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Variability and Predictability of Performance Times of Elite Cross-Country Skiers

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Analyses of elite competitive performance provide useful information for research and practical applications. ***Purpose:*** Here the authors analyze performance times of cross-country skiers at international competitions (World Cup, World Championship, and Olympics) in classical and free styles of women's and men's distance and sprint events, each with a total of 410–569 athletes competing in 1–44 races at 15–25 venues from seasons 2002 to 2011. ***Methods:*** A linear mixed model of race times for each event provided estimates of within-athlete race-to-race variability expressed as a coefficient of variation (CV) after adjustment for fixed or random effects of snow conditions, altitude, race length, and competition terrain. ***Results:*** Within-athlete variability was similar for men and women over various events for all athletes (CV of 1.5–1.8%) and for the annual top-10 athletes (1.1–1.4%). Observed effects of snow conditions and altitude on mean time were substantial (~2%) but mostly unclear, owing to large effects of terrain (CV of 4–10% in top-10 analyses). Predictability of performance was extremely high for all athletes (intraclass correlations of .90–.96) but only trivial to poor for top-10 athletes (men .00–.03, women .03–.35). ***Conclusion:*** The race-to-race variability of top-ranked skiers is similar to that of other elite endurance athletes. Estimates of the smallest worthwhile performance enhancement (0.3× within-athlete variability) will help researchers and practitioners evaluate strategies affecting performance of elite skiers.

Keywords: skiing, elite athletes, competition, intraclass correlation, reliability

The race performance of elite athletes who compete as individuals displays random variation from competition to competition. For these sports where athletes compete for best time or distance, 0.3 times the standard deviation of an elite athlete's race-to-race performance provides an estimate of the smallest worthwhile enhancement, which represents an extra medal for a top athlete in every 10 races.[1] This information is useful for sport scientists interested in investigating factors affecting elite performance. Estimates of the variability of performance of elite athletes have been published for various sports including cycling (0.4–2.4%),[2] track and field (1.0–2.8%),[3] swimming (0.6–1.0%),[4] rowing (0.9–1.1%),[5] and flat-water canoe and kayaking (0.7–1.5%).[6] However, there is currently no published information on the performance variability in elite cross-country skiing. It is unclear how variability in cross-country skiing for the various events would compare with that in other sports, given the unique technical demands and environmental effects in skiing.

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A concept related to variability of performance is the predictability of race outcomes. This concept addresses the issue of the stability of athlete ranking. A measure that can be used to quantify performance predictability is the intraclass correlation coefficient (ICC), which is calculated from the variability within and between athletes across several competitions and is effectively the usual correlation that would be observed between performances in 2 competitions.[7] To date, there is limited published information on the predictability of performance in elite athletes, with reported correlations ranging from .22 to .79 in rowing,[5] .06 to .47 in slalom canoe-kayak,[8] .44 to .89 in flat-water canoe and kayaking,[6] and .06 to .35 in skeleton.[7] The aims of this study were therefore to estimate the variability and predictability of performance of elite cross-country skiers. In addition, the relationships between the sprint qualification (prologue rank) and mean sprint finals rank were investigated.

Methods

Performance Data

There are 2 technique styles in cross-country skiing competitions: classical and free. The classical style involves the use of 2-dimensional techniques (diagonal and double-poling techniques) with use of kicking wax, while freestyle involves all skiing techniques with a major use of 3-dimensional "V techniques" without kicking wax. Race formats consist of interval start, mass start, skiathlon, and relays of various distances during standard 1-day and multiday (minitour) events. The official race distances in the Olympics and World Championships are sprint (0.8–1.4) and 10, 15, and 30 km for women and sprint (1.0–1.8) and 15, 30, and 50 km for men. Only the sprint qualification (prologue) in sprint and 10- or 15-km races, women and men, respectively, are interval starts in these major championships. In this study, we only analyzed interval-start races. Official race times and course information were downloaded from the International Ski Federation Web site (www.fis-ski.com) for World Cup, World Championship, and Olympic competitions from seasons 2002 to 2011. For the latter 2 competitions there is an athlete quota per nation, with only 4 skiers per nation for each event (plus the current World or Olympic champion) allowed to complete. Furthermore, information on official ratings of snow conditions were included and approximate start-to-finish altitude for each race location were determined to distinguish between races at above 1200 m (1492 ± 184 m, mean ± SD) or below (401 ± 372 m) this altitude. The 8 events analyzed were the classical and free styles of women's distance (10 km), men's distance (15 km), and men's (1.0–1.8 km) and women's (0.8–1.4 km) prologue. Each of these events had a total of 410 to 569 athletes competing in 1 to 44 races at 15 to 25 venues. In analyses restricted to the top 10 from each year, there were 35 to 49 athletes in 1 to 31 races (see Table 1 for a list of event disciplines and sample sizes). A subset of data, from seasons 2006 to 2011, was obtained for the analysis of sprint qualification (prologue rank) versus sprint finals rank. As these data were in the public domain and no individuals were named, written consent from athletes was not sought.

Statistical Analysis

The mixed-linear-modeling procedure (Proc Mixed) in SAS (Version 9.2, SAS Institute, Cary, NC) was used for most analyses. Race times were log-transformed before analysis, as this approach yields variability and differences as percentage of the mean (coefficients of variation; CV), which is the appropriate method for quantifying changes in most measures of athletic performance.[9] Separate analyses were conducted for data from each gender and event. The fixed effects in the model were the official ratings of snow conditions (6 levels: wet/spring, granular, compact, hard, packed, hard packed), to estimate effects of snow conditions; altitude (2 levels: yes, no), to estimate differences between races above and below 1200 m; and race length (simple numeric), to estimate effects of exact race distance. The random effects (expressed as CV) representing differences in performance time were athlete identity (to estimate true differences in mean ability between athletes), the interaction of athlete identity with competition year (to estimate within-athlete variation between seasons), competition (to estimate differences in race terrain and course difficulty), and the residual (to estimate within-athlete race-to-race variability).

Separate analyses were performed for all athletes and for the athletes who were among the top 10 each year. The top-10 athletes were identified by analyzing each year separately with a model that had only athlete identity, competition terrain, and residual random effects. The random-effects solution for athlete identity was ranked, and the athletes with the most negative values

Table 1 Descriptive Statistics for the Number of Athletes and Races Entered in the Various Event Disciplines at World Cup, World Championship, and Olympic Competitions From Season 2002 to 2011 for All Athletes and for the Top 10 Each Year

	All Athletes			Top 10		
		Number of Races			Number of Races	
	N	Mean ± SD	Max	N	Mean ± SD	Max
Men						
15-km classical	569	5.2 ± 6.9	36	38	8.7 ± 7.5	27
15-km free	555	4.4 ± 5.4	27	49	4.8 ± 5.0	22
sprint classical	525	5.1 ± 6.7	33	45	6.8 ± 6.9	29
sprint free	682	5.1 ± 7.3	44	48	7.9 ± 6.5	26
Women						
10-km classical	425	5.6 ± 7.0	36	37	8.6 ± 8.3	31
10-km free	410	4.7 ± 5.5	27	35	6.9 ± 5.5	31
sprint classical	419	5.5 ± 7.1	37	39	8.5 ± 7.4	26
sprint free	538	4.9 ± 7.2	42	44	8.5 ± 6.4	28

(representing those with the fastest mean times in the given year) were selected and aggregated into 1 data set for analysis with the full model.

The mixed models were run with the default option of allowing estimation only of positive variances for the random effects. True variances for the random effects for athlete and for interaction of athlete with competition year were expected to be positive, but small true values can result in observed negative values, owing to sampling variation. This outcome occurred for 2 of the men's events in the top-10 analyses. The variances were set to zero by the modeling procedure, and uncertainties for these variances and for the resulting zero ICCs could not be computed. For purposes of comparison of mean correlations, uncertainties for zero values were assumed to be the mean of those with nonzero values.

Analysis of residual versus predicted values displayed no evidence of nonuniformity of error. Race times that had standardized residuals >5.0, representing unusually slow times, were determined as outliers and were removed before reanalysis (53 race times were removed). The majority of these outliers were the worst performers (ie, athletes with race times in the last 3 of a given competition) in major championship events and can be attributed to there being no qualification standard for the major championship events, in contrast to the International Ski Federation point-qualification standard required for athletes (from any nation) to start in World Cup races.

Thresholds for interpreting magnitudes of differences in mean performance times as being small, moderate, large, very large, and extremely large were, respectively, 0.3, 0.9, 1.6, 2.5, and 4.0 of the within-athlete race-to-race (residual) CV of each event and gender; these thresholds represent enhancements that would provide a top athlete with 1, 3, 5, 7, and 9 extra medals in every 10 competitions.[9] To interpret the magnitude of a CV (other than the residual) representing typical differences in performance times, we doubled the CV before assessing it on the described scale.[5]

Predictability of performance was expressed as ICC. The within-year ICC (race-to-race reproducibility in any given year) was calculated as the pure between-athletes variance in a given race (sum of the variances represented by athlete and athlete × year random effects) divided by the observed between-athletes variance in a given race (sum of the pure between-athletes variance and the within-athlete variance represented by the mean residual). The between-years ICC (reproducibility between races across calendar years) was calculated as the pure between-athletes variance in a given year (represented by athlete alone) divided by the observed between-athletes variance in a race. We assessed the magnitude of the ICC with a set of thresholds based on the magnitude of the average difference in performance in 1 race between athletes who differed in performance by 2 SDs in another race; the threshold values of the ICC were .14, .36, .54, .69, and .83 for low, moderate, high, very high, and extremely high, respectively.[5]

The relationship between finishing position in the prologue and finals rank in each sprint race of each competition was analyzed as Pearson correlation coefficients and summarized as mean and SD for men and women. One competition with incomplete race-result data and 2 competitions with snow conditions that had changed between prologue and final, based on the official subjective snow ratings, were excluded. The mean and SD of the finishing position in the finals were also calculated for each position in the prologue and displayed graphically.

The uncertainty in all estimates is shown as 90% confidence limits in plus/minus (±) form for differences in mean and in times/divide (×/÷) form for SD and their ratios. Confidence limits for the ICC were derived by assuming the within-to-between-athletes ratio of the sample variance ratio and had an *F* sampling distribution; they are shown in approximate ± form. Inferential comparisons of all statistics were magnitude based, mechanistic,[9] and realized with a published spreadsheet.[10]

Results

Analysis for all athletes revealed most likely trivial differences in within-athlete race-to-race variability between sexes, event disciplines, and skiing styles (Table 2). Differences in within-athlete variability between women's and men's events, between sprint and distance events, and between classical and free events were all trivial (likely through most likely). The race-to-race variability was greater for all athletes compared with the top-10 athletes, with a most likely small difference in CV of 0.45% (90% confidence limits ± 0.04).

The between-athletes variability in performance times expressed as CV ranged from 0.00% to 0.86% for top-10 athletes and 5.2% to 7.1% for all athletes, which are extremely large in magnitude when compared. Analysis for the top 10 showed possibly small differences between sexes (women > men) and event disciplines (endurance > sprint) but a likely trivial difference between styles.

Table 2 shows the predictability of performance expressed as within-year and between-years ICC. Predictability for all athletes within and between years was extremely high overall, whereas predictability of the top-10 athletes was trivial. There were trivial differences in predictability for all athletes between sexes, disciplines, and styles, and for top-10 athletes the only substantial difference was for sex (women > men, likely small).

The correlations between sprint prologue rank and finals rank ranged from moderate to very large for the 4 events. There were similar correlations for classical and free styles for women (0.71 ± 0.11 and 0.67 ± 0.19, respectively, mean ± SD) and men (0.56 ± 0.20 and 0.48 ± 0.15, respectively). The pooled data between the sexes, as seen in Figure 1, revealed a likely small difference, with a greater correlation for women than for men. Specifically, the mean finals rank for women was closer to

Table 2 Within- and Between-Athletes Variability in Performance Times Expressed as Coefficients of Variation (CV) and Resulting Predictability of Performance Expressed as Within-Year and Between-Years Intraclass Correlation Coefficients (ICC) for Each Event for all Athletes and for the Top 10 Each Year

	All Athletes					Top 10				
	Within-Athlete CV (%)[a]					Within-Athlete CV (%)[a]				
	Within year	Between years	Between-athletes CV (%)	Within-year ICC	Between-years ICC	Within year	Between years	Between-athletes CV (%)	Within-year ICC	Between-years ICC
Men										
15-km classical	1.7	1.9	5.8	.92	.90	1.2	1.2	0.10	.01	.01
15-km free	1.8	2.0	6.2	.93	.91	1.1	1.1	0.00	.00	.00
sprint classical	1.7	1.9	6.0	.93	.91	1.2	1.2	0.00	.00	.00
sprint free	1.5	1.9	7.1	.96	.94	1.1	1.1	0.20	.03	.03
Women										
10-km classical	1.7	2.1	5.3	.91	.86	1.4	1.5	0.72	.31	.20
10-km free	1.6	2.2	6.3	.94	.89	1.2	1.3	0.86	.35	.32
sprint classical	1.8	2.1	5.2	.90	.86	1.3	1.4	0.58	.25	.15
sprint free	1.6	2.0	6.3	.94	.91	1.3	1.3	0.22	.03	.03

[a] Typical variation (error of measurement) an athlete shows between 2 competitions in the same year and in different years. 90% confidence limits for CV (as ×/÷ factors): all athletes within and between athletes ~1.05, top 10 within and between athletes ~1.1 and ~1.2. 90%. Confidence limits for ICC: all athletes ~± 0.01, top 10 ~± 0.15.

the prologue rank, with generally smaller standard deviations than with men. Furthermore, a likely small difference with a greater correlation was evident for women's free versus men's free, and a possible small difference was apparent between sexes for the classical style. The first-ranked skier in the prologue for women's free had a finals rank of 4.5 ± 3.2 (mean ± SD) and a best and worst placing of 1st and 13th, whereas the last-ranked in the prologue had a finals rank of 22.8 ± 7.2 and a best and worst placing of 9th and 30th. In comparison, for men's free, the first-ranked skier had a finals rank of 4.1 ± 3.9 and a best and worst placing of 1st and 16th, whereas the last-ranked in the prologue had a finals rank of 25.8 ± 6.5 and a best and worst placing of 3rd and 30th. These descriptive data are more distinct between the sexes for the classical style. The first-ranked skier in the prologue for women's classical had a finals rank of 2.3 ± 1.8 and a best and worst placing of 1st and 9th, whereas the last-ranked in the prologue had a finals rank of 25.8 ± 5.1 and a best and worst placing of 14th and 30th. In comparison, for men's classical the first-ranked skier had a finals rank of 4.1 ± 3.6 and a best and worst placing of 1st and 16th, whereas the last-ranked in the prologue had a finals rank of 24.0 ± 7.3 and best and worst placing of 1th and 30th.

The observed effects of differences in altitude on mean performance time for top-10 athletes were between 0.3% to 2.0% for the 2 men's and 2 women's distance events, with races conducted at moderate altitude being slower. However, the magnitudes of these effects were unclear. Furthermore, the effects of differences in altitude on sprint events were highly inconsistent, ranging from 5.2% faster to 3.5% slower, and the effects were unclear. The observed effects of differences in snow conditions on mean performance time (2% or more) were inconsistent between event disciplines, skiing styles, and sexes. The large uncertainties in these differences are likely due to the extremely large effects of race terrain for the various events, as evaluated by the random effect of race identity: CV of 3% to 5% and 7% to 10% for top-10 athletes and of 4% to 5% and 15% to 24% for all athletes, for distance and sprint events, respectively.

Discussion

This study was conducted to investigate the variability of performance of elite male and female cross-country skiers for distance and sprint events in the 2 skiing styles. The estimates of race-to-race variability have provided information on the smallest worthwhile enhancement in international competitions and on the predictability of performance.

The within-athlete variability of elite cross-country skiers is of a magnitude similar to that in other elite endurance sports.[2,3,5,6] Our finding that the better athletes (top 10) were less variable than all athletes as a group is consistent with those other studies. For example, the within-athlete variability of the top 50% of 1500-m to 10,000-m track runners was less than that of the bottom

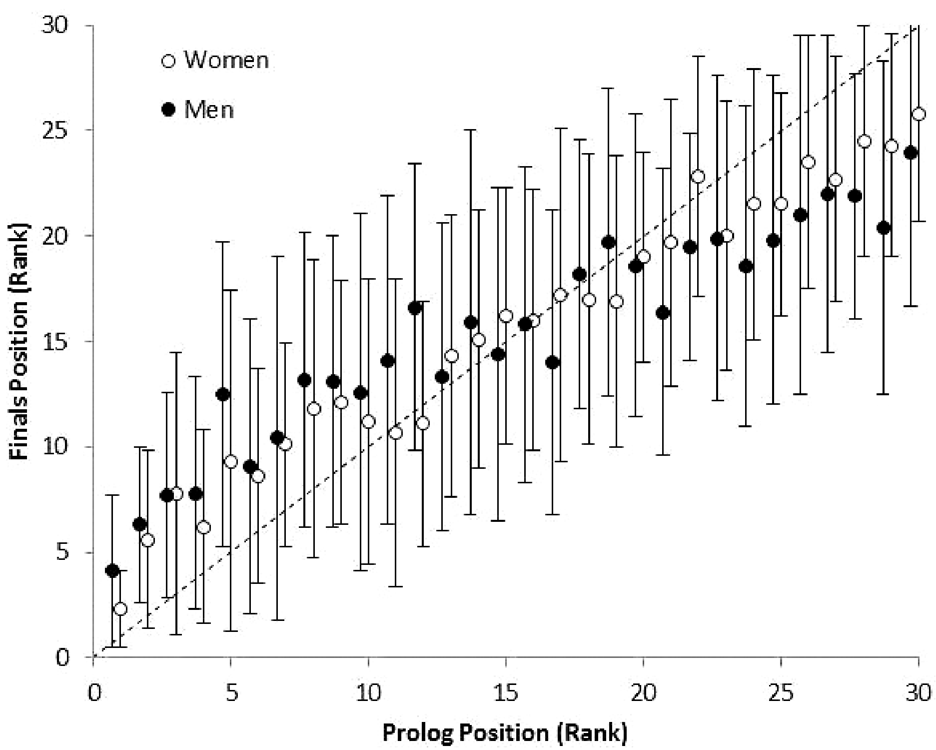

Figure 1 — Relationship between sprint prolog rank and mean finals rank (ranking after completion of quarterfinal, semifinal, and final) of pooled classical and free-technique races for women and men (n = 51 and 52, respectively). Values are means, bars are SD.

50% (1.1% and 1.6%, respectively),[3] and these differences are very similar to those in the skiing events, which were of a comparable range in performance time. Although this is speculative, the reduced variability for the better athletes is possibly due to a combination of factors such as more consistent training preparation, greater and more consistent motivation, superior race pacing, and better or more stable skis. Further research would be required to provide more information on the issue of reduced variability of subgroups of skiers and competitive level.

Although there were trivial differences in the variability of performance times between sexes, for the all-athletes analysis, female skiers demonstrated a substantially greater variability than men for the top 10. These data suggest that the depth of competition standard for the best male skiers is greater than for the best female skiers. This point is supported by another study in cross-country skiing that investigated the differential between the 1st- and 30th-place finishers for elite sprint and distance races from the years 2000 to 2008 and reported this time difference to be approximately 4.5% for men and 7% to 8% for women.[11] The tendency for a greater difference in female athletes is in agreement with studies in cycling,[2] slalom canoe and kayaking,[8] and skeleton.[7] However, in rowing, there is no evidence of differences in variability between the sexes.[5]

In general, the differences between the within-athlete variability (within year versus between years) were trivial, which indicates that the skiers' race performances are mostly consistent from one season to the next. These data are in agreement with the elite rowing data, in which overall trivial differences were reported between within-year and between-years variability.[5] Furthermore, little additional variability was reported in the elite canoe and kayak study, with those authors suggesting that this indicates that the athletes arrive at competitions in a consistent state of preparation and are consistently better or worse during a season to the same extent that they are between individual races within a season.[6] The between-athletes variation in performance time, representing the spread in skier ability, was considerable, highlighting the large differences between the very best skiers and skiers who are at a lower standard but are still of an international level.

Data simulations demonstrate that the smallest worthwhile enhancement of an elite athlete's performance is 0.3% of the standard deviation of the within-athlete race-to-race variability in performance.[1] Therefore, the smallest worthwhile enhancement in performance time for the best skiers (top 10) is 0.3% to 0.4% (ie, $0.3 \times 1.1\%$ for men and $0.3 \times 1.3\%$ for women). Coaches and sport scientists should therefore focus on improvements of as little as the smallest worthwhile enhancements stated here. For example, 0.3% of a typical duration for a distance event (30 min) would equate to an improvement in performance time of 5.4 seconds.

The ICCs were used to assess predictability of performance in the current ski data. The poor predictability of the top-10 cohort, in contrast to all athletes as a group, is likely due to the small spread in performance among the top-10 athletes. The possibly small difference in predictability between sexes, with a greater correlation for the majority of the women's events, provides further evidence of a superior depth of competition (greater uncertainty) in the men's events. Previous studies that have assessed predictability of performance have not compared a subset of top athletes with all athletes as in the current study. The predictability of rowing A finals was reported to be low to very high, with a mean of very high (0.63) for the various boat classes.[5] Likewise, the predictability of flat-water canoe and kayaking A finals was in the range of moderate to very high. Trivial to moderate predictability has been reported for the sports of slalom canoe and kayaking, as well as skeleton, which may partly reflect the unique technical demands of these sports.[7,8] The studies comparing within- and between-years ICCs have reported only trivial differences,[5,8] which is in agreement with the current ski data. Therefore, the likelihood of an athlete's placing between races in these sports would be similar whether the races were in the same year or in consecutive years.

The moderate to very large correlations between sprint prologue rank and finals rank suggest that the athletes provide a maximal effort in the prologue to qualify for the quarterfinals and that the variability in physiological power output is a major discriminatory factor for success in these events. Different reasons for a maximal effort in the prologue are likely for athletes of varying standards. The aim of the top skiers is to have a good seeding and avoid meeting other top skiers in the quarterfinals and semifinals. The aim of the other skiers is simply to qualify for the quarterfinals. As there can be more than 70 athletes entered for a given race and only 30 qualify, competition is fierce. For example, in the men's events, where the prologue duration is approximately 3 minutes, a 2-second time difference can separate 15 places. In the quarterfinal, semifinal, and final races, additional factors of race tactics and technical skill involved in racing against 5 other skiers on narrow and demanding courses are obviously important and likely to be responsible for some differences in the relationship between the prologue rank and finals rank. In addition, other factors such as optimal recovery and the physiological and psychology ability to produce repeated maximal performances with relatively short rest periods must be considered. Furthermore, the introduction of the "lucky loser" system has played a role in maintaining the average speed of these races. In this system, 2 athletes can advance on superior race time to the next round, despite not finishing in the top-2 places of the heat. The greater correlations for the women's events again provide further evidence of a greater depth of competition in the men's events.

Various environmental factors affect performance outcomes in racing sports where athletes compete as individuals. For example, the factor of wind direction and speed has been discussed in sports such as road cycling time trials and rowing.[2,5] In cross-country skiing, some important environmental factors to consider are the effect of differences in altitude, snow conditions, and race terrain. The slower mean performance times at moderate altitude (>1200 m) for all distance events in the current study were of a magnitude similar to those of elite 1500- to 10,000-m track runners (1.1–2.4%, when comparing performance below and above 1000 m), and these findings were attributed to reductions in partial pressure of oxygen in the inspired air and resultant decrease in aerobic power.[12] It has been demonstrated that running performance declines linearly from 300 m to 2800 m by 15% per 1000 m in a time-to-exhaustion test, while VO_{2max} declines by 6.3% per 1000 m.[13] In the current study the effect of altitude on mean skiing times for sprint races was highly inconsistent between events, possibly due in part to more challenging and varying race terrain at some locations at altitude (ie, different makeup of course gradients and curves). Although the observed effects of differences in snow conditions on mean performance time were occasionally substantial (>2%), they were unclear and inconsistent between events. The fact that ratings of snow conditions were subjective may have contributed to the uncertainty in these effects. Furthermore, it would be very difficult to record or control for all snow variables (ie, air and snow temperature and humidity, age of snow, size and shape of snow crystals, etc).

Practical Applications

Coaches and sport scientists working with elite cross-country skiers should focus on improvements as little as the smallest worthwhile enhancements presented in this study. Furthermore, these smallest effects for performance time in ski races will be similar to that of power output or speed in incremental tests or time trials in the laboratory, just as it is for elite runners on the track or testing on the treadmill. Future studies assessing skiing performance will need to ensure that the error of measurement in testing is, at most, similar to the smallest worthwhile enhancement to have sufficient sensitivity in quantifying these practically important changes.

Conclusions

Our results indicate that the performance time of the best cross-country skiers from race to race typically varies by a mean of 1.1% for men and 1.3% for women, suggesting a greater competition depth in the men's events. Therefore, the smallest worthwhile enhancement in performance time (0.3× within-athlete variability) for these top skiers is 0.3% to 0.4%, which is similar to other elite endurance sports. The predictability of performance is high when all international skiers are considered, as across the whole field of competitors athletes are consistent in their performance. However, it is hard to predict placing among the top 10 due to the small spread in performance ability.

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