observed among short distance runners, mid distance runners and long distance runners in relation to the type of muscle fiber in the vastus lateralis muscle (Svedenhag, & Sjödin, 1994), and has been found in long distance runners with 75% type I fiber (slow twitch fiber), and 25% of type IIa fiber (intermediate twitch fiber), and a very low percentage, even null, of type IIb fiber (fast twitch fiber). The predominance of type I muscle fiber seems to relate to VO_{2max} and the ER. A greater percentage of slow fiber tend to produce a lower amount of lactate and lower energetic consumption, bringing about a better performance in long distance races (Orgueta-Alday & García-lopez, 2016).

Strength training plays an important role in the training of endurance sports. The benefits on performance are produced thanks to neuromuscular adjustments that consist in higher recruitment and synchronization of motor units as well as intra and inter muscular coordination.

The genetics of runners

Among the best runners of the world, the percentage of Europeans dropped (11%), whereas the number of African runners have grown (85%), with the Kenyans accounting for 55%, (Vancini *et al*., 2014). The domain of African runners in long distance races has motivated researchers to study their genetics in terms of physical endurance, resulting in 200 genetic variants.

The genotype and the environment determine the phenotype. The evidence points to the interaction between genetic and environmental factors as responsible in most individual differences to respond to training (Noakes *et al*., 1990); (Tucker *et al*., 2013). In the variations of inter-individual muscular performance, the genetic factors represent between 50 and 80% (Arden & Spector, 1997).

The mitochondrial deoxyribonucleic acid (mtDNA) and chromosome Y of athletes that started as long distance runners in Ethiopia and Kenya were studied. The polymorphisms of mtDNA are inherited from the mother and only change as a result on new mutations (Atkinson *et al*., 2009). This polymorph can influence the variation of aerobic performance of humans due to their participation in the codification of different subunits of the enzymatic complex of oxidative phosphorylation (Scott *et al*., 2005). However, a cohort analysis made to elite runners in Ethiopia did not reveal the existence of mtDNA variants that influenced the performance of athletes in association with aerobic endurance during events (Scott *et al*., 2005); similar results were found in Kenyan runners (Scott *et al*., 2009).

Regarding the effects of chromosome Y on aerobic endurance and performance, the findings were similar to the ones observed in the mtDNA studies, which suggested a significant number of athletes who inherited part of their male ascendency from outside Africa.

The most commonly studied genes associated with human performance are the angiotensin converting enzyme (ACE) and aplha-actinin-3 (ACTN3), (Scott *et al*., 2005); (Yang *et al*., 2007).

The ACE gene is a polymorphism of insertion (I) whose lowest levels are associated with deletion (D) (Scott *et al*., 2005). The allele I of this gene has been associated with performance during tests of aerobic endurance (Scott *et al*., 2005), and the capacity of training cardiorespiratory aptitude seen as the maximum absorption of oxygen, which seems to be determined by the ASSL1 and 21 SNP genes (Tucker & Collins, 2012). Allele D is associated with performance during the tests of power (Wilber & Pitsiladis, 2012), where the contribution of inheritance may vary from 46% to 84% (Tucker & Collins, 2012). However, there were no significant differences in the frequency of alleles I and D in the athletes from Ethiopia, Kenya, and the general population in their respective locations (Vancini *et al*., 2014).

Gene ACTN3 has been associated with the highest level of physical endurance found in elite African runners (Yang *et al*., 2003), at different frequencies in different populations (Mills *et al*., 2001). The R577X variant was found in elite athletes of white Australian populations, though they were deficient in the ACTN3 XX genotype, with a slightly higher frequency found in elite athletes who specialize in aerobic endurance events (Yang *et al*., 2003). However, no evidence was found in relation to the possible relation of R577X polymorphism and performance in aerobic endurance events in east Africa (Yang *et al*., 2007), which suggests that ACTN3 deficiency is not a determining factor of sports success observed in African runners (Wilber & Pitsiladis, 2012).

Genetic studies in sports have gained interest as they may contribute to the identification of athletes with a higher response capacity or adaptation to physical training and the prevention of injuries (Maffulli *et al*., 2013). Practice has demonstrated that in a group of individuals who begin a sport, only a small percentage has a genetic background and the physical characteristics that confer success in sports, so they can become elite athletes (Vancini *et al*., 2014).

A study to determine if the genetic characteristics of the domain of long distance races (Ben-Zaken *et al*., 2021), evaluated the polymorphisms of genes associated with endurance (PPARD T/C), the capacity of endurance training (ACSL A/G), speed (ACTN3 R/X), strength (AGT T/C), and recovery from endurance training (MTC1 A/T and IL6 G/C), in the best Israeli long distance runners with an Ethiopian origin (n = 37), Israeli runners with a Caucasian origin (n = 76), and controls made of non-athletic Israelis (n = 55).

The results suggest that the domain of Israeli long distance runners is associated with endurance polymorphisms, polymorphism linked to higher speed performance and better training recovery capacity.

Discussion

Maximum oxygen consumption

VO_{2max} has been used as an indicator of the aerobic power of subjects evaluated largely through aerobic tests. Recent studies, however, challenge this concept (Chamari & Padulo, 2015), considering the different values achieved after showing modifications in this test (Beltrami *et al*., 2012).

In the VO_{2max} plateau, a maximum value of lactate (6-9 mmol/L^{-1}) is reached, according to research and the age of subjects), which demonstrates the anaerobic glycolytic participation, a predominant way observed before the cessation of the physical effort, because the intensities at the end of the VO_{2max} surpass the second ventilatory threshold, or the threshold of respiratory compensation (Beaver *et al*., 1986).

According to Chamari & Padulo (2015), to describe the result of an incremental test (VO_{2max}), no reference should be made to the maximum aerobic speed reached, but to the speed that permits that exercise remains longer, until reaching VO_{2max}.

The VO_{2max} test requires analysis, considering that it is an aerobic test; however, to reach the VO_{2max}, more intensity is given to physical effort, a moment in which the anaerobic glycolytic way predominates, which means no utilization of oxygen to obtain energy.

Running economy/effectiveness

The running economy is an important physiological measure for endurance athletes, the physiological and biomechanical factors determine and influence the running economy. The running economy is a useful predictor of performance in endurance race. If oxygen consumption remains stable at a given racing speed, the demand of energy is manifested when running (Barnes & Kilding, 2015).

Therefore, the runners with a good running economy use less oxygen with little running economy at a same speed in a constant state. As an indicator of performance in the endurance race, the running economy is the maximum expression of delayed fatigue (Latorre & Soto, 2000).

The running economy varies (Barnes & Kilding, 2015) up to 30% among runners trained under a similar VO_{2max}. It is thought of as a multifactorial measure that shows the function of the metabolic, cardiopulmonary, biomechanical, and neuromuscular systems.

Age and Gender

Based on the review conducted, age and gender are factors that affect optimum performance in long distance races. Within the 30-40 age range, there is an optimum balance of variables VO_{2max}, muscle strength, and ER. There is a 10% difference among the best 10 men and women of the New York marathon, between 2006-2010.

It has been observed that ER improves with age. Accordingly, one of the training objectives in the elderly is to influence on the capacities that will be affected with the passing of years.

The particularities and results of the similarities between genders (Garcia Avendaño *et al*., 2008) depend mostly on the somatotype, physiology, and body composition. The difference does not go beyond the normal limits of these biological aspects. In other words, there is no evidence that demonstrates that men are superior to women due to the features of their gender.

In relation to the similar physiology of men and women, it has been considered that the average fully matured women is characterized by lower body mass and size than men, which is translated into a smaller and slighter body structure. Consequently, women have a broader pelvis and shorter limbs, and muscles converging toward the knees, so the femur loses verticality and the lower leg bones show a smaller arch than that of men, causing a reduction in efficient mechanics when running.

The morphophysiological traits of women may cause limited performance in sports practice. Besides, they are more prone to suffer injuries due to knee instability.

The cardiopulmonary system also shows differences between the genders. The cardiac volume of a woman is below 25%. It corresponds to the morphological conditioning factor that the thorax of women is smaller and with a 10% lower pulmonary capacity than men. Likewise, the capacity of oxygen transport per litter of blood is 11% lower in women. Nevertheless, it is worth noting that for the same effort intensity, women with regular training have a similar cardiopulmonary volume to trained men or men with a similar activity level (Garcia Avendaño *et al.*, 2008).

Muscle fiber

There are different types of muscle fiber, the fiber that predominates in long distance athletics are the slow twitch fiber, also known as red fiber or type I fiber.

The slow fiber has a high capacity to produce energy anaerobically at a low potency. These fibers have metabolic adjustments for slow and prolonged effort, tolerance to exhaustion, and the capacity of maintaining muscle contractions for a longer time.

Type I fiber or slow fiber contains a large number of mitochondria, high aerobic metabolism, and greater endurance to fatigue. One of the characteristics that stand out most is the high content of myoglobin, along with a large number of mitochondria and blood capillary that favor oxygen contribution and utilization (Billat, 2002).

The percentage of different types of fiber is conditioned by the genetics, though some parameters can be modified by strength and endurance training. Hence, a high prevalence of type I fibers at the muscular level seems to be a fundamental requisite for the success of endurance sports. According to Sanchis (2015), the type I fibers in the muscles trained are linked to the previous years of endurance training.

The genetics of runners

Studies of mtDNA and chromosome Y provided no genetic evidence that support the biological background in relation to the racial differences in sports performance of African runners (Scott *et al*., 2005) (Onywera *et al*., 2006) (Scott *et al*., 2009) (Wilber & Pitsiladis, 2012).

Considering the different levels of ligament unbalances between Caucasians and Africans in the analysis of the potentially causal ACE variant (genotype A22982G), no significant differences were found in the frequencies of the Ethiopian and Kenyan athletes and the general population (Scott *et al*., 2005).

The ACE and ACTN3 genes are associated with performance in the aerobic endurance race; however, the data are insufficient to support this association. Based on the evidence provided, the phenotype possibly has a greater influence than the genotype on the success of long distance runners, (Scott & Pitsiladis, 2007). Moreover, the results of athletic performance of certain populations are multifactorial. Therefore, the success of elite athletes due to SNP5 is unlikely (Pitsiladis & Scott, 2005); it must be the result of a broad combination of advantageous genotypes (Scott & Pitsiladis, 2007).

Before considering that the genetic factors are directly responsible for the performance of African runners, it is necessary to conduct in-depth studies that determine the frequency of variants of other nuclear candidate genes in specific cohorts. According to the current trends in sports, a genomic research is recommended, so that multiple genes can be studied simultaneously, the study of the whole genome, instead of focusing on single candidate genes. That way, possible genes could be found, or the inconsistencies of this topic in relation to long distance runners could be elucidated (Wilber & Pitsiladis, 2012) (Skinner, 2001)(Roth *et al*., 2012) (Onywera *et al*., 2006).

Despite current research, the findings have produced limited results with respect to the genetic variants associated with sports performance, the capacity of athlete training, and proneness to injuries (Wang *et al*., 2016).

Conclusions

The influence of physiological factors on the performance of long distance runners can be affected by age, sex, and fatigue. Research has shown that the maximum oxygen consumption is an inappropriate predictor of endurance performance, contrary to running economy.

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Conflict of interests:

The author declares there is no conflict of interests in relation to this manuscript.