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Overview of major physiological factors affecting athletes' aerobic fitness level

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Abstract
The main purpose of this article was to review and discuss the current literature on the major physiological factors (i.e. Maximal oxygen uptake (VO2 max), running economy (RE), lactate threshold (LT), ventilator threshold (VT) and oxygen uptake kinetics) that affect athletes aerobic fitness level. Many coaches and trainers believed that athletes with higher VO2max have better performance, but a lot of studies have shown that VO2max is a poor predictor of endurance performance. Alternatively, running economy (RE), lactate threshold (LT), ventilator threshold (VT) and oxygen uptake kinetics also pridicts athletes' aerobic fitness level. Experimental Approach to the Problem PRISMA guidelines was followed to conduct this review. 1754 Records were identified through Electronic data base and from these 450 articles was used for evaluation. 1304 records were exclude because of some articles are duplicates and the rest are conference proceedings. Finally, after evaluation for quality of articles 30 articles was used for this review. Based on the available literature this review draws evidence-based conclusions on the major physiological factors of athletes' aerobic fitness level.

Keywords: Aerobic fitness, Vo2max, running economy, lactate threshold, ventilator threshold

1. Introduction
In sport there are different fitness qualities in which athletes should develop through scientific training. Aerobic fitness is an important fitness quality for exercises which require oxygen for energy production. Ben (2005) [3] states that aerobic fitness is the measure of how much oxygen your body can use during maximal exertion. changes in aerobic fitness highly depends on how much oxygen carrying blood your heart pumps to the working muscle with every beat and the ability of the muscle to use the delivered oxygen for energy production.

As a result of this, the more oxygen your body can process, the more energy you can produce and the greater your aerobic fitness (Joe, 2016) [17]. Therefore, athletes with a higher aerobic fitness can exercise high volume activities with less fatigue and can recover quickly from repeated work than athletes who has less aerobic fitness.

The aerobic fitness status of an individual largely determines the ability to take and utilize oxygen which assists with delaying the onset of fatigue, allows the athlete to sustain for high-intensity exercise during competition and to have good technical and tactical performance under fatigue (Chamari *et al.*, 2005) [7]. And also, better aerobic fitness enables athletes to sustain higher training volumes with higher intensity in a training sessions, week, month or year. Finally these higher training load leads improvement in performance (Tomlin & Wenger, 2001) [33]. Athlete's aerobic fitness is determined by different factors like the physiological makeup of the body, the age of the athlete, body composition, gender, regular training which leads improvement in the delivery and transport of oxygen etc.

There are many interrelated physiological factors which can affects athletes' aerobic fitness level. Among these maximal oxygen uptake (VO2 max), running economy (RE), running velocity at vVO 2max (vVO2max), running velocity at lactate threshold (vLT), and oxygen uptake kinetics are the major physiological attributes associated with athletes aerobic fitness level (Berg K., 2003) [4]. The purpose of this study was to review and discuss possible factors which may account for factors affecting athletes' aerobic fitness level.

2. Methods

Experimental Approach to the Problem PRISMA guidelines was followed to conduct this systematic review. An electronic search of PubMed, Web of Science, Psyc NET, and Scopus was performed to locate eligible studies. The following search terms were used to locate eligible studies: "aerobic fitness," "exercise," "Vo2 max," "running economy," "lactate threshold," "ventilator threshold," and "oxygen uptake kinetics." To be included, studies should write in English and published in a peer reviewed journal. Titles and abstracts were reviewed to remove study duplicates and those not meeting inclusion criteria. Full texts were obtained for studies that met inclusion criteria and for studies where a determination could not be made based on the abstract. The references from the included studies were reviewed as an additional search.

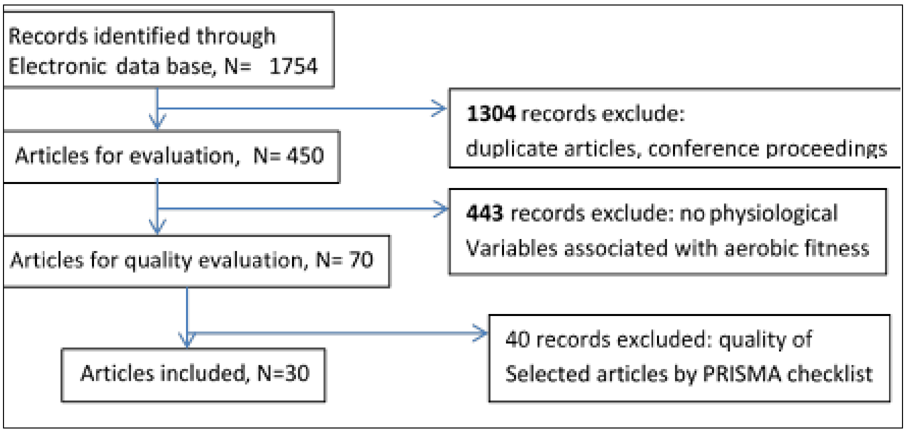

Fig 1: Study selection process.

3. Major physiological factors affecting athlete's aerobic fitness level

3.1 Maximum Oxygen Consumption (VO2max)

All the way through the process of sport training, different tests and measures can be applied to evaluate individual's aerobic and anaerobic fitness. One of the most objective measures that can be used to assess aerobic fitness is maximum oxygen consumption. Maximal oxygen consumption which is usually denoted as VO2 max is defined as the greatest amount of oxygen that a person can receive and spend during one minute of exercise (Maglischo, 2003) [19-20].

During intensive exercise, there will an increment of oxygen consumption which leads to increment in oxygen uptake plateaus and the athlete begins to utilize other energy sources (e.g., glycolytic sources) to produce ATP, The point at which oxygen uptake plateaus with an increase in workload is called maximal oxygen consumption (VO2max) (Billat *et al*., 1999) [5]. VO2max value can be used for endurance athletes to determine their current functional capacity, as an indicator of their progress through long term training, to determine their current level of aerobic fitness, to determine the optimal energy source usage, and training heart rate zones for designing specific training programs.

Most of the time elite endurance athletes will have higher VO2max values which may indicate their potential for excellent aerobic capabilities in endurance events that are dependent on aerobic energy pathways. Because there are other success predictor aerobic fitness elements, VO2max value alone doesn't give guarantee for the athletes to win the competition. In addition a value of VO2max indicates the integrity of the pulmonary, cardiac, and hematologic chain of oxygen delivery as well as the capacity of exercising muscle to extract and utilize oxygen for metabolic energy (Thomas *et al*., 1999) [32]. The magnitude to increase in VO2max level throughout training depends on different interrelated factors. Among this fitness level of the individual, the duration of training, intensity, and frequency of the training sessions are the most decisive one. Also there are physiological factors like the pulmonary diffusing capacity, maximal cardiac output, oxygen carrying capacity of the blood, and skeletal muscle characteristics (Bassett & Howley, 2000) [23].

Furthermore, VO2max is strongly related to the maximal cardiac output (Q max) which is the total volume of blood pumped by the left ventricle of the heart per minute. It is the product of heart rate (HR, number of beats per minute) and stroke volume (SV, volume of blood pumped per beat). During maximal exercise, the greater cardiac output, along with an increased extraction of oxygen by the exercising muscle, results in a greater VO2max (Spina, 1999; Shephard, 1992) [28]. Coaches and athletes use different methods of training for improving athlete's VO2max level. Eddy and Sparks (1977) [11] on their study states that exercise-training programs consisting of extended duration, continuous exercise at a moderate intensity have long been known to improve VO2max. In spite of the fact, such kinds of training programs become not appropriate for specific VO2max parameters adaptation or improvement.

More recently repeated intervals of short duration high-intensity exercise (interval training) have been demonstrated to be an effective alternative to continuous training method for improving VO2max (Burgomater *et al*., 2008; Cocks *et al*., 2013; Gorostiaga *et al*., 1991) [6, 8, 14]

According to Maglischo (2003) [19-20] Adaptations to training that increase maximum oxygen consumption (VO2max) can be divided into two groups as follows:

1. Adaptations to training that increase the amount of oxygen supplied to the muscles
2. Adaptations to training that increase oxygen utilization by the muscle.

The first group of adaptations included:

- Increased amount of oxygen transferred from the lungs into the bloodstream
- Increased total amount of blood in the body
- Increased number of red blood cells; increased cardiac output
- Increased number of capillaries around the muscle fibers
- Improved blood flow to working muscles

The second group of adaptations included:

- The increased rate of myoglobin in the muscle
- The increased size and number of mitochondria
- The increased activity of enzymes that regulate aerobic metabolism

Even though Saltin & Strange (1992) [25] in their study states that the value of VO2max is highly limited by the rate at which oxygen can be supplied to the muscles than the muscle's ability to extract oxygen from the blood it receives both adaptations contribute for individual's level of VO2max.

3.2 Lactate and Ventilator Threshold

The lactate threshold (LT) refers to the intensity of exercise at which there is a sudden increase in blood lactate levels. Ventilator threshold refers a point where your VO2you're your breathing rate starts to rise in anon linear fashion (Roberts & Robergs 1997) [24]. Pills *et al*. (1993) states that LT and VT occurs within the sub maximal exercise intensities between 50 and 80% of the maximum load and at a blood lactate concentration approximately to 4 mmol.1-1.

The main physiological determinant of a high lactate threshold is probably the ability of the mitochondria in the trained skeletal muscles to increase in volume in response to which permits more pyruvate to be oxidized at a given rate of glycolysis (Holloszy & Coyle, 1984) [16].

In athletes with several years of training experience, VO2 max may not improve any more, but LT might increase by 3-10% depending on the chosen training program. It has been observed that individuals with similar VO2max have variability in endurance capacity and that highly trained athletes usually perform at a high percentage of their VO2max with minimum lactate accumulation (Støren O, Helgerud J, Støa EM, & Hoff J., 2008) [30]

To determine a lactate threshold, a subject completes a series of tests at increasing running speeds, and after each test a blood sample is taken for lactate analysis. The speed at which the lactate concentration changes in some way is taken as the speed at the LT and is used as the predictor of performance (Weltman, 1995) [39].

To whatever extent, it has been showed that there is an individual variation that lactate and VT levels may occur. In untrained individuals, LT and VT occurs at around 50- 60% of the maximum load, while in trained ones it occurs at higher workloads (65-80% of the VO2max) (Powers & Howley, 2000) [23]. For the reason that appearance and disappearance rate of lactate becomes almost equal, there is no increment in muscle lactate when the work rate is below 50-60% of maximum oxygen uptake.

But with high-intensity exercise the rate of lactate production is faster than the body can absorb it which leads to fatigue and reduction in muscle power contraction. As a result the athlete is forced to stop doing the exercise (Welch, 1973). Supporting this idea United State department of health and human service center for chronic diseases prevention and health promotion (1996) states that;

As the intensity of exercise is increased, however, the rate of lactate entry into the blood from muscle eventually exceeds its rate of removal from the blood, and blood lactate concentrations increase above resting levels.

So, it is possible to say that because of the type of exercise and its effect on physiological aerobic fitness parameters, there will be difference in the lactate and ventilator thresholds occurrence between athletes while doing exercises with equal workload. For example, highly trained endurance athlete's lactate and ventilator threshold occurs at a higher percentage of their VO2max than athletes who participate in sprinting exercises.

Most likely, having a higher lactate and ventilator threshold means an athlete can continue at a high-intensity effort with a longer time to exhaustion.

According to Sahlin (1992) either through the effects of metabolic acidosis on contractile function or through an accelerated depletion of muscle glycogen training exercise above the LT is highly associated with rapid fatigue. To this point, an improvement in the LT with long term training is taken as an indicator for athlete's enhanced aerobic fitness.

Neary *et al*. (1985) [21] examined lactate and ventilatory thresholds under normal conditions and under glycogen depleted and/ or previously exercised states. No significant changes in ventilator threshold resulted under experimental conditions, therefore suggesting that plasma lactate accumulation was not responsible for the threshold-like responses in ventilation. Study results shows that a combination of high volume, maximal steady-state training at the level of LT or VT and intermittent training above and below the LT or VT will have a sound effect on athlete's lactate threshold improvement (Roberts & Robergs, 1997; Weltman, 1995) [24, 39].

3.3 Running Economy (RE)

Among those aerobic fitness parameters the reviewer notes that emphasis given for running economy in this area of study is low compared with other parameters. But without having better RE athletes may not be successful even they have good VO2 max, lactate threshold, and ventilator threshold. An individual with a better exercise economy will perform exercises at a lower percentage of their VO2max at any given velocity or power output.

According to Saunders, Pyne, Telford, & Hawley (2004) [27] Running economy (RE) refers the steady-state oxygen consumption (Vo2) and the energy demand of running at a constant sub-maximal speed which is directly associated with performance of athlete's aerobic capacity.

Among long-distance runners with similar peak aerobic capacities, RE may account for differences in race performance. As with VO2max, training may be important in maintaining RE as age increases (Trappe, Costill, Vukovich, Jones, & Melham, 1996) [34]. However, in trained master runners, age does not appear to have negative effects on RE, measured as VO2 (Evans, Davy, Stevenson, & Seals, 1995) [12].

It is also suggests that running economy may be more important to aerobic running performance than other parameters. Prampero *et al*., (1993) confirms that a 5% increase in running economy results an approximately 4% improvement in distance running performance. Supporting this idea Conley and Krahenbuhl (1980) in their study states that 65% of the variation in race performance between athletes was associated to running economy differences. As a result runners with good RE use less oxygen than runners with poor RE at the same steady-state exercise.

On the contrary, Williams and Cavanagh (1987) [41] in their study with the aim of identifying the relationship between running economy and various biomechanical aspects of distance running, including 10 km running performance founds that there is no significant relationship between running economy and performance. Though, their study was not in an organized form to measure athletes RE to give conclusion about their aerobic fitness performance.

RE is traditionally measured by running on a treadmill in standard laboratory conditions which is a good indication of how economical a runner is and how RE changes over time. And it is highly influenced by a number of interrelated factors like physiological, biomechanical, and anthropometric characteristics. According to Saunders *et al*. (2004a) [27] Physiological factors such as fluctuations in heart rate, ventilation threshold, muscle fiber type, and lactate threshold all are associated with changes in running economy in athletes.

In addition, improvements in muscle strength and power have resulted in improvements in running economy through changes in muscle and tendon 'stiffness' (Dumke, Pfaffenroth, McBride, & McCauley, 2010) [10]. It has been suggested that as muscle stiffness is increased, less muscle activation is required, because more energy can be stored in a more compliant spring in the translation of energy expenditure to ground force during running. Therefore, energy expenditure is decreased because less energy is being wasted in braking forces, and so efficiency of running is improved (Saunders *et al*., 2004a) [27].

Even though, heart rate and ventilator threshold and their link to running economy seems limited, both factors have been significantly and positively correlated with sub maximal oxygen consumption results in better running economy and finally improve aerobic capacity. (Pate, Macera, Bartoli, & Maney, 1989) [22].

Even though, having good running economy is susceptible on individuals genetically make up through various training methods it is also possible to improve running economy of athletes by improving metabolic, cardio respiratory, biomechanical and neuromuscular responses and adaptations.

In order to develop athletes running economy most of training adaptations are largely governed by the training load, which can be manipulated for a given athlete by increasing the volume or intensity of the training (Green, 2000) [15]. During the process of improving RE through training it is necessary to focus on the cumulative distance a runner should cover throughout the years of training than short-term bouts of high training volume per sessions.

In support, Assumpcao *et al*. (2013) [1] suggests that training programs which focuses on increasing in the oxidative muscle capacity allows athletes to use less oxygen per mitochondrial respiratory chain during sub maximal running.

Moreover, training adaptations related to improved skeletal muscle buffer capacity and increased red cell mass could also elicit improvements in oxygen delivery and utilization that could improve an athlete's running economy and finally improve athlete's aerobic fitness (Gore *et al*., 2001; Burtscher *et al*., 1996) [13].

3.4 Oxygen Uptake Kinetics

Like other aerobic fitness parameters oxygen uptake kinetics will also determine the individual cardio vascular and cardio respiratory efficiency during sub maximal exercises. Even though VO2 max considered as is the golden measure for cardiorespiratory fitness and describes the highest oxygen uptake by an individual for a given form of exercise but it doesn't measure the efficiency of oxygen uptake.

In contrast, VO2 kinetics measures the efficiency of the cardiorespiratory response during sub maximal exercise and describes the rate at which the cardiorespiratory system is able to deliver oxygen to skeletal muscle and the rate at which oxygen is consumed by skeletal muscle (Tyler, 2014) [35].

Oxygen uptake kinetics (VO2 kinetics) is determined by micro vascular O2 delivery, metabolic substrate utilization and enzymatic activation at the muscle (Suzanne, 1999) [31]. As a result, having faster VO2 kinetic profile indicates the body's ability to obtain more energy from aerobic metabolism which is essentially endless supply of energy earlier with less reliance on anaerobic metabolism which produces fatigue during sub maximal exercise. Thus, athletes having with faster VO2 kinetics will have better aerobic fitness than athletes who have slower VO2 kinetics.

Åstrand and Rodahl (1970) [2] characterizes the impact that training has on one's ability to maintain a certain percentage of V ˙O2max during prolonged exercise. Trained individuals functioned at 87% and 83% of V˙O2maxfor1and2h, respectively, compared with only 50% and 35% of V˙O2max for the untrained subjects.

According to Whipp (1994) [40] there are three phases on the process of VO2 kinetics. During phase 1 there is an abrupt increase in V̇O2 (~15 s) which is processed through an increased cardiac output (Q̇). Because of this, pit is also known as the cardio dynamic phase.

During Phase 2 V̇O2 kinetics will increase in mono exponential fashion related to the continued increase in pulmonary and muscle blood flow along with the return of deoxygenated blood. At the end of phase 2 there will a plateau or slowly rising increase in VO2 after 3 min (phase 3) then Steady-state levels of VO2 are generally attained within the first 3 min of exercise which is below the lactate threshold (LT), but continued an increase of VO2 characterizes exercise above the LT. In support of this, Koike *et al*. (1990) [18] States that the kinetics of V02 increase in response to exercise have been shown to be prolonged at work rates that induce a lactic acidosis.

In contrast, if the work rate is not associated with lactic acidosis, Vo2 reaches a steady state within 3 min. For constant intensity exercise in this domain, the oxygen deficit that is incurred at the onset of exercise may cause blood lactate to rise immediately before it returns to resting levels as exercise proceeds.

4. Conclusion

Many coaches and trainers believed that athletes with higher VO2max have better performance. Although, many recent studies have shown that VO2max alone is rather not true predictor of athletes' aerobic fitness level. It seems that actually, besides VO2max,physiological factors like RE, lactate threshold, ventilator threshold, oxygen uptake kinetics are highly associated with athletes' aerobic fitness level.

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