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Characteristics of performance in skeleton World Cup races

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Abstract

Little is known about performance characteristics in the Winter Olympic sport of skeleton, in which athletes push and then drive a sled down an ice track. In this study, official race times from World Cups held on 11 tracks over four competitive seasons were analysed with linear models for athletes placed in the top 10 (35 males in 22 races; 28 females in 25 races). Mean run time ranged from ~50 to ~70 s between tracks. Predictability of individual performance expressed as race-to-race correlations was modest (0.36 for males and females). Differences between tracks in run-to-run variability expressed as coefficients of variation (men: 0.19–0.56%; women: 0.24–0.89%) paralleled differences in popular opinion of technical difficulty of the tracks. There was an inconsistent and overall small relationship between push time and performance time on different tracks (range of correlations, 0.57 to −0.14; mean, 0.21). The home advantages of 0.15% for men and 0.32% for women were trivial and substantial respectively in relation to the smallest important performance changes of 0.18% and 0.23%, derived from race-to-race variability. In conclusion, skeleton athletes show less variability in performance time than athletes in other sports, but tracks vary substantially in difficulty and race outcomes are largely unpredictable.

Keywords: *Elite athlete, home advantage, mixed modelling, Winter Olympic sport*

Introduction

In the Winter Olympic sport of skeleton, 6–8 World Cup races are held each season. In these World Cup races, all eligible athletes participate in the first run, but only the fastest 20 finishers are permitted a second run. Both runs are performed within 2 h and the winner is determined by the lowest cumulative time over the two runs. Individual skeleton tracks vary in length (1200–1800 m), with race times lasting approximately 1 min. Five interval times are reported at the end of each race, with the first interval corresponding to the push time (start time; recorded between timing eyes at 15 and 65 m) and the next four intervals evenly distributed along the rest of the track. Athletes and coaches classify tracks according to their technical difficulty, which arises from differences in gradient, nature of the curves, and cut of the ice. A "push track" is less technically challenging than a "driving track", and a fast push time on a push track is believed to result in a fast overall time. On the other hand, the driver's ability is thought to have the greater influence on overall time on a driving track.

The sparse literature available on skeleton has focused on the push. The faster pushers in the USA national team were stronger and more powerful (Sands et al., 2005). In a study of skeleton athletes with a wide range of abilities, the correlation between push time and overall time was moderate ($r = 0.48$) and large ($r = 0.68$) for women and men respectively (Zanoletti, La Torre, Merati, Rampinini, & Impellizzeri, 2006). To date, there has been no thorough analysis of competitive performance to determine influential factors in skeleton.

Previously, competitive performance has been analysed in swimmers (Pyne, Trewin, & Hopkins, 2004; Stewart and Hopkins, 2000a, 2000b), triathletes (Paton & Hopkins, 2005), track-and-field athletes (Hopkins, 2005), and in an array of cycling events (Paton & Hopkins, 2006). These studies have helped sport scientists and coaches understand factors that affect variability of competitive performance and identify targets for performance

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enhancement in each sport. The purpose of this study was to extend this research to the comparatively new Olympic sport of skeleton.

Methods

Performance data

Official times for the top 20 competitors with repeated runs during World Cup competition over the 2002–2006 Olympic quadrennium were used. These data were downloaded from the official skeleton website available in the public domain (FIBT, 2006), thus it was not necessary to obtain informed consent from athletes for use of their data. Eleven tracks were used over four competitive seasons. In total, 22 and 25 races were included for the men and women, respectively. Severe weather conditions prevented a second run in three of the men's races and these were not included in the analyses. The number of athletes and mean number of races for athletes placed in the Top 10 and from 11 to 20 are shown in Table I.

Track classification

To classify push and technical tracks, two current skeleton coaches (one had previously coached Olympic medalists) and a current Olympic medalist classified World Cup tracks into four categories: 1, pure push track; 2, tracks with a large push component; 3, tracks with a large driving component; and 4, pure driving tracks.

Statistical analysis

The mixed linear-modelling procedure (Proc Mixed) in the Statistical Analysis System (Version 9.1, SAS Institute, Cary NC) was used for most analyses. The fixed effects (and their resulting estimates) were as follows: Track (differences in mean time between tracks), Year (annual trends in performance), Home (home advantage, yes or no), and Run (the first or second run of a race). The random effects were Athlete (different abilities between athletes), Athlete*Year (within-athlete variation between seasons), Athlete*Race (within-athlete variation

Table I. Sample sizes, sources of variation in performance time (expressed as coefficients of variation), and predictability of performance (expressed as between-race correlations) for men and women ranked 1–10 (top half) and 11–20 (bottom half) in each skeleton race at each venue (data in parentheses are 90% confidence intervals).

	Men		Women	
	Top half	Bottom half	Top half	Bottom half
Sample sizes				
Number of athletes	35	59	28	54
Races per athlete[a]	6.2 (1–18)	3.8 (1–13)	8.7 (1–23)	4.5 (1–18)
Within-athlete CV (%)				
Between runs at each venue				
Altenberg	0.56 (0.48–0.67)	0.52 (0.46–0.61)	0.52 (0.43–0.56)	0.79 (0.66–1.00)
Calgary	0.34 (0.29–0.44)	0.53 (0.46–0.63)	0.34 (0.28–0.43)	0.72 (0.60–0.93)
Cesana Pariol	0.53 (0.40–0.84)	0.53 (0.42–0.73)	0.89 (0.69–1.28)	0.59 (0.45–0.91)
Igls	0.28 (0.23–0.35)	0.43 (0.37–0.52)	0.27 (0.22–0.34)	0.38 (0.32–0.48)
Konigssee	0.28 (0.20–0.44)	0.45 (0.35–0.64)	0.51 (0.38–0.78)	0.57 (0.55–0.87)
Lake Placid	0.35 (0.28–0.47)	0.49 (0.41–0.62)	0.34 (0.29–0.42)	0.56 (0.47–0.70)
Lillehammer	0.31 (0.21–0.69)	0.42 (0.33–0.58)	0.38 (0.29–0.58)	0.38 (0.26–0.70)
Park City	0.36 (0.26–0.50)	0.58 (0.46–0.82)	0.46 (0.39–0.58)	0.78 (0.65–0.99)
Sigulda	0.43 (0.35–0.56)	0.51 (0.43–0.64)	0.42 (0.33–0.58)	0.68 (0.56–0.86)
St. Moritz	0.38 (0.31–0.51)	0.57 (0.49–0.68)	0.27 (0.20–0.45)	0.49 (0.36–0.81)
Winterberg	0.19 (0.14–0.29)	0.24 (0.19–0.35)	0.27 (0.12–0.20)	0.58 (0.44–0.84)
Between races	0.23 (0.18–0.32)	—[b]	0.34 (0.29–0.41)	0.38 (0.30–0.53)
Between years	0.22 (0.16–0.34)	—[b]	0.25 (0.18–0.40)	0.36 (0.27–0.58)
Between-athlete CV (%)				
Athlete	0.15 (0.10–0.36)	0.07 (0.03–5.20)	0.25 (0.18–0.46)	0.49 (0.35–0.81)
Predictability (race-to-race correlations)				
Within a year	0.36 (0.09 to 0.58)	0.04 (−0.18 to 0.25)	0.36 (0.05 to 0.61)	0.53 (0.35 to 0.68)
Between years	0.11 (−0.18 to 0.38)	0.04 (−0.18 to 0.25)	0.18 (−0.15 to 0.47)	0.34 (0.12 to 0.53)
Track conditions CV (%)				
Between runs	0.59 (0.47–0.81)	0.56 (0.44–0.77)	0.57 (0.46–0.77)	0.46 (0.36–0.65)
Between years	0.81 (0.54–1.76)	0.90 (0.61–1.82)	0.72 (0.49–1.41)	0.59 (0.40–1.22)

Notes: [a] Mean, with range in parentheses.
[b] Not estimable.

between races), Track*Year (variation between years in mean time at each track, representing effects of changes in a track arising from weather or preparation), and Track*Year*Run (variation in run-to-run (between-run) mean time, representing effects of similar changes within a race). A different residual was specified in the mixed model for each track, representing run-to-run variability. Separate analyses were performed for men and women and for athletes placed 1–10 (top-ranked) and 11–20 (bottom-ranked) in each race. Race times were log transformed to yield the changes and differences as percentages of the mean and variability as coefficients of variation (Hopkins, 2000). Uncertainty in all estimates is shown as 90% confidence intervals.

Plots of residual versus predicted values for each track were examined in each analysis to check for outliers, the absolute final time of which were greater than 3.5 standard deviations from the calculated mean. Three observations were thereby removed from the final analysis. On a closer inspection of the data, these outliers were either due to the sled being displaced from the start groove or a crash during the run. Uniformity of error and absence of skewness was also confirmed by visual inspection of these plots.

To assess the importance of push time at each individual track, the push-time individual intervals were correlated with the overall time for every race. Means of the correlations for each track were derived via the Fisher *Z* transformation. Magnitudes were assessed using the following scale: 0.00 to <0.09 trivial, 0.1–0.29 small, 0.30–0.49 moderate, 0.5–0.69 large, 0.7–0.89 very large, and 0.9–1.0 nearly perfect (Hopkins, 2004).

To quantify the smallest important difference for the top ranked athletes, the observed within-athlete race-to-race variability was calculated by taking the square root of the sum of the variance represented by the Athlete*Race random effect and half of the mean of residual variances over all tracks. Half of this variability is the smallest worthwhile effect (Hopkins, Hawley, & Burke, 1999). The intraclass correlation (ICC) was used as a measure of predictability. The within-year ICC was calculated as the true between-athlete variance (sum of the variances represented by Athlete and Athlete*Year random effects) divided by the observed between-athlete variance (the sum of the true athlete variance and the observed within-athlete race-to-race variance). The between-year ICC was calculated in a similar manner, but the between-athlete variation was the observed variation and the within-athlete variation the same as that calculated for the within-year ICC with the addition of the sum of the variances of Athlete*Year.

Results

The mean overall time of the different tracks estimated as a fixed effect in the mixed model ranged from 49.6 to 70.3 s for top-ranked men and 50.0 to 71.0 s for bottom-ranked men. For top- and bottom-ranked women, the ranges were 50.9 to 72.5 s and 51.7 to 73.8 s respectively.

Within-athlete run-to-run (between-run) variability on the different tracks ranged from 0.19% to 0.56% for top-ranked men and 0.27% to 0.89% for top-ranked women (Table I). Over all tracks, the mean of this variability was 0.38% and 0.46% for top-ranked men and women respectively, and somewhat greater for bottom-ranked athletes (by a factor of ~ 1.2). This variability added appropriately to the pure within-athlete race-to-race-race variability (Table I) yields the observed race-to-race variability: 0.35% for top-ranked men and 0.47% for top-ranked women. Half of this race-to-race variability is the smallest important change in performance (0.18% for men and 0.23% for women).

Home advantage was similar for top- and bottom-ranked men (0.15%, 0.03% to 0.26%; 0.19%, 0.05% to 0.33%). For top- and bottom-ranked women, the home advantage was somewhat larger (0.32%, 0.18 to 0.46%; 0.38%, 0.08% to 0.67%).

The within-athlete race-to-race (between-race) variability combines with the between-athlete variation to give the correlations representing predictability of performance. For races within a year, the predictability was moderate for the top-ranked men and women, trivial for the bottom-ranked men, and large for the bottom-ranked women (Table I). For races separated by a year or more, the predictability was worse than the between-race within-year predictability, with small and trivial predictions for top- and bottom-ranked men, and small and moderate predictions for top- and bottom-ranked women, respectively.

The fixed effect for run in the model revealed that Run 2 was slower than Run 1 by 0.25% (90% confidence interval: -0.07% to 0.56%) for top-ranked men, 0.35% (0.05% to 0.65%) for bottom-ranked men, 0.34% (0.06% to 0.63%) for top-ranked women, and 0.41% (0.25 to 0.65%) for bottom-ranked women. The random effects for track conditions are shown in Table I and represent substantial changes in mean performance over all the athletes between their first and second runs; the changes are similar for the top- and bottom-ranked men and women. The random changes in track condition between years were somewhat greater.

The experts gave each track the same rating classification: Igls and Winterberg were pure push tracks; Konigssee, Calgary, Lake Placid, and Park City were tracks with a large push component;

St. Moritz and Lillehammer were tracks with a large driving component; and Sigulda, Altenberg, and Torino were pure driving tracks. Scored on a difficulty scale of 1 (pure push track) to 4 (pure driving track), these classifications had a very large correlation with the corresponding within-competition run-to-run variability for the top-ranked men ($r = 0.87$, 0.78–0.93) and top-ranked women ($r = 0.71$; 0.51–0.84) (Figure 1).

The correlation between push time (push time, Interval 1) and overall time at the different tracks ranged from –0.14 to 0.44 (mean 0.12) for top-ranked men and -0.09 to 0.57 (mean 0.29) for top-ranked women (90% confidence limits: approximately ± 0.3 to ± 0.5). There was a trend for the correlations between interval times and overall time to increase for the intervals further down the track, plateauing from about Interval 4 ($r = \sim 0.7$ to ~ 0.8). The push correlations had a strong relationship with track classification for the top-ranked men ($r = 0.50$; 0.25 to 0.69) and a trivial relationship for top-ranked women ($r = 0.03$; -0.50 to 0.55). For the top-ranked men, the strongest relationship between interval correlations and track classification was for Intervals 2 and 3 ($r = 0.65$; 0.19 to 0.88; $r = 0.61$; 0.13 to 0.66). For top-ranked women, Interval 2 had the strongest relationship with overall time ($r = 0.41$; -0.14 to 0.77).

Discussion

Race-to-race variability in performance time of skeleton athletes is much less than that of elite triathletes (Paton & Hopkins, 2005), elite swimmers (Pyne et al., 2004; Trewin, Hopkins, & Pyne, 2004), and elite track athletes (Hopkins, 2005). The race-to-race variability in performance of an athlete in these dynamic endurance sports is related predominantly to variability in the athlete's ability to sustain power, which impacts on speed to determine the overall performance time (Hopkins, Schabort, & Hawley, 2001). In skeleton, the only contribution of athletic power output to performance is in the push section of the run, which represents only a small proportion of performance time. Variability in the time for the rest of the run must therefore be much smaller than the variability in performance time of dynamic endurance sports. The rest of the run is a controlled fall under the influence of gravity, consisting of brief periods of variable-intensity isometric exercise when the athlete negotiates the curves on the track. Variability in performance time for this part of the run is determined presumably by the ability of the athlete to contend with the curves, especially when there are changes in environmental conditions between runs and races. The ability to maintain a good aerodynamic position probably contributes to variability as well.

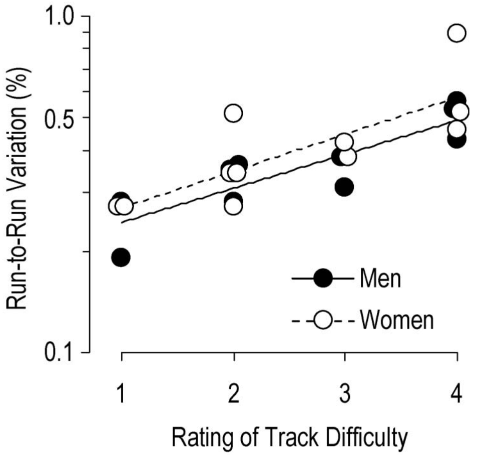

Figure 1. Within-athlete between-run coefficient of variation (%) of the top-ranked men and women for each track plotted against mean rating of track difficulty.

The lower variability in the top-ranked athletes is consistent with findings in other sports (Hopkins, 2005; Paton & Hopkins, 2006; Pyne et al., 2004). In these previous studies, it was suggested that top-ranked athletes are better prepared, more motivated from race to race, and have more racing experience (Paton & Hopkins, 2005). However, to some extent the relationship between run-to-run variability and placing in skeleton is attributable to athletes in the bottom half of a race performing one run badly, and therefore their run-to-run variability will be greater than that of athletes in the top-half of the race.

The between-athlete variation, which represents the spread in an athlete's ability, was larger for women than for men. The larger variation supports the notion that depth in the women's field is less than in the men's. The greater within-athlete variability for the women, in combination with the greater between-athlete variation, produced a similar race-to-race predictability for both sexes. For top-ranked athletes, it would appear that skeleton is not a highly predictable sport. It is not clear how one should use these correlations to interpret predictability qualitatively, but it is clear that much higher correlations are needed to rank athletes if a single race is to provide a reasonably accurate ranking of athletes (Hopkins & Manly, 1989). One possible explanation for the poor predictability is that different tracks suit different athletes. Unfortunately, predictability expressed as a correlation has not been a feature of previous analyses of competitive performance, so we do not know how the predictability of skeleton compares with that of other sports.

Race-to-race variability is of interest to athletes, coaches, and sports scientists because it defines the smallest important change in performance (~ 0.5 of this variation). The only change in performance of direct relevance to the athletes in the present study is the home advantage, which was substantial for the women but negligible for the men. Some factors responsible for home advantage, such as spectators and travel (Courneya & Carrib, 1992), might not apply here, as home advantage was important only in the women's competition. It is more likely that less depth of competition and experience of the women makes superior knowledge of a home track more advantageous.

The remaining findings in this study all relate to effects of tracks and track conditions on performance. That Run 2 was slower than Run 1 could be due to track degradation and ice softening. Before the first run on race day, water is sprayed on the track and allowed to freeze into a hard, smooth surface. Track degradation occurs through sled runners digging into the ice and athletes using their toes on the ice surface to steer the sled down the track. Track softening often occurs in World Cup competitions that are held in the morning, because ambient temperatures tend to increase as races progress. On softer ice, sleds' runners will sink deeper into the ice, thus increasing friction and consequently run time. The variability in the change in mean time between runs is attributable to differences in the extent of track degradation and effects of temperature from race to race.

Mean differences in ambient temperature on the days of competition from year to year could contribute to the variation in mean time at a given track. Ambient temperatures alter the hardness of ice, which in turn influences the types of runner and the amount of bow set an athlete will choose for that runner in each race. There will also be contributions from changes in the way the track is cut. The variability of the same track over several years is $<1\%$ (Table I: track conditions between year). Evidently, tracks change little from year to year compared with the differences between tracks. It follows that experience gained at a track is valuable for future competitions at that track.

A unique aspect of this study compared with previous published studies is that skeleton has two maximal runs within a few hours. Both runs contribute to the overall time, which allowed us to quantify the short-term variability at the different tracks. In top-ranked athletes, this variability increased as the technical difficulty of the track increased; that is, the variability was lowest in pure push tracks. The bottom-ranked athletes had greater run-to-run variability that was similar on most tracks, suggesting that for these athletes most tracks are effectively difficult (driving) tracks. On race day, skeleton athletes do not complete any training runs; rather, their first run is a competition run. Because the track conditions vary on a daily basis, it could be that the more experienced sliders have greater understanding of how environmental conditions affect sled handling and therefore have a greater ability to make subtle changes during the run.

Although the correlations between push and overall time were small, the technical difficulty of a track showed an inverse relationship with the importance of the push on overall performance in top-ranked men. Tracks that were classified as pure driving tracks (technically most difficult) tended to have a negative correlation between push and overall time for the men, suggesting that a fast push time can be detrimental for a good overall performance on these tracks. On the other hand, higher push correlations were found on technically easy tracks suggesting that the push is an aspect that the men could focus on to make further gains in overall performance. For the top-ranked women, the push has a similar (modest) importance on all tracks irrespective of the coaches' ratings of difficulty. The higher mean correlation for the push and the overall time in women suggests that any enhancements made in the push will reflect improvements in overall performance on all tracks.

The high correlations of Intervals 4 to 6 with overall performance could be because athletes attain peak speed by Interval 4. If the athletes' speed does not change markedly from this point onwards, these intervals would appear to contribute in a similar way to overall performance. The finding that Interval 2 for top-ranked women, and Intervals 2 and 3 for top-ranked men, had the highest relationship with coaches' ratings of track difficulty could be attributed to the official ruling that the more technically demanding elements (in terms of driving technique) should be located in the first stretch of the track (FIBT, 2008).

Conclusion

Skeleton athletes show lower race-to-race variability in performance time than athletes in other sports, but race outcomes are largely unpredictable. The difficulty of tracks varies substantially but is remarkably consistent from year to year. The contribution of the push phase to overall performance varies between tracks and between the sexes. Women showed a greater spread in ability and experienced a substantial home advantage compared with men. These differences could diminish as the sport matures.

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