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Authors: Thomas A Haugen[1], Paul A Solberg[2], Carl Foster[3], Ricardo Morán-Navarro[4], Felix Breitschädel[5], and Will G Hopkins[6]

Affiliations: [1]Norwegian Olympic Federation, Oslo, Norway. [2]Defense Institute, Norwegian School of Sport Sciences, Oslo, Norway. [3]Human Performance Laboratory, University of Wisconsin, La Crosse, USA. [4]Exercise Physiology Laboratory at Toledo, University of Castilla-La Mancha, Spain. [5]Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, Trondheim, Norway. [6]Institute of Sport Exercise and Active Living, Victoria University, Melbourne, Australia.

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“Peak Age and Performance Progression in World-Class Track-and-Field Athletes” by Haugen TA et al.
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Peak age and performance progression in world-class track-and-field athletes

Performance progression in athletics

Thomas A Haugen[1], Paul A Solberg[2], Carl Foster[3], Ricardo Morán-Navarro[4], Felix Breitschädel[5], Will G Hopkins[6]

1) Norwegian Olympic Federation, Oslo, Norway
2) Defense Institute, Norwegian School of Sport Sciences, Oslo, Norway
3) Human Performance Laboratory, University of Wisconsin, La Crosse, USA
4) Exercise Physiology Laboratory at Toledo, University of Castilla-La Mancha, Spain
5) Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, Trondheim, Norway
6) Institute of Sport Exercise and Active Living, Victoria University, Melbourne, Australia

This is an original investigation with 1 table and 4 figures. The abstract consists of 250 words and the text 3588 words.

Corresponding author:
Thomas Haugen
Norwegian Olympic Federation, Sognsveien 228, 0840 Oslo, Norway
E-mail: thomas.haugen@olympiatoppen.no
Telephone 0047 41900313
Fax number 0047 38141301

Abstract

The aim of this study was to quantify peak age and improvements over the preceding years to peak age in elite athletic contestants according to athlete performance level, sex and discipline. Individual season bests for world-ranked top 100 athletes from 2002 to 2016 (14937 athletes and 57049 individual results) were downloaded from the International Association of Athletics Federations' web site. Individual performance trends were generated by fitting a quadratic curve separately to each athlete's performance and age data using a linear modeling procedure. Mean peak age was typically 25-27 y, but somewhat higher for marathon and male throwers (~ 28-29 y). Females reached greater peak age than males in the hurdles, middle and long distance running events (mean difference, ±90%CL: 0.6, ±0.3 to 1.9, ±0.3 y: small to moderate). Male throwers had greater peak age than corresponding women (1.3, ±0.3 y: small). Throwers displayed the greatest performance improvements over the five years prior to peak age (mean ± SD: 7.0 ± 2.9%), clearly ahead of jumpers, long distance runners, hurdlers, middle distance runners and sprinters (3.4, ±0.2 to 5.2, ±0.2 %; moderate to large). Similarly, top 10 athletes showed greater improvements than top 11-100 athletes in all events (1.0, ±0.9 to 1.8, ±1.1 %: small) except for throws. Women improved more than men in all events (0.4, ±0.2 to 2.9, ±0.4 %) except for sprints. This study provides novel insight on performance development in athletic contestants that are useful for practitioners when setting goals and evaluating strategies for achieving success.

Introduction

Fundamental motor skills such as running, jumping and throwing develop throughout life via growth, maturation, ageing and training. The relationship between performance and age in track-and-field athletes has been studied for decades, commenced with seminal works by Dill and Moore.[1,2] While the performance development in children, youths and older ('Masters') athletes is well-documented in research literature,[3-11] corresponding data for elite competitors in the years prior to and after the age of peak performance is more limited.

A few scientific studies have investigated age of peak performance among the best track-and-field athletes. Berthelot et al.[12] calculated a mean age of peak performance of 26.0 y in male and female runners (100 m to marathon), ranging from 23.3 (10 000 m for men) to 31.6 y (marathon for men). Hollings et al.[13] estimated mean age of peak performance for men in the range 23.9 (10000 m) to 28.5 y (discus throw) and for women in the range 24.7 (pole vault) to 28.1 y (discus throw). The same authors found clear sex differences in peak age among runners (mean, ±90% CL; men 25.1, ±0.3 y vs. women 26.2, ±0.4 y) and throwers (men 28.0, ±0.4 y vs. women 26.7, ±0.6 y), as well as variations across event groups, i.e., throwers on average ~1.5 y older than runners and jumpers. In their review, Allen & Hopkins[14] revealed that peak age tended to decrease with increasing event duration for explosive events, whereas an opposite trend was observed for endurance events. While neuromuscular power production is paramount for performance in typical anaerobic disciplines,[9,10,15-17] maximal oxygen consumption (VO_2max), fractional VO_2max utilization and exercise efficiency/economy are the most crucial physiological factors for typical aerobic disciplines.[8,18-20]

Previous peak age estimations are based on a limited number of contestants (world-ranked top 12-16 athletes), and it remains unclear whether peak age varies across athlete performance level. Moreover, fundamental information regarding the realistic potential for development in elite athletic contestants throughout their senior career is currently lacking.

The International Association of Athletics Federations (IAAF) has over several years recorded and systemized competition results from athletic events for international senior athletes. This unique database provides the opportunity to investigate the long-term performance development in the very best runners, hurdlers, jumpers and throwers. Therefore, the aim of this study was to quantify peak age and improvements in elite athletic contestants over the preceding years to peak age according to athlete performance level, sex and discipline. Such background information is useful for athletes, coaches, sport institutions and sports governing bodies when properly setting realistic goals and evaluating their strategies for achieving success.

Materials and Methods

Data sample

All data were collected from the statistics section of the IAAF web site (https://www.iaaf.org/records/toplists/). The IAAF publish annual top lists categorized by athletic discipline and gender. Each record within these rankings documents performance, athlete name, birth date, competition date and venue where the result was set. Individual season bests for the 100 top world-ranked athletes each season were included for analysis in the following groups of events (specific disciplines in brackets): sprint (100, 200 and 400 m), middle distance running (800 and 1500 m), long distance running (3000 m steeple chase, 5000 m, 10 000 m, marathon), hurdles (110/100 and 400 m hurdles), jumps (long jump, triple jump, high jump and pole vault) and throws (shot put, javelin, discus and hammer throw). Decathlon and relays were excluded from analysis. To ensure equal competition regulation standards (e.g. weight of throwing implement, hurdle height, etc.) across age categories, only outdoor results obtained in senior competitions the last 15 seasons (from 2002 to 2016) were included. Athletes were included irrespective of their career status (active, retired) in 2016.

Age was calculated as competition date minus date of birth. Results obtained with illegal wind speed (≥ 2.0 $m \cdot s^{-1}$) and sprint results obtained without electronic timing, were excluded from analysis. Overall, the sample consisted of 57049 individual results across 14937 athletes. We also identified the 10 best athletes in each event over the 15-year period, to be able to compare the best athletes (top 10) with the others.

Statistical analyses

Tables of means and standard deviations of annual change scores that could be useful to coaches and athletes were generated for each year of age. Where an athlete did not compete or was out of the world top 100 for two or three years, the athlete's change score was divided by two or three respectively; change scores spanning four or more years were not included. Individual performance trends for each athlete were generated by fitting a quadratic curve separately to each athlete's performance and age data using a linear modeling procedure (Proc Mixed) in the Statistical Analysis System (University Edition version 3.5, SAS Institute, Cary, NC). For better precision, only the athletes with 5 or more annual best performances were included. Age of peak performance (based on athletes with >2 annual-best performances) was determined from the linear and quadratic coefficients by elementary calculus: for the equation Performance = $a*Age^2 + b*Age + c$, age of peak performance is given by = $-b/(2*a)$; if the quadratic peak occurred outside the age range of the performances, the peak was estimated as the age corresponding to the predicted best performance at the beginning or end of the age range (whichever represented the best predicted performance).

Magnitudes of differences in mean peak age and improvement between groups were assessed by standardization (mean difference divided by the appropriate SD). For peak age, the harmonic mean of the SD of the compared groups was used; the resulting standardized difference of the means is effectively the mean of the standardized differences obtained by using the SD of each group separately. The thresholds for assessing the observed difference in means were 0.2, 0.6, 1.2, 2.0 and 4.0 for small, moderate, large, very large and extremely large, respectively.[21] For improvement in performance, the appropriate SD was the within-athlete SD of top athletes between competitions,[22] and the corresponding thresholds were 0.3, 0.9, 1.6., 2.5 and 4.0.[21] To make inferences about true (population) values of effects, we used non-clinical magnitude-based inference rather than null-hypothesis significance testing.[21] Magnitudes were evaluated mechanistically: if the confidence interval overlapped substantial positive and negative values, the effect was deemed unclear; otherwise effects were deemed clear and shown with the probability that the true effect was substantial or trivial (whichever was greater) using the following scale: 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; > 99.5%, most likely.[21]

Results

Goodness of fit for the individual quadratics was similar in track and field events (R-squared in percent units of 53 ± 28 and 53 ± 27 respectively, mean ± SD).

Table 1 shows mean peak age and expected results for men and women across all disciplines. Mean age of peak performance ranged from 24.5 y (800 m men) to 29.0 y (marathon women).

Figure 2 shows comparisons of peak age between performance levels and sexes within events aggregated into groups and between event groups themselves. Effects of performance level differed between the event groups (Panel A): while top 11-100 middle and long distance runners displayed possibly greater peak age than corresponding top 10 athletes (mean difference, ±90%CL: 0.7, ±1.0 to 1.0, ±0.7 y; small), top 10 hurdlers, jumpers and throwers had possibly to likely greater peak age than their top 11-100 counterparts (0.7, ±0.7 to 1.2, ±0.8 y; small).

Panel B in Figure 2 shows that females very likely to most likely reached greater peak age than males in the hurdles (0.6, ±0.3 y; small), middle distance (1.9, ±0.3 y; moderate) and long distance running (1.3, ±0.3 y; small), However, male throwers showed a most likely greater peak age than female throwers (1.3, ±0.3 y; small).

Panel C in Figure 2 shows that throwers had most likely greater peak age than all other event groups (1.0, ±0.2 to 1.4, ±0.2 y; small), except for long distance runners (most likely trivial). Long distance runners displayed most likely greater peak age than middle distance runners and sprinters (0.7, ±0.2; small). When considering each sex separately, male throwers reached their peak performance at the highest age (mean ± SD: 27.9 ±3.5 y), which was most likely greater than that of every other male event group (mean difference, ±90%CL: 1.8, ±0.3 to 3.0, ±0.3 y; small to moderate). Male middle distance runners had the lowest peak age (mean ± SD: 24.9 ± 2.8 y), most likely lower compared to all other male event groups (mean difference, ±90%CL: 0.7, ±0.2 to 3.0, ±0.3 y; small to moderate). Less clear differences were observed among the female event groups, but peak age of long distance runners (27.2 ± 3.7 y) was most likely greater than that for sprinters (1.2, ±0.3 y; small), jumpers (0.9, ±0.3 y; small) and hurdlers (0.7, ±0.3 y; small). Female middle distance runners (26.8 ±3.1 y) had most likely greater peak age than female sprinters (0.8, ±0.3 y; small).

Figures 3 and 4 show annual change scores across selected athletic disciplines from 20 to 33 years of age in men and women, respectively. These data represent the expected mean change in performance and typical differences between athletes of a given age who compete at the international level.

Figure 5 shows comparisons of improvements over the 5-y period preceding the age of peak performance between performance levels and sex groups within event groups and comparisons between event groups. Top 10 athletes generally improved more than top 11-100 athletes (Panel A). Greater improvements in the range likely to very likely were observed in top 10 compared to top 11-100 sprinters (mean difference, ±90%CL: 1.3, ±0.7 %; small), middle distance runners (1.0, ±0.9 %; small), long distance runners (1.7, ±1.0 %; small), hurdlers (1.7, ±1.2 %; small) and jumpers (1.8, ±1.1 %; small). The difference between top 10 and top 11-100 throwers was trivial and unclear.

Greater improvements were observed in women than men (Figure 5, Panel B). Females displayed possibly to most likely greater improvement rates than corresponding men in middle-distance running (0.4, ±0.2 %; small), long-distance running (1.2, ±0.2 %; small), hurdles (0.7, ±0.3 %; small), jumping (1.3, ± 0.3 %; small) and throwing (2.9, ±0.4 %; moderate).

Clear differences in improvement rates across event groups were observed when men and women were grouped (Figure 5, Panel C). Throwers were most likely to improve more than all other event groups (3.4, ±0.2 to 5.2, ±0.2 %; moderate to large). Jumpers displayed most likely greater improvements than all other event groups (0.7, ±0.2 to 1.8, ±0.2 %; small to moderate), except for throws. Likely trivial differences in improvement rates were observed between long distance runners and hurdlers, but these two event groups improved likely to most likely more than middle distance runners (0.7, ±0.2 and 0.5, ±0.2 %; small) and sprinters (1.1, ±0.1 and 0.8, ±0.2 %; small, respectively).

Discussion

This is the first study to quantify annual change scores in world-leading track-and-field contestants throughout their senior career. We observed substantial differences in peak age and improvements over the five preceding years to peak age across athlete performance level, sex and discipline. Mean peak age was typically 25-27 y, but somewhat higher for marathon runners and male throwers (~28-29 y). Females generally reached their peak at a later age than males, except for the throws, while effects of performance level differed between the event groups. Top 10 athletes generally displayed greater improvement rates than top 11-100 athletes, and women improved more than men. Throwers displayed the highest relative performance advances over the five years prior to peak age, ahead of jumpers, hurdlers and long distance runners, middle distance runners and sprinters.

The goodness of fit of the individual quadratics was only modest on average, reflecting similarity of the real changes in performance with random year-to-year variability. The observed ages of peak performance across all disciplines in the present investigation (Table 1) are mainly within ±2 y, whereas there are wider ranges in previous studies.[12-14,23] Differences across studies are likely due to differences in performance level. For example, Hollings et al.[13] examined a large number of performances (typically 70-150 per athlete, depending on discipline) in world-ranked top 12-16 athletes, while the present analyses included season best results in world-ranked top 100 athletes. We observed clear differences in peak age among subsets of varying performance standards in most event groups, emphasizing the necessity to take athlete performance level into account when evaluating peak age.

Allen & Hopkins[14] observed that peak age tended to decrease with increasing event duration for explosive events, whereas an opposite trend was observed for endurance events. These trends were partly observed in this study, as peak age decreased with increasing sprinting distance (100-400 m) and peak age among the marathon runners was substantially higher than the other long-distance disciplines. However, no clear trends were observed for the running disciplines between 800 and 10 000 m.

The current findings related to sex differences in peak age are mainly in accordance with those reported by Hollings et al.[14] We can only speculate for possible explanations to the sex differences, but it is reasonable to assume that, for example, child bearing in females is a likely cause. Socio-cultural factors, varying onset of specialized training, and exposure to training and technique developments are other possible contextual explanations, and future studies should aim to investigate these features for sex differences in age of peak performance.

Throwers attained the highest peak age of all event groups, alongside long distance runners, when men and women were grouped. Throwers possess considerably higher body mass and absolute lean muscle mass than runners, hurdlers and jumpers.[24] No previous studies have investigated age of peak performance in explosive-strength exercises, but publically available results provided by the International Powerlifting Federation reveal that male (*n*=194) and female (*n*=157) medalists from the 2004-2016 World Championships in powerlifting (all weight classes) were aged 30 ± 6 and 31 ± 8 y (mean ± SD). Despite considerable spread around the mean, these observations suggest that it takes longer time to develop the required muscle mass for maximal strength performance compared to athletic disciplines with less strength demands. This suggestion is further reinforced by the fact that top 10 throwers displayed likely higher peak age than their top 11-100 counterparts (mean, ±90%CL: 1.2, ±0.8 y; small). In general, women are approximately 52% and 66% as strong as the men in the upper and lower body,[25] and the sex difference in muscular strength in equally trained men and women is almost entirely accounted for by the difference in muscle size.[26,27] The relative sex differences in throwing performance observed in the present study are less pronounced compared to general muscular strength, as the included women achieved ~70-90% of the performance compared to their male counterparts. These smaller differences are most likely due to adjusted weight of the throwing implements.

Marathon runners display ~2-3 y higher age of peak performance compared to the other running disciplines (Table 1). Previously, Knechtle et al.[28] reported that the age of the best ultra-marathon performers increase with race duration. High training volumes and number of years of running experience are one of the most important stimulants for improved running economy,[29] and it is reasonable to assume that the importance of work economy on long-distance running performance increases with running distance. Thus, the time required to maximize running economy likely explains the observed trends towards higher peak age with increasing long-distance duration. A traditional and common-sense notion among practitioners is that middle- and long-distance runners "self-select" themselves into longer endurance disciplines as they get older. However, a recent study reported that the top 90 African marathon runners from 2001-2015 likely specialized, reached peak levels of performance, and retired at younger ages than the top 90 non-African marathoners from the same period.[30] The findings are likely explained by socio-economic factors, as many Africans have a way of life that is centered on running to and from school at a very early age.[31,32] Thus, the concept of training age needs to be considered when evaluating the age of peak performance. Athletes who start with specialized training at a young age may be more likely to reach their peak performance at an earlier age stage than their counterparts who specialize somewhat later.

The current results revealed annual improvements in the range 0.1-0.3% for most disciplines when the athletes were in their early 20s, except for the throws where the change scores were considerably higher (~1%). According to Hopkins,[22] the smallest worthwhile performance enhancement is 0.3-0.5% and 0.9-1.5% for elite track and field athletes, respectively. Thus, most annual change scores observed (Figure 3 and 4) are on par or lower than the smallest worthwhile change for elite athletic contestants. Consequently, athletes must be at a very high level already in their late teens to become world-class (top 100) as seniors. Based on the annual change scores observed, the throwers within the annual world top 100 lists were at ~ 95-96% of their peak performance result at the age of 20, while athletes from the other event groups were at ~ 98-99% on average.

Top 10 athletes displayed greater improvement rates than top 11-100 athletes in all event groups but throws. Anecdotal evidence presented by Haugen et al.[33] support these findings, as they observed more pronounced performance developments in world-class vs. national level sprinters. Moreover, Boccia et al.[7] reported that young national top-level jumpers displayed greater improvement rates than lower level individuals. Seemingly, higher-performing athletes improve their performances more than athletes of lower performance standards in the preceding years to peak age. These differences may be explained by several factors (e.g. training status, responsiveness to training, coaching quality, etc.), and future studies should aim to explore the potential influence of such variables on performance progression.

Interestingly, women improved more than men in most event groups in the five years preceding age of peak performance. Seemingly, world-class women responded better to training than men during this period. This relationship is somewhat opposite during the teens, as Tønnessen et al.[6] observed higher relative annual improvements in males than females from 13-14 to 18 years of age. The widened gender gap during puberty can be explained by hormone-dependent changes in muscle and fat mass and increased red blood cell mass.[4,34-36] However, our results show that elite women catch up some of this widened gender gap in the early and mid-20s, and future studies should aim to investigate possible underlying mechanisms related to this trend.

The present results revealed that throwers exhibited the most pronounced performance advances in the five years preceding peak age. The larger improvements observed for field versus track events may be related to varying skill complexity. While running and jumping are fundamental movements mastered at early childhood, the movement patterns in, for example pole vault and hammer throw, are more complex and less inborn. It is therefore likely that most humans have maximized their potential in simple and fundamental movements at an earlier stage compared to more complex disciplines. Another plausible explanation is the higher underlying component of maximal strength in field versus track events. Most practitioners would argue that maximal strength is more responsive to training than are endurance and sprint running. Future longitudinal studies should aim to explore if and why certain skills and physiological capacities are more resistant to training adaptations than others.

Several methodological limitations are associated with the present study. First, it is reasonable to assume that athletes drop out when their performance starts to decline, and that only the most successful athletes continue to participate beyond a certain age. Following these lines, the annual change scores observed after the age of peak performance are likely underestimated, and the "real" performance decline during the early 30s is perhaps even more pronounced. Moreover, potential use of doping among a substantial proportion of the investigated athletes may have affected our results, although such abuse does not necessarily modify the age of peak performance. Numerous athletes have confessed under oath how easily the doping-detection system can be manipulated, and thus, the number of banned athletes over the years likely represent the tip of the iceberg.[37] Hence, the results of the present study reflect today's athletics, for better and worse, and the outcomes must be interpreted with this in regard. Several authors have speculated that females using testosterone or testosterone surrogates as doping agents gain greater training-related improvements and adaptations than men, who already have high levels of naturally occurring testosterone.[17,37,38]

Conclusion

This study revealed that mean peak age in world-class athletics contestants was typically 25-27 y, but somewhat higher for marathon and male throwers (~ 28-29 y). Women reached greater peak age than men in the hurdles, middle and long distance running events, while male throwers had greater peak age than corresponding women. Throwers showed the greatest performance progressions over the five years prior to peak age, clearly ahead of jumpers, long distance runners, hurdlers, middle distance runners and sprinters. Top 10 athletes improved more than top 11-100 athletes in all events except for throws. Women improved more than men in all events except for sprints.

Practical applications

This study provides novel insight on performance development in world-class athletic contestants that can be useful for athletes, coaches, sport institutions, and sports governing bodies to set realistic goals and evaluate their strategies for achieving success. Our observations also provide a point of departure for future studies aiming to investigate the possible underlying mechanisms related to peak age and performance development across athletes, modalities and physiological capacities.

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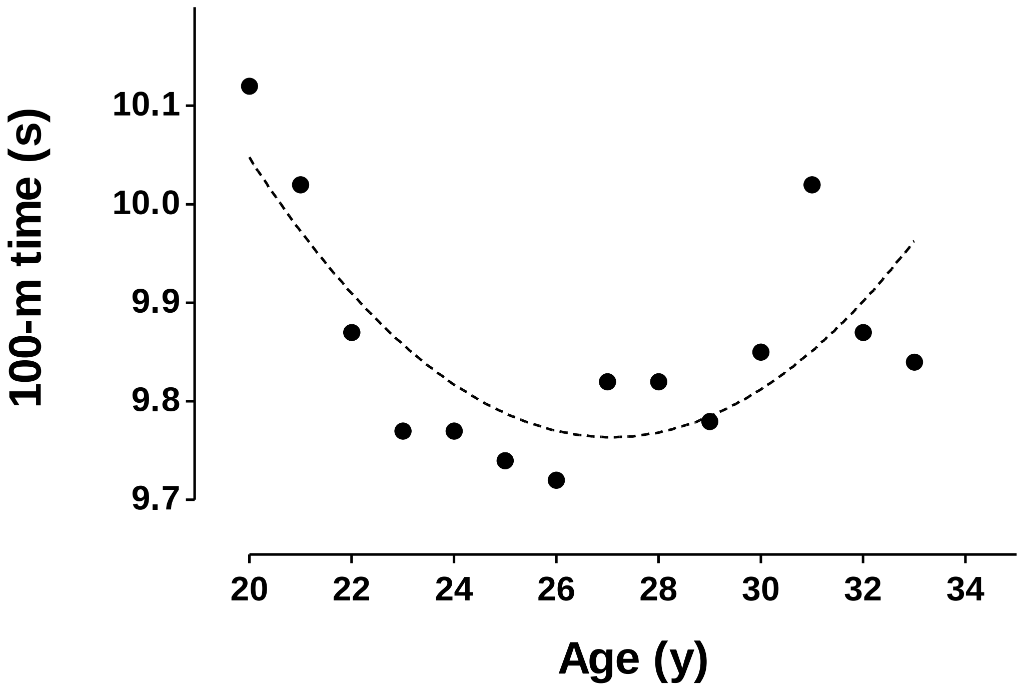

Figure 1. Age and annual best times for a 100-m sprinter, Asafa Powell. Dashed curve is the best-fitting quadratic (R^2 = 58%).

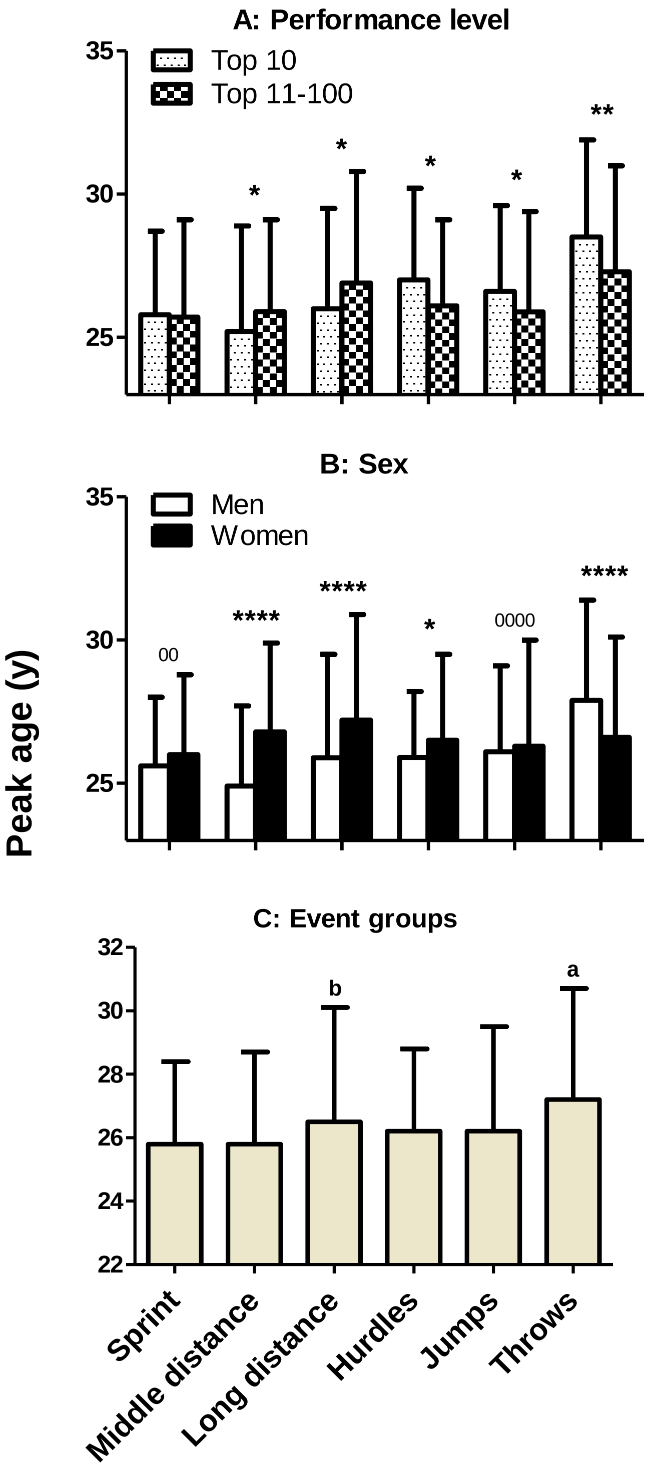

Figure 2. Age of peak performance across performance level (Panel A), sex (Panel B) and event group (Panel C). Data are means and standard deviations. Likelihood of clear substantial sex differences: *possibly, **likely, ***very likely, ****most likely. Likelihood of clear trivial sex differences: [0]possibly, [00]likely, [000]very likely, [0000]most likely. The difference between top 10 and top 11-100 sprinters was trivial but unclear. [a]Clearly greater than all other event groups, except for long distance runners (most likely trivial). [b]Clearly greater than middle distance runners and sprinters.

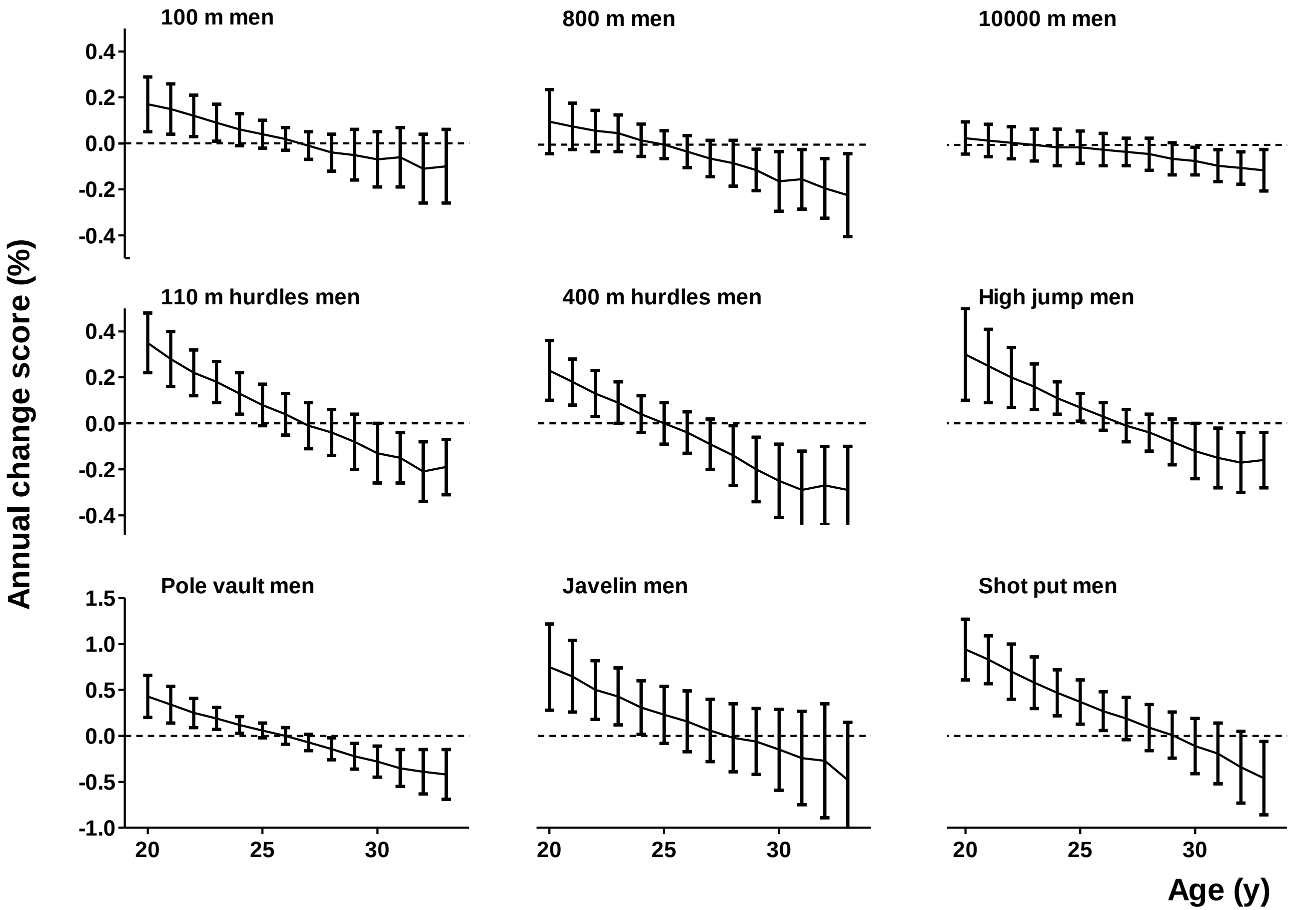

Figure 3. Annual change scores for men's selected track and field events. Bars represent mean ± SD. For chronometric events, times were converted into speeds.

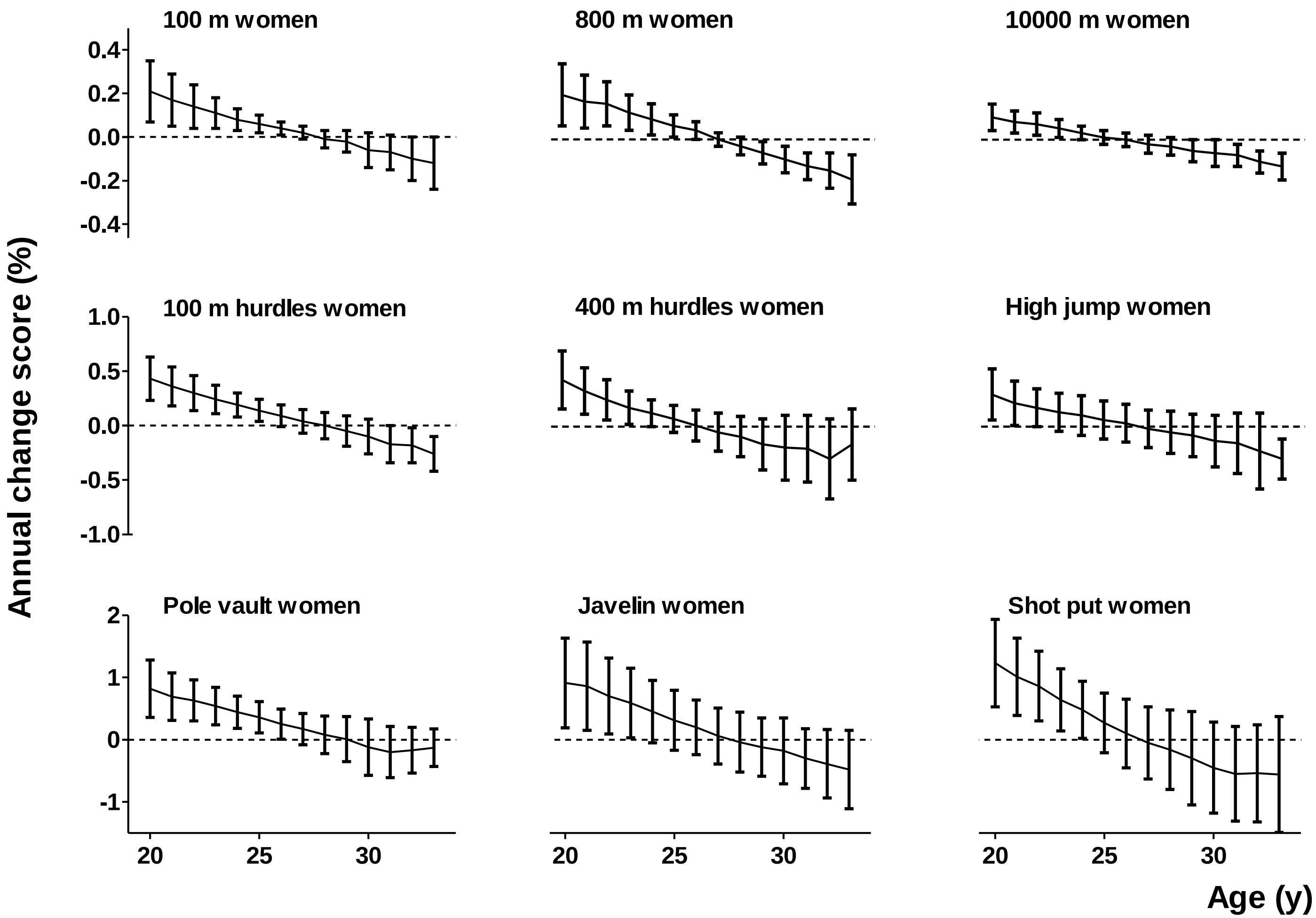

Figure 4. Annual change scores for women's selected track and field events. Bars represent mean ± SD. For chronometric events, times were converted into speeds.

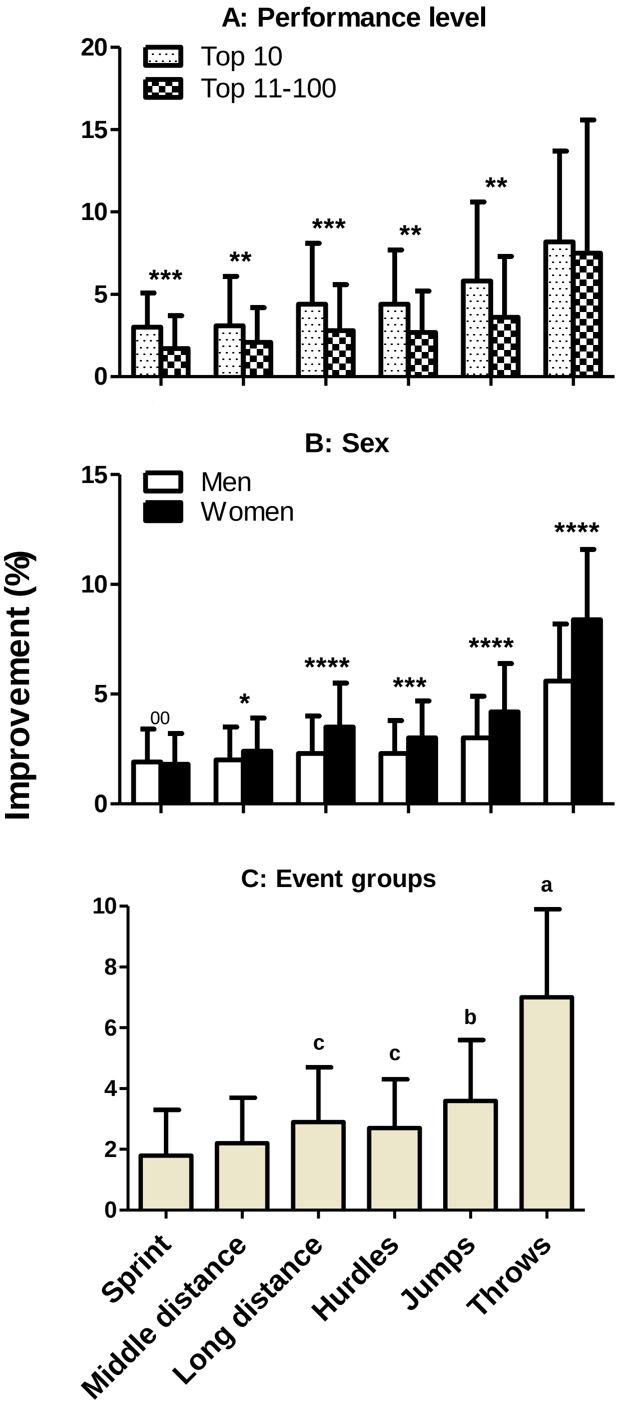

Figure 5. Improvements over the five preceding years to age of peak performance according to performance level (Panel A), sex (Panel B) and event group (Panel C). Data are means and standard deviations. Likelihood of clear substantial sex differences: *possibly, **likely, ***very likely, ****most likely. Likelihood of clear trivial sex differences: [0]possibly, [00]likely, [000]very likely, [0000]most likely. The difference between top 10 and top 11-100 throwers was trivial but unclear. [a]Clearly greater than all other event groups. [b]Clearly greater than all other event groups, except for throws. [c]Clearly greater than middle distance runners and sprinters.

Table 1. Peak age and expected result for all disciplines. Data are mean ± SD.

	n	Peak age (y)	Mean performance at peak
100 m M	221	26.0 ± 3.0	10.09 ± 0.08 s
100 m W	214	26.8 ± 3.3	11.18 ± 0.11 s
200 m M	206	25.9 ± 2.7	20.34 ± 0.17 s
200 m W	135[a]	26.2 ± 2.4	22.75 ± 0.23 s
400 m M	206	25.0 ± 1.9	45.18 ± 0.29 s
400 m W	201	24.9 ± 2.8	51.28 ± 0.50 s
800 m M	207	24.5 ± 2.8	1:45.2 min ± 0.7 s
800 m W	220	26.5 ± 2.9	2:00.1 min ± 0.9 s
1500 m M	203	25.3 ± 2.8	3:34.8 min ± 1.5 s
1500 m W	226	27.0 ± 3.3	4:05.5 min ± 2.3 s
5000 m M	222	25.2 ± 4.1	13:14 min ± 6.6 s
5000 m W	213	26.1 ± 3.9	15:08 min ± 13.6 s
10000 m M	215	24.8 ± 3.3	27:43 min ± 18 s
10000 m W	196	26.5 ± 3.0	31:53 min ± 25 s
Marathon M	219	28.4 ± 4.1	2:07.56 h ± 61 s
Marathon W	227	29.0 ± 4.2	2:26:07 h ± 107 s
110 m hurdles M	206	26.7 ± 2.3	13.44 ± 0.14 s
100 m hurdles W	223	27.0 ± 2.9	12.91 ± 0.16 s
400 m hurdles M	214	25.1 ± 2.3	49.27 ± 0.46 s
400 m hurdles W	219	25.9 ± 3.1	55.77 ± 0.82 s
3000 m steeplechase M	214	25.3 ± 3.2	8:22 min ± 6.4 s
3000 m steeplechase W	208	27.0 ± 3.8	9:39 min ± 10.6 s
High jump M	211	26.0 ± 2.9	2.28 ± 0.03 m
High jump W	226	25.5 ± 3.6	1.91 ± 0.03 m
Long jump M	215	25.7 ± 2.4	8.10 ± 0.08 m
Long jump W	214	27.2 ± 3.1	6.68 ± 0.10 m
Triple jump M	194	26.5 ± 5.8	16.88 ± 0.24 m
Triple jump W	209	26.1 ± 5.7	14.12 ± 0.26 m
Pole vault M	206	26.0 ± 2.4	5.64 ± 0.09 m
Pole vault W	228	26.3 ± 3.4	4.43 ± 0.13 m
Shot put M	214	27.8 ± 3.4	20.26 ± 0.53 m
Shot put W	216	25.6 ± 3.5	17.90 ± 0.87 m
Discus M	201	28.4 ± 3.5	63.6 ± 1.9 m
Discus W	203	27.6 ± 4.1	60.7 ± 2.7 m
Hammer throw M	188	28.2 ± 3.9	75.8 ± 2.7 m
Hammer throw W	203	26.8 ± 2.8	69.3 ± 2.8 m
Javelin M	211	27.1 ± 3.3	81.5 ± 2.4 m
Javelin W	209	26.3 ± 4.0	59.7 ± 2.5 m

M, men; W, women.
[a]Analysis based on athletes with more than three annual best performances. All others are based on more than two.