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Do older athletes reach limits in their performance during marathon running?

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Abstract In the last decades, the participation of elderly trained people in endurance events such as marathon running has dramatically increased. Previous studies suggested that the performance of master runners (>40 years) during marathon running has improved. The aims of the study were (1) to analyze the changes in participation and performance trends of master marathon runners between 1980 and 2009, and (2) to compare the gender differences in performance as a function of age across the years. Running times of the best male and female runners between 20 and 79 years of age who competed in the New York City Marathon were analyzed. Gender differences in performance times were analyzed for the top 10 male and female runners between 20 and 65 years of age. The participation of master runners increased during the 1980–2009 period, to a greater extent for females compared to males. During that period, running times of master runners significantly ($P<0.01$) decreased for males older than 64 years and for females older than 44 years, respectively. Gender differences in running times decreased over the last three decades but remained relatively stable across the ages during the last decade. These data suggest that male (≥65 years) and female (≥45 years) master runners have probably not yet reached their limits in marathon performance. The relative stability of gender differences in marathon running times across the different age groups over the last decade also suggests that age-related declines in physiological function do not differ between male and female marathoners.

Keywords Running · Aging · Master athletes · Endurance exercise · Gender differences

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Introduction

Although longevity continues to increase, some lifestyle risks might have a sufficiently large impact on mortality to halt the present upward trends in life expectancy. The lifestyle risks found in most of the populations of the world's most affluent countries are cigarette smoking, obesity, an unhealthy diet, lack of exercise, alcohol consumption, and general sedentary behavior (Harper and Howse 2008). It has been shown that regular physical activity can reduce the risk of all causes of mortality and increase life expectancy (Williams 1997, 2009a). Despite the benefits of exercise, the percentage of a population's physical inactivity increases with advancing age and according to the U.S. Department of Health and Human Services, approximately one third of persons aged 65 or older lead a sedentary lifestyle (http://aspe.hhs.gov/health/reports/physicalactivity/).

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The aging process in humans is characterized by significant decreases in physiological functions, but numerous studies have demonstrated that continued exercising such as running late into life attenuates sarcopenia and is beneficial for cardiovascular health (Trappe 2007; Faulkner et al. 2008). Careful studies of people who age successfully from a physical performance standpoint may elucidate methods and mechanisms that doctors can apply to all patients to develop a more uniform healthcare approach. Older (or masters) endurance athletes represent an ideal model to determine successful aging due to their usual participation in high intensity exercise (Hawkins et al. 2003). They are a positive example of exceptional aging and are a rich source of insight into a person's ability to maintain peak physical performance and physiological function with advancing age (Tanaka and Seals 2008). For example, it has been shown that prevalence of hypertension, hypercholesterolemia, and diabetes decreases with the frequency of marathon participation independent of annual running distance. This may be due to the inclusion of longer training runs in preparation for marathons or to genetic or other innate differences between marathon and non-marathon runners (Williams 2009b).

Since the early 1980s, participation in distance running events such as marathon has skyrocketed with hundreds of marathons worldwide and several events having more than 40,000 participants (Burfoot 2007). The marathon has become a worldwide social and fitness phenomenon, and therefore represents an interesting model to analyze the participation and performances trends of athletes across the ages over a long period of time.

To the best of our knowledge, few studies have focused on the participation and performance trends of masters athletes at the marathon distance since the early 1980s (Jokl et al. 2004; Leyk et al. 2009). Jokl et al. (2004) showed that participation in the New York City (NYC) Marathon over the 1983–1999 period increased at a higher rate in athletes above 50 years old than in younger athletes, for both men and women. In addition, over the same 1983–1999 period, the best male and female athletes older than 50 improved their running times at a greater rate than the younger athletes, whose performance levels have plateaued. However, the changes in participation and performance of elderly athletes at the NYC marathon this last decade (i.e., from 2000 to 2009) have not been yet investigated, and it is not known whether masters athletes still improved their marathon performance or whether they have reached their limits.

Gender differences in running have been well investigated for elite athletes (Sparkling et al. 1998; Pate and O'Neil 2007; Baker and Tang 2010; Hunter et al. 2011). However, there is paucity of data related to the combined interaction of age and gender on running performance (Leyk et al. 2007; Ransdell et al. 2009). Knowing that the physiological (e.g., muscle strength, oxygen carrying capacity) and morphological (e.g., percentage of body fat, muscle mass) functional characteristics change with advancing age, gender differences in endurance running performance may also change with advancing age. For example, some studies have suggested that elderly females may lose muscle mass more rapidly than do their male counterparts (Phillips et al. 1993; Samson et al. 2000), but it is not a general finding. An increase in 10-km running time with advancing age has been found to be greater in females compared to males (Tanaka and Seals 2003). Jokl et al. (2004) found that the time improvement was substantially greater for older female athletes compared to their male counterparts at the NYC marathon over the 1983–1999 period. These findings suggest that gender differences in marathon running performances for masters athletes may have decreased during the last three decades. However, the possibility of an increased gender difference in endurance running with advanced age needs to be examined.

To date, no data exist regarding the participation and performance trends in marathon running for masters athletes in the first decade of the new century. Accordingly, the first purpose of this large cross-sectional study was to expand the existing data from Jokl et al. (2004) by examining the changes in participation and performance of masters athletes at the NYC marathon over the last 30 years (from 1980 to 2009). A secondary purpose was to analyze the gender differences in running performance as a function of age across the same 1980–2009 period.

Methods

Approval for the project was obtained from the Burgundy University Committee on Human Research. This study involved the analysis of publicly available

data so content was waived. Age and time performance data for all runners completing the NYC marathon from 1980 to 2009 were obtained through the NYC marathon website: http://www.ingnycmarathon.org/. Although there is no consensus in the literature about the definition of a masters athlete, we defined masters athletes in the present study as those equal to or older than 40 years. For male and female athletes younger than 40 years, we considered two age groups of 10 years: 20–29 years and 30–39 years. To focus more on changes in participation and performance in masters athletes, we considered age groups of 5 years for males and females older than 40, as follows: 40–44 years, 45–49 years, 50–54 years, 55–59 years, 60–64 years, 65–69 years, 70–74 years, and 75–79 years. The small participation of athletes older than 65 years, especially for females, during the first decade studied (1980–1989), with sometimes less than 20 finishers per age group, justified the necessity to consider only the top 10 finishers. Averaged running time performances of the top 10 finishers of each age group for both females and males were analyzed from 1980 to 2009. If there were less than 10 finishers in an age group, the data were not considered. The magnitude of gender differences was examined by calculating the percent difference for running times between the top 10 males versus females of each age group. In order to simplify the analysis over the 30-year study period (1980–2009), we pooled data into three decades: 1980–1989, 1990–1999, and 2000–2009.

Two-way ANOVAs (age group × decade) with repeated measures on decade were used to compare percent of finishers and running times between the decades across ages, for both males and females. Two-way ANOVAs (age group × decade) with repeated measures on decade were also used to compare gender differences in running times between the decades across ages. Tukey's post hoc analyses were used to test differences within the ANOVAs when appropriate. A significance level of $P < 0.05$ was used to identify statistical significance.

Results

Participation of masters athletes

Table 1 shows that the number of total finishers increased by 65% between decade 1980–1989 and decade 1990–1999 and by only 25% between decade 1990–1999 and decade 2000–2009. The number of finishers increased more for females than for males: 145% vs. 49% between 1980–1989 and 1990–1999 and 68% vs. 11% between 1990–1999 and 2000–2009. The ratio of male and female finishers decreased over the three decades and was equal to 5.1, 3.1, and 2.1, respectively. The relative increase of finishers was greater for the masters athletes >40 years than for younger athletes for both males and females, and was greater for female masters athletes than for the males (Table 1). The distribution of finishers per age group over the three decades studied is shown in Fig. 1. Over the three decades, the percent of finishers younger than 40 years significantly decreased ($P<0.05$), while the percent of masters finishers significantly increased ($P<0.05$) for both males and females. Over the three decades 1980–1989, 1990–1999, and 2000–2009, male masters athletes represented 36%, 45%, and 53% of total male finishers, respectively, while female masters athletes represented 24%, 34%, and 40% of total female finishers, respectively.

Performances of masters athletes

The mean finish times for the top 10 of each male and female age group over the three studied decades are shown in Fig. 2. For males, ANOVA revealed that mean finish times did not change over the three decades for age groups <60–64 years. In contrast, running times significantly decreased ($P<0.01$) over the three decades for age groups ≥60–64 years. For example, average running times of males within the 65–69 years age range significantly decreased ($P<0.01$) by ~8 min (3.7%) between 1980–1989 and 1990–1999, and by ~7 min (3.2%) between 1990–1999 and 2000–2009. Average running time of males within the 70–74 years age range significantly decreased ($P<0.01$) by ~13 min (4.9%) between 1980–1989 and 1990–1999, and by ~4 min (1.6%) between 1990–1999 and 2000–2009. For females, mean finish times did not change over the three decades for age groups <45–49 years, except the time of the 30–39 years group that was lower in 2000–2009 decade compared to previous decades. Female running times significantly decreased ($P<0.01$) over the three decades for age groups ≥45–49 years. For example, average running time of females within the 55–59 years age range significantly decreased ($P<0.01$) by ~33 min (14.5%) between

Table 1 Number of finishers of each sex (M = male, F = female) per age group at the New York City Marathon over the three decades: D1: 1980–1989, D2: 1990–1999, and D3: 2000–2009; and relative changes between the decades D2 and D1 and between the decades D3 and D2

Age group (years)	Sex	Number of finishers			Changes D2–D1 (%)	Changes D3–D2 (%)
		D1 1980–1989	D2 1990–1999	D3 2000–2009		
20–29	M	28,152	34,729	28,072	23	−19
	F	8,165	19,115	25,680	134	34
30–39	M	58,410	77,269	80,582	32	4
	F	12,037	25,939	43,005	115	66
40–44	M	25,314	36,855	45,618	46	24
	F	3,971	9,834	19,213	148	95
45–49	M	15,601	27,739	31,411	78	13
	F	2,122	6,502	12,145	206	87
50–54	M	8,913	20,065	26,050	125	30
	F	922	4,034	8,308	338	106
55–59	M	3,921	9,435	13,209	141	40
	F	325	1,630	3,920	402	140
60–64	M	1,604	4,510	7,527	181	67
	F	167	694	1,701	316	145
65–69	M	541	1,712	2,650	216	55
	F	61	238	542	290	128
70–74	M	243	623	1,012	156	62
	F	17	98	157	476	60
75–79	M	54	186	274	244	47
	F	4	29	60	625	107
Total	M	142,753	213,123	236,405	49	11
	F	27,770	67,986	114,514	145	68

1980–1989 and 1990–1999, and by ~8 min (3.5%) between 1990–1999 and 2000–2009. Average running times of females within the 60–64 years age range significantly decreased ($P<0.01$) by ~16 min (6.8%) between 1990–1999 and 2000–2009.

Gender differences in running times with age

Independently of age, gender differences in running times were significantly ($P<0.001$) lower for decade 2000–2009 compared to both previous decades 1980–1989 and 1990–1999. Mean gender differences in running times were equal to 28.4±10.3%, 25.8±6.9%, and 19.7±4.2% for decades 1980–1989, 1990–1999, and 2000–2009, respectively. There was a significant age group × decade interaction for gender differences in performance times ($F=8.7$; $P<0.001$) (Fig. 3). Gender differences at age groups >45–49 years decreased over the three decades. During decade 1980–1989, gender differences were significantly ($P<0.01$) greater for age groups 55–59 years and 60–64 years compared to all younger age groups comprised between 20–29 years and 50–54 years. Interestingly, gender differences did not differ across the ages for the last two decades 1990–1999 and 2000–2009.

Discussion

The main findings of the present study were first that the participation of masters athletes at the NYC Marathon increased during the 1980–2009 period, but to a greater extent for females than for males. Second, during that period, running times of masters

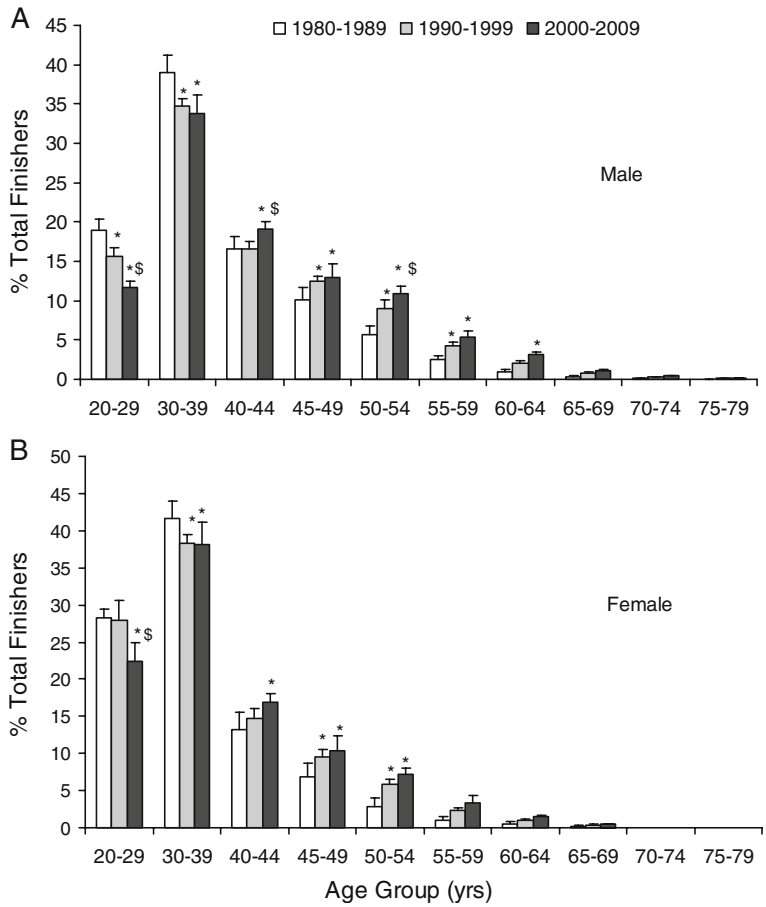

Fig. 1 Percentages of finishers within the different age groups at the New York City Marathon over the three studied decades for both males (**A**) and females (**B**). Values are mean±SD. *Significantly different from the decade 1980–1989, $P<0.05$. $^{\$}$Significantly different from the decade 1990–1999, $P<0.05$

runners has significantly decreased for males older than 64 years and for females older than 44 years, respectively. Third, gender differences in running time decreased over the last three decades but remained relatively stable across the different ages during the last decade.

Although it lacked some data about physiological (e.g., aerobic capacity) and anthropometric (e.g., body weight, lean body mass) parameters, as well as training volume (Knechtle et al. 2009) and environmental conditions of the race (Vihma 2010), the present study has provided valuable data concerning masters athletes performances at the marathon distance during the last 30 years. Indeed, masters athletes represent an ideal model to determine successful aging due to their sustained participation in exercise. While numerous research has been conducted describing the age-related declines in aerobic capacity (Harper and Howse 2008), the influence of chronic exercise on physiological capacity has been less investigated. The approach that consists of examining the changes in endurance performance with age in highly trained and competitive athletes represents an effective experimental model because changes observed with advancing age are thought to be mainly the results of primary (physiological) aging (Tanaka and Seals 2008). It is likely that the athletes finishing in the top 10 of their age group in a competitive event such as the NYC Marathon performed to their maximal physical capacity.

Increase in participation of masters athletes

The number of male and female finishers increased over the last three decades. It should be mentioned that over the years the race organization has imposed limits to the number of entries accepted, and this entry cap has increased over the years. However, if the field size limits to the NYC Marathon would alter the number of allowable finishers, it would probably not

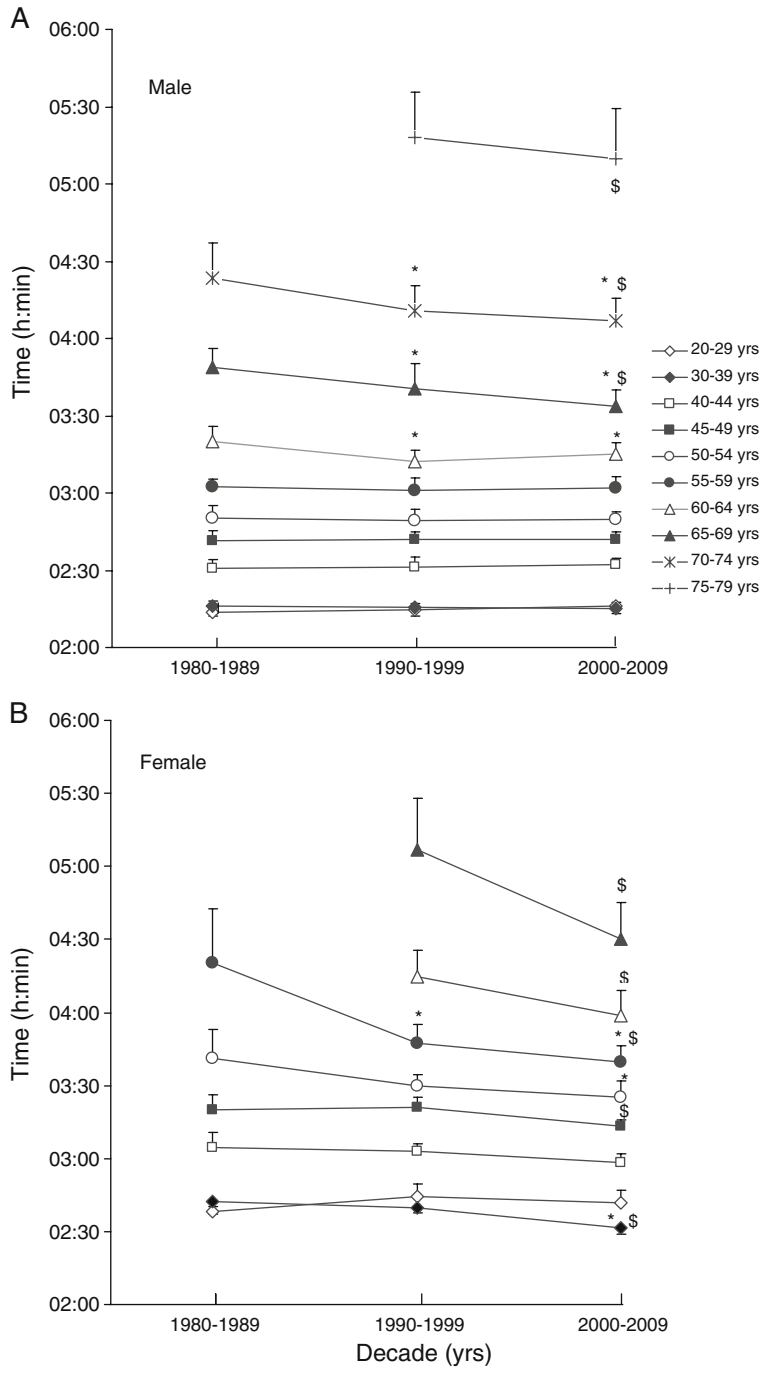

Fig. 2 Mean finish running times for the top 10 males (**A**) and females (**B**) in each age group at the New York City Marathon over the three studied decades. Values are mean±SD. *Significantly different from the decade 1980–1989 for the same age group, $P<0.01$. $^{\$}$Significantly different from the decade 1990–1999 for the same age group, $P<0.01$

change the relative proportions of males/females and ages. Based on extrapolation, Jokl et al. (2004) suggested that the male/female ratio of participation would approach 1 in 2007. Our findings did not confirm that assumption. Indeed, the relative participation of females at the NYC Marathon increased over the last 30 years (from ~17% of the total field for the 1980–1989 period to ~33% for the 2000–2009 period), but remained lower than participation of the males.

The growth of female and masters age groups in worldwide marathon racing has been particularly

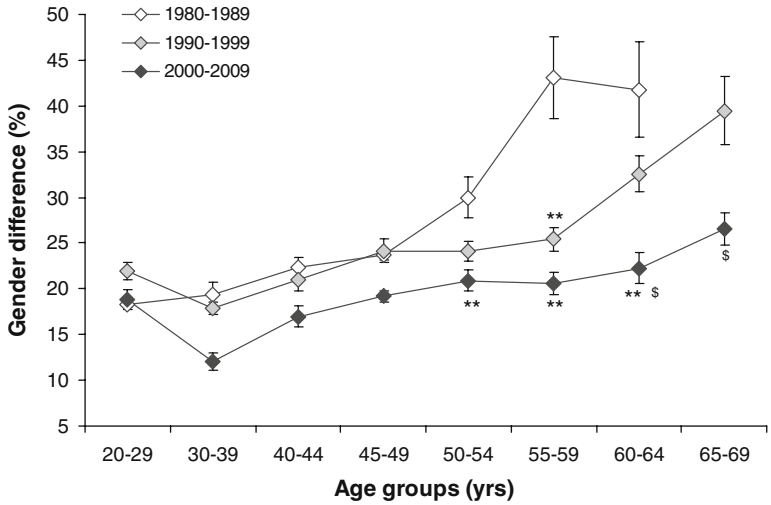

Fig. 3 Averaged gender differences in running times at the New York City Marathon over the three decades studied. Values are means±SE. **Significantly different from decade 1980–1989 for the same age group, $P<0.01$. $^{\$}$Significantly different from decade 1990–1999 for the same age group, $P<0.05$

startling over the last 30 years (Burfoot 2007). Present data confirm previous observations as the total participation of master runners at the NYC Marathon has increased during the last three decades and to a greater extent for female than for males. Throughout the 2000–2009 decade, masters runners represented more than 50% of male finishers and 40% of female finishers, respectively. In addition, the relative proportion of masters runners in the total field has also increased for both males and females over the last three decades while those of runners younger than 40 years of age decreased during the same period. Similarly, Jokl et al. (2004) found that the number of participants at the NYC Marathon (older than 50 years of age) increased at a greater rate than their younger counterparts during the 1983–1999 period. The reasons for such an increase in participation of masters runners especially in the female field are not clear but may be related to sociological phenomena. Increases in life expectancy and good health combined with a better consideration by older people of the positive effects of physical activity upon health with advancing age, i.e., "better aging", may explain this finding (Lee and Tanaka 1997). However, among the masters category, the distinction between people who started training in running late in life (i.e., after 40 years of age) and people who used to have participated in running at a younger age is not known. The exponential increase in participation of masters athletes especially in the female field in sporting events such as marathon running should lead to a re-evaluation of the aging process and how it relates to athletic performance.

Performances of masters athletes

Accordingly, the present results show that the running performance times of men within the 40–64 years age range have plateaued during the last two decades, while running times decreased for males older than 65 years. Several reasons may explain the improved performance of males older than 65 years over these 20 years, such as a greater participation of the older age groups, which would increase the probability of finding better runners in these age groups, increase training facilities for older people, and increase the competitive spirit in these older groups. In addition, if masters athletes performed at such a high level for so long, it is reasonable to expect that those destined to maintain that intensity could do so because they remained largely injury free (Knobloch et al. 2008). On the contrary, the relative stability of running performances for males within the 40–64 years age range suggests that this category of "young" men masters athletes has nowadays approached the limits of their marathon performance.

In contrast to males, the running performance times of female masters athletes decreased during the last two decades for all age groups except for the 40–44 years one. These results suggested that the youngest female master runners have already reached their limits in performance during marathon. Improve-

ments of masters running performance have been much greater for females than for males as it has already been observed by Jokl et al. (2004). For example, female running times with the 60–64 years age range decreased by ~7% over the last two decades, while it remained stable for their male counterparts. These data suggest that females older than 50 years may still improve their marathon performance in the future as the new generation of well-trained young female athletes will move into the older age group competitions. In addition to better performances for older female athletes, an increase of density such the top 10 spreads of each age group may also be expected in the future.

Gender difference in running time

The gender gap between male and female world best marathon performances has narrowed during the last 30 years. In 1980, the world record for males was 2:08:34 and for females 2:25:41, corresponding to a differential of 13.3%. The current world marathon record is 2:15:25 for females and 2:03:59 for males (Joyner et al. 2011), corresponding to a gender gap of 9.2%. The present results showed that independently of age, the gender differences in running performance times decreased over the last three decades, suggesting that females have reduced the gap to males. During the last decade, gender differences in running times ranged from ~12% for the 30–40 years age group to ~26% for the 65–69 years age group. This finding corroborates the results of Hunter et al. (2011) and Ransdell et al. (2009) who examined gender differences in elite and age group runners over several marathons. During the decade 1980–1989, the difference between males and females in their performance times increased significantly with advancing age from 55 years up to ~40%. However, since the 1990–1999 decade differences between female and male running times decreased for older age groups, therefore gender differences did not significantly differ across the age. Recently, Lepers and Maffiuletti (2011) have shown that during the 2006–2008 period, gender differences in an ultra-endurance event (Ironman triathlon) performance times increased with advancing age from 55 years. Ironman triathlon is a newer endurance event (the first event held in 1982) with less participants (~2,000), compared to NYC Marathon (Lepers 2008), and that may explain why gender differences across the age in Ironman triathlon are currently similar with to those that were observed for NYC Marathon 30 years ago.

The relative stability of gender differences in marathon running times across the ages observed during the last decade suggests that the age-related declines in physiological function did not differ between males and females. Age-related changes in the physiological determinants of endurance performance (e.g., maximal oxygen uptake, lactate threshold, and running economy) between males and females have not received considerable attention. For example, Holloszy and Kohrt (1995) suggested that the relative rates of decline in maximal oxygen consumption with age are similar between the sexes. However, further investigations are required in order to analyze the age-related declines in other physiological parameters such as lactate threshold and running economy in males and females.

Conclusion

The participation of masters runners at the NYC Marathon increased over the last 30 years, and it will probably still grow in the future in the New York and other marathons worldwide. Interestingly, in the last two decades the master runner's performances have plateaued within the 40–64 years age range for males, but only within the 40–44 years range for females. The present data suggest that male (≥65 years) and female (≥45 years) master runners have probably not yet reached their limits in marathon performances. The relative stability of gender differences in marathon running times across the age these last decades also suggests that the age-related declines in physiological functions did not differ between males and females. Literature on the masters athletes improvements in performance has already and should still stimulate further research on the understanding of age-related physiological changes and the potential slowing of some of the aging processes through athletic training. Further investigations are required in order to analyze participation and performance trends of masters athletes for other sporting endurance events such as swimming, cycling, or triathlon to see if present findings on NYC Marathon are similar for other endurance events.

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References

Baker AB, Tang YQ (2010) Aging performance for masters records in athletics, swimming, rowing, cycling, triathlon, and weightlifting. Exp Aging Res 36:453–477

Burfoot A (2007) The history of the marathon. Sports Med 37:284–287

Faulkner JA, Davis CS, Mendias CL, Brooks SV (2008) The aging of elite male athletes: age-related changes in performance and skeletal muscle structure and function. Clin J Sport Med 18:501–507

Harper S, Howse K (2008) An upper limit to human longevity? Popul Ageing 1:99–106

Hawkins SA, Wiswell RA, Marcell TJ (2003) Exercise and the master athlete—a model of successful aging? J Gerontol Med Sci 58A:1009–1111

Holloszy JO, Kohrt WM (1995) Exercise. In: Masoro EJ (ed) Handbook of physiology: aging. Oxford University Press, Oxford, pp 633–666

Hunter SK, Stevens AA, Magennis K, Skelton KW, Fauth M (2011) Is there a sex difference in the age of elite marathon runners? Med Sci Sports Exerc 43:656–664

Jokl P, Sethi PM, Cooper AJ (2004) Masters's performance in the New York City marathon 1983–1999. Br J Sports Med 38:408–412

Joyner MJ, Ruiz JR, Lucia A (2011) The two-hour marathon: who and when? J Appl Physiol 110:275–277

Knechtle B, Wirth A, Knechtle P, Zimmermann K, Kohler G (2009) Personal best marathon performance is associated with performance in a 24-h run and not anthropometry or training volume. Br J Sports Med 43:836–839

Knobloch K, Yoon U, Vogt PM (2008) Acute and overuse injuries correlated to hours of training in master running athletes. Foot Ankle Int 29:671–676

Lee MS, Tanaka K (1997) Significance of health fitness appraisal in an aging society. Appl Hum Sci 16:123–131

Lepers R (2008) Analysis of Hawaii ironman performances in elite triathletes from 1981 to 2007. Med Sci Sports Exerc 40:1828–1834

Lepers R, Maffiuletti N (2011) Age and gender interactions in ultra-endurance performance: insight from triathlon. Med Sci Sports Exerc 43:134–139

Leyk D, Erley O, Ridder D, Leurs M, Rüther T, Wunderlich M, Sievert A, Baum K, Essfeld D (2007) Age-related changes in marathon and half-marathon performances. Int J Sports Med 28:513–517

Leyk D, Erley O, Gorges W, Ridder D, Rüther T, Wunderlich M, Sievert A, Essfeld D, Piekarski C, Erren T (2009) Performance, training and lifestyle parameters of marathon runners aged 20–80 years: results of the PACE-study. Int J Sports Med 30:360–365

Pate RR, O'Neil JR (2007) American women in the marathon. Sport Med 37:294–298

Phillips SK, Rook KM, Siddle NC, Bruce SA, Woledge RC (1993) Muscle weakness in women occurs at an earlier age than in men, but strength is preserved by hormone replacement therapy. Clin Sci (Lond) 84:95–98

Ransdell LB, Vener J, Huberty J (2009) Masters athletes: an analysis of running, swimming, cycling performance by age and gender. J Exerc Sci Fit 7:61–73

Samson MM, Meeuwsen IB, Crowe A, Dessens JA, Duursma SA, Verhaar HJ (2000) Relationships between physical performance measures, age, height and body weight in healthy adults. Age Ageing 29:235–242

Sparkling PB, O'Donnell EM, Snow TK (1998) The gender difference in distance running performance has plateaued: an analysis of world rankings from 1980 to 1996. Med Sci Sports Exerc 30:1725–1729

Tanaka H, Seals DR (2003) Invited review: dynamic exercise performance in masters athletes: insight into effects of primary human aging on physiological functional capacity. J Appl Physiol 95:2152–2162

Tanaka H, Seals DR (2008) Endurance exercise performance in masters athletes: age-associated changes and underlying physiological mechanisms. J Physiol 586: 55–63

Trappe S (2007) Marathon runners. How do they age? Sports Med 37:302–305

Vihma T (2010) Effects of weather on the performance of marathon runners. Int J Biometeorol 54:297–306

Williams PT (1997) Relationship of distance run per week to coronary heart disease risk factors in 8283 male runners. The National Runners' Health Study. Arch Intern Med 157:191–198

Williams PT (2009a) Incident hypercholesterolemia in relation to changes in vigorous physical activity. Med Sci Sports Exerc 41:74–80

Williams PT (2009b) Lower prevalence of hypertension, hypercholesterolemia, and diabetes in marathoners. Med Sci Sports Exerc 41:523–529