CLINICS

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Analysis of performance and age of the fastest 100-mile ultra-marathoners worldwide

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OBJECTIVES: The performance and age of peak ultra-endurance performance have been investigated in single races and single race series but not using worldwide participation data. The purpose of this study was to examine the changes in running performance and the age of peak running performance of the best 100-mile ultra-marathoners worldwide.

METHOD: The race times and ages of the annual ten fastest women and men were analyzed among a total of 35,956 finishes (6,862 for women and 29,094 for men) competing between 1998 and 2011 in 100-mile ultra-marathons.

RESULTS: The annual top ten performances improved by 13.7% from 1,132±61.8 min in 1998 to 977.6±77.1 min in 2011 for women and by 14.5% from 959.2±36.4 min in 1998 to 820.6±25.7 min in 2011 for men. The mean ages of the annual top ten fastest runners were 39.2±6.2 years for women and 37.2±6.1 years for men. The age of peak running performance was not different between women and men ($p>0.05$) and showed no changes across the years.

CONCLUSION: These findings indicated that the fastest female and male 100-mile ultra-marathoners improved their race time by ~14% across the 1998–2011 period at an age when they had to be classified as master athletes. Future studies should analyze longer running distances (>200 km) to investigate whether the age of peak performance increases with increased distance in ultra-marathon running.

KEYWORDS: Running; Ultra-Endurance; Sex Difference; Athlete.

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INTRODUCTION

Knowledge of the age of peak athletic performance is of major importance for elite athletes (1). When the age of peak performance is known, a high-level athletic career, such as participation in a World Championship or in the Olympic Games, can be better planned. Several studies investigated the age of peak performance for different endurance sport disciplines, such as swimming (2,3), running (2,4–7), track and field (2), and triathlon (8–11).

The age of peak endurance performance has been suggested to depend upon gender (2,6) and the duration of the performance (2,4,8). An analysis of Olympic track and field and swimming data from 1896 to 1980 indicated that the age of peak performance increased with the distance of a foot race for both men and women and that women generally achieved peak performances at a younger age than men (2). In the triathlon, elite Ironman triathletes achieved peak performance at 33±3 years in men and 34±4 years in women (8,9). In elite marathoners, women were fastest at the age of 29.8±4.2 years and men were fastest at 28.9±3.8 years (6). Finishers in a 78-km mountain ultra-marathon reached peak running performance at 33.9±4.2 years in men and 34.4±2.5 years in women (4).

The age of peak performance appears to increase with increased length of an ultra-endurance performance. In ultra-triathletes, the mean age of the finishers of Deca Iron ultra-triathlons (covering 38 km swimming, 1,800 km cycling, and 420 km running) was significantly higher at 41.3±3.1 years compared with finishers of Triple Iron ultra-triathlons (covering 11.4 km swimming, 540 km cycling and 126.6 km running) at 38.5±3.3 years (10). For ultra-marathon performance, there appears to be an interaction between sex and age. In 78-km mountain ultra-marathoners in the 'Swiss Alpine' between 1998 and 2011, the annual top ten women showed no change in their running times across years, whereas the annual top ten men's running times increased. The age for peak running times increased over

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time for both the annual top ten women and the annual top ten men (4). In 161-km ultra-marathoners in the 'Western States 100-Mile Endurance Run' between 1974 and 2007, the mean finish times among all finishers appeared to increase relatively linearly with age for both men and women. The age of the annual top five women and men increased over time from approximately 30 years at the beginning of the race to the upper 30 s in 2007. The trends in the finish times among the annual top five women and men between 1979 and 2007 indicated that the women's performance improved by 37 min per decade but that the men's performance did not improve (12).

Most of the studies investigating the age of peak performance analyzed data from a single race (3,4,8,12,13) or a race series (14). To date, only a few studies have attempted to determine the age of peak ultra-endurance performance (3,4,8,13), defined as events that exceed 6 hours in duration (15). Additionally, only a few studies have investigated whether the age of peak endurance performance changed across the years (4,8). For elite Ironman triathletes competing in 'Ironman Switzerland' between 1995 and 2011, the age of peak performance increased across the years for women from 30 ± 4 years to 36 ± 5 years, whereas the age for men remained unchanged at 31 ± 3 years. Additionally, both women and men improved their race times (8).

There are not yet any studies analyzing data from races held worldwide. The analysis of a single race or a single race series might miss the inclusion of the world's best athletes in the specific discipline. To fill this gap in the literature, we investigated the age of peak ultra-marathon performance by analyzing all race results from 100-mile ultra-marathons held between 1998 and 2011. The purpose of this study was to examine the changes in running performance and the age of peak running performance of the best 100-mile ultra-marathoners worldwide between 1998 and 2011. We hypothesized the following: first, that the 100-mile ultra-marathoners would improve their performance across the years, and second, that the age of peak ultra-marathon performance would increase across the years for both women and men.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of St. Gallen, Switzerland, with a waiver of the requirement for informed consent given that the study involved the analysis of publicly available data. In this study, all athletes who ever participated in a 100-mile ultra-marathon (161-km ultra-marathon) worldwide between 1998 and 2011 were analyzed regarding their participation, race times, and ages for both women and men. The data set for this study was obtained from the website www.ultra-marathon.org. This database collects all race results from ultra-marathon races held worldwide. Data before 1998 appeared incomplete and were therefore not reliable for the data analysis.

Data analysis

Between 1998 and 2011, 827 editions from 183 races were held in 23 countries. To analyze the running performance of the fastest runners and the age of peak running performance, the race times and age of the annual top (i.*e.*, annual fastest race time) and annual top ten (i.*e.*, annual ten fastest race times) women and men were examined. The sex difference in performance was calculated using the equation ([race time in women] – [race time in men])/[race time in men] × 100. The sex difference was calculated for every pairing of equally placed athletes (*e.g.*, between the woman and man in 1st place, between the woman and man in 2nd place, etc.) before calculating the mean value and standard deviation of all the pairings. To facilitate reading, all sex differences were transformed to absolute values before the analysis. The performance densities were calculated for women and men using the equation ([running time of the 10th place] – [running time of the annual fastest])/[running time of the annual fastest] × 100. The performance density shows the difference in the running time between the winner and the 10th place expressed as the percentage of the winner's time to indicate the density of the ten fastest athletes.

Statistical analysis

To increase the reliability of the data analyses, each set of data was tested for a normal distribution and for the homogeneity of variances prior to the statistical analyses. The normal distribution was tested using the D'Agostino and Pearson omnibus normality test, and the homogeneity of variances was tested using Levene's test. To identify significant changes in the development of a variable across the years, linear regression was used. To find significant differences between two groups, Student's *t*-test was used in the case of normally distributed data (with Welch's correction in the case of unequal variances), and the Mann-Whitney test was used in case of non-normally distributed data. To test whether the interaction between age and sex has an impact on performance, a two-way ANOVA (age × sex) with subsequent Bonferroni post-hoc analysis was performed. The statistical analyses were performed using IBM SPSS Statistics (Version 19, IBM SPSS, Chicago, IL, USA) and GraphPad Prism (Version 5, GraphPad Software, La Jolla, CA, USA). Significance was accepted at $p<0.05$ (two-sided for *t*-tests). The data in the text are given as the means ± standard deviations (SD).

RESULTS

Data were available from 36,425 finishers, including 6,929 women and 29,496 men. For 67 women and 402 men, the data (race time or age) were incomplete and had to be excluded. A total of 35,956 finishers (6,862 women and 29,094 men) could be included in the analysis.

Participation trends

Between 1998 and 2011, the number of finishes increased exponentially for both women and men (Figure 1). In 1998, a total of 1,491 athletes finished a 100-mile ultra-marathon, and the number of finishes increased to 35,956 in 2011. The number of women increased from 249 in 1998 to 6,862 in 2011, and the number of men increased from 1,242 to 29,094. The percentage of women finishers increased from 16.7% to 19.1% across the years.

Performance trends

The annual fastest men and women improved their race times across the years with no change in the sex difference (Figure 2A). The fastest women reduced their race time from 1,031 min to 896 min (−13.1%), and the fastest men were

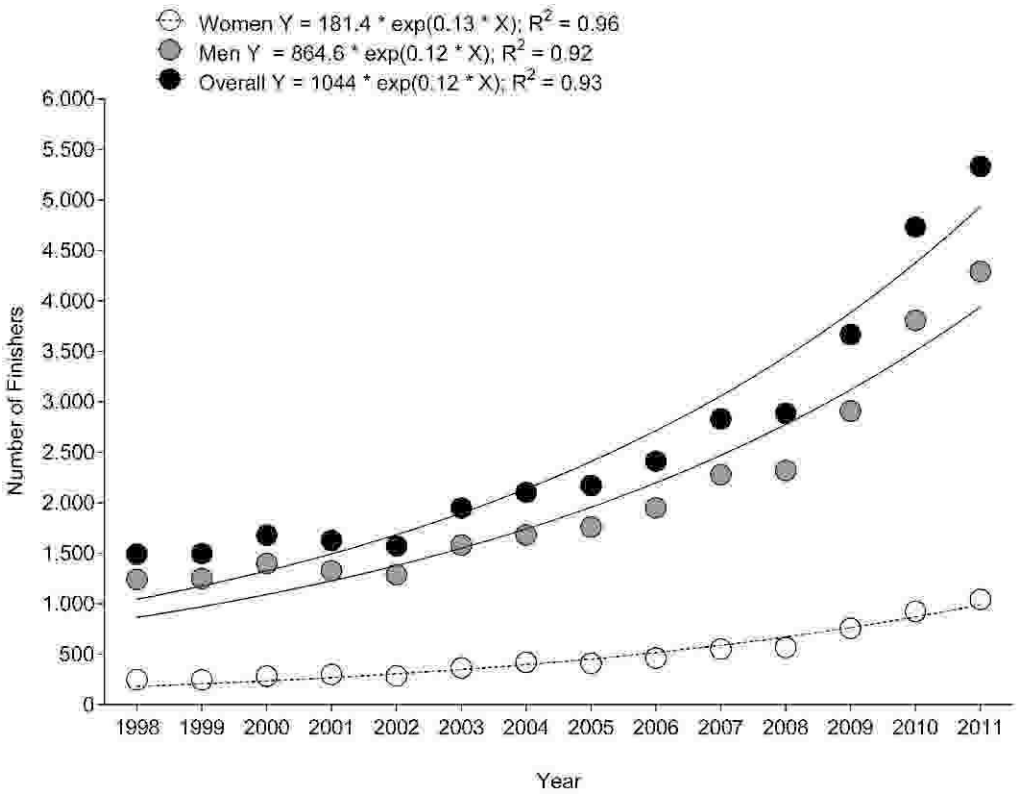

Figure 1 - Changes in the number of annual female and male 100-mile finishes with overall finishes across the years.

able to reduce their race time from 896 to 765 min (−14.6%). The sex difference in performance remained unchanged at 15.0±8.3% across the years ($p>0.05$). Similarly, the annual top ten fastest women and men reduced their running times with no change in the sex difference (Figure 2B). The annual ten fastest women reduced their race times by 13.7% from 1,132±61.8 min in 1998 to 977.6±77.1 min in 2011. The annual ten fastest men lowered their running times by 14.5% from 959.2±36.4 min to 820.6±25.7 min. The sex difference in performance remained unchanged at 17.0±4.1% over time ($p>0.05$).

Figure 3 shows the difference between the annual fastest and the 10th-place finisher expressed as a percentage of the annual fastest race time for women and men between 1998 and 2011. Overall, the difference between the fastest and the 10th-place athlete were 19.6±9.7% (180.0±71.9 min) for women and 13.0±3.6% (123.3±34.1 min) for men. Between 1998 and 2011, there were no changes in the time differences for both men and women ($p>0.05$).

The age of peak running performance

The annual fastest women and men experienced no changes in their age of peak running performance ($p>0.05$) (Figure 4A). The ages of the annual fastest runners were 39.0±5.5 years for women and 37.0±6.0 years for men. Similarly, for the annual fastest top ten women and men, the age of peak running time showed no changes across the years ($p>0.05$) (Figure 4B). The age of the annual top ten fastest runners was 39.2±6.2 years for women and 37.2±6.1 years for men. The age of peak performance did not differ between women and men ($p>0.05$).

Interaction between age and sex for race times

The interaction analysis between age and sex on the race times revealed a significant interaction, with age showing a higher effect than sex. The analysis between age and race times showed a significant ($F=203.97$, $p<0.0001$) interaction, with age accounting for 64.9% of the total variance. The analysis between sex and race times revealed a significant interaction ($F=610.37$, $p<0.0001$), with sex accounting for 21.6% of the total variance.

DISCUSSION

The aim of this study was to examine the changes in performance and age of peak running performance in the best 100-mile ultra-marathoners worldwide between 1998 and 2011. The most important finding was that both female and male ultra-marathoners improved their performances, though their ages of peak performance remained unchanged. Although this cross-sectional data analysis suffers some limitations because variables such as training (16,17), anthropometric characteristics (17,18), previous experience (19–22), and nutrition (23) were not considered, it provided valuable data in the field of ultra-endurance exercise.

Exponential increase in finishes

The number of female and male finishes increased in an exponential manner over the last 14 years. Participation and performance trends in the 100-mile ultra-marathons in the USA, such as the 'Western States 100-Mile Endurance race', have been investigated by Hoffman et al. (12,14,24). Between 1977 and 2008, a total of 32,352 finishes were

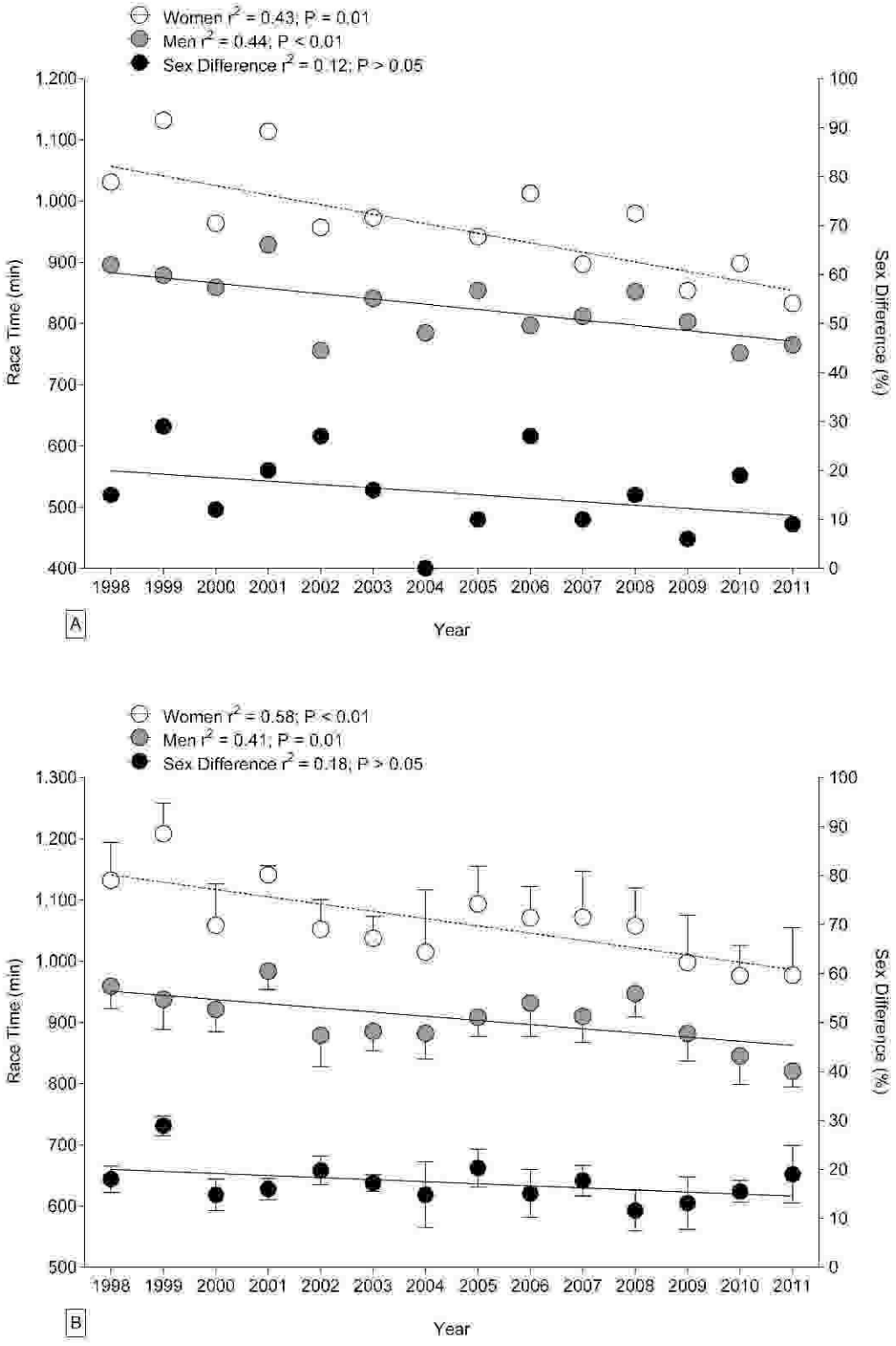

Figure 2 - Changes in the running speeds of the annual fastest (Panel A) and annual ten fastest (Panel B) female and male 100-mile ultra-marathoners across the years.

achieved in the USA by 9,815 individuals (14). The annual number of races and annual number of finishes increased exponentially through a combination of an increase in the participation of runners older than 40 years and a growth in the participation of women (14). The increase in participation among runners >40 years of age changed from less than 40% of the finishes prior to the mid-1980s to 65-70% of the finishes since 1996. Regarding women, the increase went from virtually no women starters in the late 1970s to nearly 20% since 2004 (12,14). Additionally, there was an increase in the

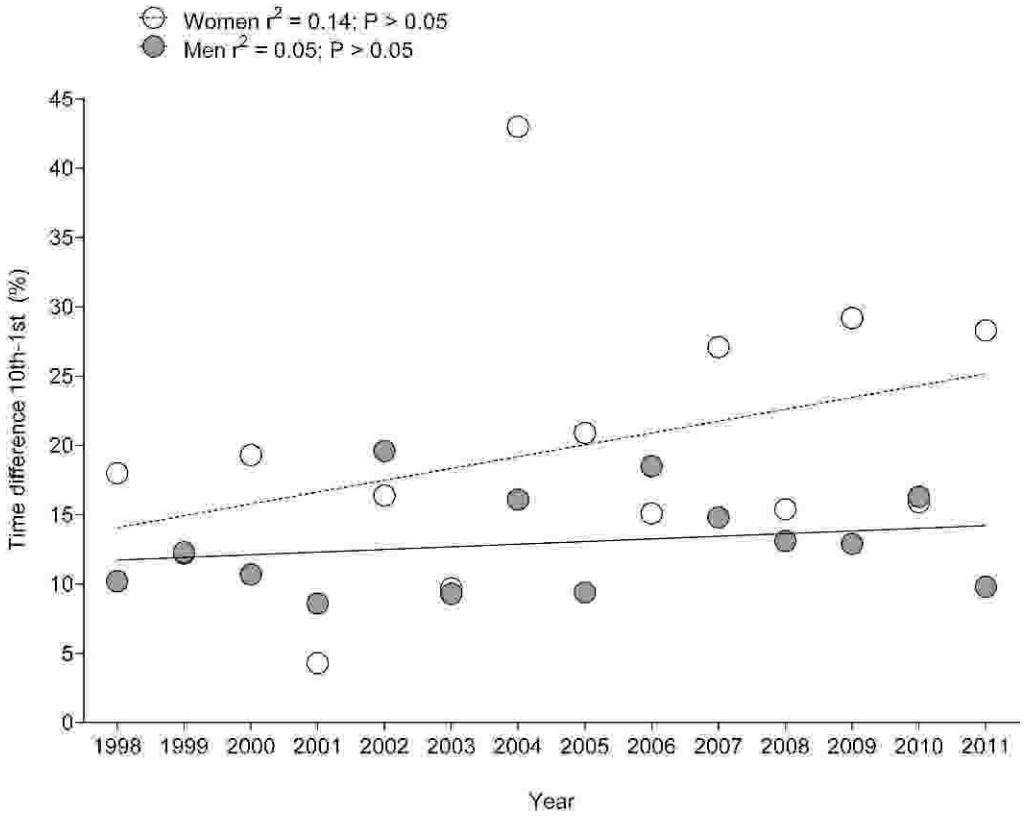

Figure 3 - Changes in the time differences between the annual fastest and 10th-place 100-mile runners across the years, expressed as a percentage of the annual fastest time between women and men.

average annual number of races completed by each individual to 1.3 (14).

The best ultra-runners improved their race times across the years

Both the annual fastest and the annual ten fastest ultra-marathoners improved their race times across the years. This finding is in contrast with those of Hoffman and Wegelin (12) for the 'Western States 100-Mile Endurance Run' between 1974 and 2007, in which the annual top five men showed no change in their finish times between 1979 and 2007 but the annual top five women improved by 37 min per decade from 1980 through 2007. These differences might be explained by the investigated period and the level of the participants. Although Hoffman and Wegelin (12) investigated the participation and performance trends in a single race between 1974 and 2007, we investigated all race results between 1998 and 2011 held in all 100-mile ultra-marathons worldwide. In the 'Western States 100-Mile Endurance Run', the runners ascend a cumulative total of 18,090 feet (5,500 m) and descend a total of 22,970 feet (7,000 m) on mountain trails before reaching the finish. Because we included both road- and trail-based 100-mile ultra-marathons, the performances might be different and may result in greater variability in the data.

Another important finding was that the sex difference in performance remained unchanged at 17.0±4.1% across the years. Hoffman and Wegelin (12) investigated the participation and performance trends in the 'Western States 100-Mile Endurance Run' between 1974 and 2007. The annual top five men showed no change in their finish times between 1979 and 2007. However, the annual top five women improved by 37 min per decade from 1980 to 2007. Therefore, the difference in the average finish times between the annual top five women and annual top five men as a percentage of the average time for the annual top five men also diminished at a rate of 4% per decade to approximately 14% in 2007. A potential explanation for the higher sex difference in performance in the present findings might be the different time periods and samples investigated.

The difference between the fastest and the 10th-place athlete between 1998 and 2011 was higher in women (19.6±9.7%) than in men (13.0±3.6%), with no change over time. This finding suggests that the top ten performance density was higher in men than in women. Similar findings were reported for other ultra-endurance events, such as the 'Ironman Hawaii' triathlon, in which the top ten performance density was also higher in men than in women (25).

The fastest 100-mile ultra-marathoners are master athletes

The annual top ten fastest women and men were, on average, 39.2±6.2 and 37.2±6.1 years old, respectively, when achieving the fastest 100-mile race times worldwide.

The age of peak performance did not differ between women and men. This age is older than 35 years, when elite athletes generally became master athletes. Master athletes are typically older than 35 years of age and systematically train for, and compete in, organized forms of sport specifically designed for older adults (26). The increased age might be explained by socio-demographic reasons. Hoffman and Fogard (24) performed a cross-sectional

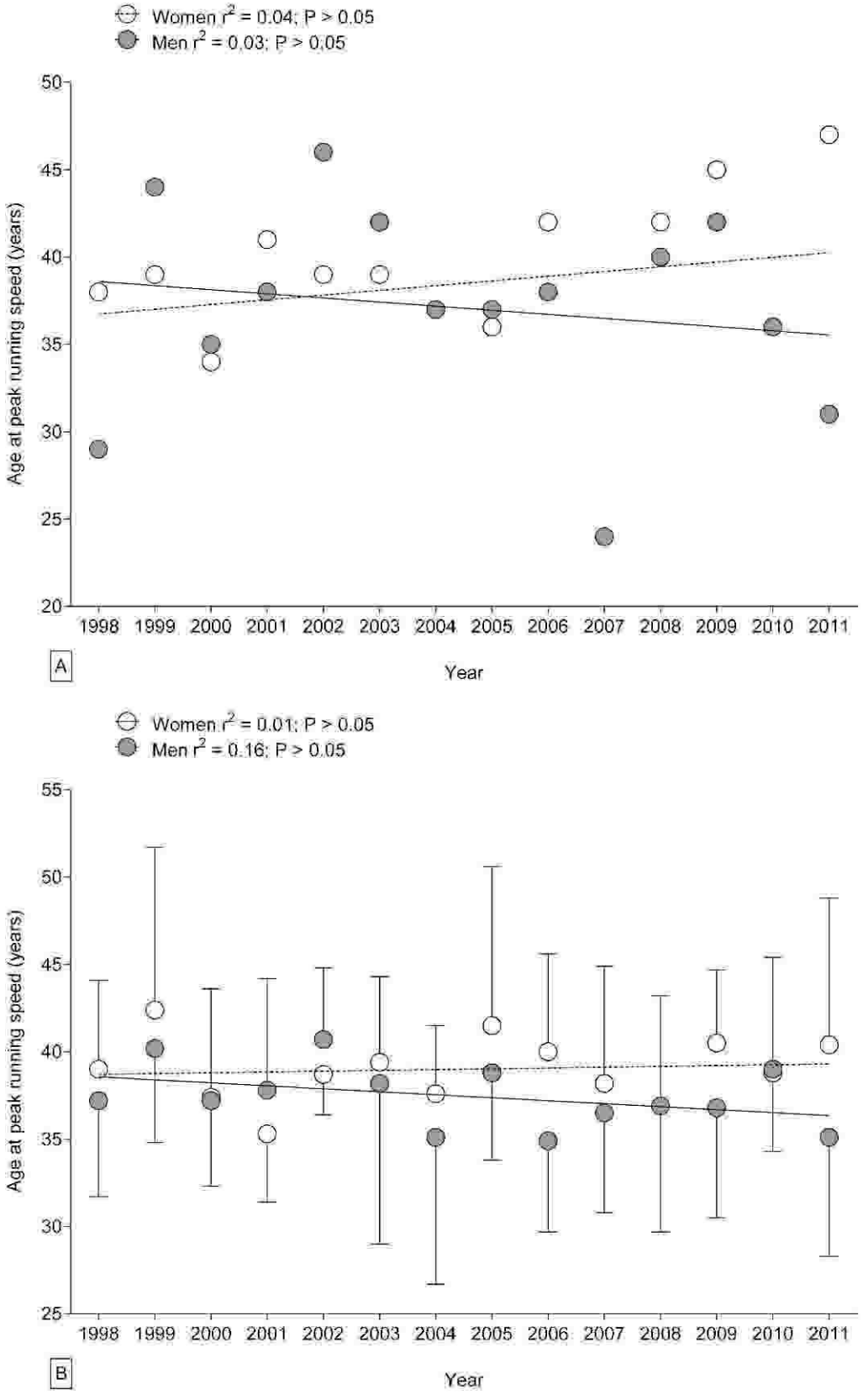

Figure 4 - Changes in the ages of peak running speed of the annual fastest (Panel A) and annual ten fastest (Panel B) female and male 100-mile ultra-marathoners across the years.

analysis in the 'Western States Endurance Run' and the 'Vermont 100 Endurance Race'. In these races, the participants were asked for the general characteristics of individuals participating in these events, including age, sex, education level, marital status, running history, and the injury and illness history from the previous year. Participants in 100-mile ultra-marathons had a mean age of 44.5±9.8 years (range 20–72 years), were generally men (80.2%), were married (70.1%), and had bachelor's (43.6%) or graduate (37.2%) degrees.

Generally, the number of runners >40 years of age is high in the 100-mile ultra-marathons (5,12,14,16,24). Hoffman et al. (14) examined the participation trends in the 100-mile ultra-marathons held in North America from 1977 through 2008. The annual number of races and number of finishes increased exponentially over the study period. The growth in the number of finishes occurred through a combination of an increase in participation among runners >40 years of age from less than 40% of the finishes prior to the mid-1980s to 65–70% of the finishes since 1996. Furthermore, an increase in the participation among women from virtually none in the late 1970s to nearly 20% since 2004 has occurred. There was also an increase in the average annual number of races completed by each individual to 1.3.

The age of the fastest finishers showed no changes over time, in contrast to the findings of Hoffman and Wegelin (12) for the 'Western States 100-Mile Endurance Run' between 1974 and 2007. The ages for the top five men increased over the history of the race from approximately 30 years to the upper 30s. For women, the ages of the top five finishers also gradually increased since 1990 in a similar pattern to that of the men, reaching the upper 30 s in recent years (12). The differences might be explained by the investigated period and the level of the participants. Whereas Hoffman and Wegelin (12) investigated the participation and performance trends in a single race between 1974 and 2007, we investigated all race results between 1998 and 2011 held in all 100-mile ultra-marathons worldwide.

These findings revealed that the world's fastest female and male 100-mile ultra-marathoners improved their race times by ~14% across the 1998-2011 period at ages when they must be classified as master athletes. The age of peak performance did not differ between male and female ultra-runners and showed no changes over time. Future studies need to analyze greater running distances to investigate whether the age of peak performance could change with increasing length in ultra-marathoners. The definition that master runners are >35 years must be called into question, especially for ultra-marathoners.

AUTHOR CONTRIBUTIONS

Rüst CA performed the statistical analyses and drafted the manuscript. Knechtle B designed the study, collected the data, and helped drafting the manuscript. Rosemann T critically revised the manuscript for important intellectual content. Lepers R provided assistance with the statistical analyses and helped drafting the manuscript.

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