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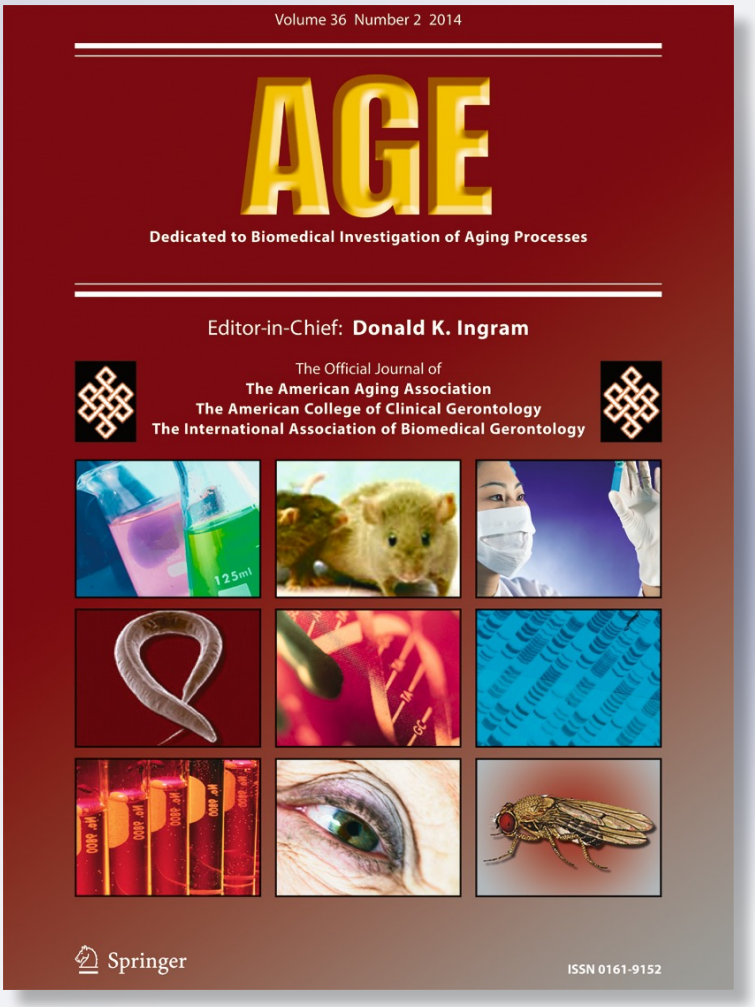

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The relationship between age and running time in elite marathoners is U-shaped

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Abstract Several investigations have demonstrated that running performance gradually decreases with age by using runners >25 years grouped in 5-year age brackets. The aim of this study was to determine the relationship between race time in marathon and age in elite marathoners by including all ages and 1-year intervals. Running times of the top ten men and women at 1-year intervals (from 18 to 75 years) in the New York City marathon were analyzed for the 2010 and 2011 races. Gender differences in performance times were analyzed between 18 and 70 years of age. The relationship between running time and runner's age was U-shaped: the lowest race time was obtained at 27 years (149±14 min) in men and at 29 years (169±17 min) in women. Before this age (e.g., 27 years for men and 29 years for women), running time increased by 4.4±4.0 % per year in men and 4.4±4.3 % per year in women. From this age on, running time increased by 2.4±8.1 % per year in men and 2.5±9.9 % per year in women. The sex difference in running time remained stable at ~18.7 ±3.1 % from 18 to 57 years of age. After this, sex difference progressively increased with advancing age. In summary, endurance runners obtained their best performance in the marathon at 27 years in men and 29 in women. Thus, elite marathon runners should program their long-term training to obtain maximal performance during their late 20s.

Keywords Aging · Gender · Endurance performance · Distance running · Marathon · Sex difference

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Introduction

In the last few decades, participation in marathons has exponentially increased with hundreds of marathons worldwide, several of them attracting more than 40,000 participants (Trappe 2007). The increase in participation is, overall, due to the boom in amateur middle-aged and master endurance runners. For example, the number of male runners of over 40 years of age in the New York City marathon increased threefold from the 1980s to the 2000–2009 decade, while the number of female participants increased sevenfold during this same period (Lepers and Cattagni 2012). The higher presence of master athletes in the marathon is not only related to massive participation but also to impressive improvements in peak exercise performance. Master athletes of over 70 years of age have surpassed the winning time at the first Olympic Games held in Athens (Tanaka and Seals 2008). Because completing a marathon race requires regular endurance training and an appropriate lifestyle (i.e., marathon runners are typically free from negative factors such as smoking, physical inactivity, or incorrect diet (Leyk et al. 2009)), marathon running times of master and elderly runners have been used to assess age-related declines in endurance performance.

Several investigations have found that running times in endurance events increase with age in a curvilinear fashion (Trappe 2007; Tanaka and Seals 2008; Hunter and Stevens 2013; Lepers and Cattagni 2012; March et al. 2011). Overall, these investigations have used data from marathon finishers >25 years grouped in 5-year intervals. Outcomes from these investigations indicate that endurance running performance is well maintained until ~35 years of age, followed by moderate decreases until 50–60 years of age and with a more abrupt reduction thereafter. It seems that the pattern of endurance performance reduction is very similar in both elite and non-elite athletes (Joyner 1993). Regarding the three main physiological determinants of distance running performance (e.g., VO_{2max}, lactate threshold, and running economy (Joyner et al. 2011)), scientific data confirm a progressive reduction of VO_{2max} with increasing age (Tanaka et al. 1997), while lactate threshold as a percentage of VO_{2max} (Wiswell et al. 2000) and running economy (Quinn et al. 2011) are not primarily decreased by age.

Biological sex differences allow male athletes to have a superior endurance performance in the marathon to their women runner counterparts despite it being suggested that women would outrun men over this distance (Whipp and Ward 1992). Men have a higher VO_{2max} (Wiswell et al. 2000), greater hemoglobin content (Stray-Gundersen et al. 2001), and a greater muscle mass per unit of body weight (Cheuvront et al. 2005) that confer on them the capacity to run faster in endurance events. However, running economy and lactate threshold as a percentage of VO_{2max} do not appear to be different between men and women (Wiswell et al. 2000). In general, aging lessens endurance running performance in both male and female participants, although the magnitude of this decline with advancing age is greater in female than in male participants (Lepers and Cattagni 2012). However, it has been suggested that the increase of the sex difference with advancing age is confounded by the smaller number of women runners in master categories, compared to their male counterparts (Hunter and Stevens 2013).

Because previous investigations (Trappe 2007; Tanaka and Seals 2008; Hunter and Stevens 2013; Lepers and Cattagni 2012; March et al. 2011) have analyzed the relationship between age and running performance by using only marathon finishers >25 years grouped in 5-year intervals, the aim of this investigation was to re-analyze the relationship between running time in the marathon and age when including the whole range of ages (from 18 to 75 years) and by using a more sensitive analysis (1-year intervals). The second purpose was to evaluate the sex difference in the running performance with advancing age. We hypothesized that the inclusion of younger marathon runners (e.g., <25 years) would change the curvilinear relationship between age and endurance running performance.

Methods

Finishing times of the top ten men and top ten women, between 18 and 75 years in men and between 15 and 70 years in women were analyzed for the New York City marathon over the last two editions (2010 and 2011). The data were obtained from a public online data source (New York City Marathon 2013). In this database, finishing times were available in 10-year-age brackets, but we increased the sensitivity of these data by including actual age. Thus, the present data include running times of the ten fastest marathon finishers at 1-year intervals for the 2010 and 2011 editions (e.g., 20 participants for each age). The same data extraction was performed for both male and female participants. Although there were marathon finishers older than 75 years, insufficient data for these ages preclude a meaningful analysis; thus, if there were less than ten finishers by age and by edition, the data were not considered.

Statistical analysis

All data are presented as mean ± SD at 1-year intervals. To simplify the analysis of the sex difference with advancing age, we set 5-year intervals. A non-linear quadratic regression was calculated for the relationship between running times and age. A one-way ANOVA was used to determine the differences in running times among ages. After a significant F test, differences between means were identified using Tukey's HSD post hoc procedure. The decline on running performance per year of age was calculated as the percentage of change with respect to the best race time. The data were analyzed with the statistical package SPSS v 20.0 (SPSS Inc., Chicago, IL, USA). The significance level was set at $P<0.05$.

Results

A total of 45,103 marathoners in 2010 and 47,340 in 2011 finished the New York City marathon. Figure 1

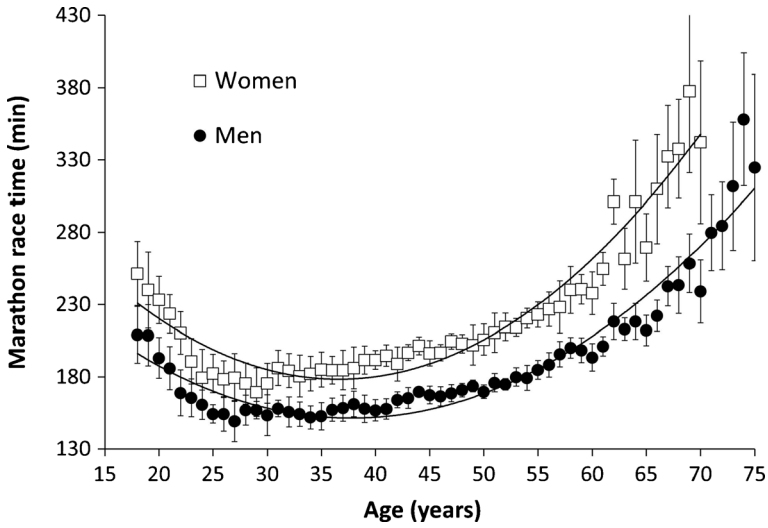

Fig. 1 Mean marathon race time of the top ten male and female athletes according to their age. Values are means ± SD for the 2010 and 2011 races in the New York City marathon. R^2=0.92/y=0.1146x^2–8.6553x+314.85 for men. R^2=0.92/y=0.1519x^2–11.12x+381.87 for women

depicts the relationship between a runner's age and finishing time in the marathon for both the top ten men and top ten women at 1-year intervals. The relationship between these two factors was U-shaped and significant for men (R^2=0.92; y=0.1146x^2–8.6553x+314.85; P<0.05) and for women (R^2=0.92; y=0.1519x^2–11.12x+381.87; P<0.05). The lowest race time was obtained at 27 years (149±14 min) for men and at 29 years (169±17 min) for women. Before this age, younger runners increased their running times at a rate of 4.4±4.0 % per year in men and 4.4±4.3 % per year in women. Beginning at this age, running time increased by a mean of 2.4±8.1 % per year in men and 2.5±9.9 % per year in women. Despite the progressive increase of running time after the age of maximal performance, the mean running time was significantly higher in runners of 42 years of age or older (P<0.05) for men and 40 years of age or older for women (P<0.05). Interestingly, runners of 18 years of age presented a similar running performance to runners of 55–60 years of age for both male and female participants.

Figure 2 depicts the sex difference in running time according to the participant's age by using 1-year intervals. The lowest sex difference (10.2±5.5 %) between the top ten male and female runners was obtained at 29 years. Interestingly, the sex difference remained stable at ~18.7±3.1 % from 18 to 57 years of age. From this age, the sex difference progressively increased to 28.2±3.2 % at 65 years of age and to 43.9±19.8 % at 70 years of age.

Discussion

The aim of the present investigation was to analyze the relationship between age and endurance performance in top ten male and female marathoners. We analyzed the marathon running times at 1-year intervals to find out the exact age with the highest endurance performance in the marathon. Our main outcomes were as follow: (a) there was a strong relationship between the running time in the marathon and the participant's age, while the best-fit regression equation to explain this relationship was a non-linear U-shape quadratic equation; (b) the best performance in the marathon was obtained at 27 years in men and at 29 years in women; (c) the lowest sex difference in endurance performance was obtained at 29 years, coinciding with the best race time for women; and (d) the sex difference remained stable from 18 to 57 years of age, but it progressively increased after this age. All these data indicate that there is a specific age to obtain the maximal performance in endurance running events (27–29 years). After this age, the running performance decreased at a rate of 2–4 % per year, although this decrease was minor during the first decade after the maximal performance (e.g., from 30 to 40 years).

The relationship between age and running performance in the marathon has been previously investigated (Trappe 2007; Tanaka and Seals 2008; Hunter and Stevens 2013; Lepers and Cattagni 2012; March et al. 2011). Because the objective of these previous investigations was to analyze the effects of aging on endurance performance, the data were typically retrieved from

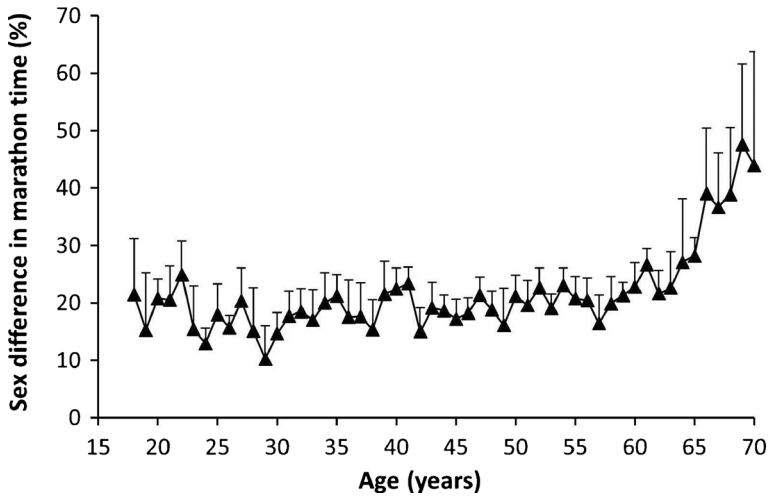

Fig. 2 Mean sex difference in marathon race time of the top ten male and female athletes according to their age (5-year intervals). Values are means ± SD for the 2010 and 2011 races in the New York City marathon

finishers <20–25 years of age and grouped in 5- or 10-year intervals. With this type of analysis, most of these investigations have found that age and endurance performance in the marathon are related in a curvilinear fashion: running times in the marathon are similar in participants aged 20 to 35 years. Even in the recreational population of runners, there are no differences in the performance of runners aged 20 to 55 years (Leyk et al. 2009). Typically studies showed that running time exponentially increases with advancing age beginning with 35 years of age.

The present investigation, by increasing the sensitivity of the data analysis (1-year age brackets) and by including all the ages of the participants in the marathon (beginning with participants of 18 years of age), presents some novelties. First, the relationship between endurance performance in the marathon and the participant's age is U-shaped, indicating that there is a brief age range for maximal performance in the marathon. Before or after this age range, endurance running performance decreases. While it is well established that aging progressively reduces VO_{2max} while the lactate threshold as a percentage of VO_{2max} and running economy are probably unaffected by this process (Tanaka et al. 1997; Wiswell et al. 2000; Quinn et al. 2011), it is unclear why younger marathon participants obtain a decreased performance, in comparison to the age of maximal performance. Figure 1 suggests the existence of a "maturation" process for marathon performance, although this effect might be related to training (young athletes typically compete over shorter distances) rather than a biological explanation.

Second, Hunter et al. (2011) indicated that men and women physiologically peaked at a similar age in marathon running performance. The maximal performance of the top five runners in the World Marathon Majors Series and in the International Athletic Association Federation World Championship was obtained at ~30 years of age for both sexes, while older runners (from 30 to 54 years) obtain the best race times in 100-km competitions (Knechtle et al. 2012). In the present study, we have found that maximal performance in the marathon is earlier than previously believed since peak performance was obtained at 27 years in men and at 29 years in women. Interestingly, our data coincide with the mean age of the 100 best all-time records in the marathon for men (26.6±4.4 years) and for women (28.2±3.8 years) as obtained from the International Association of Athletic Federations website (International Association of Athletic Federations 2013). All this information suggests that maximal performance in the marathon is probably obtained before the age of 30. These data might be of interest for athletes, trainers, and exercise physiologists when planning long-term training for future performance during the athlete's career.

Despite the evidence that men and women age similarly in the physiological factors that influence endurance performance (Joyner 1993; Wiswell et al. 2000), several investigations have found that sex differences in marathon performance increase with advancing age (Hunter and Stevens 2013; Lepers and Cattagni 2012). The present investigation indicated that female participants obtained a running time in the marathon <20 % higher than male participants of the same age. However,

this difference progressively increased in participants older than 60 years, as has been found in the Ironman triathlon (Lepers and Maffiuletti 2011). Despite having used the top ten running times for both male and female runners, the number of male participants older than 60 years was ~7 times higher than the number of female participants. Thus, it is likely that the amplified sex difference in older participants was related to the lower number of women finishers than men, as previously suggested (Hunter and Stevens 2013).

The present investigation also includes limitations. First, the data obtained for the New York City marathon database only included finishing times and age of the participants. Factors such as training volume and intensity, previous experience, ethnicity, and physiological variables (VO_{2max}, lactate threshold, and running economy) known to affect endurance running performance were not included in the analysis. It is still possible that some part of the variance in endurance performance explained by age is actually related to these other factors. For this reason, the outcomes found in this investigation should be reinforced by collecting experimental data. A second limitation is the scope of the application. The statistical analysis was performed by including the top ten (e.g., elite) male and female participants. It could be interesting to study the effects of age on endurance performance in recreational runners.

In summary, the relationship between endurance performance in the marathon and the participant's age was U-shaped. There is a small age range for maximal performance in the marathon, and this range is probably before 30 years of age. Thus, marathon runners should program their long-term training to obtain maximal performance during their late 20s. From 18 to 57 years of age, women obtained race times on average ~19 % higher than men, although the difference in endurance performance between men and women reached only ~10 % at 29 years, when women obtained their maximal performance in the marathon. After 57 years of age, the sex difference exponentially increased in marathon runners.

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Conflict of interest The authors declare that they have no conflict of interest derived from the outcomes of this study. This study did not receive any funding.

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