Pacing and Sprint Performance in Speed Skating During a Competitive Season

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Purpose: This study assessed the effect of time spent in several race sectors (S) on finishing time and determined the variance in distribution of skating time and in total race time for official 1000-m sprint races conducted during a competitive season. Methods: Total race and sector times for the first 200 m (S1) and the following two 400-m laps (S2 and S3) of 34 female and 31 male elite speed skaters performed during a series of World Cup Meetings were analyzed. Results: Overall, skaters started fast, reached their peak in S2, and slowed down in S3, irrespective of race category considered (eg, rank of athlete, number of race, altitude of rink, starting lane). Regression analyses revealed that spending a shorter fraction of time in the last (women in S3: B = 239.1; P < .0001; men in S3: B = 201.5; P < .0001) but not in the first (women in S1: B = –313.1; P < .0001; men in S1: B = –345.6; P < .0001) race sector is associated with a short total race time. Upper- compared with lower-ranked skaters varied less in competition-to-competition sector and total race times (women: 0.02 to 0.33 vs 0.02 to 0.51; men: 0.01 to 0.15 vs 0.02 to 0.57). Conclusion: This study confirmed that skaters adopted a fast start pacing strategy during official 1000-m sprint races. However, analyses indicate that shortening time in the closing but not in the starting sector is beneficial for finishing fast. In addition, findings suggest that lower-ranked skaters should concentrate training on lowering their competition-to-competition variability in sector times.

Keywords: race analysis, prediction/variance of performance, elite female/male athletes, performance level

Competitions in ice speed skating are organized as a series of World Cup Meetings. Races over sprint (500 m, 1000 m), middle (1500 m), and long distances (3000 m, 5000 m, 10,000 m) take place in different countries over the duration of several months. During these races, the aim is to reach the finish in the minimal time possible. To reach this goal, it is necessary to distribute the individual energetic resources over the course of the race.1,2

For sprint competitions (ie, short-lasting events of less than 30 to 80 s), data from modeling studies suggest that skaters’ performance will benefit from a fast start/all-out effort pacing strategy.3,4 Furthermore, data from laboratory-based trials in disciplines like cycling, kayaking, and running also showed that performance...
may be improved if athletes use a fast start/all-out effort instead of a slow start or an even pacing strategy. The advantage of a fast start compared with other start versions is generally explained by the high velocity at the onset of a race. This has been found to be more important than the speed at the end of the race, because the energy that is left at the finish has been wasted through not being used during the event.

To the authors’ knowledge, there are no studies available examining the pacing adopted during real competition scenarios like official sprint events in ice speed skating over the course of a season. Furthermore, studies on the variability of pacing behavior from competition to competition in ice speed skating events are also lacking. Previous studies have examined the variability of performance outcome in terms of finishing time between two competitions, such as in swimming, from race to race in running or between different phases of a cycling season. These studies showed that upper-ranked athletes varied less in their performance outcome than lower-ranked athletes. However, possible changes in pacing pattern (ie, variations in the distribution of time or velocity) were not examined in these studies.

Therefore, the purpose of the current study was to assess the effect of the time spent in several race sections on total race time and to determine the variance in distribution of skating time and in performed total race time for official 1000-m sprint-races conducted during a competitive season. We hypothesized based on the aforementioned studies in swimming and running that variance would be small especially in upper- compared with lower-ranked elite athletes. Based on the results from previous research on optimal pacing behavior in sprint-distance skating, the authors further assumed that a fast start/all-out pacing pattern might be beneficial for a small total race time. Information about the behavior of elite athletes during official competitions is important for a number of applied and theoretical reasons. From a practical perspective, detecting differences in the importance of several race parts for skating performance as well as in the variability of pacing and total race time between successful and less successful skaters, may provide some guidance for training speed skaters. From a theoretical point of view, knowledge regarding an optimal distribution of skating time during the 1000-m sprint event is useful to specify and extend existing pacing strategies.

**Methods**

**Athletes and Competitions**

Final and split times (recorded by an automatic timekeeping system) were performed during Essent World Cup Speed Skating competitions 2007/2008 organized by the International Skating Union. A total of seven competitions were held for the 1,000-m sprint distance. One of these competitions was performed outdoors (Inzell, Germany) and was excluded from analysis, because weather conditions may have confounding effects on performances. In addition, the final competition held in Heerenveen (The Netherlands) was also excluded from analysis, because only skaters who were among the top 24 in the current World Cup ranking were allowed to start. This left five competitions, which could be analyzed, whereas at least four competitions had to be performed by each athlete. This criterion was fulfilled by 34 female and 31 male speed skaters. For some competitions, two races
over 1000 m were offered, with the athlete accumulating the lowest total of points will win this race format. In such competitions (eg, competitions held in Salt Lake City and Erfurt) only the first race was analyzed to avoid a possible confounding due to fatigue. All of the included races took place at an indoor ice rink (400 m oval). All data were downloaded from publicly accessible official skating websites (eg, www.isu.org); therefore, informed consent was not obtained from athletes for use of this information. The study was approved by the ethics committee Beider Basel, Switzerland.

Data Analysis

For the 1000-m sprint event, split times in the following sectors (S) of the race were obtained: 0 to 200 m (S1), 200 to 600 m (S2), and 600 to 1000 m (S3). Afterward, sector times to distance plots considering different race categories (rank of athlete: upper- vs lower-ranked; number of race: 1st competition, 2nd competition, etc.; altitude of rink: low vs high; starting lane: inner vs outer) were created. For group of athlete, total race times of all skaters were ranked from fastest to slowest based on their mean performance in all of the analyzed competitions.9 Afterward, athletes were divided into an upper- and a lower-ranked group at the median.

To predict total race times among and within athletes, we first computed relative sector times (Srel) by dividing absolute sector times (Sabs) by the total time of the respective race. For each race, we then determined the differences (dSrel) of the relative sector times from the corresponding mean values Srel of the respective athlete. As predictors of total race time, we then considered both the mean relative sector times Srel and the race-specific deviations dSrel from these means. The effects of these variables were estimated using mixed linear models with the maximum likelihood option. Models included the individual means S1rel, S2rel and S3rel, along with one of the difference variables dS1rel, dS2rel or dS3rel as predictors of total race time while the athlete was treated as a random factor. Furthermore, we assessed whether effects prevailed when additionally controlling for starting lane (inner/outer lane) and altitude of the oval (low/high altitude).

Variance components of absolute sector times and total race time during the entire season between (vb) and within skaters (vw) were estimated using a mixed linear model with race number as fixed and athlete as a random factor. Between-subject variance refers to the variability in sector/total race times between skaters in a certain group (ie, upper- or lower-ranked group). Here smaller values indicate less heterogeneity between athletes. Within-subject variance refers to the variability in sector/total race times of skaters from competition-to-competition (eg, from the 1st to the 2nd to the 3rd competition). Here, smaller values indicate less longitudinal variation within athletes. Differences in the within-subject variance between upper- and lower-ranked skaters were assessed using chi-square tests. In addition, intra class correlation (ICC) was computed as the ratio vb / (vb + vw). All analyses were conducted separately for female and male athletes. Plots of residual vs predicted values showed that the distributions of the variables were not far from normal and that a logarithmic transformation was therefore not warranted before conducting statistical analyses. All analyses were performed using Statistical Analysis Software (SAS) version 9.1. The significance level was set at $P < .05$. 
Results

Type of Pacing Pattern

Irrespective of race category considered, skaters adopted a pacing pattern where acceleration during the starting phase was followed by a fast second race section and a reduction in pace during the last race sector (Figures 1 to 3). Both, upper- and lower-ranked female and male skaters showed a similar pattern of sector times (Figure 1). However, whereas the better skaters were faster during the middle section (women: Δ 0.93 s, men: Δ 0.91 s) and slowed less in the closing race sector (women: Δ 1.52 s, men: Δ 1.04 s), resulting in a shorter total race time (women: 76.42 ± 1.34 s vs 78.99 ± 1.73 s, Δ 2.57 s, P < .001; men: 69.13 ± 1.15 s vs 71.58 ± 1.83 s, Δ 2.45 s, P < .001). Mean times for each race sector over the course of the five analyzed races are shown for female skaters in Figure 2A and for male skaters in Figure 2B. During all races, both showed a similar pattern of sector times, but the second and third race sector was performed faster during races held in Salt Lake City (1st competition) and Calgary (2nd competition) than at the other locations. The shorter times for S2 (–2.3% for women and –2.8% for men) and S3 (–3.4% for women and –3.6% for men) found in Salt Lake City and Calgary could be due to their exposed location. Indeed, both offer venues at high altitude. Comparison of pacing patterns adopted at these locations with those at low altitude confirmed the former finding (Figure 3A) and showed that the average total race time was significantly shorter for races at high altitude (women: 76.68 ± 1.76 s vs 78.44 ± 1.85 s, Δ 1.76 s, P < .001; men: 69.13 ± 1.56 s vs 70.98 ± 1.80 s, Δ 1.85 s, P < .001). Furthermore, when comparing skaters according to whether they started from the inner or outer lane, a similar pacing pattern was observed (Figure 3B), resulting in no significant differences in total race time (women: 77.60 ± 1.93 s vs 77.74 ± 2.08 s, Δ 0.14 s, P = .68; men: 69.96 ± 1.77 s vs 70.51 ± 2.04 s, Δ 0.55 s, P = .10).

Figure 1 — Sector times to distance plots (mean + SD) for the entire season of female and male skaters by rank of athlete. Note. Classification of athletes was done at the median based on the average total race time achieved during all analyzed races.
Prediction of Pacing Pattern

Table 1 shows the effects of differences from mean relative sector times on total race time for female and male skaters. Irrespective of gender, associations were negative and highly significant for dS1_{rel} and total race time (women: $B = -313.1$, $P < .0001$; men: $B = -345.6$, $P < .0001$) and partly significant for dS2_{rel} and total race time (women: $B = -91.1$, $P = .15$; men: $B = -106.4$, $P = .04$). In other words, spending a short fraction of time in the second race sector and particular in the starting sector is related to a larger total race time. A highly significant but positive

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**Figure 2** — Sector times to distance plots (mean + SD) of female (A) and male (B) skaters by number of race.
Muehlbauer, Schindler, and Panzer

Association was found between dS3rel. and total race time (women: $B = 239.1$, $P < .0001$; men: $B = 201.5$, $P < .0001$), indicating that spending a short fraction of time in the final race sector is related to a shorter total race time. After adjustment for starting lane (inner/outer lane) and rinks' location (low/high altitude) all associations kept their direction and those, which were highly significant before, remained highly significant (see also Table 1).

For a better understanding of changes in athletes’ pacing behavior in the starting sector (S1: 0 to 200m) on subsequent sector times and total race time, we calculated two possible scenarios (Table 2). As an example, a female skater showed a total

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**Figure 3** — Sector times to distance plots (mean + SD) of female and male skaters by altitude of rink (A) and starting lane (B). *Note.* Finishing times for races at high altitude were significantly shorter than at low altitude ($P < .001$).
race time of 77.70 s (100%) with a distribution of time of 18.65 s (24.0%) in S1, of 28.75 s (37.0%) in S2, and of 30.30 s (39.0%) in S3. A two-tenths of a percent reduction of relative time in S1 (ie, to 23.8%) and a one-tenth of a percent extension of relative time to 37.1% in S2, are associated with a one-tenth of a percent increase of relative time in S3 (ie, to 39.1%), resulting in a larger total race time of 77.90 s. However, a two-tenths of a percent extension of relative time in S1 (ie, to 24.2%) and a one-tenth of a percent reduction of relative time to 36.9% in S2, are associated with a one-tenth of a percent decrease of relative time in S3 (ie, to 38.9%), resulting in a shorter total race time of 77.50 s.

Table 1 Results of regression analyses for the deviations of relative sector times from the respective athletes’ corresponding means as predictors of total race time in elite female and male skaters

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<thead>
<tr>
<th>Race Sector</th>
<th>B</th>
<th>SE</th>
<th>P Value</th>
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<tr>
<td><strong>Women (n = 34)</strong></td>
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<tr>
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<td><strong>Adjusted for rink altitude &lt;sup&gt;b&lt;/sup&gt;</strong></td>
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Notes. B, parameter estimate; SE, standard error.

<sup>a</sup> Inner/outer lane.

<sup>b</sup> Low/high altitude.
For all skaters, the between- and within-subject variability in total race time and in absolute sector times were smaller in upper- compared with lower-ranked skaters (Table 3). Differences in within-subject competition-to-competition variability became statistically significant between groups for total race time \((P < .001)\) and for absolute time in \(S_1_{\text{abs.}}\) \((P = .013)\) and in \(S_3_{\text{abs.}}\) \((P = .002)\) in male skaters. In female skaters, a significant difference could be found only for absolute time in \(S_3_{\text{abs.}}\) \((P = .02)\). Intraclass correlation ranged from 0.56 to 0.91 and was smaller in upper- compared with lower-ranked skaters for total race time and absolute time in \(S_1\) and \(S_2\) but not for absolute time in \(S_3\).
Discussion

The purposes of the current study were to assess the effect of the time spent in several race sections on finishing time and to determine the variance in distribution of skating time and in performed total race time for official 1000-m sprint-races conducted during a competitive season. The main findings were (1) that both female and male elite ice speed skaters adopted a similar pacing pattern by starting fast, followed by a fast 200 to 600-m section and a decline in pace in the closing race sector, irrespective of race category considered; (2) that shortening time for the last but not for the first race sector is associated with a short total race time; (3) that within-subject competition-to-competition variance for several sector times and total race time varied less in upper- compared with lower-ranked skaters, which was more pronounced in men than in women.

Type of Pacing Pattern

Regardless of rank of athlete, number of race, altitude of rink, and starting lane, female and male skater performed a pacing pattern during 1000-m races, which is typical for sprint distances in ice speed skating. After acceleration during the starting phase, skaters performed a fast second race section before they gradually slowed down during the third and last race sector. Processes of fatigue toward the end of the race are one of the causes responsible for the output loss. For example, Kindermann and Keul were able to show that after finishing the 1000-m sprint distance, female/male ice speed skaters averaged values of about 14 and 15 mmol/L lactate in the arterial blood.

Upper- compared with lower-ranked skaters were faster during the middle race section and slowed less in the closing stage, resulting in a shorter finishing time. Physiological and/or technical aspects could be stated as one reason for these differences. Van Ingen Schenau et al showed, for instance, that elite skaters had a significantly higher oxygen consumption as well as a higher external power output compared with well-trained skaters. In addition, their analysis of the skating technique revealed that elite athletes were using a higher stroke frequency and a smaller preextension knee angle, offering a better skating position.

The second and third race sector was performed faster during races held at high compared with low altitude, resulting in significantly shorter total race times (–2.3% for women and –2.7% for men), which are in accordance with that reported by de Koning and van Ingen Schenau. A possible explanation could be that at high altitude the air pressure and therefore the air resistance decreases, so that faster times may be expected than at low altitude.

Quite similar sector times and total race times were observed for skaters starting from the inner or outer lane, which suggests that the effect of starting lane on the distribution of skating times and there on the performance outcome is potentially smaller than the issue of low vs high altitude tracks.

This study is a preliminary examination of the broad issue of factors that affect pacing and performance in official speed skating competitions. Much work remains to be done until we have a more complete picture. For further research it would be valuable to determine whether rinks’ altitude and/or starting lane influences the pacing pattern and the performance outcome during ice speed skating sprint races but also in middle- and long-distance races.
Prediction of Pacing Pattern

Irrespective of race category considered (starting lane, altitude of the oval), opposite associations were found between total race time and deviations from mean relative times in different sectors of the race, ie, a negative association in S1 and a positive one in S3. First, this would indicate that to shorten the fraction of time early in the race might not be beneficial for a small total race time. Second, this underlines the importance to develop a strong finish by spending a shorter proportion of total race time in the final race part. Form a practical point of view this indicates that for performance enhancement coaches/athletes should concentrate training on improving time for the closing rather than for the starting race section. The adoption of a fast start during 1000-m sprint races supports previous findings from van Ingen Schenau et al3 and de Koning et al.4 Their results derived from modeling studies suggest that a fast start is crucial for sprint events in ice speed skating. The advantage of a fast start is generally explained by the high speed at the onset of a race being more important than the speed at the end of the race because it is argued that energy that is left at the finish has been wasted through not being used during the event.3,4 However, producing maximal velocities at the beginning is a critical issue, because it causes early fatigue and may lead to a massive slowdown later in the race.14,18

The importance to develop high velocities during the last race sector suggests that skaters in the analyzed sprint races were regulating their speed as well as their energetic resources. This finding is consistent with an anticipatory regulation of exercise intensity, whereby athletes anticipate the work required to complete a given exercise task.19,20 Moreover, an anticipatory control of behavior has the advantage to retain an energetic reserve, which protects from early exhaustion and helps to avoid an extensive loss of speed during later race stages.3,6,19,21

Variability of Pacing Pattern

Within-subject competition-to-competition variance in sector times and in total race time was less in upper- compared with lower-ranked female and male skaters. This observation is consistent with the results from Stewart and Hopkins9 and from Hopkins and Hewson10 who found that successful athletes had less variation in performance outcome than less successful ones. Traditionally, aspects like more experience in competitions and/or longer periods of training are mentioned to explain these results.9,10 However, successful as well as less successful athletes have years of training and experience. Therefore, individual differences in the amount and the rate of liberation of anaerobic and aerobic energy supply and utilization could be stated as one of the causes.14 Also, as mentioned earlier, we cannot rule out differences in technical factors between upper- and lower-ranked skaters, which are recognized to affect race performance.

This study involves the use of official split-times. Their usage has the advantage of being derived from real competition scenarios, which are free of experimental manipulation, like fixed exercise intensity, fixed duration trial, and/or prescribed pacing behavior. On the other hand, they only enable a rough characterization of an athlete’s overall pacing pattern, and do not provide detailed insight into the distribution of velocity throughout the event. This may be less of a problem in a discipline like ice speed skating, where competitions are mostly held indoors. Thus, there
are only few changes in the physical characteristics of the racing environment (e.g.,
changes in temperature, humidity). Consequently, split-times within track races
may be used as relatively accurate indicators of pacing pattern.\textsuperscript{22,23}

In conclusion, our data showed that a pacing pattern typical for short-distance
events (i.e., a fast starting section and after fastest time was reached in the middle
part, athletes gradually slowed down during the closing section) was used in 1000-m
ice speed skating races, regardless of race category considered. Furthermore, the
observed effects of relative time spent in several race sectors on total race time sug-
gest that athletes not starting too fast but showing a strong finish tend to be faster
overall. This finding supports the notion of using a fast start/all-out pacing strategy
for 1000-m sprint-events in ice speed skating, but also strengthens the importance
of pacing during the closing race section to achieve optimal performance. This
could, for example, be trained by varying velocity throughout the different racing
sectors. In addition, upper-ranked skaters performed with a smaller within-skater
competition-to-competition variability in sector times than lower-ranked skaters,
which is probably explained by physiological and/or technical differences and by
variations in competitive experience and years of training.

\textbf{Acknowledgment}

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