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Differences in Age of Peak Marathon Performance between Mountain and City Marathon Running - The 'Jungfrau Marathon' in Switzerland

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Abstract

The age of the best marathon performance has been well investigated for flat city marathon running, but not for mountain marathon running. The aim of this study was to determine the age of the best mountain marathon performance and to compare to results of a flat city marathon. Race times and ages of finishers of a mountain marathon with 1,830 m of altitude change (Jungfrau Marathon, Switzerland) and two flat city marathons (Lausanne Marathon and Zurich Marathon, Switzerland) were analysed using linear, non-linear and mixed-effects regression analyses. Race times were slower in the mountain compared to the city marathon. In both the mountain marathon and the city marathons, women and men improved performance and men were faster than women when the fastest per year and all per year were considered. When the fastest runners in 1-year age intervals were considered in the mountain marathon, the fastest man (3:01 h:min) was ~35.6 years and the fastest women (3:28 h:min) ~34.5 years old. When all finishers were considered in 1-year age intervals, the fastest men (4:59 h:min) were ~29.1 years old and the fastest women (5:16 h:min) were ~25.6 years old. In the city marathons in 1-year age intervals, the fastest man (2:10 h:min) was ~23.7 years old and the fastest woman (2:36 h:min) ~32.2 years old. When all finishers were considered in 1-year age intervals, the fastest men (3:41 h:min) were ~35.0 years old and the fastest women (4:00 h:min) ~33.8 years old. In summary, the age of the fastest women and men was higher in the mountain marathon compared to the city marathons when the fastest runners were considered. However, when all finishers were considered the age of the fastest women and men was lower in the mountain marathon compared to the city marathons.

Key Words: age, athlete, man, running, woman

Introduction

Every sports discipline has its specific age of peak performance (1, 19, 41). In marathon running, the age of peak marathon performance was reported to be between ~20 and ~50 years for both women and men depending upon the investigated races or data and the kind of analysis (19, 24, 27, 28, 31). Hunter *et al*. (19) analysed the five fastest men and women (*i.e.* peak running speed) in seven major marathon events. Women (29.8 ± 4.2 years) were older than men (28.9±3.8 years), but for only two (Chicago and

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London) of the seven marathons (19). When marathon race times of the top ten men and women (from 18 to 75 years) in the 'New York City Marathon' were analysed in 1-year intervals for the 2010 and 2011 races, the fastest race times were obtained at ~27 years in men and at ~29 years in women (27). When world single age records in marathon running were analysed in 1-year intervals for women and men, performance was quite linear between ~20 and ~35 years, but started to decrease at the age of ~35 years in a curvilinear manner with increasing age in both women and men (24). In male marathoners competing from 1979 to 2014 in the 'Stockholm Marathon', the best performance was achieved at the age of ~34 years (28). At around the age of ~50 years both women and men show a decline in running speed, but more pronounced in women (31). Leyk *et al*. (31) demonstrated that running speed showed no changes before the age of ~50 years in both marathoners and half-marathoners.

Different anthropometric (3), physiological (29), and training characteristics (4, 38) seemed to influence running speed depending upon both the length and the duration of an endurance event (20). Several predicting factors were found over the years, where body mass and raw muscle strength seemed to be particularly critical variables (9). Body mass and raw muscle strength seemed to influence peak running speed the most (13, 35). Male elite runners seemed to have higher skeletal muscle mass and lower body fat (35) compared to elite female runners.

Regarding age in mountain marathon running, one study investigated the change in age of peak performance in a mountain ultra-marathon, the 78-km 'Swiss Alpine' in Davos, Switzerland (11). There seemed to be an increase in the age of peak running performance over the years. The authors found an increase in the age of peak running performance in the top ten runners from ~33 years in 1998 to ~37 years in 2011 over a time span of 14 years (11). The findings were explained with the fact that maximal oxygen intake does not significantly differ among athletes between the age of 35 and 49 years (5). Age seems also related to experience in running (25). In time-limited ultra-marathons held from 6 h to 10 days during 1975-2013, the age of peak ultra-marathon performance increased with increasing race duration and with increasing number of finishes. Furthermore, these athletes improved race performance with increasing number of finishes (25). Apart from age, experience is an important variable in runners such as mountain ultra-marathoners (22). In male mountain ultra-marathoners competing in a 7-day mountain ultra-marathon over 350 km with a total of 11,000 m of altitude, average speed in running during training and personal best marathon time were related to race performance suggesting that training and previous experience are of increased importance in mountain ultra-marathoners (22). Since mountain marathon winner times[1] were considerably longer than winner times in flat city marathons (19), the change in altitude must be considered particularly. The popularity of mountain ultra-marathon running events, such as the 'Western States 100-Mile Endurance Run' in the USA, has increased over the past years (18). Since a mountain marathon topographically differs from a city marathon and the trail conditions change continuously, running experience is a major factor in mountain marathon running. A mountain marathon runner does not need one single pace for the whole run, but planning and pacing is of outmost importance; this planning may be accomplished better by older and experienced runners (32).

These mentioned factors such as body mass, skeletal muscle mass, sex, and previous experience leads to the assumption that the optimal elite mountain marathon runner a lean and experienced man in his early to mid-30s, but older than a conventional elite city marathoner. For this reason, the 'Jungfrau Marathon' in Switzerland with its 1,830 m of altitude difference and race time of about 4 h (47) stands between a city marathon and an ultra-marathon event. Therefore, the age of peak running speed is supposed to be between ~20-35 years for male and female marathoners (19, 24, 27) and ~32-42 years for female and male mountain ultra-marathoners (11).

To the best of our knowledge, there is no previous work addressing the age of peak performance in mountain marathon running. This information is of great practical value for coaches and athletes in order to set age-tailored goals and design according to their training program, especially considering that an increasing number of runners participate successfully in marathon races (25). This increased number of runners is accompanied by a great range of ages of participants highlighting the need to examine the variation of performance by age. Compared to the past, when the range of runners' age was shorter, nowadays coaches train runners of variety of ages, thus, it is of practical value for them to be aware of the relationship between age and performance. Sport scientists might also benefit from knowledge of age of peak performance, as they can use such information as reference in future studies.

The aim of the present study was, therefore, to examine the age of peak running performance in a mountain marathon compared to a flat city marathon. We hypothesized that the age of peak running performance would be higher in a mountain marathon (≥35 years) compared to a flat city marathon (≤35

[1] World Mountain Running Association, website www.wmra.ch/index.php

years). This hypothesis was relied on the physiological and biomechanical differences between mountain and flat running. For instance, in level running an equal elastic energy storage and recovery was observed, whereas asymmetrical fluctuations in mountain running were noticed (42). In another study, it has been shown that athletes should alter their uphill running patterns for a more economical step mechanics during mountain running (45). These biomechanical differences might imply the need for more expertise in running technique in mountain running which in turn might result from a longer experience in the event, *i.e.* older age. Moreover, the different duration of the two events (*i.e.* mountain marathon *vs.* flat city marathon) might impose different nutritional requirements (7, 26). To test this hypothesis we compared running times and ages of athletes competing between 2000 and 2015 in the 'Jungfrau Marathon' in Switzerland with more than 60,000 finishers to data from the 'Lausanne Marathon' and the 'Zurich Marathon', two flat city marathons also held in Switzerland, with more than 75,000 finishers during the same period of time. We used a second order polynomial regression in 1-year age classes with both the best women and men and all women and men for each age class following Lehto (28).

Materials and Methods

Ethics

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 Races

In this study, all athletes who finished the 'Jungfrau Marathon' and two city marathons, the 'Lausanne Marathon' and the 'Zurich Marathon' between 2000 and 2015 were analysed for participation, race time, age, and sex. We included two city marathons in order to have a similar and comparable number of female and male finishers for both mountain and city marathon running. The data set for this study was obtained from the race websites of the 'Jungfrau Marathon' [2], the 'Lausanne Marathon' [3], and the 'Zurich Marathon' [4]. The 'Jungfrau Marathon' in Switzerland was established in 1993, after mountain running was becoming popular in Europe. Nowadays, it is one of the most popular mountain marathons in the world. The race is held annually in the autumn. It starts in Interlaken (565 m above sea level) and finishes at the 'Kleine Scheidegg' (2,095 m above sea level). It covers 1,830 m of altitude gain, and 305 m of loss. The first quarter is mostly flat and only about 300 m of altitude difference are covered up to half the marathon. The end stands at 2,095 m above sea level, right next to the world famous Eiger. In 2007 and 2012, the 'Jungfrau Marathon' was the official World Championship race in mountain running, which is held annually along a different race each year.

The 'Lausanne Marathon' was established in 1992 and is the second most important city marathon in Switzerland behind the 'Zurich Marathon'. The race is held annually in the autumn in the city of Lausanne, on the border of Lake Léman, where the course is flat. After the first half, the course turns and goes back to Lausanne. Furthermore, the 'Lausanne Marathon' hosts the annual semi-marathon Swiss Championship, a quarter marathon race, and a mini race for kids. All these races make the 'Lausanne Marathon' the most important marathon event held in Switzerland. The 'Zurich Marathon' is held annually since 2003 and more than 8,000 women and men successfully finish the race each year.

Data Analysis and Statistical Analysis

Data from 11,595 women and 48,564 men competing in the 'Jungfrau Marathon' were included for the mountain marathon. For the analysis of a flat city marathon, data from 3,973 women and 19,745 men competing in the 'Lausanne Marathon' and 8,723 women and 42,619 men competing in the 'Zurich Marathon' were considered. Overall, data from 60,159 mountain marathoners (19.3% women and 80.7% men) and 75,060 city marathoners (12,696 women, 16.9%, and 62,364 men, 83.1%) were analysed. In order to compare race times of both races, we produced and compared their box-whiskers plots (Figs. 1 and 2). Since the change in sex difference in endurance is assumed to be non-linear (36), we assumed that change in performance in endurance ought to be non-linear, too. And since performance in marathon running seems to follow a quadratic (second order polynomial) function (28), we determined the non-linear regression model with a second order polynomial function (y=a×x2+b×x+c) that fits the data best. Outlier (Q = 1.0%, minimum sum-of-squares) were identified and excluded from

[2] Website of 'Jungfrau Marathon', www.jungfrau-marathon.ch
[3] Website of 'Lausanne Marathon', www.lausanne-marathon.com
[4] Website of 'Zurich Marathon', www.zurichmarathon.ch

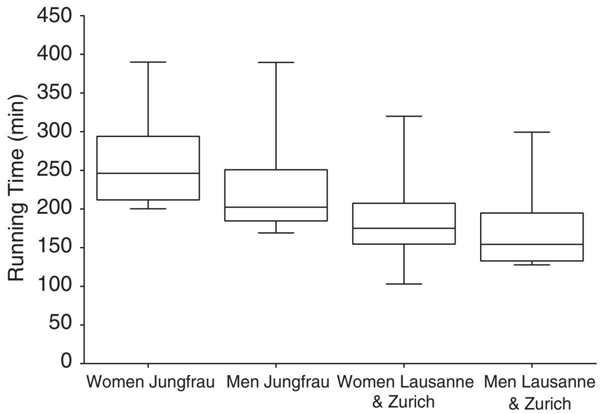

Fig. 1. Box-Whisker-Plot for running time (min) for the mountain and the city marathons for the fastest women and men in 1-year intervals.

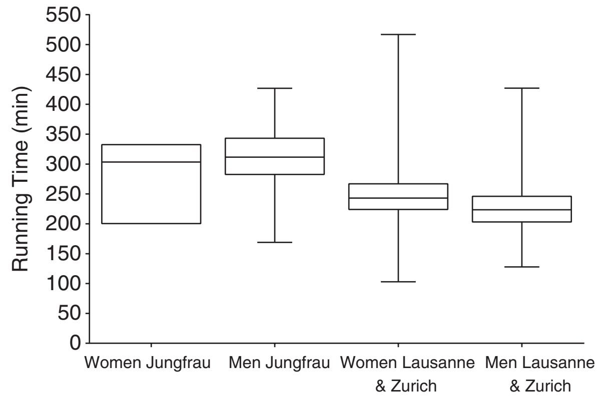

Fig. 2. Box-Whisker-Plot for running time (min) for the mountain and the city marathons for all female and male finishers in 1-year intervals.

analysis. Finally, age of peak performance and corresponding performance was determined by calculating the vertex of the quadratic function $p(x|y) = \left(-\frac{b}{2a} \middle| c - \frac{b^2}{4a}\right)$. To investigate changes in performance of finishers, a mixed-effects regression model with finisher as random variable to consider finishers who completed several races was used. We included sex, age, squared age and calendar year as fixed variables. We also considered interaction effects between sex and age and between sex and squared age. The final model was selected by means of Akaike information criterion (AIC). To account for a potential influence on environmental conditions (*e.g.* temperature, sunshine, precipitation) we used a further mixed-effects regression model with race time as the dependent variable and sex, calendar year, age, change in altitude, temperature, sunshine duration and precipitation as the independent variables (Table 1). Data for environmental conditions were obtained from Bundesamt für Meteorologie und Klimatologie MeteoSchweiz[5]. In addition, runners were grouped by performance percentiles in each sex as following: P_{0-30}, < 30% percentile (*i.e.* the slowest group); P_{30-60}, 30-59.9% percentile; P_{60-80}, 60-79.9% percentile; P_{80-90}, 80-89.9% percentile; P_{90-95}, 90-94.9% percentile; P_{95-100}, 95-100% percentile (the fastest group). A two-way analysis of variance (ANOVA) examined the sex×performance group interaction and the main effects of sex and performance group on age. Differences among performance groups were examined using a one-way ANOVA separately for each sex. *Post-hoc* Bonferroni test was used to identify which groups differed. The magnitude of differences among performance groups was tested using eta squared (η^2) classified as small ($0.010 < \eta^2 \leq 0.059$), moderate ($0.059 < \eta^2 \leq 0.138$) and large ($\eta^2 > 0.138$). Statistical analyses were performed using IBM SPSS Statistics (Version 22, IBM SPSS, Chicago, IL, USA) and GraphPad Prism (Version 6.01, GraphPad Software, La Jolla, CA, USA). Significance was accepted at $P < 0.05$ (two-sided for *t*-tests). Data in the text and figures are given as mean ± 95% confidence interval (CI).

Results

Performance Trends

Race times were slower for both women and men in the mountain marathon compared to the city marathons and women were slower than men for both races (Figs. 1 and 2). In the mountain marathon, women and men improved performance and men were faster than women when the fastest per year and all per year were considered (Table 2). Sex and age showed no interaction for the fastest but there was a significant interaction for sex and age for all finishers in 1-year intervals. In the city marathons, women and men improved performance and men were faster than women when the fastest per year and all per year were considered (Table 3). Sex and age showed a significant interaction for both the fastest and all finishers in 1-year intervals. The results showed no changes when change in altitude and environmental conditions such as temperature, sunshine duration and amount of precipitation were considered (Table 4).

Age Trends

When the fastest runners in 1-year age intervals were considered in the mountain marathon, the fastest

[5] Bundesamt für Meteorologie und Klimatologie MeteoSchweiz, www.meteoschweiz.admin.ch

Table 1. Change in altitude, temperature, sunshine and precipitation for the three races

Race	Change in altitude (m)	Daily maximum temperature (°C)	Sunshine (h)	Precipitation (ml)
Zurich Marathon				
2015	99	13	4	0
2014	99	19	7	2
2013	99	7	0	0
2012	99	13	6	0
2011	99	15	12	0
2010	99	11	11	0
2009	99	22	5	0
2008	99	11	5	0
2007	99	6	11	0
2006	99	4	0	0
2005	99	17	12	0
2004	99	14	1	0
2003	99	17	12	0
Lausanne Marathon				
2015	253	16	5	0
2014	253	14	9	0
2013	253	20	1	21
2012	253	5	1	0
2011	253	16	4	0
2010	253	11	1	1
2009	253	16	9	0
2008	253	14	7	0
2007	253	9	8	0
2006	253	18	9	0
2005	253	15	0	26
2004	253	20	9	0
2003	253	7	0	40
2002	253	9	13	0
2001	253	17	5	11
2000	253	15	3	0
Jungfrau Marathon				
2015	1829	21	7	0
2014	1829	19	6	0
2013	1829	20	1	2
2012	1829	24	8	0
2011	1829	27	9	0
2010	1829	23	8	0
2009	1829	21	8	0
2008	1829	20	9	0
2007	1829	18	6	0
2006	1829	24	8	0
2005	1829	22	6	0
2004	1829	19	1	2
2003	1829	22	1	0
2002	1829	21	5	0
2001	1829	20	9	0
2000	1829	17	1	40

Table 2. Results of the mixed-effects regression analyses for running time in the mountain marathon

Parameter	Estimate	Standard error (SE)	Degree of freedom (df)	t	P-value
The fastest in 1-year age intervals					
Constant term	3097.12	767.65	104.23	4.03	< 0.0001
[Sex=female]	94.08	27.59	92.65	3.41	0.001
[Sex=male]	0	0	.	.	.
Calendar year	-1.38	0.38	104.28	-3.64	< 0.0001
Age	-6.59	0.94	90.64	-6.95	< 0.0001
Age^2	0.08	0.01	91.48	8.23	< 0.0001
[Sex=female] × Age	-3.43	1.36	96.40	-2.52	0.013
[Sex=male] × Age	0	0	.	.	.
[Sex=female] × Age^2	0.04	0.01	99.25	2.93	0.004
[Sex=male] × Age^2	0	0	.	.	.
All in 1-year age intervals					
Constant term	-507.55	79.50	50521.23	-6.38	< 0.0001
[Sex=female]	17.06	7.55	46359.59	2.25	0.024
[Sex=male]	0	0	.	.	.
Calendar year	0.43	0.03	50584.20	10.91	< 0.0001
Age	-3.45	0.14	50857.64	-23.69	< 0.0001
Age^2	0.05	0.0016	50950.96	32.08	< 0.0001
[Sex=female] × Age	0.13	0.35	47630.13	0.37	0.712
[Sex=male] × Age	0	0	.	.	.
[Sex=female] × Age^2	-0.0008	0.0041	48475.24	-0.20	0.837
[Sex=male] × Age^2	0	0	.	.	.

Table 3. Results of the mixed-effects regression analyses for running time in the city marathons

Parameter	Estimate	SE	df	t	P-value
The fastest in 1-year age intervals					
Constant term	5644.05	797.83	106.00	7.07	< 0.0001
[Sex=female]	109.2	21.08	106.00	5.18	< 0.0001
[Sex=male]	0	0	.	.	.
Calendar year	-2.73	0.39	106.00	-6.86	< 0.0001
Age	-2.52	0.72	106.00	-3.46	< 0.0001
Age^2	0.04	0.0081	106.00	5.35	< 0.0001
[Sex=female] × Age	-4.23	1.03	106.00	-4.11	< 0.0001
[Sex=male] × Age	0	0	.	.	.
[Sex=female] × Age^2	0.05	0.01	106.00	4.42	< 0.0001
[Sex=male] × Age^2	0	0	.	.	.
All in 1-year age intervals					
Constant term	-13030.26	49.47	65439.58	-263.34	< 0.0001
[Sex=female]	17.80	2.98	53512.49	5.95	< 0.0001
[Sex=male]	0	0	.	.	.
Calendar year	6.60	0.02	65492.36	268.70	< 0.0001
Age	-0.66	0.06	51651.41	-10.90	< 0.0001
Age^2	0.01	0.0007	51613.43	14.51	< 0.0001
[Sex=female] × Age	-0.62	0.14	53819.25	-4.24	< 0.0001
[Sex=male] × Age	0	0	.	.	.
[Sex=female] × Age^2	0.008	0.001	54229.03	4.91	< 0.0001
[Sex=male] × Age^2	0	0	.	.	.

Table 4. Results of the mixed-effects regression analyses for the considered races with inclusion of change in altitude, temperature, sunshine and precipitation

Parameter	Estimate	SE	df	t	P-value
Lausanne and Zurich Marathon					
Constant term	4722.943	1606.752	106.000	2.939	0.004
[Sex=female]	115.493	22.489	106.000	5.136	< 0.0001
[Sex=male]	0	0	.	.	.
Calendar year	-2.280	0.802	106.000	-2.844	0.005
Age	-2.320	0.768	106.000	-3.021	0.003
Age^2	0.042	0.008	106.000	5.006	< 0.0001
[Sex=female] × Age	-4.471	1.115	106.000	-4.010	< 0.0001
[Sex=male] × Age	0	0	.	.	.
[Sex=female] × Age^2	0.052	0.012	106.000	4.171	< 0.0001
[Sex=male] × Age^2	0	0	.	.	.
Change in altitude	-0.017	0.045	106.000	-0.394	0.695
Temperature	0.567	0.453	106.000	1.251	0.214
Sunshine	0.208	0.337	106.000	0.616	0.539
Precipitation	0.062	0.280	106.000	0.223	0.824
Jungfrau Marathon					
Constant term	3653.936	866.226	103.062	4.218	< 0.0001
[Sex=female]	96.564	27.387	94.428	3.526	0.001
[Sex=male]	0	0	.	.	.
Calendar year	-1.667	0.429	103.029	-3.880	< 0.0001
Age	-6.625	0.938	88.624	-7.060	< 0.0001
Age^2	0.087	0.010	89.479	8.360	< 0.0001
[Sex=female] × Age	-3.514	1.348	97.255	-2.606	0.011
[Sex=male] × Age	0	0	.	.	.
[Sex=female] × Age^2	0.045	0.015	99.363	2.982	0.004
[Sex=male] × Age^2	0	0	.	.	.
Change in altitude	0	0	.	.	.
Temperature	-0.202	0.600	50.475	-0.337	0.738
Sunshine	1.001	0.705	49.659	1.420	0.162
Precipitation	2.467	2.359	48.655	1.046	0.301

Fig. 3. Age of fastest race time for the fastest woman and man for each year in the mountain marathon in 1-year intervals.

man (3:01 h:min) was ~35.6 years and the fastest women (3:28 h:min) ~34.5 years old (Fig. 3). When all finishers were considered in 1-year age intervals, the fastest men (4:59 h:min) were ~29.1 years old and the fastest women (5:16 h:min) were ~25.6 years old (Fig. 4). In the city marathons in 1-year age intervals, the fastest man (2:10 h:min) was ~23.7 years old and the fastest woman (2:36 h:min) ~32.20 years old (Fig. 5). When all finishers were considered in 1-year age intervals, the fastest men (3:41 h:min) were ~35.0 years old and the fastest women (4:00 h:min) ~33.8 years old (Fig. 6). Table 5 summarizes the results for the difference in the age of peak performance between mountain and flat marathon runners for women and men in 1-year age intervals and for all ages. The age of the fastest women and men was higher in the mountain marathon compared to the city mara-

Table 5. Difference in the age of peak performance (years) between mountain and flat marathon runners

	Ages in 1-year-Intervalls				All Ages			
	Jungfrau Marathon		Lausanne and Zurich Marathon		Jungfrau Marathon		Lausanne and Zurich Marathon	
	Women (n=59)	Men (n=65)	Women (n=57)	Men (n=66)	Women (n=10206)	Men (n=40990)	Women (n=11793)	Men (n=57876)
Minimum	17	11	17	15	17	11	17	15
25% percentile	31	29.5	30.5	30.75	37	38	33	35
Median	46	46	45	47.5	43	45	40	42
75% percentile	61	62.5	59.5	64.25	49	51	47	48
Maximum	75	78	76	80	75	78	76	80
Mean	46	45.95	45.7	47.5	42.81	44.55	40.22	41.76
SD	17.18	18.99	16.72	19.2	9.143	9.78	9.55	9.72
SE of mean	2.236	2.355	2.215	2.363	0.090	0.048	0.088	0.040
Lower 95% CI of mean	41.52	41.25	40.63	42.78	42.63	44.45	40.05	41.68
Upper 95% CI of mean	50.48	50.66	49.51	52.22	42.99	44.64	40.39	41.84

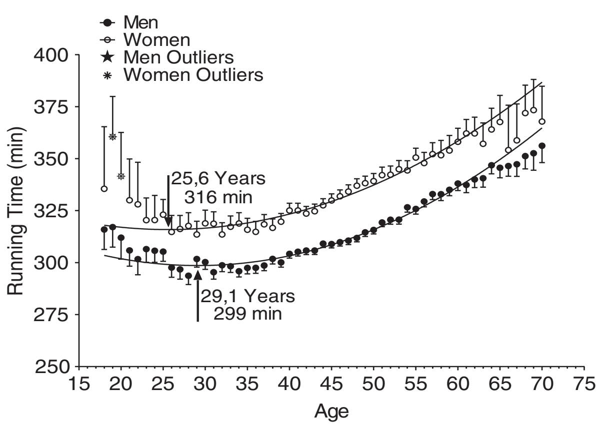

Fig. 4. Age of fastest race time for all female and male finishers for each year in the mountain marathon in 1-year intervals.

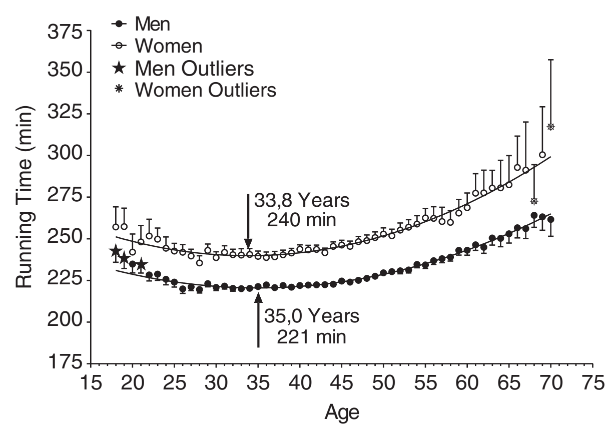

Fig. 6. Age of fastest race time for all female and male finishers for each year in the city marathons in 1-year intervals.

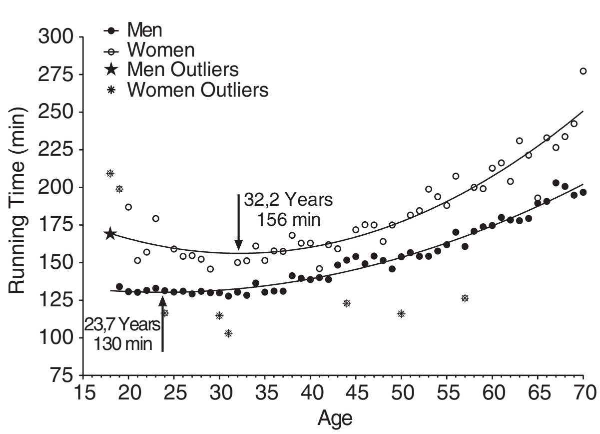

Fig. 5. Age of fastest race time for the fastest woman and man for each year in the city marathons in 1-year intervals.

thons when the fastest were considered ($P < 0.001$ to $P < 0.0001$). When all finishers were considered, the age of the fastest women and men was lower in the mountain marathon compared to the city marathons ($P < 0.001$ to $P < 0.0001$).

The two-way ANOVA showed a main effect of sex of trivial magnitude ($P < 0.001$, $\eta^2 = 0.002$) and of performance group of small magnitude on age ($P < 0.001$, $\eta^2 = 0.032$) (Fig. 7). There was no sex×performance group interaction on age ($P = 0.712$, $\eta^2 < 0.001$). In women, all performance groups differed among them for age ($P < 0.001$, $\eta^2 = 0.057$, small magnitude) with the faster groups being younger than their slower counterparts. The same trend was observed in men ($P < 0.001$, $\eta^2 = 0.051$, small magnitude).

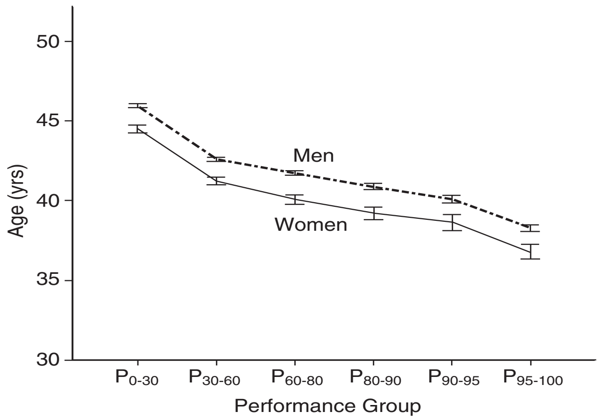

Fig. 7. Age of marathon runners by performance level and sex. $P_{0\text{-}30}$, < 30% percentile (*i.e.* the slowest group); $P_{30\text{-}60}$, 30-59.9% percentile; $P_{60\text{-}80}$, 60-79.9% percentile; $P_{80\text{-}90}$, 80-89.9% percentile; $P_{90\text{-}95}$, 90-94.9% percentile; $P_{95\text{-}100}$, 95-100% percentile (the fastest group). All performance groups differed among them for age.

Discussion

The aim of the study was to examine the age of peak running performance in a mountain marathon ('Jungfrau Marathon') compared to a flat city marathon ('Lausanne Marathon' and Zurich Marathon) with the hypothesis that the age of peak running performance would be higher in a mountain marathon compared to a flat city marathon. The most important findings were (i) the age of the fastest women and men was higher in the mountain marathon for the fastest but (ii) the age of the fastest women and men was lower in the mountain marathon when all finishers were considered. Our hypothesis that the age of peak marathon performance would be higher in a mountain marathon (≥ 35 years) compared to a flat city marathon (≤ 35 years) can only be confirmed for the fastest, but not for all runners.

Lower Age in the Mountain Marathon Compared to the City Marathon

A potential explanation for this finding of a lower age in the mountain marathon when all finisher were considered could be anthropometric characteristics. In the 'Jungfrau Marathon', athletes have to climb a total ascent of 1,830 m. It has been shown that low body fat was predictive for a fast marathon race time for male marathoners competing in a flat city marathon (3) and body fat increases with increasing age in marathoners (23). It seems very likely that younger runners with lower body fat are able to run faster uphill than older runners with higher body fat.

In contrast to the findings of Lehto (28) were the age of the best marathon performance was ~34 years when using both the whole sample of male 'Stockholm Marathon' finishers and the best 'Stockholm Marathon' results in each 1-year age-class, the fastest men were 29.1 years and the fastest women 25.6 years old in the 'Jungfrau Marathon'. When we considered the fastest women and men, the ages were 35.6 and 34.5 years, respectively. These ages would be in line with our hypothesis of an expected age of peak performance of ~30-35 years. The disparate findings between Lehto (28) and our findings might be explained by the larger sample of runners in the 'Stockholm Marathon' with more than 310,000 runners and the longer time frame from 1979 to 2014. Another explanation could be the increase in elderly runners in mountain running. For example, in the 78-km 'Swiss Alpine Marathon', the number of women older than 30 years and men older than 40 years increased (39).

We found a discrepancy between the fastest woman and man compared to all women and men. When the fastest runners in 1-year age intervals were considered in the 'Jungfrau Marathon', the fastest man was 35.6 years and the fastest women 34.5 years old. When all finishers were considered in 1-year age intervals, the fastest men and women were younger with 29.4 and 25.6 years, respectively. In other words, the fastest female and male mountain marathoners were considerably older compared to the whole field of female and male mountain marathoners. Burtscher *et al*. (5) analysed the results of the World Masters Athletic Championships in mountain running held in 2007. The race times of the first five finishers in 5-year age groups did not differ significantly from the age of 35 to 49 years (5). Oxygen uptake at the anaerobic threshold was held at top levels in humans up to the age of 45-49 years in both sexes (5). Most probably elite mountain marathoners achieve indeed their best performance at higher ages compared to city marathoners.

A further important finding was that the age of peak marathon performance in the 'Lausanne Marathon' and the 'Zurich Marathon' was ~33-35 years for both women and men when all female and male finisher were considered in 1-year age intervals. When the fastest women and men were considered, the ages were lower, especially for men. In large city marathons, women and men achieved their best performance at the age of ~29-34 years (19, 28). This seems to depend upon the selection of the races (19, 28, 39). For the seven major marathon events, for the five fastest males and females, Hunter *et al*. (19) reported that peak running speeds were accomplished at more or less the same age of ~29 years in men and at ~30 years in women. Women were older than men (29.8 ± 4.2 *vs*. 28.9 ± 3.8 years), but for only two of the seven marathons, the 'Chicago Marathon' and the 'London Marathon' (19). In the present study, the fastest women were ~1 year older than the fastest men in the 'Lausanne Marathon' and we can confirm the findings of Hunter *et al*. (19).

In the present study, we can also confirm the findings of Lehto (28) with the age of ~34.3 years for men in the 'Stockholm Marathon' and ~35.0 years for men in the 'Lausanne Marathon'. Considering female marathoners, Lehto (28) unfortunately provided no data analysis. Lehto (28) found an identical age of ~34.1 years for the single best result in 1-year age intervals. In contrast, we found for men the best age at ~23.7 years and for women at ~32.2 years. A potential explanation for these disparate findings could be the share of African runners. A study investigating the age and nationality of marathoners competing in Switzerland showed that best African male marathoners were younger and faster than the best non-African runners (2). The share of African runners seemed lower in the 'Stockholm Marathon (28) compared to marathons held in Switzerland (2).

Sex Difference in Performance

Women were slower than men in both the 'Jungfrau Marathon' and the 'Lausanne Marathon' although one might assume that the lower body fat and the lower body mass in female compared to male marathoners (40, 50) might be an advantage in mountain climbing. However, the sex gap in running performance appears biological in origin (6). Success in distance running and sprinting is determined largely by aerobic capacity and muscular strength (6). Since men have a larger aerobic capacity and greater muscular strength, the gap in running performances between men and women is unlikely to narrow naturally (6). Cheuvront *et al*. (6) found the sex difference to be constant at ~8-14% in competitions ranging from 1,500 m to 42,195 m. In longer distances Coast *et al*. (8) found a mean gender difference of ~12.4% for running distances ranging from 100 m to 200 km.

The sex difference in endurance performance was a frequently discussed topic (15, 43) and found to be present in many different sports disciplines (34). Nevertheless, the sex difference in performance is smaller or even not existing in some sports such as ultra-endurance swimming (10). About 20 years ago, Whipp and Ward (49) reported that the slope of improvement in the men's and women's running records would eventually result in a performance intersection of the sexes across a variety of running distances. The average difference between men and women is decreasing over the years but currently it does not seem that women will outrun men in the near future (6). The sex difference in running velocity varies across different races but it is on average ~11% of the effective running time (19, 43). Lepers and Cattagni (30) found a relative stability of sex difference in marathon running times across the different age groups for the last decade in the 'New York City Marathon'. In swimming, a study of the 'English Channel Swim' between 1975 and 2011 showed a similar constant sex difference in performance of ~12% (14).

Limitations and Strengths

This study is limited since variables such as physiological parameters (4), anthropometric characteristics (21, 22), training data (16, 17), previous experience (32) nutrition (33, 37), fluid intake (48), and weather (12, 44, 46) were not considered. These variables may have had an influence on the outcome of the different races. In details, a high maximum oxygen uptake (VO_2max) may improve performance whereas a low (VO_2max) may impair performance (4). Low body fat enhances running performance whereas high body fat impairs (21, 22). Athletes with a running speed during training (16, 17) and fast personal best times in shorter races (32) run faster than athletes with low running speed and slow personal best time. Low carbohydrate (33, 37), low fluid intake (48) and hot environmental temperatures (12, 44, 46) may impair running performance where sufficient carbohydrate, adequate fluid intake and low to moderate temperatures may enhance performance. Furthermore, the data set in the present study was smaller compared to the data set in the study of Lehto (28). Future studies should attempt to identify and analyze runners that participated in both mountain and flat marathon races, which would make it possible to use within-subjects statistical analysis. Also, another issue that should be addressed in the future would be the consideration demographic data, such as personal characteristics, training status and race history, which would explain partially the variation in race performance. On the other hand, this is the first study to examine the age of peak performance in mountain marathon running, especially in a large number of runners, and the findings might help both sports scientists and running practitioners to improve their understanding on the differences between mountain and flat long-distance running. To sum up, the main limitation of our results was that other confounding parameters that might have influenced running performance were not considered, whereas the strength of the present study was its novelty and the large number of participants (~135,000).

Practical Applications

For athletes and coaches, the age of the fastest women and men was higher in the mountain marathon compared to the city marathons when the fastest were considered, but when all finishers were considered the age of the fastest women and men was lower in the mountain marathon compared to the city marathons. Based upon this analysis we may recommend that athletes intending to compete fast in a mountain marathon should first compete in city marathons in order to achieve a fast marathon race time in a flat race and then switch to mountain marathon running. In addition, athletes and coaches should set different age-tailored race time goals depending on whether participating in flat or mountain race.

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