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ORIGINAL ARTICLE

Variability and predictability of elite competitive slalom canoe-kayak performance

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Abstract

Little is known about the race performance characteristics of elite-level slalom canoeists or the magnitude of improvement necessary to enhance medal-winning prospects. Final placing in this sport is determined by the aggregate of semi-final and final run times inclusive of penalty times. We therefore used mixed linear modelling to analyse these times for finalists ranked in the top and bottom half in the men's canoe, men's kayak, and women's kayak boat classes at World Cups, World Championships, and Olympic Games from 2000 to 2007. The run-to-run variability for top-ranked athletes at different courses ranged from 0.8% to 3.2% (90% confidence limits $\times/\div 1.11$–1.31), reflecting differences in how challenging these courses were. The race-to-race variability of aggregate run time was 1.2–2.1% ($\times/\div \sim 1.09$); 0.3 of this variability yields the smallest worthwhile enhancement of 0.4–0.6%. The variabilities of bottom-ranked finalists were approximately double those of top-ranked finalists. The home advantage was small (0.3–0.8%), and incurring a penalty had a marginal effect on reducing actual run time (0.2–0.7%). Correlation coefficients for performance predictability within competitions (0.06–0.35), within years (0.12–0.47), and between years (0.12–0.43) were poor. In conclusion, the variability of performance and smallest worthwhile enhancements in slalom canoe-kayaking are larger than those of comparable sports, and race outcomes are largely unpredictable.

Keywords: *Athlete, home advantage, intraclass correlation, penalty, reliability*

Introduction

The primary aim of elite coaches and sports scientists is to enhance performance of their athletes. For sports in which athletes compete as individuals against other athletes for a best time, distance or other performance score, 0.3 of the standard deviation of a top athlete's race-to-race (competition-to-competition) performance provides an estimate of the smallest worthwhile enhancement in performance that affects medal prospects substantially (Hopkins, Hawley, & Burke, 1999). Researchers are recognizing the importance of the variability in competitive performance by publishing values in various sports, including junior swimmers (1.4%) (Stewart & Hopkins, 2000), elite swimmers (0.8%) (Pyne, Trewin, & Hopkins, 2004), elite Paralympic swimmers (1.2–3.7%) (Fulton, Pyne, Hopkins, & Burkett, 2009), sub-elite distance runners (1.2–4.2%) (Hopkins & Hewson, 2001), elite triathletes (1.6–3.6%) (Paton & Hopkins, 2005), elite track-and-field athletes (1.0–2.8%) (Hopkins, 2005), elite cyclists (0.4–2.4%) (Paton & Hopkins, 2006), elite skeleton athletes (0.35–0.47%) (Bullock, Hopkins, Martin, & Marino, 2009), and elite flat-water canoeists (0.7–1.5%) (Bonetti & Hopkins, 2010). There has been no previous published analysis on the variability of performance of elite slalom canoe-kayakers.

The discipline of slalom canoe-kayak is contested down a white-water course of varying degrees of difficulty designated by gate placement, depth of water, magnitude of waves, and velocity of water flow (Shephard, 1987). Depending on the course design and boat class, the duration of a slalom run in international competitions ranges from approximately 90 to 120 s. Slalom canoe-kayak

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competition provides two novel challenges to the analysis of variability of performance. First, final competition standings are determined by the aggregate score of the semi-final (Run 1) and final (Run 2) times. Second, overall performance time consists of the non-penalized or raw time (time taken to complete a run) plus penalties incurred for touching (2 s) or missing (50 s) a gate. The aims of the present study, therefore, were to characterize the effect of international slalom courses on variability of performance, progression in performance from semi-finals to finals, and impact of penalties on raw performance time. Estimation of home advantage (potential gain in performance when the course is located in the country for which the athlete is competing) and estimation of predictability of performance as a correlation coefficient are further aspects of the present study neglected in previous studies of variability of competitive performance.

Methods

Athletes and races

The four boat classes in slalom canoe-kayak competition are the men's kayak (MK1), men's single canoe (MC1), men's double canoe (MC2), and women's kayak (FK1). Official semi-final and final times for the finalists in World Cup, World Championship, and Olympic events from 2000 to 2007 were obtained from event websites. As these data were in the public domain, written consent from athletes was not sought. To contribute to the analysis of reliability, athletes had to compete in two or more races in the same boat class. The number of athletes competing in each boat class and the mean number of races per athlete included in the analyses were 31–45 and 7.0–8.1 respectively (MC1: $n=37$ and 7.1; MC2: $n=31$ and 8.1; MK1: $n=45$ and 6.0; FK1: $n=38$ and 7.0 respectively).

Data modelling

We used the mixed linear modelling procedure (Proc Mixed) in the Statistical Analysis System (Version 9.1, SAS Institute, Inc., Cary, NC). Fixed effects in the model were: Home (*yes* or *no,* to estimate home advantage), Race (a unique identifier for the course and date of competition, to estimate the mean performance time for each race), and Run (*semi-final* or *final,* to estimate progression in performance time within competitions). Analyses were also performed in which Home and Run were both interacted with a variable (Split) representing finalists ranked in the top and bottom half of a given race (to estimate the effect of the athlete's placing on home advantage and on progression in performance time). The effect of at least one penalty on raw performance time was assessed in a separate analysis with an additional fixed effect consisting of the interaction of a variable Penalty (*yes* or *no*) and Split (to estimate any gain in overall raw performance time at the expense of technical proficiency).

The random effects in the model were: Athlete (to estimate differences in ability between athletes), Athlete*Race (to estimate within-athlete race-to-race variability), Athlete*Year (to estimate within-athlete variation between seasons), and the residual (to estimate run-to-run variability). We specified residual variances for the top- and bottom-ranked finalists at each course. For estimation of intraclass correlation coefficients (see below), we calculated the mean residual weighted by degrees of freedom over all courses and finalists.

The dependent variable was the log transform of run time; effects and errors were back-transformed to percent changes and coefficients of variation respectively, as is appropriate for data of this nature (Hopkins, Marshall, Batterham, & Hanin, 2009). We performed separate analyses for each boat class and for non-penalized and penalized time. Outcomes are presented for penalized time unless otherwise specified.

We compared the variability in performance of non-penalized and penalized time and of subgroups by calculating the ratio of CV provided by Proc Mixed, under the assumption that the ratio is log-normally distributed. As reported previously (Drinkwater, Hopkins, McKenna, Hunt, & Pyne, 2007), we considered ratios >1.1 as being substantially more variable, ratios <0.9 as substantially less variable, and those within a range of 0.9–1.1 as trivial. Magnitudes of fixed-effect outcomes have been interpreted probabilistically (Batterham & Hopkins, 2006). Uncertainty of the estimates was provided by Proc Mixed and reported as confidence limits at the 90% level, which is appropriate for the kinds of non-clinical or mechanistic measures reported here (Hopkins et al., 2009). The confidence limits are expressed as "$\pm$" for uncertainty of differences in means and a $\times/\div$ factor uncertainty for coefficients of variation.

There were six race times in which the athletes incurred a 50 s penalty during a run, and all were excluded before analysis. Plots of residual versus predicted values from the analyses showed no evidence of non-uniformity of error. There were six observations (race times) included in the analysis with standardized residuals $\sim$4–5, representing unusually slow times; these all belonged to athletes in the bottom half of the field for the given race.

Variability and predictability of canoeing performance

Variability of performance was quantified as a within-athlete coefficient of variation (CV), which is the standard deviation of performance time of an athlete expressed as a percentage of the athlete's mean performance time after statistically controlling for factors affecting performance (fixed effects in the statistical model). The smallest worthwhile enhancements to performance are reported as 0.3 of the within-athlete race-to-race coefficient of variation (Hopkins et al., 1999) for top-ranked finalists. Between-athlete variation, representing differences in athlete ability in a given race, was also estimated as a CV.

The intraclass correlation coefficient (ICC), defined as pure between-athlete variance divided by observed between-athlete variance, was used as a measure of predictability of performance that is effectively a test–retest correlation coefficient. The within-competition ICC (run-to-run reproducibility) was calculated as the pure between-athlete variance in a given run (sum of the variances represented by Athlete, Athlete*Year, and Athlete*Race random effects) divided by the observed between-athlete variance in a given run (sum of the pure between-athlete variance and the within-athlete variance represented by the mean residual). The within-year ICC (race-to-race reproducibility in a year) was calculated as the pure between-athlete variance in a given race (sum of the variances represented by Athlete and Athlete*Year random effects) divided by the observed between-athlete variance in a given race (sum of the pure between-athlete variance and the within-athlete variance represented by Athlete* Race and half the mean residual, which is the residual for the mean of two runs). The between-year ICC (reproducibility between races across calendar years) was calculated as the pure between-athlete variance in a given year (represented by Athlete alone) divided by the observed between-athlete variance in a single race (as above).

Analytical derivation of exact confidence limits for the ICC was beyond the ability of the researchers, and empirical derivation via bootstrapping would have taken a prohibitively long time. We therefore derived conservative confidence limits via the Fisher transformation for a sample size given by the number of athletes in each boat class. The resulting 90% confidence limits were ± 0.25 (for $n = 45$) to ± 0.30 (for $n = 31$) (Hopkins, 2007). Confidence limits for the mean of all correlations in the four boat classes were conservatively ± 0.13 (for $n = 151$). A spreadsheet (Hopkins, 2006) was used to make mechanistic magnitude-based inferences (Hopkins, 2007) for the comparison of correlations. Magnitudes of correlations and their differences were assessed using the following scale: 0.00 to <0.10 trivial, 0.11–0.29 small, 0.30–0.49 moderate, and ≥ 0.5 large (Cohen, 1988).

Results

Variability and predictability of performance

The mean overall performance time of the bottom half of finalists was substantially longer than that of the top half in each boat class (MC1: 3.1%, 90% confidence limits $\pm 0.4\%$; MC2: 3.1%, $\pm 0.5\%$; MK1: 2.5%, $\pm 0.3\%$; FK1: 3.7%, $\pm 0.4\%$).

Table I presents the between- and within-athlete variation in non-penalized and penalized time and for the top- and bottom-ranked subgroups in each boat class. The between-athlete variability in performance increased by a factor of ~ 1.1 for penalized

Table I. Between- and within-athlete variability expressed as coefficients of variation (CV) in non-penalized and penalized time for the top and bottom half of finalists in each boat class

Boat class	Between-athlete CV (%)		Within-athlete CV (%)	
	Non-penalized time	Penalized time	Non-penalized time	Penalized time
Men's canoe (MC1) ($n = 37$)				
Top half	1.8	2.0	1.2	1.6
Bottom half	2.6	3.0	2.3	2.8
Men's double canoe (MC2) ($n = 31$)				
Top half	2.9	3.2	1.7	2.1
Bottom half	3.6	4.1	2.7	3.6
Men's kayak (MK1) ($n = 45$)				
Top half	1.4	1.4	1.0	1.2
Bottom half	3.0	3.3	3.0	3.5
Women's kayak (FK1) ($n = 38$)				
Top half	2.2	2.5	1.5	1.9
Bottom half	3.2	3.6	2.9	3.4

Uncertainty (90% confidence limits) in CV: between-athlete, $\sim \times/\div 1.20$; within-athlete, $\sim \times/\div 1.10$.

compared with non-penalized time, whereas the within-athlete variation increased by a factor of ~1.2. For bottom-ranked finalists in each boat class, the within-athlete variation was approximately double that of top-ranked finalists (MC1: ratio 1.8, ×/÷1.1; MC2: ratio 1.7, ×/÷1.2; MK1: ratio 2.9, ×/÷1.1; FK1: ratio 1.8, ×/÷1.1). For top-ranked finalists, women were more variable than men in the kayak class (ratio 1.6, ×/÷1.1), yet there was little difference for bottom-ranked finalists (ratio 1.0, ×/÷1.1). The smallest worthwhile enhancement for canoeing performance (0.3 of the within-athlete race-to-race variability of the top-ranked athletes) was 0.4–0.6% across the four boat classes.

Correlations representing predictability of performance within competitions, within years, and between years were in the trivial-to-moderate range (Table II). Uncertainty in these correlations was too great to allow trustworthy conclusions about pairwise differences. However, there was little observed difference between the values for any subgroups. Non-penalized time (data not shown) was only slightly more predictable than penalized time (mean correlations across all four boat classes, 0.32 and 0.25 respectively; difference 0.07, ±0.17).

Table II. Predictability of penalized performance time expressed as intraclass correlation coefficients within competition and within and between year

Boat class	ICC		
	Within competition	Within year	Between years
Men's canoe (MC1) ($n=37$)	0.17	0.28	0.27
Men's double canoe (MC2) ($n=31$)	0.35	0.47	0.43
Men's kayak (MK1) ($n=45$)	0.06	0.12	0.12
Women's kayak (FK1) ($n=38$)	0.20	0.34	0.23

Uncertainty (90% confidence limits) in correlations: ~±0.30.

Variability of courses, effect of penalties, and home advantage

Estimates of run-to-run variability of penalized time at a given course were similar across boat classes, so means were recorded (separately for top- and bottom-ranked finalists), as shown in Table III. Performance time was least variable at Merano, Italy for both groups of finalists, whereas variability was greatest at Shunyi, China and Penrith, Australia for top- and bottom-ranked finalists respectively. Bottom-ranked finalists were more variable than top-ranked finalists by a factor of 1.1–3.0. Course variability increased by a factor of 1.0–1.6 for penalized compared with non-penalized time (data not shown).

Table III. Run-to-run variability expressed as coefficients of variation (CV) in penalized time for the top and bottom half of finalists at different courses

Course location	Course CV (%)	
	Top half	Bottom half
Merano, Italy	0.8	1.5
Foz Do Iguassu, Brazil	1.4	2.4
Guangzhou, China	1.6	4.7
Tibagi, Brazil	1.8	3.3
Prague, Czech Republic	1.9	3.0
Athens, Greece	2.1	4.9
Augsburg, Germany	2.1	2.6
Bourg St. Maurice, France	2.1	5.3
La Seu D'Urgell, Spain	2.1	3.4
Penrith, Australia	2.6	6.0
Tacen, Slovenia	2.8	5.3
Bratislava, Slovakia	3.0	4.7
Shunyi, China	3.2	3.6

Note: Courses are sorted by CV of the top half of athletes. Uncertainty (90% confidence limits) in CV: top half. ~×/÷1.11–1.31; bottom half, ~×/÷1.10–1.67.

Analyses of the effect of penalties on raw (non-penalized) time revealed trivial to small reductions (enhancements) in performance time for top-ranked finalists in runs when a penalty occurred (MC1: −0.5%, ±0.4%; MC2: −0.4%, ±0.4%; MK1: −0.7%, ±0.3%; FK1: −0.2%, ±0.4%). For bottom-ranked finalists, incurring a penalty produced a trivial effect on raw time in all but the women's kayak class, where there was a substantial impairment (MC1: 0.0%, ±0.4%; MC2: −0.1%, ±0.6%; MK1 −0.1%, ±0.3%; FK1: 1.1%, ±0.6%).

When athletes competed at their home course, there was an improvement in performance time of 0.3–0.8% (~±0.5%) in the four boat classes. There was little difference in the home advantage between top-and bottom-ranked finalists.

Within-competition performance progression

For top-ranked finalists, there was a trivial change in time for Run 2 in the men's single canoe (MC1: 0.2%, ±0.4%), men's kayak (MK1: 0.2%, ±0.3%), and women's kayak (FK1: −0.1%, ±0.4%), but Run 2 was faster than Run 1 in the men's double canoe (MC2: −0.9%, ±0.3%). Run 2 was slower than Run 1 for bottom-ranked finalists for all boat classes (MC1: 3.1%, ±0.5%; MC2: 1.6%, ±0.6%; MK1: 3.3%, ±0.5%; FK1: 3.1%, ±0.6%).

Discussion

We investigated factors affecting variability in competitive slalom canoe-kayak performance times and thereby quantified the smallest worthwhile enhancements needed to improve the medal-winning prospects of these athletes. We also adopted a novel approach using intraclass correlations to quantify predictability of performance.

The race-to-race variability of 1.2–2.1% is generally greater than that of elite athletes in sports comparable in duration and intensity: swimmers, 0.8% (Pyne et al., 2004); 100- to 1500-m runners, 1.0% (Hopkins, 2005); kilo cyclists, 1.2% (Paton & Hopkins, 2006); and flat-water kayakers, 0.7–1.5% (Bonetti & Hopkins, 2010). In these sports, variability in performance appears to be related mainly to athletes' abilities to sustain high-intensity exercise, so variability in performance time is directly related to variability in such exercise from race to race. Slalom canoe-kayaking, on the other hand, is a technically demanding sport requiring athletes to exercise at high intensity while negotiating gates and paddling against the direction of water flow; variability in performance time is therefore likely to be attributable to intensity and technical ability. Indeed, a contribution of technical demands to the variability is apparent in the increase in such variability (by a factor of 1.2) between non-penalized and penalized time. The substantial differences in run-to-run variability between courses (Table III) can also be explained only by differences in the technical demands arising from differences in the gate placement, velocity of water flow, and depth of waves.

Top-ranked finalists displayed substantially lower variability than bottom-ranked finalists, which is consistent with findings in other sports (Pyne et al., 2004; Hopkins, 2005; Paton & Hopkins, 2005; Bullock et al., 2009). It has previously been suggested that top-ranked athletes display lower variability because they are more motivated, better prepared for competition, or have greater racing experience (Paton & Hopkins, 2005), and these factors likely apply to slalom canoe-kayaking. However, the manner in which athletes reach the final in this sport provides an additional explanation for the difference in variability between top- and bottom-ranked finalists. Athletes who perform an uncharacteristically fast run in the semi-final will qualify for the final, but they are then likely to perform a characteristically slower run. The bottom half of the field therefore consists of some athletes who performed well in the semi-final but less well in the final, in addition to athletes who performed consistently less well than the top athletes in both runs. Top-ranked athletes are, of course, more likely to perform both runs characteristically quickly. It follows that the mean time for the final run is longer and the variability is higher for the bottom-ranked than for the top-ranked athletes, as we observed.

Hopkins et al. (1999) defined the smallest worthwhile enhancement of an athlete's performance as the change in performance time or other score that would increase the athlete's chances of winning a medal by an absolute 10%. Simulations showed that this enhancement is 0.3 of the standard deviation of within-athlete race-to-race variability in performance. The smallest worthwhile enhancement in performance time for top-ranked finalists competing in slalom canoe-kayaking is therefore 0.4–0.6%, which is still much less than the enhancements that occur typically with acute and chronic interventions. Studies of such enhancements are obviously best performed with top athletes on white-water courses, although ergometer-based investigations are logistically more feasible and would be possible when the relationship between changes in ergometer performance and changes in on-water performance is established.

Armed with this smallest worthwhile enhancement, we can now assess the importance of home advantage and the effect of penalties on performance. The mean effect of home advantage in the four boat classes is an enhancement of 0.3–0.8%, which, when interpreted with the uncertainty ($\sim\pm0.5\%$), represents a possibly beneficial effect. If we assume home advantage is mediated at least partly via knowledge of a course, the traditional strategy adopted by most high-performance canoeists to attend training camps at a course prior to competition might therefore be cost-effective. There was a similar outcome with top-ranked finalists for the effect of penalties on raw (non-penalized) performance time (enhancements of 0.2–0.7%; uncertainty $\sim\pm0.4\%$), although for bottom-ranked finalists in some boat classes penalties were accompanied by a substantial increase in raw time (0.0–1.1%). The automatic cost of each penalty is a 2 s or $\sim$2% impairment, which more than offsets the mean gain in raw performance time when a top-ranked athlete incurs penalties. Clearly, it is always important for an athlete to have a "clean run".

We have used correlation coefficients to assess predictability of performance of finalists in slalom canoe-kayaking, but at present there are no published correlations in other sports for comparison. There is also no research directed specifically at identifying how high a correlation has to be for performance in a sport to be considered predictable, although previous work on validity correlation coefficients indicates the correlation might need to be in excess of 0.9 (Hopkins & Manly, 1989). With correlations of $\sim$0.1–0.5, slalom canoe-kayak appears to be largely unpredictable. The poor within- and between-year predictability could in part be explained by the variable nature of the course design from race to race, causing technically challenging courses or those demanding greater speed–strength components to suit different athletes. However, the technical demands of different courses do not explain the poor within-competition predictability, as the challenges of a course effectively remain consistent between semi-final and final runs. The poor predictability could be a feature of the small spread in ability demonstrated by elite athletes (between-athlete variability) compared with their race-to-race variability (within-athlete). One implication of poor predictability is that athletes with low true ranking still have a reasonable chance of winning a medal, but this assertion needs to be quantified in future research.

Conclusion

The variability of performance in slalom canoe-kayaking is greater than that of comparable sports, presumably because of the variability that arises from the technical demands of this sport. Courses vary substantially in their challenge to different competitors and require different contributions of skill and speed–strength components, which could in part explain the poor predictability. There is a possible beneficial effect of home advantage, suggesting it is cost-effective for athletes to train at a given course prior to major competitions. The occurrence of penalties magnified the variability of performance and had a small effect on the raw performance time of top-ranked athletes, although the cost of the penalty offset any gains in time. To improve the medal-winning prospects of top-ranked athletes, the findings of the present study indicate coaches and sports scientists should focus on enhancements of at least 0.4–0.6%, which are exceeded by many acute and chronic interventions.

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