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Nikolaidis, Pantelis Theodoros ; Knechtle, Beat

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DOI: https://doi.org/10.1080/02640414.2017.1325965

Originally published at:
Nikolaidis, Pantelis Theodoros; Knechtle, Beat (2018). The age-related performance decline in marathon cross-country skiing - the Engadin Ski Marathon. Journal of Sports Sciences, 36(6):599-604.
DOI: https://doi.org/10.1080/02640414.2017.1325965

The age-related performance decline in marathon cross-country skiing – the Engadin Ski Marathon

Running head: Age and performance in cross-country skiing

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Abstract

The aim of the present study was to determine the age-related performance decline in the 'Engadin Ski Marathon', a cross-country race covering the marathon distance of 42.2km. Demographic and performance data from 197,825 athletes competing in this race between 1998 and 2016 were analysed. During these 17 years, ~5 times more men finished than women. When all finishers per age group were considered, there was no gender difference in race time (2:59:00 in women *versus* 2:59:09 h:min:s in men; $p=0.914$, $\eta^2<0.001$) and the main effect of age group on race time was trivial ($p<0.001$, $\eta^2=0.007$). When the top 10 finishers per age group were considered, men were faster than women (1:27:32 *versus* 1:34:19 h:min:s, respectively; $p<0.001$, $\eta^2=0.373$), there was a large effect of age group on race time ($p<0.001$, $\eta^2=0.590$) and the gender difference was larger in the older than in the younger age groups ($p<0.001$, $\eta^2=0.534$). The age of peak performance for all finishers by 1-year interval age group was 40.3 and 39.6 years in all women and men, respectively. The top 10 finishers by 1-year interval age group achieved their peak performance in the age of 38.4 and 42.2 years in women and men, respectively. In summary, the age of peak performance was older and the age-related performance decline occurred earlier in marathon cross-country skiing compared to road-based marathon running.

Key words: athlete, female, male, winter sport

Introduction

It is well known that athletic performance decreases with increasing age (Gava, Kern, & Carraro, 2015; Tanaka & Seals, 2008). The best endurance performances are often achieved at the age of ~35 years with a small and linear decline until the age of ~50-60 years and a more pronounced decline after that age (Tanaka & Seals, 2008).

The age-related performance decline is also dependent upon the mode of physical exercise. For example, physical performances involving mostly upper limbs (*e.g.* shot put, javelin throw) show a higher rate of decline (1.4% per year) compared to performances where the lower limbs are mostly involved (*e.g.* long jump 1.1%, track events 0.6-0.7% per year) (Gava et al., 2015). Most importantly, the performance decline with ageing is related to the duration of an event, as it has been observed that sprint or power sports show higher rates of decline than endurance sports with ageing (Allen & Hopkins, 2015).

Apart from the mode of physical performance, there is also an influence of gender on the age-related performance decline. For example, in running there is a difference in the age-related decline by both distance and gender (Zingg, Rüst, Rosemann, Lepers, & Knechtle, 2014). In track and field athletes, differences were reported in the rates of percentage decline in running events among various distances, and significant differences between women and men were found in a study, where the decline with increasing age was greater for women and for longer endurance running events (Baker, Tang, & Turner, 2003).

In running, the age-related performance decline has been well-investigated in female and male marathoners. Leyk et al. (2007) reported that a significant age-related

decline in marathon running performance did not occur before the age of ~50 years. Indeed, they showed that female and male marathoners can achieve a similar race time between the ages of 20 and 50 years. A more recent study investigating female and male master marathoners competing in the 'New York City Marathon' between 1980 and 2009 showed that male (≥65 years) and female (≥45 years) master runners may not have reached their limits in marathon running performance (Lepers & Cattagni, 2012).

These findings for the age-related performance decline in marathon running are most probably due to the fact that master athletes have significantly improved their performance over years (Ahmadyar, Rosemann, Rüst, & Knechtle, 2016) whereas the performance of younger athletes has remained the same (Akkari, Machin, & Tanaka, 2015). In running and swimming, the magnitude of improvements over four decades was greater in athletes in older age groups gradually closing the gap in athletic performance between younger and older athletes (Akkari et al., 2015). Recently, it has been shown that even athletes older than 100 years are able to achieve outstanding endurance performances (Lepers, Stapley, & Cattagni, 2016).

Although we know the age-related performance decline for shorter (Akkari et al., 2015; Gava et al., 2015) and longer running distances such as the marathon distance (Leyk et al., 2007), we have no knowledge about the age-related performance decline in cross-country skiing, and especially on the marathon distance in cross-country skiing. Cross-country skiing is a very popular sport, especially in Scandinavian and Central European countries. Consequently, knowledge about the age-related trends in performance might be of great importance for athletes' coaches and sport scientists. Sport scientists might use this knowledge to better understand the variation of age-

125 related changes among different modes of exercise, whereas coaches might develop
126 gender- and age-tailored training goals and programs.

127 Therefore, the aim of the current study was to determine the age-related performance
128 decline in marathon cross-country skiing in the 'Engadin Ski Marathon', a cross-
129 country race covering the distance of a marathon (42.195 km). Based upon findings
130 for road-based marathon running following Leyk et al. (2007) showing that a
131 significant age-related decline in marathon running performance did not occur before
132 the age of ~50 years, we hypothesized that the age-related performance decline in
133 marathon cross-country skiing would not occur before the age of 50 years for both
134 women and men.

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Methods

Ethical approval

All procedures used in the study were approved by the Institutional Review Board of Kanton St. Gallen, Switzerland with a waiver of the requirement for informed consent of the participants given the fact that the study involved the analysis of publicly available data.

The race

All athletes who finished the 'Engadin Ski Marathon' between 1998 and 2016 were considered. Data with name, age and gender of the athletes, *i.e.* 34,833 women and 162,992 men, were obtained from the publicly available race website of the 'Engadin Skin Marathon' at www.engadin-skimarathon.ch.

The 'Engadin Ski Marathon' is an annually held cross-country ski race taking place on the second Sunday of March in the upper Engadin valley in Switzerland, Europe, between Maloja and S-chanf. The race started in 1969 and is one of the major cross-country skiing events in the Swiss Alps. Each year, between 11,000 and 13,000 skiers participate in the race. Since 1998, the total distance covered is 42 km. In that year, the race was extended by 2 km to match the distance of a full running marathon and the track was changed slightly resulting in a more difficult topography and longer race times. While it is a freestyle race, there are separate tracks for skiers practicing classic style for all but the narrowest parts of the race. Participation is open to anyone from the age of 16 years and no license is required to enter the event. The start of the race takes place in Maloja at the Maloja Palace Hotel with an elevation of 1,820 meters above sea level and the finish at an elevation of 1,670 meters above sea level.

Statistical analysis

All statistical analyses were performed using the statistical package IBM SPSS v.20.0 (SPSS, Chicago, USA). The figures were created using the software GraphPad Prism v. 7.0 (GraphPad Software, San Diego, USA). Data were presented as mean±standard deviation. We examined the association of gender and age group, *i.e.* whether the distribution of gender varied by age group, using chi-square (χ^2) and Cramer's phi (φ_C) to evaluate the magnitude of association. We used two approaches to classify the participants into age groups; (a) 5-year age groups from <20 to 75-79 years and (b) 1-year age groups from 17 to 92 years. Furthermore, in each approach we examined both the top 10 and all skiers. The men-to-women ratio was calculated for the whole sample and for each age group. A two-way ANOVA examined the main effects of gender and age group, and the gender × age group interaction on race time, followed by a Bonferroni post-hoc analysis. The magnitude of differences in the ANOVA was evaluated using eta-squared (η^2) as trivial ($\eta^2<0.01$), small ($0.01\leq\eta^2<0.06$), moderate ($0.06\leq\eta^2<0.14$) and large ($\eta^2\geq0.14$) (Cohen, 1988). The above mentioned ANOVA was run twice, one considering all finishers and one considering only the top 10 skiers. We used a mixed-effects regression model to examine differences in race time by gender and age group (Tabachnick & Fidell, 2013). In the model, finisher was inserted as random variable, and gender and age group as fixed variables. In addition, we examined interaction effects between these fixed variables. Akaike information criterion (AIC) was used to select the final model. The alpha level was set at 0.05.

Results

Full data with gender, age and race time from a total of 197,826 female and male athletes were available. In one athlete an extreme value was found and this athlete was deleted, leaving 197,825 athletes for data analysis.

Gender × age group chi square

The overall men-to-women ratio was 4.7. However, a gender×age group association was observed (χ^2=6130.13, p<0.001, Cramer's φ=0.176), where the men-to-women ratio was ranged from 2.4 (20-24 years age group) to 130.5 (80-84 years age group) (Figure 1). A trend was shown where the men-to-women ratio was higher in the older than in the younger age groups. In addition, the distribution of women and men in age groups followed a different pattern with most women in the age group 30-34 years whereas most men were in age group 40-44 years.

Gender × age group ANOVA

When all finishers were considered, no main effect of gender on race time was observed (p=0.914, η^2<0.001), where the scores were 2:59:00 and 2:59:09 h:min:s in men and women, respectively (Figure 2). A trivial main effect of age group on race time was observed (p<0.001, η^2=0.007) with the age group 40-44 years the fastest and the oldest age group the slowest (Figure 3). No gender × age group interaction on race time was observed (p=0.773, η^2<0.001). The findings of the mixed-effects regression analysis are presented in Table 1.

When the top 10 finishers were considered for each age group, a large main effect of gender on race time was observed (p<0.001, η^2=0.373) with men significantly faster than women (1:27:32 and 1:34:19 h:min:s, respectively). Also, a large main effect of

age group on race time was shown ($p<0.001$, $\eta^2=0.590$) with the oldest group the slowest. A large gender × age group interaction on race time was observed ($p<0.001$, $\eta^2=0.534$) with men significantly faster than women in most age groups and the gender difference increased with age. The results of the mixed-effects regression analysis are presented in Table 2.

The age of peak performance

The age of peak performance was 40.3 and 39.6 years in all women and men, respectively, when they were examined in 1-year intervals (Figure 4). The top 10 finishers by 1-year interval age group achieved their peak performance at the age of 38.4 and 42.2 years in women and men, respectively.

When 5-year intervals were considered, the age group of peak performance was 40-44 years in both all women and men, but it was 40-44 years in women and 55-59 years in men when the top 10 finishers were considered.

Discussion

This study determined the age-related performance decline in marathon cross-country skiing. It was hypothesized that this age-related decline in performance would not occur before the age of 50 years in contrast to previous findings in marathon running. The main findings of the present study were that (*i*) the number of men finishers was ~5 times more than women and the men-to-women ratio was higher in the older than in the younger age groups; (*ii*) when all finishers in each age group were considered, there was no gender difference in race time and the effect of age group on race time was trivial; (*iii*) when the top 10 finishers in each age group were considered, men were faster than women and there was a large effect of age group on race time and the gender difference increased with age; and (*iv*) the age of peak performance was ~40 years for both women and men.

Gender difference in performance

A potential explanation for the difference in the fastest women and men cross-country skiers could be the fact that most women were in the age group 30-34 years and most men in the age group 40-44 years. Furthermore, the men-to-women ratio was higher in the older cross-country skiers than in the younger age groups indicating that relatively more men competed in the older age groups compared to women. Also, the men-to-women ratio was ~5:1 in these athletes whereas in marathon running, the men-to-women ratio decreased in the 'New York City Marathon' from 5.6:1 in 1983 to 2.5:1 in 1999 indicating an increase in female athletes (Jokl, Sethi, & Cooper, 2004).

Differences in the age-related performance decline between women and men

A major finding was that the age-related performance declined in these marathon cross-country skiers after the age of 40-44 years when all women and men were considered. However, when the 10 top skiers per age group were considered, the decline started after the age of 40-44 years in women and 50-59 years in men. This finding is in contrast to marathon running where the age-related decline in performance did not occur before the age of 50 years for both women and men (Leyk et al., 2007).

Older age of peak performance compared to marathon running

Another important finding was that the age of peak marathon cross-country performance was at the age of ~40 years for both women and men. In marathon running, the age of peak performance is at ~30-35 years, depending upon the sample and the method of analysis (Hunter, Stevens, Magennis, Skelton, & Fauth, 2011; Lara, Salinero, & Del Coso, 2014; Lehto, 2016; Nikolaidis, Onywera, & Knechtle, 2016). With regards to the general physiological functions of humans, the age of performance peak was 26 years in a study that examined the development of sport and chess performances across the lifetime (Berthelot et al., 2012).

The difference of ~10 years between marathon cross-country skiing and marathon running might be explained by differences in analyses, performance level and mode of movement. Cross-country skiing performance relies on factors limiting endurance such as maximal oxygen uptake, anaerobic threshold and exercise economy (Tanaka & Seals, 2008) as in other exercise modes including running, cycling and swimming. On the other hand, in addition to these physiological factors, cross-country skiers need to interact efficiently with their equipment as skiing is a sport that relies more in

technique and recruits the upper and lower body, which might explain why they maintain peak performance in older age than in other exercise modes such as marathon running.

A factor explaining the peak performance in older age in cross-country skiing compared to marathon runners could be fact that studies investigating age of peak marathon running performance have used data from flat city marathons at close to sea level (Hunter et al., 2011; Lara et al., 2014; Lehto, 2016; Nikolaidis et al., 2016) while the cross-country skiing marathon examined in the current study was held in hilly Alps and at altitude. A recent study investigating age of peak marathon running performance comparing flat city marathons and a mountain marathon showed significant differences in the age of peak marathon performance between mountain and city marathon running (Knechtle, Nikolaidis, Zingg, Rosemann, & Rüst, 2017). In that study, the age of the top 10 women and men was older in the mountain marathon compared to the city marathons when the fastest runners were considered in 1-year age-intervals, but when all finishers were considered in 1-year age-intervals, the age of the fastest women and men was younger in the mountain marathon compared to the city marathons. An explanation of a younger age of peak performance in exercise in mountain compared to flat might be the additional muscle work and muscle power demands during exercise in mountain. Considering that the age of the peak of muscle power performance is younger than that of endurance, it is deduced that an the age of peak performance in an exercise demanding more muscle power would be younger than an exercise demanding more endurance capacity.

316 ***Limitations, strength, implications for future research and practical applications***

317 A limitation of the present study was that since every cross-country skiing marathon
318 possesses its own unique characteristics in terms of number participants,
319 environmental conditions, duration and topography, the current findings should be
320 generalized with caution. Although the findings were limited to a single skiing
321 marathon race, they were focused on a major skiing event in Alps with large
322 international participation. Future studies might investigate other races of the same or
323 similar distance and environmental conditions. Moreover, the large number of
324 finishers covering the adult life span was a major strength of the present study that
325 allowed for the robust examinations of differences among age groups. The gender-
326 and age-related differences observed add theoretical knowledge that may be useful for
327 sport scientists studying the variation of performance decline with aging in different
328 exercise modes. In addition, coaches and fitness trainers working with cross-country
329 skiers may benefit from the findings by setting gender- and age-tailored goals and
330 developing optimal training programs. For instance, considering that there was no
331 gender difference in performance when all finishers were analysed, recreational
332 athletes should be advised independent of their gender. However, since elite men were
333 faster than women, this should be taken into account when training more competitive
334 athletes.

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Conclusions

In marathon cross-country skiers competing in the 'Engadin Ski Marathon' between 1998 and 2016, the age of peak performance was 40.3 and 39.6 years in all women and men, when they were examined in 1-year intervals. The top 10 finishers examined by 1-year intervals achieved their peak performance at the age of 38.4 and 42.2 years in women and men, respectively. When the age-related performance decline was considered in 5-year intervals, the age group of peak performance was 40-44 years in women and men when all finishers were considered, but it was 40-44 years in women and 55-59 years in men when the top 10 finishers only were considered. Compared to existing findings for road-based running marathon, the age of peak performance was higher and the age-related performance decline occurred earlier in marathon cross-country skiing.

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Table 1 Results of the mixed-effects regression analysis for race time considering all finishers in each 5-year age group

Parameter	Estimate	SEE	P value
Intercept	10379.78	20.43	<0.001
Group	57.16	2.92	<0.001
[Gender=Women]	334.69	45.71	<0.001
[Gender=Men]	0[a]	0	.
[Gender=Women] ×Age group	-60.14	7.66	<0.001
[Gender=Men] ×Age group	0[a]	0	.

[a]This parameter is set to zero because it is redundant.
SEE=standard error of estimate.

Table 2 Results of the mixed-effects regression analysis for race time considering the top 10 finishers in each 5-year age group

Parameter	Estimate	SEE	P value
Intercept	4246.49	254.81	<0.001
Group	262.57	28.02	<0.001
[Gender=Women]	371.16	375.56	0.324
[Gender=Men]	0[a]	0	.
[Gender=Women] ×Age group	-9.15	44.65	0.838
[Gender =Men] ×Age group	0[a]	0	.

[a]This parameter is set to zero because it is redundant.
SEE=standard error of estimate.

List of figures

Figure 1

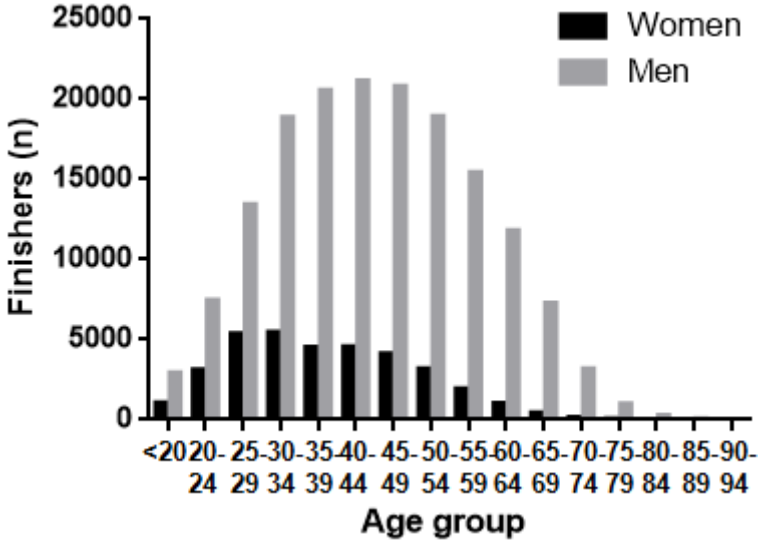

Women
Men
Finishers (n)
25000
20000
15000
10000
5000
0
<20
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90-94
Age group

Figure 2

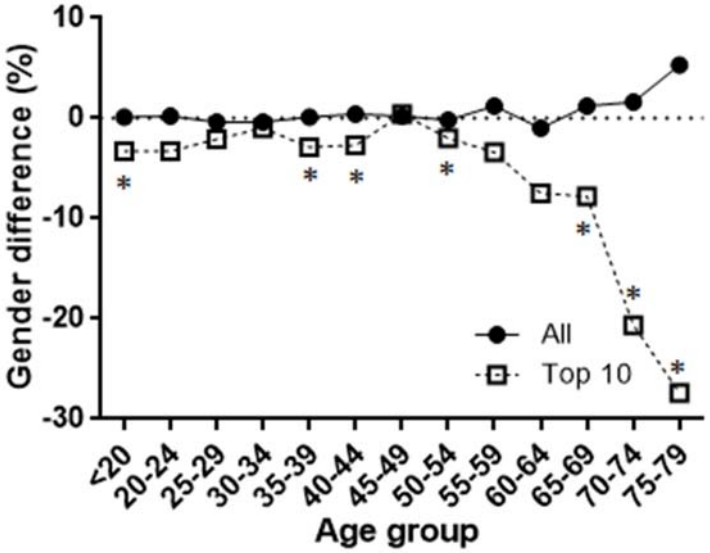

10
0
-10
-20
-30
Gender difference (%)
All
Top 10
<20
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
Age group

Figure 3

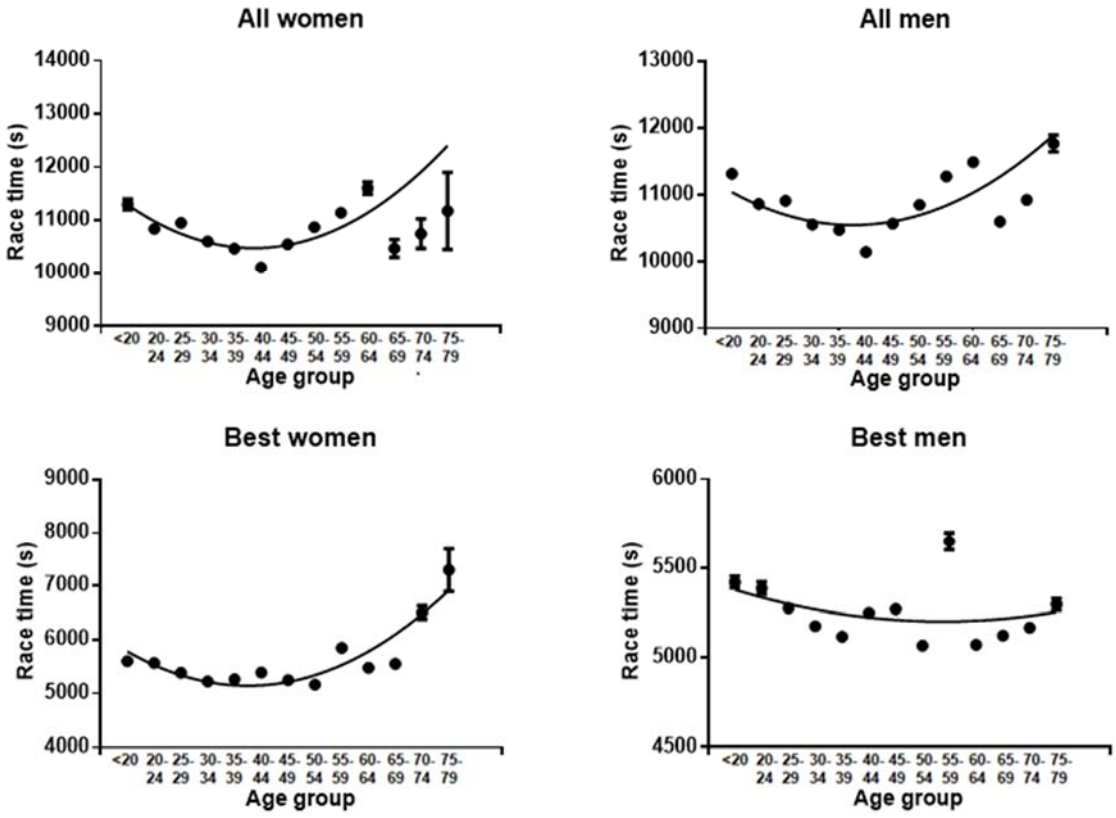
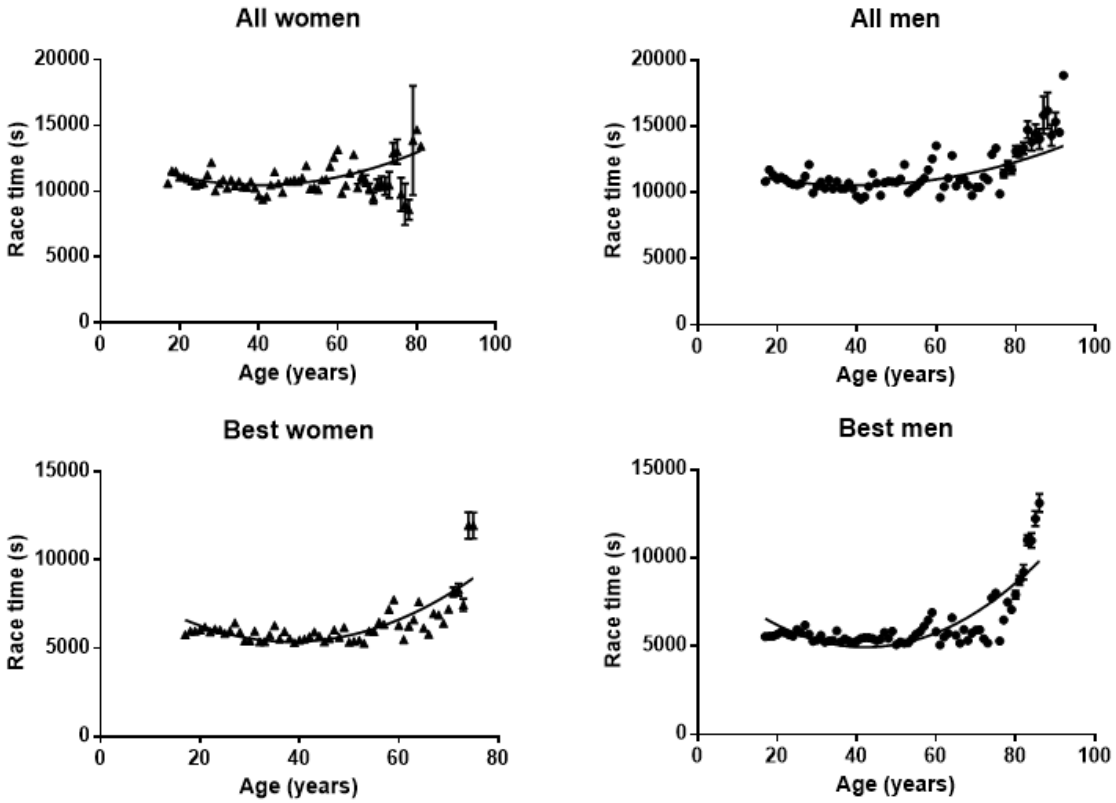

All women
Race time (s)
14000
13000
12000
11000
10000
9000
<20 20-24 25-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69 70-74 75-79
Age group
All men
Race time (s)
13000
12000
11000
10000
9000
<20 20-24 25-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69 70-74 75-79
Age group
Best women
Race time (s)
9000
8000
7000
6000
5000
4000
<20 20-24 25-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69 70-74 75-79
Age group
Best men
Race time (s)
6000
5500
5000
4500
<20 20-24 25-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69 70-74 75-79
Age group

Figure 4


All women
Race time (s)
Age (years)
All men
Race time (s)
Age (years)
Best women
Race time (s)
Age (years)
Best men
Race time (s)
Age (years)