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Marathon progress: demography, morphology and environment

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Marathon progress: demography, morphology and environment

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Abstract

As opposed to many other track-and-field events, marathon performances still improve. We choose to better describe the reasons for such a progression. The 100 best marathon runners archived from January 1990 to December 2011 for men and from January 1996 to December 2011 for women were analysed. We determined the impact of historical, demographic, physiological, seasonal and environmental factors. Performances in marathons improve at every level of performance (deciles). In 2011, 94% of the 100 best men athletes were African runners; among women athletes they were 52%. Morphological indicators (stature, body mass and Body Mass Index (BMI)) have decreased. We show a parabolic function between BMI and running speed. The seasonal distribution has two peaks, in spring (weeks 14 to 17) and autumn (weeks 41 to 44). During both periods, the average temperature of the host cities varies close to optimal value for long distance race. African men and women runners are increasingly dominating the marathon and pushing its record, through optimal eco-physiological conditions.

Keywords: *Marathon, performance, demography, morphology, environment*

Introduction

Completion of a marathon in less than 2 h is yet to occur. Joyner, Ruiz, and Lucia (2011) estimated that this time limit might be broken by about 2021, with an improvement of 10 s per year until then. The quest to break this record has been on in all five continents for some 40 years. During this time there has been a marked increase in the number of races that occur annually (644 in 1990 to 2820 in 2011) and the number of participants (234,000 registered in 1990 and 1.48 million in 2011) have also increased (Association of Road Racing Statisticians ARRS, s. d.). Coincidentally, new world records in track-and-field have become scarcer. For example, 64% of track-and-field events have had no new records since 1993 (Berthelot et al., 2010). A new world marathon record was set in September 2011 in Berlin by Patrick Makau, a Kenyan runner, in 2 h 3 min and 38 s.

Individual performance depends on endogenous factors such as anthropometric, genetic and physiological characteristics (Lippi, Favaloro, & Guidi, 2008; Macarthur & North, 2005) and environmental factors that affect all athletes (El Helou et al., 2012; Ely, Cheuvront, Roberts, & Montain, 2007; Galloway & Maughan, 1997; Vihma, 2010). Globally, the number of participants has increased and so presented a larger genetic diversity in this event. However, the best performances are mainly achieved by runners originating from East Africa who possess physiological characteristics that allow higher standards of performance. Furthermore, the marathon is a track-and-field discipline that is affected by environmental conditions such as temperature, humidity, pollutants, atmospheric pressure and winds. Among these factors, temperature appears to have most influence on performance (El Helou et al., 2012). Because of cultural, media-related and commercial reasons, prestigious international competitions such as the Olympic Games and World Championships, are held in the summer (July and August), under warm and less favourable conditions. The objective of this study is to identify factors that influence best performances in the marathon, considering historical, demographic,

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anthropometrical and seasonal characteristics for the 100 yearly best performers from 1990 to 2011. This could allow the identification of the most appropriate profiles as well as the most favourable conditions.

Method

Data collection

We collected the results of the top 100 world best performers each year from January 1990 to December 2011 for men and from January 1996 to December 2011 for women. This produced a total of 3800 results (2200 for men and 1600 for women) collected from the open-access website http://www.iaaf.org/. For inclusion, men had to have completed races in less than 2 h 18 min, while the equivalent for women was less than 2 h 34 min. For each athlete, birth date, nationality, date and place of the event, race time (converted into speed, in $m \cdot s^{-1}$), plus stature and body mass were recorded. BMI was calculated.

Running speed

For men and women, the groups of the 100 top performers were categorised into speed deciles. For each year and each group, the mean and confidence intervals were calculated for each decile and for both sexes as a basis for comparison (equation and coefficient of determination were calculated for men and women).

A Student test was performed to compare the speed of runners integrating the top 100 in 1990 for men and 1996 for women to the speed of those integrating the top 100 in 2011.

Demography

Athletes' nationalities were categorised into one of the six world regions: Africa, Asia, Europe, North America, South America and Oceania. For each year and both sexes, the contribution of each continent in the top 100 was calculated. One-way between groups ANOVA compared means of the 10 best performers of each continent and identified demographic trends for both sexes. Then, the means of the 10 best performers of each continent were also compared in pairs for both the sexes using a Mann–Whitney test because the sample does not follow a normal distribution and n is less than 30 (Table I).

Morphology

The mean and confidence intervals for the top 100 men runners by year were calculated, and a Student Test was performed to compare the stature, body mass and BMI of runners integrating the Top 100 in 1990 for men and 1996 for women to those integrating the Top 100 in 2011.

Then, we determined if there was a correlation between BMI and running speed to complete a marathon. This was done by identifying the maximal running speed for each BMI.

Seasonal performance

For races between 1990 and 2011 for men and 1996 and 2011 for women, we analysed the number of performances for each week of the year (2200 for men and 1600 for women). The weekly percentage of performances of the total was calculated for both sexes to compare seasonal effects:

$$\frac{n\,(number\ of\ performance\ \ by\ week) * 100}{N\,(total)}$$

Statistical analyses were performed with the R software. Statistical significance was considered at $P < 0.05$. Effect size for One-Way ANOVA was Cohen's d and evaluated with Cohen's conventional criteria (Field, 2009). For Mann–Whitney test, the formula for the calculation of effect size is $r = Z/\sqrt{N}$, with criteria evaluation: abs(r)= 0.1 small size, abs(r) = 0.3 medium size, abs(r)= 0.5 large size.

Results

Running speed

The mean running speed of the top 100 performers has continually increased since 1990 for men and since 1996 for women in all deciles with at least $P < 0.001$ for men (decile10) and $P < 0.02$ (decile1) for women. For men, the mean speed was of $5.30 \pm 0.08\ m \cdot s^{-1}$ in 1990 and $5.52 \pm 0.06\ m \cdot s^{-1}$ in 2011, $P < 0.001$. For women, this trend was similar and rose from a mean speed of $4.68 \pm 0.06\ m \cdot s^{-1}$ in 1996 to $4.85 \pm 0.07\ m \cdot s^{-1}$ in 2011, $P < 0.001$. Each year, the best performances of the Top 100 men marathoners were run in 31 ± 5 races. Their mean ranking at the end of each race in which they were engaged was 4 ±3. The best performances of the top 100 women runners occurred in 31 ± 3 races. Their mean ranking was 4 ± 3. Annual modifications in running speed for both sexes were similar for all decile groups throughout the study period (Figures 1 (a) and (b)).

Demography

Top 100. Since 1990, 55% of men's performances were attributable to African runners (of these, 83% were from Kenya and Ethiopia), 24% were from Europe and 15% were from Asia. Since 1996, 39%

Table I. Mean speed of top 10 athletes by continents and sexes, statistically comparing by a test of mean ranks – Mann–Whitney test for men and women.

Sex	Region	Mean ± SD	*p*-value Africa	Europe	Asia	South America	North America
Men	Africa	5.67 ± 0.03					
	Europe	5.53 ± 0.02	***				
	Asia	5.52 ± 0.03	***	0.153			
	South America	5.49 ± 0.05	***	*	0.057		
	North America	5.47 ± 0.08	***	*	*	*	
	Oceanic	5.39 ± 0.05	***	***	***	**	**
Women	Africa	5.00 ± 0.04					
	Europe	5.00 ± 0.08	NS				
	Asia	4.99 ± 0.05	NS	0.82			
	South America	4.75 ± 0.09	***	***	***		
	North America	4.82 ± 0.10	**	**	**	0.081	
	Oceanic	4.76 ± 0.09	***	***	***	NS	0.14

Note: *<0.05 ; **<0.01; and ***<0.001.

	For Men:	For women:
Africa VS Europe:	U = 100, Z = 3.82, P < 0.001, r = 0.85;	U = 60.5, Z = 0.81, P = 0.44, r = 0.18;
Africa VS Asia:	U = 100, Z = 3.80, P < 0.001, r = 0.85;	U = 60, Z = 0.76, P = 0.47, r = 0.17;
Africa VS South America:	U = 100, Z = 3.80, P < 0.001, r = 0.85;	U = 100, Z = 3.80, P < 0.001, r = 0.85;
Africa VS North America:	U = 99, Z = 3.72, P < 0.001, r = 0.83;	U = 92, Z = 3.19, P < 0.01, r = 0.71;
Africa VS Oceania:	U = 100, Z = 3.79, P < 0.001, r = 0.85;	U = 100, Z = 3.80, P < 0.001, r = 0.85;
Europe VS Asia:	U = 31, Z = –1.47, P = 0.15, r = 0.33;	U = 46.5, Z = –0.27, P = 0.80, r = 0.06;
Europe VS South America:	U = 22.5, Z = –2.12, P < 0.05, r = 0.47;	U = 0.5, Z = –3.75, P < 0.001, r = 0.84;
Europe VS North America:	U = 20, Z = –2.29, P < 0.05, r = 0.51;	U = 8, Z = –3.18, P < 0.01, r = 0.71;
Europe VS Oceania:	U = 100, Z = 3.82, P < 0.001, r = 0.86;	U = 99, Z = 3.71, P < 0.001, r = 0.83;
Asia VS South America:	U = 0, Z = –1.94, P = 0.06, r = 0.43;	U = 0, Z = –3.79, P < 0.001, r = 0.85;
Asia VS North America:	U = 20, Z = –2.28, P < 0.05, r = 0.51;	U = 9.5, Z = –3.08, P < 0.01, r = 0.69;
Asia VS Oceania:	U = 100, Z = 3.80, P < 0.001, r = 0.85;	U = 99, Z = 3.72, P < 0.001, r = 0.09;
South America VS North America:	U = 24, Z = –1.98, P < 0.05, r = 0.44;	U = 73.5, Z = 1.78, P = 0.08, r = 0.40;
South America VS Oceania:	U = 93.5, Z = 3.31, P < 0.01, r = 0.74;	U = 45, Z = –0.38, P = 0.73, r = 0.09;
North America VS Oceania:	U = 84.5, Z = 2.63, P < 0.01, r = 0.59.	U = 70, Z = 1.52, P = 0.14, r = 0.34.

of women's performances were by Europeans, 30% by Asians and 24% by Africans runners. These percentages have continually evolved (Figure 2 (a) and (b)). For women, the percentage of African runners increased from 6% in 1996 to 52% in 2011. Likewise, for men, the percentage of African runners increased from 16% in 1990 to 94% in 2011. As a result, the demographic contribution of other regions has progressively decreased; the percentage of European women runners was 48% in 1996 but only 24% in 2011. For men, the proportion of European runners reduced from 47% in 1990 to 0% in 2011. The crossing point showing the start of African dominance in the top 100 appeared in 1996 for men. For women, this crossing point occurred 13 years later, in 2009.

Top 10 men and women performers for each continent

Men nationalities in each continental top 10. There are two nationalities for Africa (8 Kenyan and 2 Ethiopian), six for Europe (5 French, 1 Ukrainian, 1 Italian, 1 Portuguese, 1 Belgian and 1 Swiss), two for Asia (8 Japanese and 2 South Korean), two for South America (6 Mexican and 4 Brazilian), two for Oceania (8 Australian and 2 New Zealander) and only one nationality for North America (10 USA).

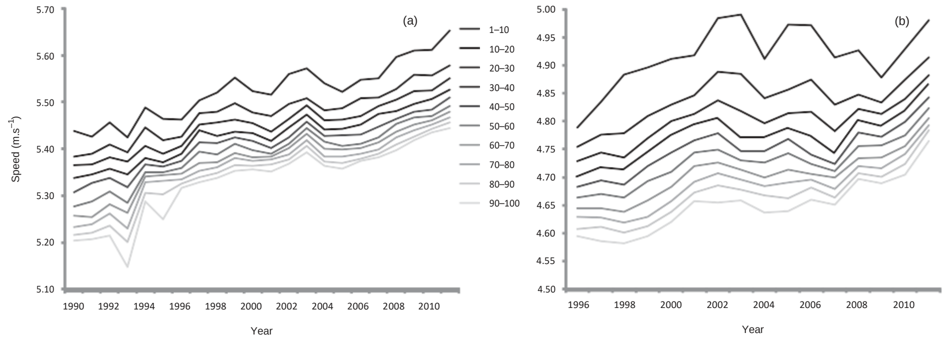

Figure 1. Mean race speeds by season for each decile from the top 100: (a) 1990 to 2011 for men; (b) 1996 to 2011 for women.

Note:

For men:

$y_1 = -12.56 + 0.009x$; $R^2 = 0.87$;
$y_2 = -10.70 + 0.008x$; $R^2 = 0.90$;
$y_3 = -10.38 + 0.007x$; $R^2 = 0.91$;
$y_4 = -10.66 + 0.008x$; $R^2 = 0.91$;
$y_5 = -10.93 + 0.008x$; $R^2 = 0.91$;
$y_6 = -12.33 + 0.008x$; $R^2 = 0.89$;
$y_7 = -13.45 + 0.009x$; $R^2 = 0.89$;
$y_8 = -14.26 + 0.009x$; $R^2 = 0.87$;
$y_9 = -15.56 + 0.010x$; $R^2 = 0.87$;
$y_{10} = -17.40 + 0.011x$; $R^2 = 0.84$.

For women:

$y_1 = -8.43 + 0.006x$; $R^2 = 0.32$;
$y_2 = -8.82 + 0.006x$; $R^2 = 0.54$;
$y_3 = -9.0 + 0.006x$; $R^2 = 0.64$;
$y_4 = -9.30 + 0.007x$; $R^2 = 0.62$;
$y_5 = -9.80 + 0.007x$; $R^2 = 0.66$;
$y_6 = -10.72 + 0.007x$; $R^2 = 0.73$;
$y_7 = -11.76 + 0.008x$; $R^2 = 0.78$;
$y_8 = -12.70 + 0.008x$; $R^2 = 0.79$;
$y_9 = -13.62 + 0.009x$; $R^2 = 0.81$;
$y_{10} = -14.05 + 0.009x$; $R^2 = 0.82$.

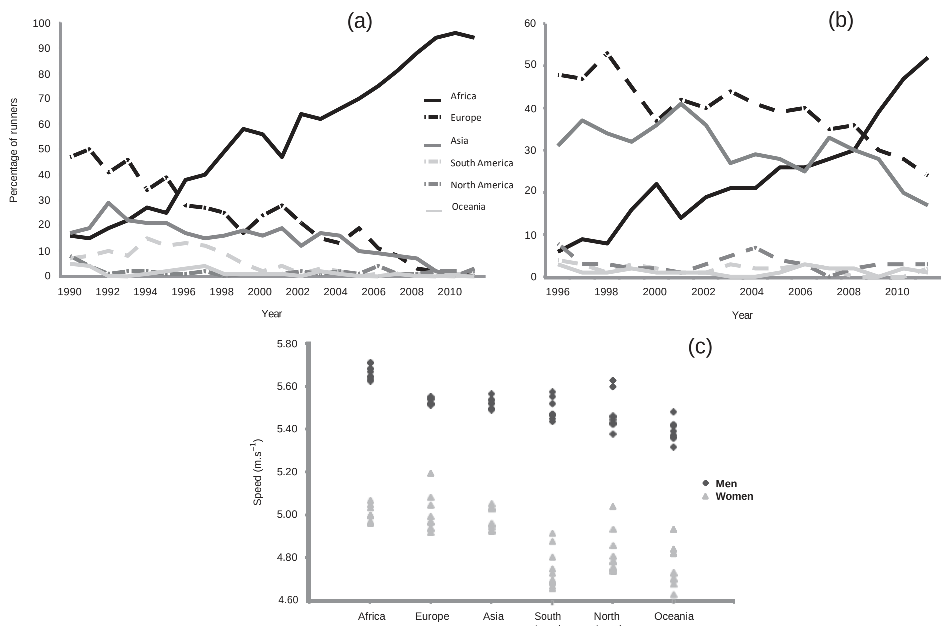

Figure 2. Continental distributions of runners among the top 100 by season (a) from 1990 to 2011 among men and (b) from 1996 to 2011 among women. (c) Race speeds of 10 best performers for the studied season for men and women by continent. Demographic trends are calculated by a one-way ANOVA test for men ($P < 0.001$) and women ($P < 0.001$).

Women nationalities in each continental top 10. There are two nationalities for Africa (7 Kenyan and 3 Ethiopian), five for Europe (5 Russian, 2 Romanian, 1 English, 1 German and 1 Belgian), two for Asia (7 Japanese and 3 Chinese), five for South America (5 Mexican, 2 Brazilian, 1 Argentinean, 1 Colombian and 1 Ecuadorian), two for Oceania (6 Australian and 4 New Zealander) and only one nationality for North America (10 USA).

Mean speeds differed by nationality for men (ANOVA men $P < 0.001$) with a large effect ($d = 0.88$ for men). The fastest were the 10 best African men runners (22 years) whose speeds ranged from 5.63 to 5.72 $m \cdot s^{-1}$, with an overall mean of 5.67 ± 0.03 $m \cdot s^{-1}$.

Running speeds for men also differed according to origin (ANOVA men $P < 0.001$; effect size 0.83) with African men the fastest at least 5.63 $m \cdot s^{-1}$.

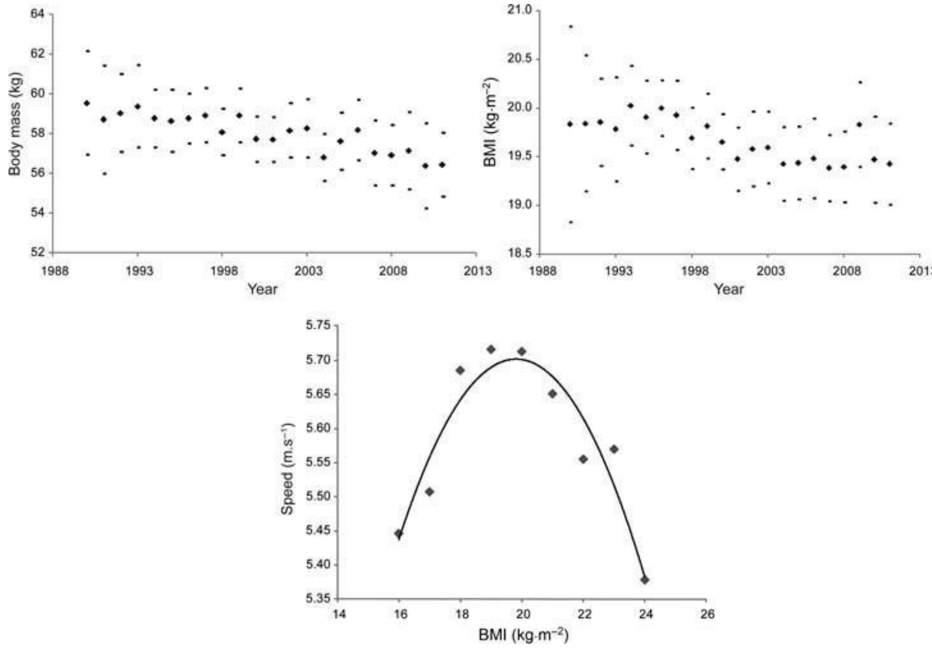

Figure 3. Mean body mass (a) and BMI (b) of the Top 100 men runners and its standard deviation by season (1990 to 2011) (c) Race speed record of the Top 100 men runners by BMI. Modelling function: $y = -1.4387 + 0.7208x - 0.0182x2$ and $R^2 = 0.89$.

Mean speed of the African 10 best is 5.67 ± 0.03 m·s^{-1}. These runners are faster than all others competitors (Figure 2 (c) and Table I). The 10 best European and Asian men runners have similar performances with a mean race speed of 5.53 ± 0.02 m·s^{-1} and 5.52 ± 0.03 m·s^{-1}, respectively. In contrast, for women runners, this distribution was less variable across regions (ANOVA women $P < 0.001$; effect size 0.50). The mean performance for the 10 best African runners was 5.00 ± 0.04 m·s^{-1}, it is 5.00 ± 0.08 m·s^{1} for Europeans and 4.99 ± 0.05 m·s^{-1} for Asian runners. However, the athletes from other continents, such as South America, North America and Oceania, have mean speeds of 4.75 ± 0.09 m·s^{-1}, 4.82 ± 0.1 m·s^{-1} and 4.76 ± 0.09 m·s^{-1}, respectively. They are slower than athletes from Africa, Europe and Asia $P < 0.01$.

Morphology and running speed of the Top 100 performers

For men, stature, body mass and BMI decreased from 1990 to 2011 (Figure 3 (a) and (b)). Over the entire study period, the stature of the runners ranged from 156 to 190 cm, the body mass from 45 to 78 kg and BMI ranged from 15.78 to 23.05 kg/m^2. The mean body mass for men decreased significantly from 59.6 ± 2.30 kg in 1990 to 56.2 ± 1.10 kg in 2011 ($P < 0.01$). The mean BMI also decreased significantly from 19.83 ± 1.70 kg/m^2 in 1990 to 19.42 ± 1.30 kg/m^2 in 2011.

In addition, BMI and maximal race speeds were correlated. When modelled with a second-order polynomial function ($y = -1.4387 + 0.7208x - 0.0182x^2$, $R^2 = 0.89$), the optimal BMI for men was 19.8 kg·m^2 for a maximal speed of 5.70 m·s^{-1}. Equivalents for women were 18.2 kg·m^2 and 5.19 m·s^{-1} (Figure 3 (c)).

Seasonality

Annual performances spread over 50 weeks for men and 47 weeks for women. The distribution shows two peaks. The first peak occurs in weeks 14, 15, 16 and 17 (April) while the second occurs during weeks 41, 42, 43 and 44 (October) (Figure 4). These eight weeks contain 48.7% of women's performances (27.6% for April and 21.1% for October) and 54.4% of men's performance (29.4% for April and 25.0% for October). Performances during weeks 25 to 32 (from early June to late August) represent less than 1% of the total.

Discussion

Our study is the first to analyse the overall pattern of elite-standard men and women marathoners over the last 25 years to identify factors that influence performance.

Race speeds

This study shows that marathon performances improved for each decile and for both sexes among the annual 100 best runners. This contrasts with sports performances in general that have tended to

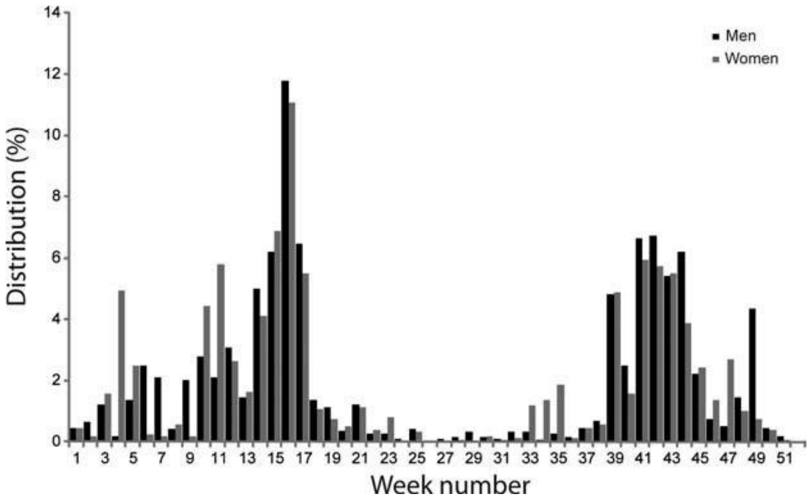

Figure 4. Percentage distributions of the 2200 performances collected from the top 100 of each year of the season (1990 to 2011) for men represented by black columns. Percentage distributions of the 1600 performances collected from the top 100 of each year of the season (1996 to 2011) for women represented by grey columns.

reach a limit; 64% of track-and-field events have not improved since 1993 (Berthelot et al., 2010; Nevill & Whyte, 2005). Moreover, this trend is apparent in many other sports where best performances have stagnated (Berthelot et al., 2008; Desgorces et al., 2008). This might be because of saturation effects, i.e. interactions between genomics (Macarthur & North, 2005; Williams & Folland, 2008), physiology, demography and environmental factors (Desgorces et al., 2008; El Helou et al., 2012). Notably, annual variations in race speeds were similar for each decile. When the first decile (Top 10 speed races) increased or decreased, the last decile (Top 90–100 speed races) varied in the same way. These variations could be associated with mean seasonal climatic conditions recorded in the host cities. This probably explains why the best performances of the top 100 men and women marathoners are accomplished each year in a mean of 31 ± 5 races (in different cities) for men and 31 ± 3 for women (Association of Road Racing Statisticians ARRS, s. d.).

Demography

The best performances by men in marathons were by athletes from East Africa (mainly Kenya and Ethiopia) and this trend has been progressive from 1990 to 2011 (16% to 94%). Conversely, other nationalities, initially dominant in the list of top 100 performers (from Europe, Asia, South America, North America and Oceania), are increasingly less prominent over the same period, 84% in 1990 to 6% in 2011. This change in domination also occurred in the speed of the 10 best performers from each continent since 1990. While the top 10 African runners ran at a mean speed of $5.68 \pm 0.03\ m{\cdot}s^{-1}$, other top 10 runners from other continents were slower ($5.48 \pm 0.07\ m{\cdot}s^{-1}$) during the same period. Several studies have attempted to explain the success of Africans. One of the reasons for the dominance could be their physiological characteristics. Despite comparable maximum oxygen uptake, Africans tend to run at a higher percentage of their maxima during competition than Europeans. This results in improved economy (Bosch, Goslin, Noakes, & Dennis, 1990; Larsen, 2003). Kenyan runners also have greater activity of the β-oxidative enzyme HAD (3-hydroxyacyl- CoA-dehydrogenase activity) in their muscles (Saltin, Kim, et al., 1995; Weston, Karamizrak, Smith, Noakes, & Myburgh, 1999). Other authors have shown that sporting ability is characterised by specific genotypes that still need to be identified. Macarthur and North (2005) showed that variation in human performance and athletic ability has long been recognised as having a strong heritable component. Indeed, Rivera et al. (1997) demonstrated strong associations between a restriction fragment length polymorphism in muscle-specific creatine kinase and the response of maximal oxygen uptake (VO_2max) after 20 weeks of endurance training in 240 unrelated members of the heritage family cohort. East African runners also exhibited greater fatigue resistance (Coetzer et al., 1993). Furthermore, (Onywera, Scott, Boit, & Pitsiladis, 2006), reported that Kenyan runners differed from the general population because of greater physical activity during childhood and adolescence during their travels to school. A higher proportion of athletes had run to school each day (controls 22%, national athletes 73% and international athletes 81%) and covered greater distances than other groups. It has been shown that Kenyan boys who travelled to school by walking and running had 30% greater VO_2max than those who did not (Saltin, Larsen, et al., 1995) and those results were confirmed for Ethiopian runners (Scott et al., 2003). Also, chronic altitude exposure, as experienced by many young East African runners, combined synergistically with endurance training to induce haematological adaptations, which partially accounted for their greater physiological capabilities (Schmidt et al., 2002). However, despite a marked increase in number of African athletes in the world-best performances in recent years, African women runners' superiority is not as strongly established as for men (in 2011, 94% in men as opposed to 52% in women). For performance during the study period, the 10 best race speeds of African women were not greater than those in runners from Europe and Asia.

This difference could be explained by their later and gradual arrival in this activity. Indeed, the increase of women's participation in the Olympic Games has grown from only 1.9% in 1900 to 42.3% in 2008 in Beijing (Olympics at Sports Reference, s. d.). In particular for the marathon, the first appearance of women occurred less than 30 years ago in the Los Angeles Olympic Games of 1984 (O'Brien, 1985). Today, women's mean participation in international marathons is 33% (Association of Road Racing Statisticians ARRS, s. d.). This percentage varies depending on the competition's location (Boston 42%, New York 35%, Berlin 20%). The proportion of African women marathoners will probably increase and reinforce their dominance over other international athletes.

Morphology and running speed

The morphology of athletes has changed in recent years. Decreases in stature, body mass and BMI have occurred both in men and women runners (Norton & Olds, 2001). Athletic performances require mix attributes, but a key factor might be biometric optimisation. This study shows an optimum BMI of 19.8 kg/m^2, even if the 10 best performers of all time have a BMI between 17.5 and 20.7 kg/m^2. Morphology and success in various disciplines is linked (O'Connor, Olds, & Maughan, 2007; Sedeaud et al., 2012). Indeed, the BMI of marathoners is one of the lowest of all disciplines. Several studies have investigated biometrical characteristics of runners, especially those from Africa (Dennis & Noakes, 1999; Kong & de Heer, 2008; Larsen, 2003; Marino et al., 2000).

As regards thermoregulation, the superior running performance of African runners can be partly attributed to their lower BMI. Their ability to run faster is particularly notable in warm conditions where differences in performance are even greater between Africans and non-Africans. This could be attributable to improved ability to release heat than heavier Caucasian runners (Marino et al., 2000). It has also been shown that small body size could be an advantage in distance running, particularly in the heat (Dennis & Noakes, 1999; Marino et al., 2000). A greater proportion of lean body mass could account for differences in running performance in the heat between individuals of different sizes. It has been hypothesised that a rise of ambient temperature from 25 to 35°C causes larger and heavier runners to run slower because of greater accumulation of body heat that increases body temperature and so accelerates the onset of fatigue (Dennis & Noakes, 1999; Marino et al., 2000).

Kong and de Heer (2008) claimed that the gracile limbs of Kenyan endurance runners contribute to improved performances because of their lower moments of inertia, and hence, required less internal mechanical work to be done during each running stride. In addition, the reduced ground contact time in these runners could improve running economy. Such a reduction in turn reduces braking forces to decelerate forward motion. The morphology of these athletes could be advantageous in terms of thermodynamics (Larsen, 2003). Indeed, their lighter legs compared with those of Nordic athletes' produced less heat and allowed an easier and faster stride.

Seasonality

The best performances occurred in late April (weeks 14 to 17) and late October (weeks 41 to 44). The major races occurred in London, Boston, Rotterdam and Paris for the first peak, and New York, Berlin, Chicago and Amsterdam for the second one. Best performances by men during these two periods are greater than those by women, 54.4% against 48.6%, respectively. This can be explained by the dissociation of races between sexes. For women, peaks at weeks 4, 10 and 11 corresponded to marathons exclusively for women, respectively, in Osaka, Nagoya and Seoul (Osaka: start time 12:00 with mean temperature since 2001 of 7.3°C ± 1.8°C; Nagoya: start 09:00 with a mean temperature since 2005 of 8.8°C ± 3.4°C). However, the two peaks of the year match the optimal mean temperature condition for a marathon (10°C) recorded during these periods in the northern hemisphere during races (El Helou et al., 2012). Furthermore, no world records and few good annual performances are established in the summer during the Olympic Games, Continental or International Championships. Despite the high standard of competition in these events, the lack of great performances can be explained by the temperatures during this period of year: they are too far from the optimum value during a marathon (Athens Olympic 2004: 25.6°C, Beijing 2008: 25.0°C and world Championship Berlin 2009: 20.7°C). Temperature has adverse effects on marathon runners. Heat causes a major alteration of cardiovascular, metabolic, neuromuscular and thermoregulatory function, and consequently, hyperthermia appears to be the key limiter of exercise performance in the heat (Galloway & Maughan, 1997; Hargreaves, 2008). A study of the Stockholm Marathon (Vihma, 2010) and a large epidemiological study on all participants in the Boston, Chicago, New York, Paris, London and Berlin marathons from 2001 to 2010 confirmed this trend and showed that ambient temperature is influential (El Helou et al., 2012).

Conclusion

In this study, we have identified the main factors that will allow marathoner runners to improve. Each decile of the Top 100 has continued to progress over the last 20 years with similar annual variation. We have demonstrated that demography plays an important role in the improvement of top performances, with a progression of domination of African runners' performances. Furthermore, the best performances were made during periods characterised by lower temperatures (April and October) in response to optimal temperatures for endurance running (approximately 10°C). Thus, when all these conditions are assembled, performance will probably continue to improve.

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