

Review

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Review

Physiology of Marathon: A Narrative Review of Runners' Profile and Predictors of Performance

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Abstract: The marathon sport events and those who participate in these have grown over the last years reflecting notably an augmentation of women and master runners participation. The aim of the present narrative review was to briefly present the results of studies on anthropometric, physiological and training characteristics, as well as predictors of performance, in marathon runners. It was observed that performance was better in runners with small body weight, body mass index, body fat percentage, and rate of endomorphy. With regards to physiology, an increased maximal oxygen uptake, anaerobic threshold, and improved running economy could result in faster race time. The training variables that could predict performance involved weekly training volume (distance) and intensity (running speed), as well as history of training (years). A combination of these three broad categories of characteristics may offer an approximate estimation of the race speed considering that other aspects (*e.g.*, nutrition, biomechanic and motivation) influence race performance, too. In summary, the findings of the present study provided an overview of anthropometric, physiological and training characteristics associated with marathon race time; thus, an optimization of any of these characteristics would be expected to improve race time.

Keywords: age; exercise intensity; long-distance running; maximal oxygen uptake; running economy; sex

Introduction

The term marathon may refer either to a phenomenon of extreme length or a running race of 42.2km or a geographic location in Greece (Mahler & Loke, 1984). The first marathon race was performed in the first modern Olympic Games (Athens 1896) and the Boston Marathon started one year later (Mahler & Loke, 1984). During the 128 years since that period, this race distance has grown in popularity with an increased number of annual races and participants, especially concerning women and master runners (Knechtle, Di Gangi, Rüst, Rosemann, & Nikolaidis, 2018; Reusser et al., 2021; Vitti, Nikolaidis, Villiger, Onywera, & Knechtle). Not surprisingly, marathon running has attracted an increased scientific interest covering a wide range of topics from physiology and biomechanics to psychology and sociology resulting in a large body of literature requiring reviews to systematize the knowledge resulting from original studies (Braschler et al., 2024; Grivas, 2024; Jastifer, 2022; Shu et al., 2024).

Recently, several aspects of marathon running – such as personality (Braschler et al., 2024), participation trends (Grivas, 2024), use of non-steroidal anti-inflammatory drug (Jastifer, 2022), impact of running on intervertebral discs (Shu et al., 2024), sleep (P. T. Nikolaidis, Weiss, Knechtle, & Trakada, 2023), nutrition (Kali & Meda, 2024), the risk of cardiovascular disease (O'Riordan, Savage, Newell, Flaherty, & Hartigan, 2023) and myocardial injury (Dong, Zhao, Zhao, Fang, & Zhang, 2023) – have been reviewed. On the other hand, a bibliometric analysis of the literature on marathon running during the last 15 years (2009-2023) highlighted the physiology of runners as the first research hotspot (Yan et al., 2024). Nevertheless, no comprehensive review has been ever conducted on physiological aspects. Therefore, the aim of the present narrative review was to briefly

present the results of studies on anthropometric, physiological and training characteristics, as well as predictors of performance, in marathon runners. For the purpose of this study, the scopus database was searched on 27 June 2024 using the syntax 'marathon AND (training OR anthropometric OR physiological OR predictors)' in the title of candidate articles resulting in 241 entries. Then, the literature of the selected articles was handsearched for more literature.

2. Antropometry

Anthropometry has been referred to the evaluation of human body using surface dimensional measurements (Lennie, 2022). The information about the anthropometric profile of marathon runners has been based on studies that (a) profiled high-performance runners such as Kenyans (Vernillo et al., 2013), (b) compared marathon runners of different performance level according to either the personal best time or the race time on a particular race (Bale, Rowell, & Colley, 1985; Pantelis T. Nikolaidis & Knechtle, 2020; Roca, Nescolarde, Brotons, Bayes-Genis, & Roche, 2020; Yang, Wang, Bao, & Hu, 2015), or (c) marathon runners with runners of shorter distances (Legaz Arrese, González Badillo, & Serrano Ostáriz, 2005), half-marathon (Zillmann et al., 2013) and ultramarathon runners (Rüst, Knechtle, Knechtle, & Rosemann, 2012), triathletes (Rossi & Tirapegui, 2011), track-and-field athletes (Silva, Medeiros, assumption, & Simim, 2021), other sports (Fleck, 1983), university students (Costill, Bowers, & Kammer, 1970), and sedentary adults (Marra et al., 2018). Most of these studies used laboratory or field measurements; however, it was possible to collect data (e.g., height, body weight and body mass index, BMI) using questionnaires from a large number of runners (Pantelis T. Nikolaidis & Knechtle, 2020). Considering the validity of self-reported anthropometric characteristics in recreational marathon runners, self-reported values overestimated their height by 0.44 cm, underestimated their actual body mass by 0.65 kg and their actual BMI by 0.35 kg·m⁻² (Pantelis T. Nikolaidis & Knechtle, 2020). Moreover, women underestimated body mass values more than men, and it was noticed that the differences between self-reported and actual values in the abovementioned study were smaller than those observed in non-athletes indicating a relatively good self-perception of their physique (Pantelis T. Nikolaidis & Knechtle, 2020).

The anthropometric assessment concerned not only the height and weight, but also other noninvasive quantitative measurements of the body such as somatotype and skinfold thickness (SKF), a measure of fatness and an approach to estimate body fat percentage (BF) (Pantelis T. Nikolaidis, Vancini, Andrade, de Lira, & Knechtle, 2021; Roca et al., 2020; Vernillo et al., 2013). Since BF could be estimated by different methods in marathon runners, a comparison of two assessment methods of BF (SKF *versus* bioimpedance analysis, BIA) was conducted in female and male marathon runners (Pantelis T. Nikolaidis, Vancini, et al., 2021). A very large correlation was found between the two assessment methods, where SKF provided a higher score than BIA by 3.9% in men and similar score in women. Furthermore, both methods showed a positive correlation with age, i.e., a higher BF was observed in the older age. It should be mentioned that the commonly used measures were BMI and BF.

With regards to the profile of high-performance runners, male Kenyan marathon runners (best race time 2:07:16 h:min:s) had age 27.7 years, height 171 cm, body weight 58kg, training volume 200km weekly, BF 8.9%, somatotype consisted of endomorphy 1.5, mesomorphy 1.6 and ectomorphy 3.9 (Vernillo et al., 2013). About the variation of body weight by performance level, it has been observed in fast (marathon race time <3:24 h:min) and slow runners (>3:24 h:min), that fast runners were lighter than slow runners by 4.9 kg and with lower BMI by 2.5 kg·m⁻² (Roca et al., 2020). In addition, difference in SKF by performance level has also been shown in female professional marathon runners (international, personal best < 2:34 h:min; national, 2:34-2:45 h:min; and average level 2:45-3:19 h:min), where iliac crest SKF was smaller in the international than national group, and all skinfolds were smaller in these groups than in the average level group (Yang et al., 2015). In recreational female and male marathon runners (age 40.1 and 44.3, respectively), the abdominal SKF was the largest in both sexes, whereas the smallest was the biceps and chins, respectively (Pantelis Theodoros Nikolaidis, Rosemann, & Knechtle, 2020). Interestingly, this research reported that the slowest runners had comparatively more fat in the arm and trunk.

In female and male marathon runners (~50km weekly training load), the smallest SKF in women was chin and in men was biceps (Pantelis Theodoros Nikolaidis et al., 2020). A comparison of 10 anatomical sites identified the triceps as the SKF with the largest sex difference. The fastest runners had less SKF in the arms and trunk. Elsewhere, female marathon runners were categorized in three performance groups based on their marathon race time (Bale et al., 1985). These three groups did not differ in height, bone widths, circumferences and body weight. The body weight and BF of all runners was lower than sedentary women. The fastest runners had lower BF (especially, triceps SKF), and were more ectomorphic and less endomorphic than the slower one. In addition, a comparative research conducted on male novice (≤ 3 finishes in marathon races) and experienced (> 4 finishes) runners (Pantelis T. Nikolaidis, Clemente-Suárez, Chlábková, & Knechtel, 2021) showed that the experienced runners were faster, had lower abdominal and iliac crest SKF, and BF.

Compared with runners of shorter distances, marathon runners had the smallest SKF; in addition, BF was related to performance only in the marathon runners (Legaz Arrese et al., 2005). These findings were partially attributed to the increased fat metabolism in training and race in marathon runners. Compared with half-marathon runners, marathon runners were lighter, thinner arms and thighs, smaller sum of SKF thickness, lower BF and FFM, with more years of sport experience, larger weekly training volume and training time (Zillmann et al., 2013). Furthermore, the marathon race time had half of its variance explained by BF and speed in running during training. Compared to 100 km ultramarathon runners, marathon runners had smaller calf circumference, larger pectoral, axilla and suprailiac SKF, fewer hours and distance in weekly training which was at faster speed (Rüst et al., 2012). In marathon runners, race time was related with BF and speed in running during training. Furthermore, in a comparison of track-and-field athletes, it was supported that long-distance runners such as marathon runners had relatively low muscle and fat mass (Silva et al., 2021). In this context, marathon runners should not have increased muscle mass since this would lead to increased energy demands to deform and overcome the inertial load (first law of Newton) (Hazari et al., 2021).

Compared to triathletes, male marathon runners did not differ for BF (Rossi & Tirapegui, 2011). An estimation of BF based on SKF in male national level marathon runners showed a score of 7.5%, which was 5% smaller than that of age-matched university students (Costill et al., 1970). A comparative study examined differences between marathon runners and sedentary adults (Marra et al., 2018). Marathon runners had smaller body weight, BMI, arm and forearm circumferences, and skinfold thickness, and increased BIA ratios and phase angle for the whole body. A comparison of international level male athletes of 26 Olympic events found that the marathon runners were among the athletes with the smallest BF (6.4%) (Fleck, 1983). Marathon runners had less fat mass and fat-free mass than swimmers (Gravante, 1997). In summary, with a few exceptions, the literature indicated that the fast runners were lighter and with less BF than their slower counterparts. The abovementioned studies highlighted the role of anthropometric characteristics in marathon runners. Based on this body of literature, coaches and sport scientists should develop specific programs to optimize these characteristics.

3. Physiological characteristics

The studies on marathon runners' physiological characteristics have focused so far more on aerobic capacity-related parameters, such as maximal oxygen uptake (VO_2max) (Gabrielli et al., 2018; Kim, Lee, & Hah, 1979; Legaz-Arrese et al., 2011; Maldonado, Mujika, & Padilla, 2002; Maron & Horvath, 1988; Shibayama, Nishijima, & Ebashi, 1980; Tam et al., 2012), and less on neuromuscular fitness, such as flexibility and anaerobic performances (Pantelis T. Nikolaidis, Clemente-Suárez, et al., 2021; Serresse et al., 1989). It should be noted that VO_2max referred to the maximal capacity of the O_2 transport system from air to mitochondria limited by cardiovascular, respiratory and muscle system (Wagner, 2023). Marathon runners have been characterized by large VO_2max ; e.g., a case study of two marathon runners showed VO_2max about $61 \text{ mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$, maximal minute ventilation (VEmax), $100 \text{ L} \cdot \text{min}^{-1}$, HRmax 188 bpm (Shibayama et al., 1980). A case study reported for a master runner (age 59 years; race time at this age, 2:30:15 h:min:s) HRmax 165 bpm, VEmax $115 \text{ L} \cdot \text{min}^{-1}$, maximal lactate

concentration $5.7 \text{ mmol}\cdot\text{L}^{-1}$, and VO_2max $65.4 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, running economy (RE) at his race pace $210 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ with VO_2 corresponding to 91% of his VO_2max (Lepers, Bontemps, & Louis, 2020).

Considering the increased participation of women in marathon races during the last years, a few studies examined sex differences in physiological characteristics (Daniels & Daniels, 1992; Helgerud, 1994; Helgerud, Ingjer, & Strømme, 1990; Vernillo et al., 2013). VO_2max in female and male marathon runners (age 20-30 years) of the same level (race time 3:20 h:min) was similar ($\sim 60 \text{ mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$) (Helgerud et al., 1990). In the same study, women and men of the same performance level did not differ in anaerobic threshold (83% of VO_2max or 89% of HRmax), whereas RE in women was worst (i.e., higher VO_2 at given submaximal speed). It should be noted that the anaerobic threshold (other relevant terms included lactate threshold, onset of blood lactate accumulation and heart deflection point) referred to one's ability to sustain a high fractional utilization of VO_2max (Ghosh, 2004).

In another study, a comparison between national level female and male marathon runners showed that men had larger VO_2max than the women (Daniels & Daniels, 1992). Furthermore, at given running speeds, men had better RE using less oxygen. Elsewhere, female and male runners were examined for aerobic capacity, and it was shown that both VO_2max and submaximal VO_2 were larger in men than in women (Helgerud, 1994). Moreover, female and male runners were tested during a 1 h run on a treadmill at the pace of a recently finished marathon race (Vernillo et al., 2013). Female runners ran at a higher exercise intensity and with a lower RE. In summary, women had lower VO_2max and lower RE than men.

VO_2max (68.5 versus $74.1 \text{ mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$) and the energy cost of running (0.182 versus $0.192 \text{ mL}\cdot\text{O}_2\cdot\text{kg}^{-1}\cdot\text{m}^{-1}$) in male marathon runners were lower than in 5-10km runners (Maldonado et al., 2002). In another research, male marathon runners (best race time 2:12:04 h:min:s) did not differ in submaximal scores (VO_2 , heart rate, HR, and lactate), VO_2max , HRmax , but had smaller velocity at VO_2max ($v\text{VO}_2\text{max}$) than 3km steeplechase runners (Legaz-Arrese et al., 2011). Marathon runners were compared with university and school student runners, and had a lower resting HR, and a higher resting VO_2 (Kim et al., 1979). Furthermore, Kenyans were examined together with European marathon runners and no difference was observed in VO_2max , $v\text{VO}_2\text{max}$ and energy cost of running (Tam et al., 2012).

With regards to neuromuscular fitness, an observational research on cycle ergometer all out short-term tests showed a worse performance in marathon runners than in sprinters indicating differences in anaerobic power endurance and power athletes (Serresse et al., 1989). Moreover, moderate scores of neuromuscular fitness were observed in female marathon runners (age 40 years, personal best race time 4:34 h:min), considering the standards of general population (Pantelis Theodoros Nikolaidis, Rosemann, & Knechtle, 2018). Furthermore, the younger runners performed better in jumping and maximal power cycle ergometer tests, and the slowest performed better in sit-and-reach test, a measure of flexibility. In summary, not surprisingly, most of the studies on physiological characteristics investigated aerobic capacity parameters, mostly VO_2max , anaerobic threshold and RE suggesting that good scores in these characteristics were associated with a fast marathon race time.

4. Training

Exercise training has been typically described in terms of intensity, frequency, duration and mode (Westcott et al., 2009). Outcome measures of exercise intervention in marathon runners have included BF, fat-free mass, VO_2max , anaerobic threshold, RE, perceived fitness, rate of perceived exertion, and maximal isometric force of knee extension (Dolgener, Kolkhorst, & Whitsett, 1994; Ferrauti, Bergemann, & Fernandez-Fernandez, 2010; Klausen, Breum, Sørensen, Schifter, & Sonne, 1993; Larumbe-Zabala, Esteve-Lanao, Cardona, Alcocer, & Quartiroli, 2020; Lee, Snyder, & Lundstrom, 2020; Noble, Maresh, Allison, & Drash, 1979; Rumley et al., 1988). In female and male marathon runners (age 38 years), a 16-week training program increased perceived fitness and anaerobic threshold, and improved RE (Larumbe-Zabala et al., 2020). In another study, female and male marathon runners (age 34 years, personal best race time <3:30 h:min) were tested at 10 weeks

and 1.5 week pre-race (Lee et al., 2020), and it was observed that BF decreased by 2% and VO_2max increased by $12.3 \text{ mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$.

Furthermore, sedentary female and male adults (age 34 years, race time 4:13 h:min) participated in a training program to run a marathon and were tested for physical activity using accelerometers pre- and post-race (Swartz, Miller, Cho, Welch, & Strath, 2017). During this period, sedentary behavior did not change, whereas physical activity was lower one month post-race than two months pre-race. The effect of a 30-week marathon training program in sedentary male adults was examined in a study with measurements of VO_2max on a cycle ergometer at baseline, week 15 and week 30 (Rumley et al., 1988). The cardiorespiratory fitness parameters (VO_2max and anaerobic threshold) improved at week 15 and did not change at week 30. VO_2max and submaximal VO_2 did not change in male marathon runners during four weeks pre-race and one week post-race (Maron & Horvath, 1988). In 39-years-old marathon runners, VO_2max was larger in the more trained ($\geq 100 \text{ km}$ per week, $59 \text{ mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) than in the less trained ($< 100 \text{ km}$ per week; $50 \text{ mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) (Gabrielli et al., 2018).

A study examined the effects of three weeks of training break and four weeks of retraining in male marathon runners (Klauser et al., 1993). VO_2max decreased during the break and increased during retraining, whereas BF did not change. Elsewhere, a 15-week training program was tested in novice marathon runners in groups practicing either four or six days weekly (Dolgener et al., 1994). Both groups applied the same exercise intensity, but the first one had less training volume. Both groups reduced BF and increased both VO_2max and fat-free mass. With regards to exercise intensity, the speed in running during training in high-performance level marathon runners was identified at 85% of VO_2max (Hagerman, 1992). In the context of the preparation for a marathon race, runners applied either only endurance or combined endurance/strength 8-week training (Ferrauti et al., 2010). The maximal isometric force of knee extension improved only in the combined training, whereas both groups improved similarly both VO_2max and submaximal performances.

The scientific interest has been focused not only on the effect of training on marathon performance, but also on the influence of a single or multiple marathon races on training parameters (Berger et al., 2021; Chlíbková, Nikolaidis, Rosemann, Knechtle, & Bednář, 2018; Ganzit, Verzini, Hajdarevic, & Riganti, 2010; Karstoft, Solomon, Laye, & Pedersen, 2013; Noble et al., 1979). Exercise testing including 30 min constant speed running on a treadmill was conducted in runners one week pre-marathon race, one and two weeks post-race (Noble et al., 1979) in a research where RPE increased in the first week post-race and VO_2 was lower in the second week post-race compared to pre-race scores. A case study of a female runner (age 54 years; VO_2max $53 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) examined physiological responses to 10 consecutive marathon running in 10 days on a treadmill at a constant pace corresponding to 60% of VO_2max (Berger et al., 2021). During this period, weight decreased by 2.6 kg, BF by 3.1% and muscle mass by 0.4 kg, due to a total energy deficit of 12,700 kcal. Elsewhere, a research analyzed the impact of seven marathon races within a week in female and male runners (age 42.6 years; average race time 4:44 h:min) with measurements pre-race, post-first, post-fourth and post-seventh race (Chlíbková et al., 2018). Although body weight decreased, plasma volume, fluid and electrolyte balance did not change post-race suggesting that the decrease of body weight did not correspond to changes in the hydration status.

Furthermore, a case study of a master runner completing 51 marathon races in consecutive days was examined. Fat mass and mean race HR decreased during this period (Ganzit et al., 2010). A blood and urine analysis showed no muscle damage or renal dysfunction. A multi-stage run consisting of seven marathon races in corresponding consecutive days was analyzed (Karstoft et al., 2013). A small elevation of muscle damage markers, liver cell damage markers, and inflammatory markers was noticed post-race. Fat mass decreased and fat-free mass increased post-race, whereas body weight did not change. In summary, training programs lasting 8-30 weeks improved body composition and VO_2max showing a clear interplay among training, anthropometry and physiology.

5. Predictors

The profile of anthropometric, physiological and training characteristics has been described in the previous three sections of this review. The present section shows how these characteristics might

predict race performance in marathon runners, where race performance referred either to race time or average race (running) speed. Since the knowledge of predictors of performance has had large theoretical and practical value for scientists and coaches working with marathon runners, respectively, many studies have focused on this topic (Alvero-Cruz et al., 2020; Noakes, Myburgh, & Schall, 1990). A review of 21 studies on marathon concluded that $\text{VO}_{2\text{max}}$, $\text{vVO}_{2\text{max}}$, training intensity and load, and BF were the best predictors of marathon running performance (Alvero-Cruz et al., 2020). It has been observed that marathon runners with a similar race time had a large variation of $\text{VO}_{2\text{max}}$ suggesting that other factors (e.g., RE and anaerobic threshold) may play a crucial role on race performance (Sjodin & Svedenhag, 1985). In the same study, anaerobic threshold was reported to be the best predictor of marathon race time.

Race speed (km/h) in the Athens Authentic Marathon 2017 could be predicted using the formula " $8.804 + 0.111 \times \text{VO}_{2\text{max}} + 0.029 \times \text{weekly training distance in km} - 0.218 \times \text{BMI}$ " (Pantelis T. Nikolaidis, Rosemann, & Knechtle, 2021). In a study that examined $\text{VO}_{2\text{max}}$, anaerobic threshold, race time in various long distances, marathon race time could be predicted by race time in 10km or half-marathon (Noakes et al., 1990). The findings of Noakes et al. (Noakes et al., 1990) indicated the role of performance in other than marathon distances with affinity with marathon race considering that marathon runners competed not only to their target-distance, but also to 10km, half-marathon and ultramarathon races.

Regarding the methodological approach of the relevant literature, the selection of candidate predictors should be highlighted during the interpretation of the findings. For instance, in male recreational runners (41 years; race time in the Madrid Marathon 226min), age, running experience, number of marathon races finished, mean kilometers run weekly in the last three months, and previous personal best time in a 10 km, a half marathon, a marathon, Ruffier Test and wholebody isometric force test were considered as potential predictors of race time in the particular marathon (Salinero et al., 2017). Their best prediction model included BF, HR change during recovery from the Ruffier test and HM personal record. The predictors of performance might vary by age; it has been observed that predictors of race time in master runners were $\text{VO}_{2\text{max}}$, diastolic blood pressure, age and training volume, whereas in younger runners included height, resting HR, systolic blood pressure and $\text{VO}_{2\text{max}}$ with $\text{VO}_{2\text{max}}$ being the best predictor in both age groups (Hartung & Squires, 1982). In another study, in female marathon runners (4:11 h:min), the marathon race time in min could be predicted by using the formula ' $184.4 + 5.0 \times (\text{circumference calf in cm}) - 11.9 \times (\text{speed during training in km.h}^{-1})$ ' (Schmid et al., 2012), and was related with body weight, BMI, thigh and calf circumference, front thigh and medial calf SKF, weekly training volume (km) and number of weekly sessions.

In female (2:34:53 h:min:s) and male marathon runners (2:12:04 h:min:s), predictors of race time were subscapular SKF, serum ferritin and the sum of six SKF in women, and lactate at 10km.h^{-1} , left ventricular telodiastolic diameter and lactate at 22 km.h^{-1} (Legaz Arrese, Munguía Izquierdo, & Serveto Galindo, 2006). In male runners, the marathon race time was related to the percentage of slow twitch fibers, $\text{VO}_{2\text{max}}$, RE, VO_2 and treadmill speed at the onset of plasma lactate accumulation (Farrell, Wilmore, Coyle, Billing, & Costill, 1979). From these parameters, the prediction model of race time included only OPLA. In addition, the runners paced the race by 5 m.min^{-1} faster than the treadmill speed at OPLA. In female and male marathon runners, the personal record in this race (4:02:53 h:min:s) could be predicted from BF and right ventricular end-diastolic area (Christou, Pagourelas, Deligiannis, & Kouidi, 2021). In this study, other correlates of race time were the maximum minute ventilation indexed to body surface area, haemoglobin concentration and haemoglobin mass.

In marathon runners, the running velocity corresponding to the onset of blood lactate accumulation could be predicted very largely by the weekly training volume (Sjodin, Jacobs, & Karlsson, 1981). In addition, it could be predicted largely by the enzyme activities of the lactate dehydrogenase, phosphofructokinase and citrate synthase. In male marathon runners (best record 2:15-4:54 h:min), the best predictors of race time included CPK, age, training volume, SKF and cortisol (Dotan et al., 1983). In summary, a combination of anthropometric, physiological and training

characteristics may offer an approximate estimation of the race speed considering that other aspects (e.g., nutrition, biomechanic and motivation) influence race performance, too.

6. Conclusions

In summary, the present review highlighted the role of anthropometric, physiological and training characteristics for marathon performance. These findings would have large practical applications considering the number of runners and professionals (e.g., coaches, sport scientists, nutritionists, physiotherapists, physicians, and psychologists) involving in marathon training. Since most of the existed literature has focused on men of middle age, future studies need to examine women, and less studied age groups such as underage and elder runners.

Table 1. Abbreviations and definition of terms.

Abbreviation	Term
BIA	Bio-impedance analysis
HR	Heart rate
HRmax	Maximal heart rate
Lamax	Maximal lactate
RE	Running economy
SKF	Skinfold thickness
VEmax	Maximal minute ventilation
VO ₂	Oxygen uptake
VO ₂ max	Maximal oxygen uptake
vVO ₂ max	Velocity at maximal oxygen uptake

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