Peak age and relative performance progression in international cross-country skiers

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This manuscript has been read and approved by all the listed co-authors and meets the requirements of co-authorship as specified in the Human Kinetics Authorship Guidelines. This Manuscript is original and not previously published, nor is it being considered elsewhere until a decision is made as to its acceptability by the IJSPP Editorial Review Boards.

This is an original investigation with 2 figures. The abstract consists of 248 and the text 3320 words.

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Abstract

Purpose: To quantify peak age and relative performance progression towards peak age in cross-country (XC) skiing according to event type, sex and athlete performance level. **Methods:** International Ski Federation (FIS) points (performance expressed relative to the best athlete) of athletes born between 1981 and 1991 and competing in junior world championships or finishing top 30 in world championships or Olympics were downloaded from the FIS website. Individual performance trends were derived by fitting a quadratic curve to each athletes FIS point and age data. **Results:** Peak age was 26.2 (2.3) years in distance and 26.0 (1.7) years in sprint events. The sex difference in peak age in sprint events was ~0.8 years (small, $P = .001$), while there was no significant sex difference in peak age in distance events ($P = .668$). Top-performers displayed higher peak ages than other athletes in distance (mean difference, ±95% CL: 1.6 y, ±0.6 y, moderate, $P < .001$) and sprint events (1.0, ±0.6 y, moderate, $P < .001$). FIS point improvement over the 5 years preceding peak age did not differ between event types ($P = .325$) while men improved more than women in both events (8.8, ±5.4%, small, $P = .002$ and 7.5, ±6.4%, small, $P = .002$). Performance level had a large effect on improvement in FIS points in both events ($P < .001$). **Conclusion:** This study provides novel insights on peak age and relative performance progression among world-class XC skiers and can assist practitioners, sport institutions and federations with goal setting and evaluating strategies for achieving success.

Keywords: age of peak performance, XC skiing, FIS points, elite athletes, gender differences

Introduction

Competitive performance in sports evolves and devolves throughout life via growth, maturation, training and ageing. Understanding the relationship between age and performance is important for practitioners, scientists, sport institutions and sport governing bodies, as such knowledge is fundamental to goal setting, long-term training planning, season evaluation, talent development benchmarking, athlete selection processes and allocation of funding and resources.[1–3] Accordingly, several scientific publications are devoted to determination of age of peak performance (peak age) and performance progression. So far, these analyses have been mainly restricted to summer Olympic sports such as athletics,[4–6] swimming[7] and weightlifting.[8]

Cross-country (XC) skiing is a weight-bearing, full-body locomotion modality with plyometric muscle actions involved, and this sport has always been a cornerstone of the winter Olympic program. A variety of competition formats (sprint-, distance- and team-events) is performed in the classic and skating styles, while managing hilly terrain.[9] Individual races in XC skiing range from sprint races, covering a distance of four times 1.3 to 1.8 km (initial qualification and three knockout heats) to distance races, ranging from 10 to 30 km for women and 15 to 50 km for men performed as either mass starts or individual time trials. Despite the large number of published studies dealing with XC skiing, no valid information is currently available regarding peak age and progression in relative performance in elite XC skiers.

A review of the literature within typical endurance sports showed that peak age and performance progression differ as a function of sport events, athlete performance level and sex.[6,8,10] For example, peak age tended to increase with increasing event duration for endurance events,[10] although these trends were less pronounced in a recent study in athletics.[6] Here, only trivial to small differences were observed for the running disciplines between 800 and 10 000 m, but peak age was clearly higher in marathon compared to 1500 m. The race duration in these events is comparable to a 50 km and sprint races, which raises the question about possible differences in peak age between sprint and distance XC skiing. Similarly, athletes with top 16 positions or better in international competitions tend to have ~1 y lower peak age across several sports.[6,8,11] Differences between male and female athletes, however, are varying among endurance sports. While female long-distance runners displayed a 1-2 y higher peak age than males,[4,6] the opposite pattern was shown for triathletes[11] and swimmers.[7] In contrast, women showed a larger performance progression in the years leading up to peak age than men,[6–8] which was also the case for top-performers compared to athletes of lower level within both sexes.[6,8,11]Despite being a traditional Olympic sport,[12] cross-country skiing has continuously evolved over the last decades, which subsequently could have influenced peak age.

In the context of talent selection and the development process, understanding the relationship between junior and senior performance is of high interest, especially for sport institutions. However, previous studies investigating athletics indicate that performing well at junior age not necessarily leads to high senior performance.[2,13]

The International Ski Federation (FIS) has recorded and systemized competition results of international junior and senior athletes in XC skiing events over several decades. The database is based on the FIS point system (see a detailed description in the methods), which measures performance in relation to the best athletes (relative performance) and provides the opportunity to investigate the long-term relative performance development of XC skiers. Therefore, the aim of this study was to quantify peak age and progression in relative performance in the preceding years to peak age in XC skiers according to event type, sex, and athlete performance level. In addition, average absolute FIS points and a prediction of peak performance based on junior performance were reported to provide reference values for sports practice. Such information is useful for athletes, coaches and sport institutions for proper goalsetting, talent developing benchmarking and evaluating strategies for achieving success.

Methods

Data acquisition

All data were collected from the FIS website (https://www.fis-ski.com/en/cross-country). FIS has established the FIS point system, where an individual FIS race point is calculated for each athlete competing in that specific race. The FIS race point takes race duration, the gap to the winning athlete and the race format into account, by presenting race performances relatively. In addition to the FIS race points, a FIS points list is provided. Here, athletes are ranked according to the mean of their five best FIS race points during the last 365 days. Based on the FIS point system, relative race performance and performance level can be monitored, even though race distances, styles, profiles and weather conditions differ between races within the same format. The FIS point system is the most valid way to express race performance and is well established in science within the field of XC skiing.[14–17] FIS race points of all athletes born from 1981 to 1991 and competing in the junior world championships between 2001 and 2011 were selected, as long as these athletes were competing in FIS races (i.e. minimum three races per year) for at least four years after they turned senior. To prevent us from missing late-developing athletes, all top 30 finishers in Olympic winter games and world championships were included, even when they did not compete in junior world championships but met the other criteria. FIS points were calculated for each individual race and competitor according to international competition rules with the following equation:

$$FIS\ race\ point = \frac{F * T_x}{T_o} - F$$

where F is the factor for the race type (800 for interval starts, 1200 for sprints/pursuits with a break, 1400 for mass starts and pursuits without a break), T_x and T_o are the competitor's and winner's race time in seconds. Based on this calculation, the best race point value and thereby the highest performance achievable is zero. To consider the participants' performance level for all races other than world cup, world championships and Olympics, a race penalty was added to each individual race point. The penalty was calculated by selecting the values of the top 5 finishers from the FIS point list and summating the three lowest values among them and dividing the sum with 3.75. If this calculated race penalty was lower than the minimum penalty, which is defined for each race category in the international competition rules, this minimum penalty was applied. For all athletes included in this study, the three official races with the best FIS race points of each season beginning from the last junior season until the end of the 2019 season or the individual end of the career were averaged separately for sprint and distance events. When an athlete was not competing or was out of competition for more than two years or having less than three sprint or three distance races per season after turning senior, data were not included. To avoid the uncertainty of extrapolating performance trends, only athletes that were active for at least five years prior to their estimated peak age were included. Athletes that met the inclusion criteria for both event groups were additionally defined as all-round athletes for complementary differentiation.

Additional data, such as sex, nationality and date of birth were also collected from the FIS website. Results of all individual races at the Olympic winter games, world championships and world cup of included athletes were used to categorize them as "top-performers" (having finished top 3 at least twice in the named races which closely matches the criteria used in previous studies[8,11]) and "others". Age was calculated according to FIS international competition rules by subtracting the year of birth from the year in which the season ended. As all data collected are publicly available, individual informed consent was not required.

Statistical Analysis

A quadratic regression was performed to each athlete's performance and age data using SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA). Peak age was determined as the minimum of the quadratic equation: Performance = a*Age^2 + b*Age +c. If the peak occurred outside the age range of the performances or the quadratic curve was turned upside down, data were not included. Relative performance progression preceding peak age was determined based on the individual quadratic curve by subtracting peak performance from performance five years prior to the estimated peak. Peak age and relative performance progression are presented as mean and standard deviation (SD). The data were analyzed using mixed models with the dependent variables peak age and relative performance progression, respectively, and the level of significance was set at $\alpha \leq 0.05$. Event type (sprint or distance), sex and performance level were each fixed explanatory variables for the three separate analyses. To respect the hierarchical structure of the data, nationality was defined as a random factor. Chi square statistics and -2 log-likelihood were used to check if a factor improved the fit of the model. Effects sizes (ES) were calculated as Cohen's d, and criteria for interpretation were 0.0–0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, and > 2.0 very large.[18]

Results

Overall, 9719 annual performances from 949 athletes were initially selected according to the inclusion criteria. Due to inadequate data, 382 athletes had to be removed. Thus, 379 athletes were finally included in the distance and 188 in the sprint group. The number of men was more than 1.5-times the number of women (348 vs. 219) whereas there were almost 5-times less top-performers (99) than other athletes (468). Mean goodness of fit of the individual quadratic curves was similar in distance and sprint skiers (R^2 = 0.73 [0.22] and 0.73 [0.20]).

Peak age

Peak age was 26.2 (2.3) years in distance events and 26.0 (1.7) years in sprint events (ES 0.1, *P* = .003). When analyzing all-round athletes only (frequently competing in both events), peak age remained consistent. Trends of peak age in distance and sprint skiing across years of birth are presented in Figure 1.

Figure 1

Differences in peak age as a function of sex and performance level were analyzed separately by event type (Figure 2). Peak age did not differ between men and women in distance events (mean difference, ±95 % CL: <0.1, ±0.5 y, ES<0.1, *P* = .668), whereas significant differences were observed in sprint events (0.8, ±0.5 y, ES=0.5, *P* = .001). Top-performers in distance events reached their peak age 1.6 y later than other athletes (±0.6 y, ES=0.7, *P* < .001), while top-performers in sprint events were 1.0 y older when reaching their peak age compared to others (±0.6 y, ES=0.6, *P* < .001).

Figure 2

Relative performance progression

No significant difference was found in percentage improvement in relative performance over the five preceding years to peak age when comparing athletes in distance and sprint events (48.3% [26.4%] and 52.4% [22.0 %], ES=0.2, *P* = .325).

Percentage improvements in relative performance over the five preceding years to peak age according to sex and performance level are presented in Figure 3. Men improved more than women in both distance (8.8, ±5.4 %, ES=0.4, P = .002) and sprint events (7.5, ±6.4 %, ES=0.4, P = .002). Top-performers improved their relative performance more than others in both distance (42.9, ±6.1 %, ES=1.6, P < .001) and sprint events (26.9, ±6.6 %, ES=1.4, P < .001).

Figure 3

Relative performance at junior and peak age

Relative performance based on individual quadratic trends in the last junior season (age 20 y) was higher in distance events (87.9 [31.1] FIS points) than in sprint events (110.8 [25.6] FIS points, ES=0.6, P <0.001). Estimated relative peak performance was 43.3 (26.7) FIS points in distance and 49.6 (34.9) FIS points in sprint events (ES=0.2, P < .001). No sex differences were observed at peak or junior age in sprint events. In distance events men displayed better FIS point scores than women at both junior (81.3 [27.7] and 99.1 [33.4] FIS points, ES=0.6 P < .001) and peak age (38.1 [26.3] and 52.1 [25.0] FIS points, ES=0.5, P < .001). Top-performers in both event groups displayed better FIS point scores at junior age (58.2 [20.7] vs. 93.2 [29.7] FIS points in distance and 74.4 [25.0] versus 121.3 [42.1] FIS points in sprint events, ES 1.4 and P < .001 in both events).

Relative performance at junior age based on the individual performance trends explained 45 % of the variance in observed relative peak performance in distance (R^2=0.445, p<0.001) and 54 % in sprint events (R^2 = .538, P < .001).

The FIS point change scores were calculated based on original FIS point values for each year, beginning from age 18 until 30 y, separated after event type, sex and performance level, and can be found in the Supplementary Material (available online).

Discussion

This is the first study to quantify peak age and relative performance progression in distance and sprint XC skiing. The main findings were firstly, that differences in peak age between distance and sprint events were trivial, also when considering only all-round athletes that frequently competed in both events. Relative performance among the analyzed athletes was higher in distance events at any time compared to sprint events. Secondly, we found substantial sex differences in sprint peak age, where men peaked ~0.8 y earlier than women. Male XC skiers showed a higher relative performance progression in the five years preceding peak age. Lastly, top-performers displayed a higher peak age, performed better at junior age and improved their relative performance more in the preceding years to peak age than other athletes, independent of event type.

The estimated peak ages of ~26 y in distance and sprint events are in line with previous studies of athletics.[4,6,10] It has to be mentioned that in all these sports, peak age might be affected by training age, as for example an earlier specialization may increase the likelihood of an earlier peak age. Our data do not support the trend of an increasing peak age with increasing event duration in endurance events, as reported by Allen & Hopkins.[10] However, the character of sprint races in XC skiing is different to events in other sports that last ~3-4 minutes, as the race consists of four runs within 4 hours. It seems reasonable that different attributes like the ability to recover fast after a run are needed in XC skiing sprint events, and that those attributes are related to the demands of distance events. The trivial difference in peak age between XC skiing event types demonstrates that a simultaneous development in sprint and distance skiing is generally possible. This is supported by previous publications showing a high similarity in training and physiology of sprint and distance skiers.[19] The analyzed peak ages of all-round athletes were consistent with the overall analysis and showed no chronological preference in the development of these athletes. Interestingly, we observed a decreasing trend in peak age for years of birth in both distance and sprint events, indicating that athletes who were born later reached their peak age earlier. We can only speculate about possible reasons, and future studies should examine even younger age groups and additional parameters such as training age to confirm or disconfirm these findings.

No sex differences were observed in peak age in distance events. However, while peak age among women in sprint events was in line with distance events, men displayed significantly lower peak age in sprint events. We can only speculate for possible reasons. One could be the tendency of a higher degree of specialization towards sprint or distance events in men, which could support a theory of a less simultaneous development compared to generally more all-round orientated women. This was supported by the higher percentage of all-round athletes among female athletes. Our findings related to sex differences in peak age in distance events are somehow contradictory to the trends reported by Haugen et al.[6] More studies should focus on sex-related performance trends in the context of endurance sports.

Top-performers in this study reached their peak age significantly later in both distance (1.6 y) and sprint events (1.0 y) compared to other athletes. These findings differ from earlier investigations on endurance athletes,[6] but we can only speculate about possible reasons for these discrepancies. As described by Tucker and Collins,[20] less successful athletes may have a lower genetic potential or they do not manage to realize their potential to the same degree as top-performers. Both aspects may explain an earlier turning point in sport careers. Furthermore, it is also reasonable to assume that the rate of dropout due to a lack in motivation before exploiting their individual potential is higher among less successful athletes, thereby affecting the general career duration. Interestingly, peak age in top-performers was clearly higher in distance than in sprint events. Although this finding contrasts with the overall results of the present study, it is in line with earlier reports indicating increasing peak ages with increasing event duration.[10]

Calculated FIS points for skiers in distance events were 6.3 points lower at peak age and 22.9 points lower at junior age compared to sprint events. The difference reflects generally higher competitiveness in distance events, especially at junior age. However, the percentage improvement towards peak age did not differ between distance and sprint events. We hypothesize that sprint events have been introduced later and have not evolved in the same way as distance events. Further, the number of competitors and the frequency of races in the two event types differ, reflecting the number of athletes that met all inclusion criteria for this study (i.e., three races per season per event), that was twice as high in distance events. In major championships, such as world championships and Olympics, three individual distance races are part of the program, while only one sprint race takes place. Thus, media attention and the higher number of successful athletes favor distance events, which probably affects goal setting and the focus of young athletes. Similar issues may explain the higher relative performance progression in male versus female athletes. Most practitioners would argue that a smaller number of female competitors also causes less pressure on individual development, which could affect the percentage improvement.

Progression in relative performance in the years preceding peak age was clearly higher in top-performers, which has also been reported in other sports.[6] The clearly higher performance level at junior age (large effects in both distance and sprint events) might be an explanation, as this is associated with a higher aerobic capacity that probably allows top-performers to train more and respond better.[21–23] Further, better athletes usually get more access to and higher quality in support staff, including trainer, physician, psychologist and technician. However, regression analyses of relative junior and peak performance based on the individual performance trends revealed R^2 values of only ~0.5. Future studies should therefore aim to investigate the longitudinal development in training and physiology with respect to different performance levels to get a deeper understanding of the long-term development in endurance sports.

There are several limitations to the study design. Firstly, time as direct measurement of performance in a XC skiing race is not comparable with other races, due to varying race profiles, weather and snow conditions. Hence, performance can only be described in relation to the winner (FIS-points). Thus, all expressions of performance are influenced by the level of the best performing athletes. Consequently, the percentage progression in relative performance cannot be compared to previous data. Moreover, FIS-points in sprint are only related to the qualification and not to overall sprint performance. However, additional analysis of 13068 individual results revealed a strong correlation ($r=0.660$, $p<0.001$) between the rankings in qualification and final. Furthermore, no data is available regarding the participants training age, which is probably a strong predictor of peak age. Finally, potential use of prohibited substances (doping) and improvement in equipment may have influenced individual performance data.

Practical applications

This study provides novel insight on peak age and relative performance progression in world-class XC skiing contestants that can be useful for goal setting, long-term training planning, seasonal evaluations, talent development benchmarking, athlete selection processes and allocation of funding and resources. Specifically, these findings indicate that practitioners, sport institutions and federations aiming for fast success should focus specifically on sprint skiing and female athletes and should not consider junior performance as primarily criterion for talent selection. Furthermore, the identified dynamics in peak age are useful as motivational factor for young athletes. In addition, our observations also provide a point of departure for future studies aiming to investigate the possible underlying mechanisms related to peak age and relative performance progression across athletes, exercise modalities and physiological capacities.

Conclusions

The present study revealed that mean peak age was ~26 y in both distance and sprint skiing, indicating that a simultaneous development in both events is possible. Male XC skiers showed a higher relative performance progression in the five years preceding peak age. Top-performers performed better at junior age, improved more and over a longer time frame than other athletes. Moreover, we found that competitiveness was lower in sprint events and among women in both event types. Furthermore, we found that junior performance can only account for half of the variance in peak performance.

Acknowledgement

We thank Øyvind Salvesen for his valuable input on the statistical analyses.

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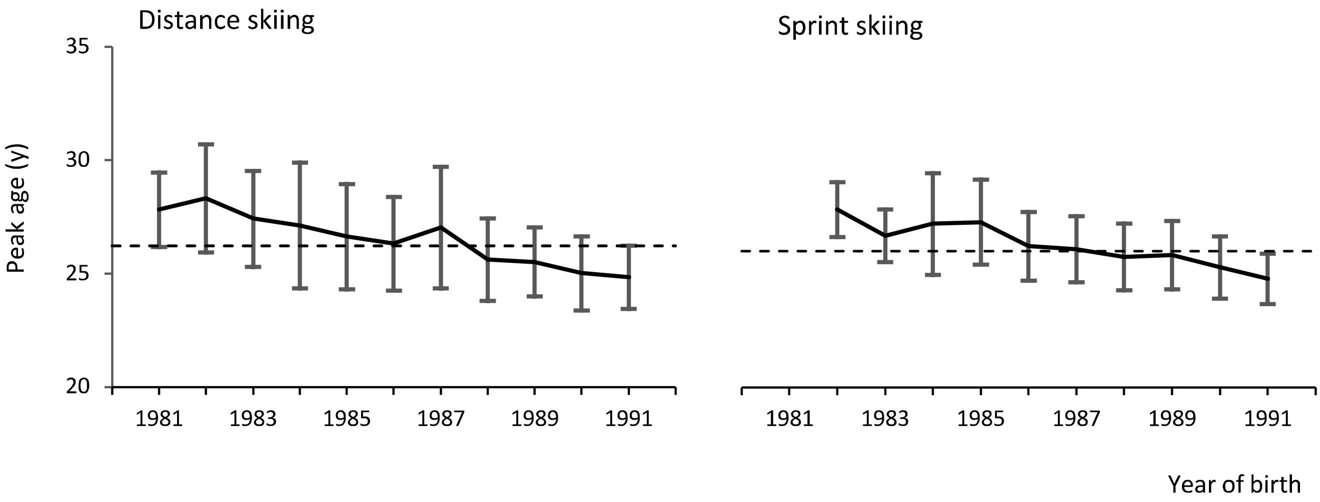
Figure captions

Figure 1. Age of peak performance among cross-country skiers across years of birth in comparison to the overall means (dotted lines). Data are means and standard deviations.

Figure 2. Age of peak performance among cross-country skiers across sex (Panel A) and performance level (Panel B). Data are means and standard deviations. Effect sizes: * trivial, ** small, *** moderate.

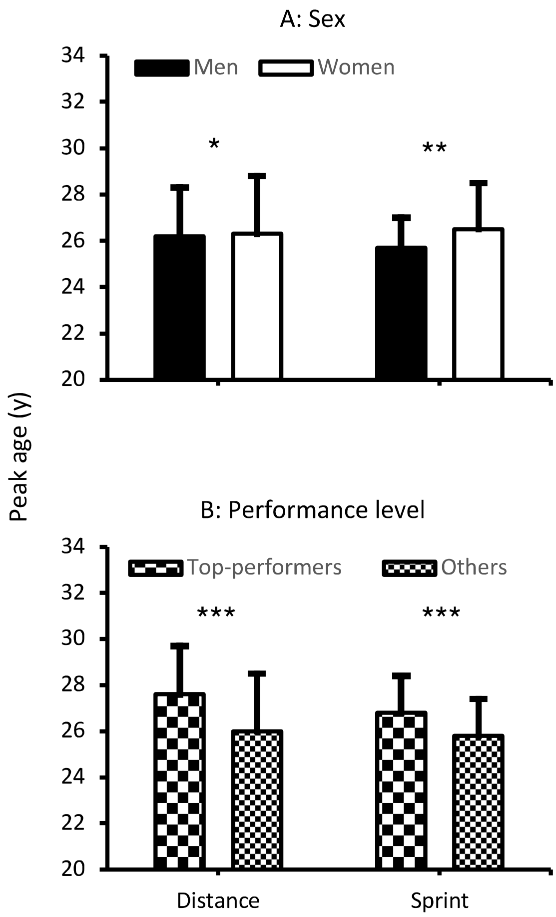
Figure 3. Improvement in FIS points in cross-country skiers over the five preceding years to age of peak performance across sex (Panel A) and performance level (Panel B). Data are means and standard deviations. Effect sizes: ** small, **** large.

Figure 1



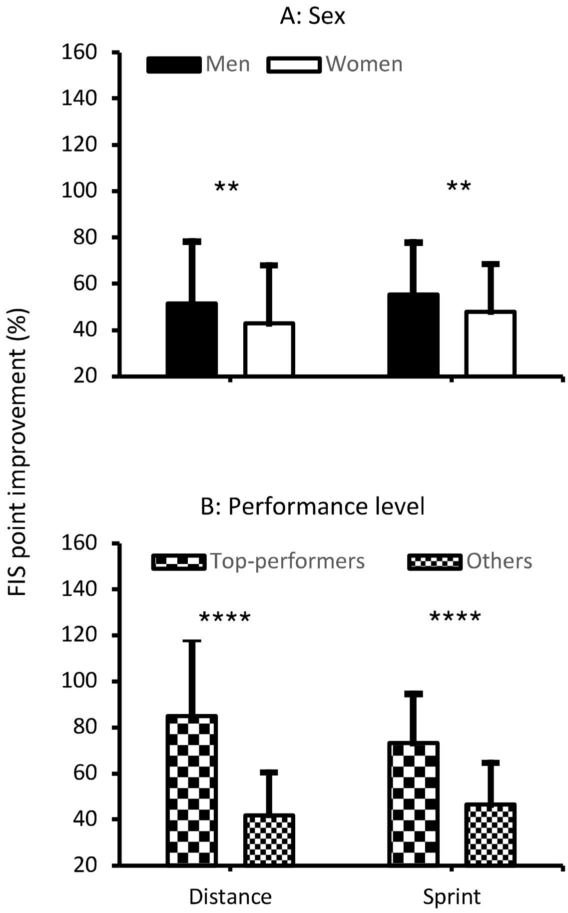
Distance skiing
Sprint skiing
35
30
25
20
Peak age (y)
1981
1983
1985
1987
1989
1991
1981
1983
1985
1987
1989
1991
Year of birth

Figure 2



A: Sex
Men
Women
*
**
B: Performance level
Top-performers
Others
***
***
34
32
30
28
26
24
22
20
Peak age (y)
Distance
Sprint

Figure 3



A: Sex
Men
Women
**
**
160
140
120
100
80
60
40
20
FIS point improvement (%)
B: Performance level
Top-performers
Others
****
****
160
140
120
100
80
60
40
20
Distance
Sprint