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MAXIMUM PERFORMANCE OF MASTER CROSS-COUNTRY SKIERS IN LOPPETS:
Relationship with age

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BACKGROUND. Most participants in long-distance cross-country ski races (loppets) are masters (age ≥ 30 yrs). They represent an effective study population to quantify the age-performance relationship. AIM. 1) to determine the relationship between age, gender, skiing style and performance of master skiers; 2) to test the force development theory that suggests that the decreased performance with age should be larger for the more strenuous free style technique than for the classic style, for both men and women. MEASURES. Cross-sectional data were gathered from nine loppets from the Worldloppet Circuit that comprised 89 events in total between 1995 and 2005. A total of 190,304 master men and 24,917 master women took part to these events. Participant age was classified mainly in 5-year categories while average speed was calculated from the loppet distance divided by individual race times. MODELING APPROACH. The boundary line approach was used to select the maximum performance by age class in each event. ANALYSES. A general modified power model was fitted to the relative average maximum speed achieved in each age category for each event. Loppets were considered as random factor and each event within loppets as subjects in a repeated-measure regression analysis. OUTCOMES. Age, gender and skiing style influenced maximum performance. The general model fit was considered good ($r^2 = 0.70$; $p < 0.001$). Maximum performance of skiers decreased with age, with more moderate declines for men than for women, and also for the classic style compared with the free style. Age correction factors were calculated direct from the general model, giving preliminary age-graded factors making comparable performances at different ages in various loppet events. CONCLUSIONS. The results supported the force development theory. However, the study of longitudinal data is needed to confirm or refine age-graded factors, particularly for elderly skiers (≥ 60 yrs).

KEYWORDS: age-performance relationship, age-graded performance, cross-country ski, cross-sectional data, loppet, skiing technique.

INTRODUCTION

Background

Many investigators have shown that performance in sports peaks in the late twenties or early thirties for both men and women and then declines gradually. This trend has been reported for short as well as long track and field running distances (Baker et al., 2003; Grogan et al., 1991; Korhonen et al., 2003), swimming (Weir et al., 2002), and even in solely anaerobic muscular sports such as weightlifting and powerlifting (Anton et al., 2004).

A loppet is a mass participation long-distance cross-country ski race (>30 km), which demands prolonged regular physical training. Although participants in loppets have increased risk of acute mortality during long-distance ski races (Farahmand et al., 2007), they have lower mortality in the long term (Farahmand et al., 2003). Also, most of the participants in loppets are masters (≥ 30 yrs of age). Master skiers from loppets represent an effective study population to quantify the age-performance relationship in long-distance cross-country ski races because age-related changes observed in these healthy trained and motivated athletes should reflect the consequences of physiological aging (Böttiger, 1971).

There is evidence that age-associated changes in performance are influenced by the tasks involved in the practice of sports (Tanaka and Seals, 2003). In cross-country skiing, good technique is essential for best performance, with the classic style being considered more technical and oxygen demanding than the free style because of the time-coordinated diagonal striding movements involved (Hoffman, 1992). However, since the arm force used in the free technique is usually higher than in the diagonal classic technique (Smith, 1989), the free style is generally considered to represent a more strenuous sport than the classic style since the free style engages upper and lower large muscle groups more simultaneously and dynamically. Consequently, speed is in general 5-15% greater with the free style technique.

Aim

Both force development (Anton et al., 2004; Bilodeau et al., 1996; Korhonen et al., 2003) (for example peak force) and cardiovascular functions (Tanaka and Seals, 2003; Wiebe et al., 1999) (for example maximal oxygen consumption rate) are main fitness factors declining with age. According to the force development theory (Weir et al., 2002) which states the decline in force development with increasing age is the main factor for decreased performance, I hypothesised the greatest performance declines in performance with increasing age for both master men and women should be seen in the free style technique, which requires more force than the classic style. Besides testing this hypothesis, the other objective of this study was to build age-graded factors that could be used to compare the performance in loppets among master skiers of different ages.

The constraints inherent to the study of cross-country ski races data are: 1) every ski race is unique, even from year to year for a same course, given snow and weather conditions strongly influence the absolute speed the racers can maintain; 2) maximum performance in long-distance races is generally reached at ages ranging from the end of the 20's up to the mid 30's (the age of World Cup cross-country champions in the last ten years (1997-

2006) for men and women ranged from 25 to 34 yrs and from 24 to 31 yrs, respectively (FIS Cup Standings available from www.fis-ski.com)); 3) the entry for participants at loppets under study was open, that is not all the possible best racers at every age class could be present at every event, which means for instance that for a given race a 60 year-old skier could do better than a 30 year-old; 4) the study design was cross-sectional; 5) I wished to compare the change of performance with age across the different events.

METHODS

Measures

The data for this study were the available official historical time results obtained from nine loppet organizations. The selected loppets were part of the Worldloppet Circuit of the Worldloppet Ski Federation, an international sports federation of cross-country skiing marathons (www.worldloppet.com). The races were selected according to the availability of individual race time results and indication of sex and age, birth year or age category of the participants. Cohorts from 44 race events in classic style and 45 in free style were used for the regression analysis (Table 1).

Table 1. Summary of the data used in this study. The number of master men and women in the last two columns refer to the total number of ≥ 30 year-old participants and for which their age or age class was recorded.

Loppet	Country	Years (n)	Distance (km)	Master men	Master women
Classic style					
American Birkebeiner	USA	2002-2005 (4)	51	1763	309
Birkebeinerrennet	Norway	1999-2005 (7)	54	41275	5820
Jizerská Padesátka	Czech Rep.	1999-2005 (7)	50	12441	522
Keskinada Loppet	Canada	1997-2005 (9)	42-53	2061	407
König Ludwig Lauf	Germany	1997-2005 (8)[z]	45-55	7413	675
Marcialonga	Italy	2003-2005 (3)	70	9788	968
Tartu Maraton	Estonia	1998-2005 (6)[y]	42-63	11947	1345
Total number of events / participants		44		86688	10046
Free style					
American Birkebeiner	USA	2002-2005 (4)	51	9514	1404
Engadin Skimarathon	Swiss	1998-2005 (8)	42	62324	10852
Kangaroo Hoppet	Australia	1997-2005 (8)[x]	42	1772	350
Keskinada Loppet	Canada	1997-2005 (9)	42-53	3596	380
König Ludwig Lauf	Germany	1997-2005 (8)[z]	46-55	4343	396
Marcialonga	Italy	1995-2002 (8)	70	22067	1489
Total number of events / participants		45		103616	14871

[z] The 2002 event was cancelled.

[y] The available data for years 2000 and 2004 were incomplete and were thus excluded from the analysis.

[x] The 2003 loppet was shortened to 21 km, and thus was excluded from the analysis.

NOTE: maximum age class was > 70 yrs for Kangaroo Hoppet, Keskinada and Marcialonga, and ≥ 75 yrs for Tartu Maraton.

Modeling approach

I used the boundary line approach (Webb, 1972) to select the best performance by age class (5-year intervals for all events, except for Marcialonga races for which data were available in 10-year intervals). The steps consisted in 1) plotting all data of mean absolute average speed against age or age category for each ski event to analyze the distribution pattern; 2) determining its suitability and potential for use, and identify obvious outliers (Figure 1A); 3) calculating the relative speed for each event by style and sex, that is individual speed divided by the maximum speed achieved at the event for age ≥ 30 yrs (Figure 1B; the first master age category was 21-34 for Tartu Maraton) and 4), selecting only the highest point for each age class interval for further regression analysis (Figure 1C). The age values used in analysis were then median age of each age class. The selection method is considered conservative for loppets for which the exact age of each participant was available (American Birkebeiner, Engadin Skimarathon, Jizerská Padesátka, and König Ludwig Lauf) since the best relative performance that was usually made by youngest skiers within a given category was assigned to the median age within the same category.

Analyses

The curve of potential human performance for master athletes generally decreases with age. Preliminary examination of graphs suggested that maximum performance was in general related negatively to skier age and this trend increased with age. The change in performance with age by sex and skiing style was thus assessed using a modified power function of the form:

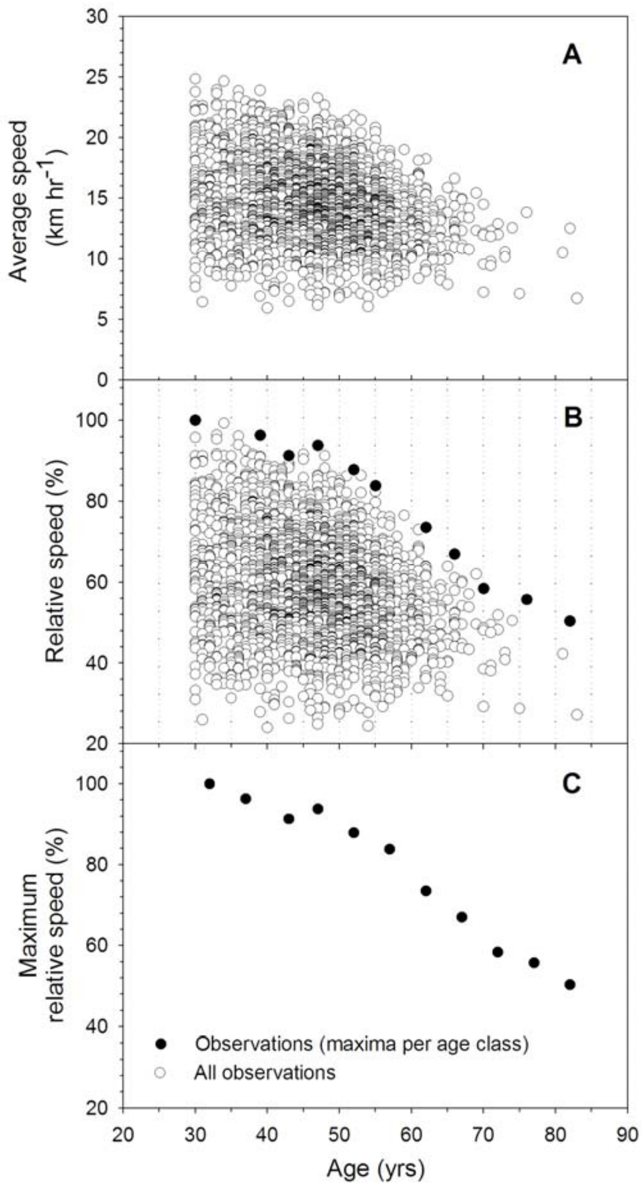
$$y = 100 - A \times age^{B1} \times e^{B2\times style} \times e^{B3\times sex} \times e^{B4\times style\times sex} \times age^{B5\times style} \times age^{B6\times sex} \times age^{B7\times style\times sex}$$

where y: relative maximum speed (%), age (yrs), A: empirical coefficient, B's: empirical exponent coefficients, and style and sex were categorical variables. The maximum value of y was set to 100%. The model was linearised for regression analysis in following the form:

$$\log_n(101 - y) = \log_n(A) + B_1 \times \log_n(age) + B_2 \times style + B_3 \times sex + B_4 \times style \times sex + B_5 \times \log_n(age) \times style + B_6 \times \log_n(age) \times sex + B_7 \times \log_n(age) \times style \times sex$$

The dependent variable has become the log of predicted relative difference with maximum performance. The value of one (1) was added to the maximum value (100%) to include the observations with relative speed equal to 100% in the analyses ($\log_n(1) = 0$). The empirical coefficients were determined by restricted maximum likelihood estimation using the MIXED procedure of SAS (SAS Institute Inc., 2003). In the analysis, loppets were considered as random factor and event years within loppets as subjects.

Figure 1. Method used to select best performance per age class. The example depicts the 2005 American Birkebeiner edition (men, 50 km free style, n=2437). A) Plot of skiers' individual average speed (distance/time) as a function of age. B) Individual relative speed as a function of age, and selection of the best performance per 5-year age class (black dots). C) Data used in regression analysis.



RESULTS AND DISCUSSION

Maximum performance

The number of participants to the loppets under study decreased with age for both the classic and free style, particularly for men ≥ 70 years and women ≥ 55 years (Figure 2). When considering only the fastest man and woman in every ski event, the average maximum speed in classic style was 12.5% lower than in free style (p = 0.001), with a similar decline for both men and women (p (style x sex) = 0.485) (Figure 3). The average maximum speed for men in the studied loppets was on average 14.9% higher than for women (p < 0.001) independently of skiing style.

Figure 2. Frequency distribution of master participants as a function of age in all the loppet events under study.

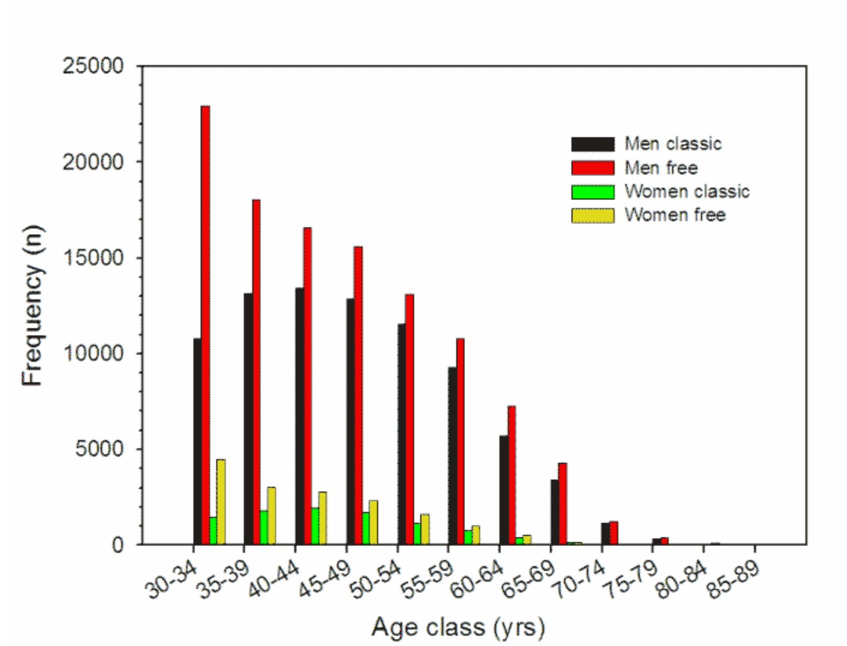
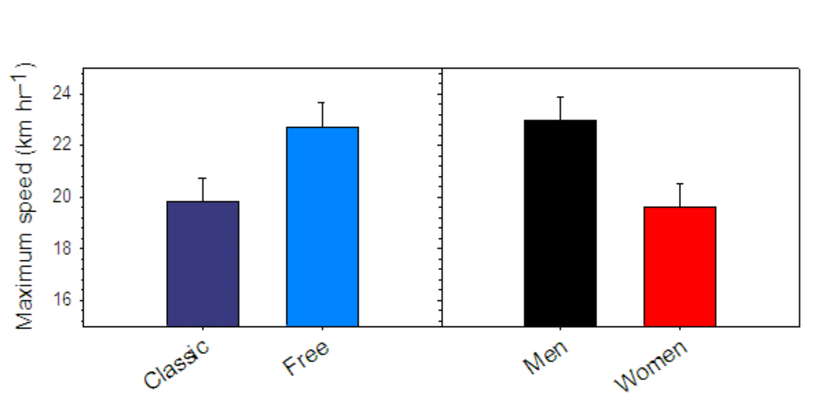
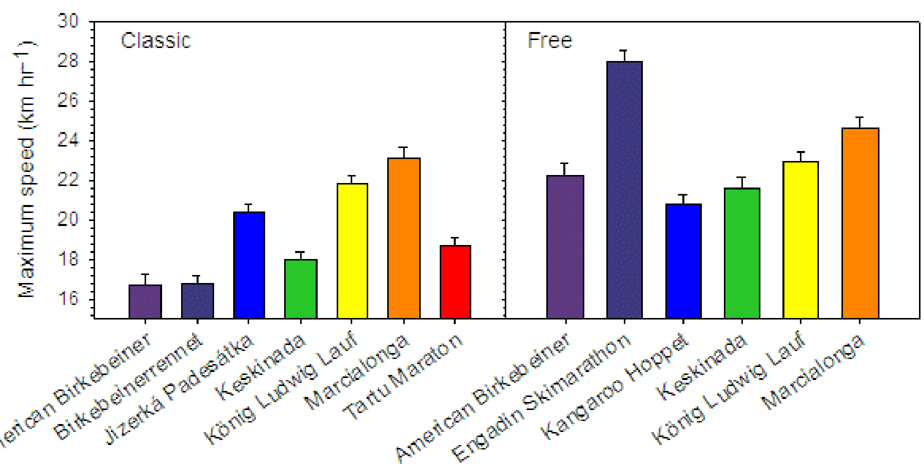


Figure 3. Average maximum ski speed achieved in the loppets under study by skiing style and gender.



In classic style events, the average maximum speed was the slowest for the American and Norwegian Birkebeiner loppets (16.73±0.47 km hr^{-1}) while the fastest average maximum speed was noted for Marcialonga (23.09±0.62 km hr^{-1}) (Figure 4). In free style events, the average maximum speed was the slowest for the Kangaroo Hoppet and Keskinada (21.19±0.51 km hr^{-1}) while the fastest average maximum speed was noted for the Engadin Skimarathon (27.99±0.53 km hr^{-1}). Differences in courses topography, weather, and snow conditions are believed to be the main factors explaining these distinct performances.

Figure 4. Average maximum speed achieved in the loppets under study.



Age – performance relationship

General model

The regression coefficient estimates of the general model are presented in Table 2. The fit of this model including all loppets combined was good (r^2 = 0.70). The coefficient of variation of predicted values is equal to 14.8%. The log of predicted relative difference with maximum performance (log_n (101-maximum relative speed) depended not only on the skier's age, but also on its sex and the skiing style practised. To ease the model interpretation, the log of predicted relative difference with maximum performance as a function of log_n (age), skiing style and gender can be summarized in a simpler model form (log_n (101-y) = log_n (A) + B (log_n (age)) for each skiing style and gender by combining the coefficient estimates, giving:

- For "Master men in classic style": log_n (101-y) = -10.78 + 3.3489 x log_n (age)
- For "Master men in free style": log_n (101-y) = -12.92 + 3.8728 x log_n (age)
- For "Master women in classic style": log_n (101-y) = -12.95 +3.9743 x log_n (age)
- For "Master women in free style": log_n (101-y) = -14.84 + 4.4982 x log_n (age).

Figure 5 sketches the general model differences among skiing style and gender. The general model showed the intercept and slope of the log of predicted relative difference with maximum performance of master skiers increased with the woman gender compared with man, and with the free style compared with the classic style. Thus, the decrease in performance for master men with age was more moderated than for women for both cross-country skiing styles and, also, the decrease in performance for both master men and women skiers in the classic style was more moderated than in the free style. The "$\log_n$ (age) x style x sex" interaction was not significant ($p = 0.207$), signalling the decrease in performance with age for the free style compared with the classic style was not different for men and women. Therefore, this interaction term was excluded in the final regression analysis.

Another notable result from the general model analysis was that the "style x sex" interaction was significantly different only for "men in classic style". What this means is the log of relative difference with maximum performance of master men in classic style was systematically slightly smaller at any age than any other gender-skiing style combination.

Table 2. Coefficient estimates for the linear form of the modified power equation and specific coefficients for the Birkebeinerrennet and Engadin Skimatathon loppets.

Parameter	Coefficient estimate B_i (SE)	$P \neq 0$ (α = 0.05)	Lower CL (95%)	Upper CL (95%)
General model for all loppets[a]				
Intercept (Log_n (A))	-14.84 (0.41)	<0.001	-15.65	-14.02
Log_n (age)	4.4982 (0.1026)	<0.001	4.2969	4.6995
Style: classic	1.8868 (0.4290)	<0.001	1.0448	2.7287
Gender: male	1.9171 (0.4474)	<0.001	1.0391	2.7951
Style x gender: classic & male	0.2562 (0.0518)	<0.001	0.1546	0.3579
Log_n (age) x style classic	-0.5239 (0.1081)	<0.001	-0.7360	-0.3118
Log_n (age) x gender: male	-0.6254 (0.1112)	<0.001	-0.8436	-0.4071
Model variance	0.01910			
Model r^2	0.70			
Birkebeinerrennet only[b]				
Intercept (Log_n (A))	-11.36 (0.73)	<0.001	-12.88	-9.84
Log_n (age)	3.4921 (0.1747)	<0.001	3.1287	3.8555
Gender: male	-2.3640 (0.8912)	-0.030	-4.1521	-0.5759
Log_n (age) x gender: male	0.4730 (0.2133)	0.011	0.0467	0.8993
Model variance	0.07236			
Model r^2	0.71			
Engadin Skimarathon (women in free style only)[c]				
Intercept (A)	148.46 (3.47)	<0.001	141.38	155.53
Age	-1.4235 (0.0613)	<0.001	-1.5482	-1.2989
Model variance	47.61			
Model r^2	0.90			

[a] Power equation in the linear form:

$$\log_n(101-y) = \log_n(A) + B_1 \times \log_n(age) + B_2 \times style + B_3 \times sex + B_4 \times style \times sex + B_5 \times \log_n(age) \times style + B_6 \times \log_n(age) \times sex$$

where *y* is the maximum relative speed (%) and units for age are expressed in years.

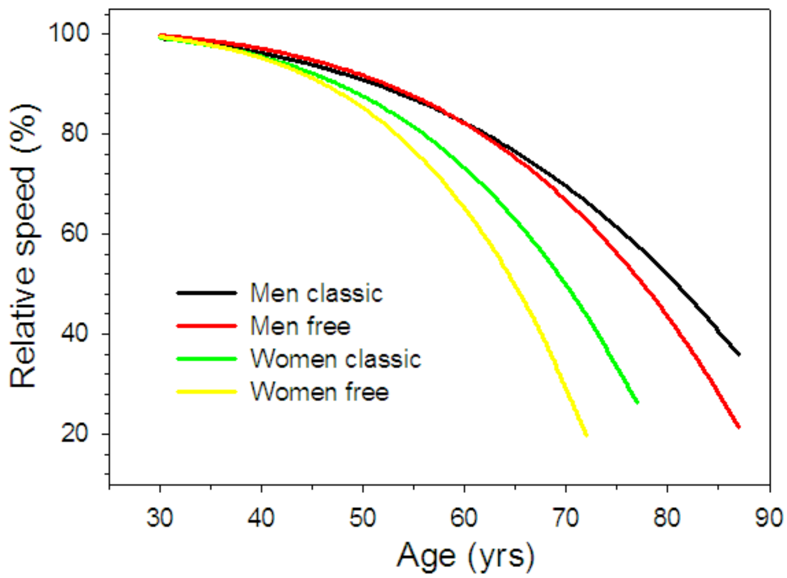
[b] Power equation in the linear form:

$$\log_n(101-y) = \log_n(A) + B_1 \times \log_n(age) + B_2 \times sex + B_3 \times \log_n(age) \times sex$$

[c] Linear equation in the form:

$$y = A + B_1 \times age$$

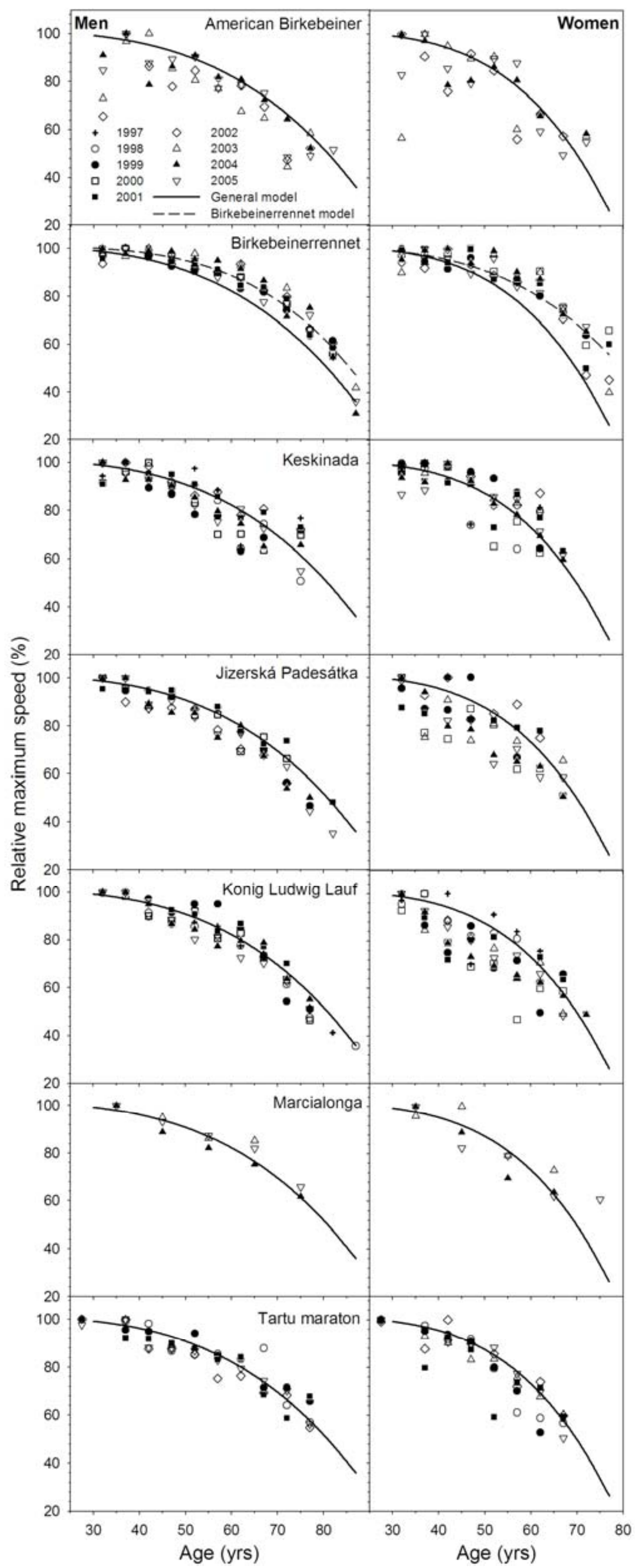
Figure 5. General model describing the relationship between cross-country master skier age and relative maximum performance by skiing style and gender.



Classic style

The observations for classic loppets were generally more spread for women than for men (Figure 6). The general model obviously fitted well the loppets. However, the general model tended to lie below the observations for the loppet with the greatest number of master men and women participants, the Birkebeinerrennet. A specific regression analysis of this loppet improved the model fit only slightly (Table 2; Figure 6).

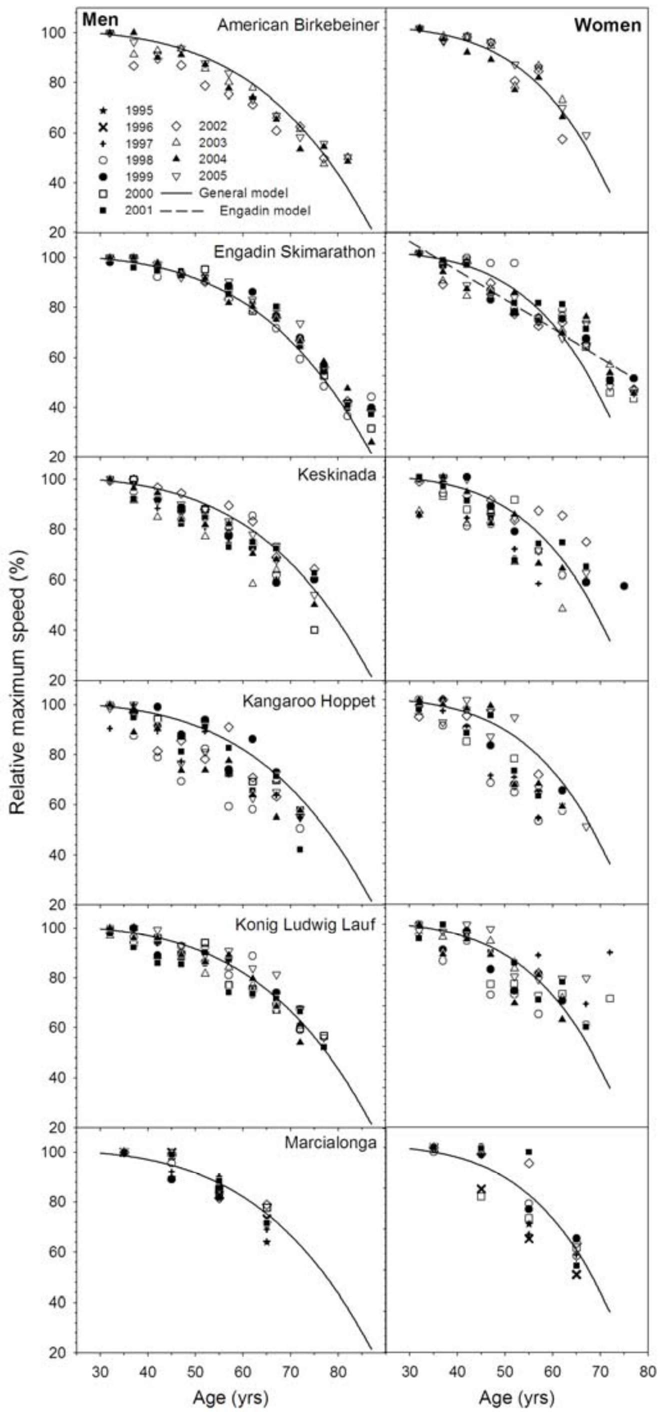
Figure 6. Relationships between age of cross-country master men and women and relative maximum speed in classic style for the loppets under study. The curves correspond to regression lines described in Table 2.



Free style

As for the classic loppets, observations were generally more spread for women than men for the free style loppets (Figure 7). The general model followed well the age – relative maximum speed trend for all loppets, but clearly not as good as it should for women in the Engadin Skimarathon, incidentally the loppet that included the greatest number of master women participants. A specific regression analysis of this loppet using a simple linear model improved the fit markedly (Table 2; figure 7). The correlation between observed relative maximum speed and predicted values for this linear model ($r = 0.95$) was slightly better than the one between observed and back-transformed predicted values the general model in the original units ($r = 0.85$).

Figure 7. Relationships between age of cross-country master men and women and relative maximum speed in free style for the loppets under study. The curves correspond to regression lines described in Table 2.



Outcomes

In this study I examined the relationship between master skier's age and maximum performance in loppets. As expected, the results point out there were marked differences between gender and between skiing styles. Maximum performance of skiers decreased with age, with more moderate declines for men than for women, and for the classic style than for the free style. The only published study I found on this subject in the past was from Böttiger (Böttiger, 1971) who reported a similar decrease for the 1970 Vasaloppet, a 85 km classic loppet for men. The faster rate of performance decline with age is consistent with observations made in other sports in cross-sectional studies (5-15% by decade). The nonlinear trend described by the general model agrees with the force development theory (Weir et al., 2002) as maximum performance in loppets declined with age more rapidly with the more strenuous free style technique than with the more aerobic classic style for both men and women.

Age-graded performance

Although the loppets under study represent a sample of all possible long-distance ski race events, they provide a starting point from which age-corrected performances can be estimated. The general model presented in Table 2 can be used to calculate the so-called "age-graded performances" for loppet events to standardize a given participant's performance with master skiers of any age (Table 3). For example, a 50 year-old woman raced a classic loppet in 3h 30min 30s. The conversion factor for women in classic style is y = 87.6% according to the general model. (That means that a 50 year-old woman should ski a classic loppet 12.4% slower than when she was in her prime). Her age-graded time is thus equal to 3h 4min 25s (3h 30min 30s x 0.876).

Table 3. Age correction factors (%) for men and women calculated from the general model of Table 2.

Age	Men		Women	
	Classic	Free	Classic	Free
30	99.2	99.7	99.2	99.4
35	97.9	98.7	97.8	97.8
40	96.2	97.1	95.5	95.2
45	93.8	94.8	92.2	91.2
50	90.8	91.7	87.6	85.2
55	87.0	87.6	81.4	76.8
60	82.2	82.2	73.4	65.2
65	76.5	75.4	63.0	49.7
70	69.6	66.9	50.0	29.4
75	61.4	56.4	33.9	n.e.
80	51.8	43.7	n.e.[a]	n.e.
85	40.8	28.6	n.e.	n.e.

[a]n.e.: not evaluated because age is outside the model interpolation range.

However, age-correction factors drawn from the model may possibly overestimate the rate of performance decline with age (particularly the elderly for which the number of participants was low) because the model was based on cross-sectional data. As skiing technique is important for performance, it should not worsen as much with aging and should provide an asset to older experienced skiers. It appears, at least in track and field running, that longitudinal data (that is individual age-performance trend) do not suffer the same rate of age-decline as cross-sectional data (Young and Starkes, 2005). Thus, the use of the models presented here may provide an advantage to the elderly (≥ 60 yrs) when calculating age-graded performances.

Being a cross-country skier, my own observations in many regional and provincial loppets suggested that older participants were not necessarily the best in their prime time, but they were among the most motivated to complete the race, and not essentially motivated to break records. These observations agree with the possibility the cross-sectional data used may indeed overestimate the real age-decline rate for the elderly.

A careful longitudinal design is needed to confirm or refine age-graded performance factors obtained in the present study for the elderly. In that respect, I invite willing ≥ 60 year-old cross-country master women and men skiers, who have at least 20-year records of their ski performances in cross-country races, to contact me to take part in this longitudinal study for better quantifying the age-skiing performance relationship.

CONCLUSIONS

The rate of age-decline performance of cross-country skiers in loppets was consistently higher with the free style technique compared with the classic style, and this for both men and women. The general model describing age-performance relationship can be used to evaluate age-graded performances for master participants in loppets. However, because of the nature of the cross-sectional data, these could probably be improved, particularly for the elderly, by the study of longitudinal data.

ACKNOWLEDGMENTS

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