

Hanna Wolf

Performance - differences in speed profiles and tactical choices in a cross-country skiing mass-start competition

Master's thesis in Physical Activity and Health - Exercise Physiology

Supervisor: Øyvind Sandbakk

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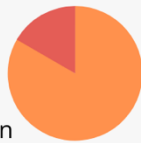
Norwegian University of Science and Technology
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PERFORMANCE - DIFFERENCES IN SPEED PROFILES AND TACTICAL CHOICES IN A CROSS-COUNTRY SKIING MASS-START COMPETITION

WHY



Lack of knowledge on mass starts!



10/12 races are mass-starts

What **Speed profile?**

→ **Tactics** more important
→ **Drafting** possible

WHAT



Analysis of a mass-start competition



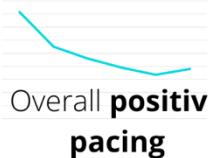
Combined GNSS & IMU to measure position and speed

Questionnaire



about tactics & experiences

RESULTS & CONCLUSION



Overall **faster skiers more even** speed profile than weaker skiers

Speed in **uphills** most important for performance



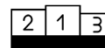
Tactics



- **Follow** as long as possible
- **Higher ranked skiers more able to implement their strategies** than weaker skiers



Final sprint important for ranking within groups of skiers



Abstract

The aim of the present study was to compare speed profiles and tactical choices between cross-country skiers on different performance levels in a mass-start cross-country skiing competition by describing the race development and individual speed profiles over the entire race and identifying differences in speed profiles and the tactical choices distinguishing skiers on different performance levels.

45 skiers were tracked with a GNSS device during a 21 km skating style cross-country skiing mass-start competition in the Norwegian Cup. Additionally, all skiers answered a questionnaire with quantitative and qualitative questions about their tactics and experiences during the race. The skiers showed an overall positive speed profile with a higher average speed in the first three laps than the average speed in the whole race ($3.7 \pm 1.41\%$, $p < .001$), with reduced speed in the last part of the race. The Top 10 performing skiers showed a more even pacing pattern than groups of skiers ranked 11-20, 21-30, and 31-40, indicated by significantly less % difference between the first three laps and the whole race ($p < .01$ for all groups). Speed in uphill terrain was most important for overall performance ($r = .964$, $p < .001$), and speed differences between groups were largest in uphill terrain with a 2.0%, 5.5%, 6.0% difference between Top 10 skiers and groups ranked 11-20, 21-30, and 31-40, respectively, ($p < .001$ for all). Performance in the final sprint decided outcome within groups of skiers skiing together. The questionnaire indicated that the skiers in general planned to start as hard as the lead and keep up as long as possible. There was no pattern for performance-level differences in planned tactics between groups, but after the race, skiers ranked 1-10 to a greater extent felt that they were able to complete the race according to their strategies. In conclusion, while an overall positive speed profile was observed, better performing skiers showed a more even speed profile over the race. Performance in uphill is most decisive for overall performance, but the final sprint is important for the final outcome within groups of skiers skiing together. Most skiers, independent of performance in this specific race, had the tactic to follow the lead as long as possible. Higher ranked skiers were more able to implement their strategies than their counterparts.

Acknowledgements

I want to express my special gratitude to my supervisors Øyvind Sandbakk and Jan Kocbach for their guidance and advice all throughout my master project. I would like to extend my sincere thanks to Trine Seeberg for her help planning and executing the data collection in Gjøvik, and all her help and feedback afterwards. I am very grateful to Rune Talsnes, especially for his help before and during the data collection. Lastly, I want to thank Tore Berdal for his help along the whole way of my master project, including data collection, and the many times I asked for his opinion.

Thank you all for answering all my questions with patience and kindness.

Introduction

Cross-country skiing (XC skiing) is a challenging winter endurance sport requiring high physical demands in combination with technical and tactical skills (Holmberg, 2015; Sandbakk & Holmberg, 2014). The different types of competition vary in distance (usually 1.5 – 50 km), type of start-procedure (individual or mass-start), and style (classic or freestyle).

XC skiing races are performed in hilly terrain which results in fluctuations in speed, work rate, and energy expenditure (Andersson et al., 2010; Bolger et al., 2015; Losnegard, 2019; Sandbakk et al., 2011). In short uphill sections, the skiers achieve the highest work rates which can be significantly above their $VO_2\text{max}$ (Gløersen et al., 2020; Karlsson et al., 2018; Sandbakk et al., 2011). Therefore, XC-skiers not only require an extremely high $VO_2\text{max}$ (Sandbakk & Holmberg, 2017), but also anaerobic capacity (Losnegard et al., 2012) as well as the ability to recover quickly in flat and downhill sections (Gløersen et al., 2020; Losnegard et al., 2015) and recuperate anaerobic power during submaximal periods are needed (Ardigò et al., 2020; Gløersen et al., 2020; Gløersen et al., 2018). This combination of very high work rates alternating with recovery distinguishes XC skiing from other endurance sports (Losnegard, 2019). To tackle these fluctuations, the skier has to change between different sub-techniques of either classic or skating and regulate cycle length and cycle rate (Losnegard, 2019; Pellegrini et al., 2013; Sandbakk & Holmberg, 2017; Seeberg et al., 2021; Solli et al., 2018). Freestyle (skate-skiing) can be divided into six different sub-techniques (Losnegard, 2019). They are chosen depending on the demand imposed by the terrain, velocity, snow conditions and personal performance level (Sandbakk & Holmberg, 2017). Lower gears are used in uphill sections and higher gears are used when skiing at higher speed in flatter sections (Andersson et al., 2010).

Understanding the specific demands of each race format can help to target training and to optimize race strategy. The mass-start format was introduced to the Winter Olympic Games in 2002 (B. Pellegrini et al., 2018) and is now the most common XC skiing race format (Seeberg et al., 2021). For example, in Olympic and World Championships, 10 out of 12 races are performed as some kind of mass-start format (Losnegard et al., 2016; Sandbakk & Holmberg, 2017). However, the mass start has rarely been investigated scientifically in a real-life competition.

In a mass-start event, all skiers start together and the first skier crossing the finish line is the winner. With many skiers close together, tactical choices are crucial (Abbiss & Laursen, 2008) and may also influence physiological and biomechanical demands (Seeberg et al., 2021). Changing position in fluctuating terrain, with resulting rapid changes in work rate, is difficult (Sandbakk & Holmberg, 2017) and provides skiers who have tactical and technical flexibility with an advantage (Barbara Pellegrini et al., 2018). Additionally, the skiers can benefit from the effect of drafting behind other skiers and thereby reduce drag. In a drafting position, energy expenditure is lower at the same speed (Brisswalter & Hauswirth, 2008) which means they can either save energy at the same speed or ski faster at the same energy cost. Furthermore, it may provide a motivational effect to follow a slightly faster skier.

Besides physical and technical abilities, pacing strategy, and with it the distribution of power output in a race, can have a significant effect on performance (Abbiss & Laursen, 2008; Formenti et al., 2015; Stöggl et al., 2018; Sundström et al., 2013). In individual sprint-time-trials and distance races, elite XC skiers show a positive speed profile, with velocity decreasing from the first to the last lap (Andersson et al., 2010; Bolger et al., 2015; Losnegard et al., 2016; Welde et al., 2017), or a reverse J-shaped pacing strategy with overall decline, but a faster last lap than the previous (Formenti et al., 2015; Stöggl et al., 2018). However, (Losnegard et al., 2016) found that overall faster skiers showed a more even pacing pattern with lower decrease of skiing velocity over laps than slower skiers which suggests that a quick start relative to personal average velocity decreases performance.

In contrast to other endurance sports, an optimal speed profile in XC-skiing is much more complex due to the variability in energy demand and power production during different terrain sections. The model for optimal micro-pacing strategy in cross-country skiing by (Sundström et al., 2013) suggests an ideal micro-pacing strategy with variable propulsive power to aim at a speed as constant as possible throughout the race to minimize drag. In real-life time trials, skiers spend about 50% of their time racing uphill (Bolger et al., 2015; Losnegard, 2019), and an athlete's performance there has been shown to be the most important factor determining overall performance (Andersson et al., 2010; Bolger et al., 2015; Sandbakk et al., 2011; Sandbakk, Hegge, et al., 2016).

Achieving an ideal personal speed profile may be even more difficult in mass-starts because it is influenced by other skiers (Losnegard et al., 2016). It is likely that weaker skiers try to follow the leaders as long as possible to benefit from the drafting effect, as it has been observed in mass-start races in mountain biking (Abbiss et al., 2013; Granier et al., 2018; Impellizzeri & Marcora, 2007). This may result in a non-optimal pacing pattern for them personally. Even though they benefit from the drafting effect, it can be expected that keeping their position is too fatiguing and results in decreased performance. This may in many cases lead to packs of similar performing skiers instead of following the leader as is the case in other long endurance sports such as half marathon running and triathlon (Hanley, 2015; Vleck et al., 2008). Since skiers can see their competitors in a head-to-head race, they get constant feedback on their performance. In contrast to an individual time trial, where skiers race against the clock, in a head-to-head race they only have to be slightly faster than the opponents to know that they win. Therefore, they can adapt their speed profile and other tactical choices throughout the whole race accordingly. Another aspect that likely occurs in a mass-start is the “accordion effect” which has previously been described in cycle races. It occurs with fluctuations in speed in a group of athletes, for example around tight corners. Athletes in front reduce speed which results in a tighter field behind them, and the following athletes have to reduce speed to a greater extent to avoid accidents. The reduction of speed accelerates further back through the group and causes a congestion (Blocken et al., 2018; Trenchard, 2010). In a mass-start XC-ski race this is expected in the transition from easy terrain to a steep uphill.

The outcome of the mass-start race is often decided in long, steep uphill at the last part of the race or in the final all-out-sprint (Sandbakk & Holmberg, 2014). The ability to generate high forces in crucial moments like the aforementioned position change or the final sprint is essential for high performance (Losnegard, 2019; Sandbakk & Holmberg, 2017; Seeberg et al., 2021). A recent study analysing a simulated mass-start found that skiers with a high VO_{2max} and gross efficiency achieved better performance in both the overall race and the final sprint because these translated into a lower relative intensity and the skiers entered the final sprint with less fatigue (Seeberg et al., 2021). Furthermore, the ability to exert rapid cycles to accelerate at the start, during breakaway, and the final sprint is advantageous (Losnegard, 2019).

To the best of my knowledge, there is very limited research related to real-life mass-start events in XC skiing. Identifying speed patterns in different terrain sections of the leading skiers in comparison with the following skiers may provide an initial insight on speed profiles and tactics. Since previous research have shown that skiers skiing in a pack can benefit from drafting, and that a more even speed profile is beneficial, it is hypothesized that packs of athletes with a similar level are found in which they can ski at a speed that is more optimal personally which leads to less decrease in speed over the race.

Therefore, this study aims to compare speed profiles and tactical choices between skiers of different performance levels in a skating style mass-start competition in cross-country skiing by (1) describing the race development and speed profiles over the whole race and different terrain sections, (2) identifying differences in speed profiles, and (3) the tactical choices distinguishing skiers on different performance levels.

1 Methods

1.1 Participants & design

The data collection was performed in Gjøvik, Norway on the 29.01.2022 during the mass-start race for male seniors in the Norwegian cup. The 57 best ranked XC-skiers agreed to participate in the study. Due to signal loss on 7 sensors, and 5 skiers not finishing the race, 45 were included in the study. However, most of the analysis included only 35 of the top 40 ranked skiers. Exclusively for analysis of skiers forming packs, all 45 skiers were used. The skiers' anthropometrics and physical characteristics are presented in **Table 1**. The skiers were recruited by information given at the teams meeting two days before the race and at bib collection on race day. Additionally, all skiers completed a questionnaire about strategies and experiences during the race.

Groups of skiers

To identify differences in speed profile based on performance, the skiers were divided into four groups based on final ranking. Group 1 ($n = 7$, 55.4 ± 12.3 FIS points) consisting of the skiers with a final ranking between 1 and 10 (rank 3, 7, 8 missing), Group 2 ($n = 9$, 80.0 ± 20.6 FIS points) with a final ranking of 11-20, Group 3 ($n = 9$, 109.5 ± 31.8 FIS

points) with a final ranking of 21-30, and Group 4 (n = 10, 129.2 ± 46.8 FIS points) with a final ranking of 31-40. Hereafter, they are referred to as “Group 1”, “Group 2”, “Group 3” and “Group 4”. For analysis of skiers forming packs, all 45 skiers were included. Group numbers here refer to the groups the skiers formed during the race.

Table 1 | Anthropometric and physical characteristics of the 35 participating elite male cross-country skiers and 45 skiers used for pack analysis.

Variable	Mean ± SD	
	35 skiers	45 skiers
Age (yrs)	23.7 ± 2.8	23.3 ± 2.6
Body height (cm)	182.2 ± 6.0	182.8 ± 6.6
Body mass (kg)	75.3 ± 5.3	75.5 ± 6.2
Body mass index (kg·m ⁻²)	22.7 ± 1.0	22.6 ± 1.0
FIS- points	98.7 ± 41.5	109.0 ± 47.7

1.1 Ethics Statement

Ethical approval was not required for this study on human participants in accordance with the local legislation and institutional requirements. Approval for data security and handling was obtained from the Norwegian Centre for Research Data (project number 761888) in front of the study. The participants provided their written informed consent to participate in this study.

1.2 Competition

Course, elevation profile and speed were tracked with a high-end 10Hz GNSS device (AdMos, Advanced sports instruments, Switzerland) a multisensory-device that also comprises a barometer and an inertial measurement unit (IMU). The units have previously been validated in alpine skiing (Jølstad et al., 2021). The GNSS has a speed accuracy of 0.05 m/s based on Doppler effect (Advanced Sport Instruments, 2021). In front of the race, pockets to hold the units had been stapled to the inside of the upper back of the race bibs. On race day, 10 min before the race-bibs were handed out, the units were turned on and placed outside in an open field with no trees to ensure satellite connection. When the skiers collected the race bibs up to two hours prior to race, the units were put into the pockets of the bibs. After the race, the units were collected from the bibs.

1.3 Questionnaire

Within three weeks after the race, all skiers filled out the online survey including physical characteristics and a questionnaire. The questionnaire consisted of both quantitative and qualitative questions related to planned and actual tactics, speed profiles as well as perceived opportunities and challenges (see Appendix A). The questionnaire contained 17 quantitative questions with a statement on which the skiers had to rate their agreement on a scale of 1 to 10 (1 = I do not agree at all, 10 = I agree completely). The first 6 questions were about the skiers' strategies prior to the race, while the following 11 questions asked about the skiers' experiences on race day. The 6 qualitative questions asked for additional strategies before the race, and experienced challenges and opportunities during the race.

1.4 Data processing

Data was downloaded from the units the day after competition. The data was processed using MATLAB (version R2020a, MathWorks Inc., Natick, MA). Using the GPS- and elevation data, a 3D track profile was created. Section times were calculated using the time mapped to the GPS.

Elevation data is based on the barometer data measured by the AdMos units. The elevation profile was then created by averaging the elevation data of all skiers on all laps with a resolution of 1 m along the course. Also, due to the non-standard course-setup with a shortened first lap, the course profile is made of three parts; the common first part, the common last part and the extra part for lap 2-6 including sections 5 and 6. The individual GPS-tracks are fit to each of the three parts for each lap (only the first and last part for lap 1), and then the complete mapping is made from these parts ($6*2 + 5*3$ parts).

1.5 Track

So that all laps started and ended in the same position, parts of the 21.75km competition track at the start and finish as well as between laps were cut. The resulting investigated racecourse of 20.92 km consisted of 6 laps, with an elevation difference of 21 m and a total climb of 93 m in the first lap, and an elevation difference of 42 m and a total climb of 114 m in laps 2-6. The first lap was 3170 m long, followed by the 2nd -6th laps with 3550 m. The distance for the final sprint over 109 m was analysed separately.

The racecourse was divided into uphill, flat, and downhill terrain based on position and altitude data from GNSS measurements collected along the course, following the procedure described in Sandbakk, Losnegard, et al. (2016).

The total uphill, downhill, and flat sections made up for 37.2%, 42.4%, and 20.4% of the total race, respectively. The first lap was divided into 12 sections (S1-4 and S7-14), while lap 2-6 were divided into 14 sections (**Figure 1**). For analysis of the last kilometre of the race, the last 900m of the last lap and the final sprint over 109 m were analysed together. The distance there was divided into 100 m sections.

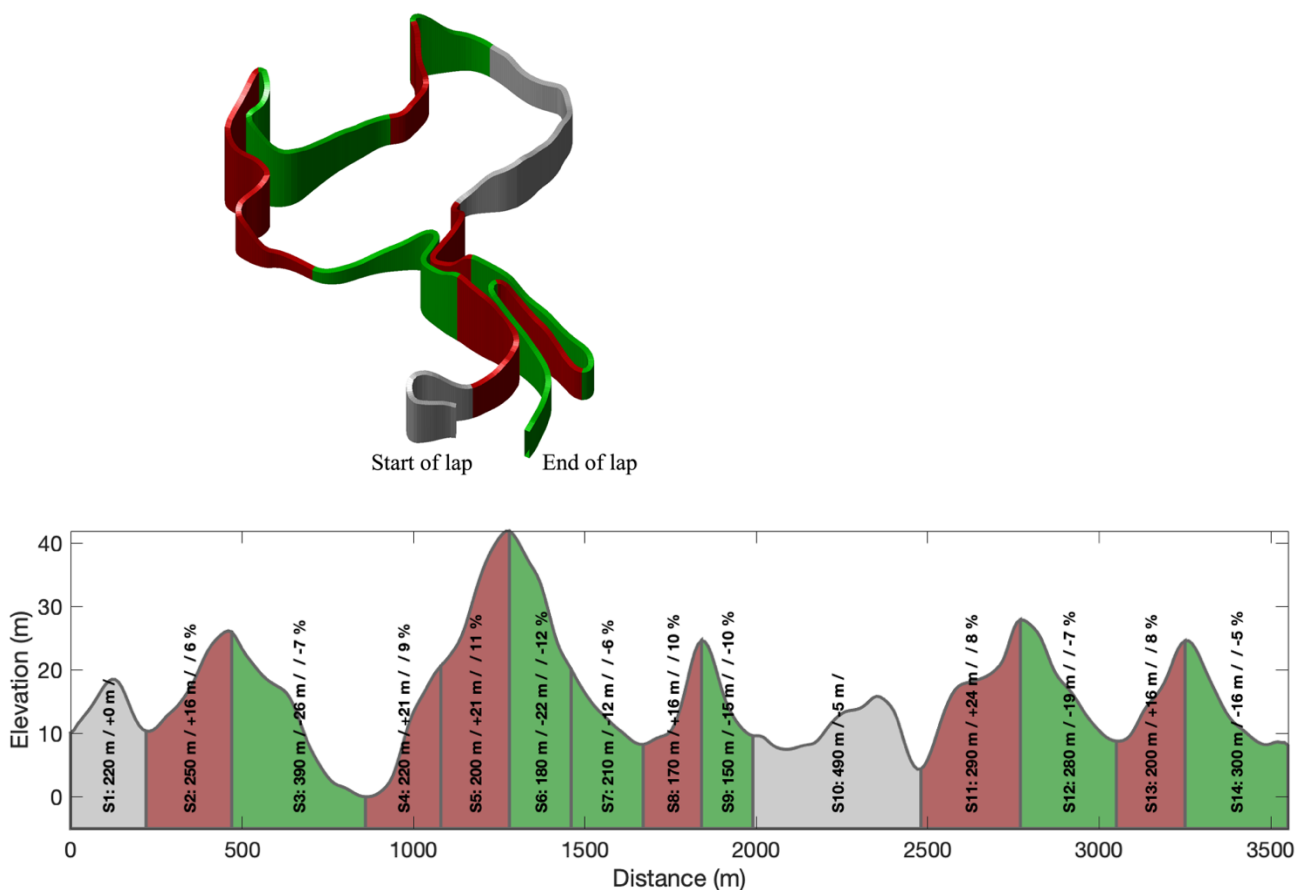


Figure 1 | 3D & 2D Illustration of course profile and sections (S1-14) with distance, climb, average time, and inclination of one 3550m lap examined in the current study. Uphill sections highlighted in red, flat sections highlighted in grey, downhill sections highlighted in green

1.6 Calculations

Section speed was calculated as measured distance over measured time in the section of interest. To estimate the difference in reduction of propulsive power from a drafting position in uphill sections with different incline, the power balance model was used, using

the average slope angle, average speed and start/end speed for each uphill segment. Based on results for speed skaters (Elfmark et al., 2019), a drag reduction estimate of 10% (from 0.55 to 0.495) has been assumed for being behind. Effect for reduced friction was neglected as the effect of drag reduction is assumed to be larger with the current snow conditions. Since snow friction has not been measured, a value of 0.03 was assumed. For mass, the average body mass of the group of 35 skiers was used. In downhill sections, the skiers use less to no propulsive power which makes calculations more difficult. Therefore, it has only been done in sections only containing uphill.

Formula for propulsive power:

$$P = \mu * m * g * \cos(\alpha) * v + m * g * \sin(\alpha) * v + 0.5 * \rho * C_d A * v^3 + m * v * dv/dt$$

where

- μ (snow friction coefficient) = 0.03
- m (body mass in kg) = 75
- g (gravitational force) = 9.81
- α (average angle of uphill) = segment elevation difference/segment length
- v = average velocity over segment
- ρ (density of air) = 1.3018
- $C_d A$ (drag coefficient) = 0.55 in front position; 0.495 in drafting position
- dv = speed at beginning of segment minus speed at end
- dt = time

1.7 Statistical Analysis

All continuous measures are presented as mean \pm SD. A Shapiro-Wilk test in combination with visual inspection of histograms were used to assess normal distribution of the variables. Accordingly, parametric tests were used if the data was normally distributed and otherwise, non-parametric tests were chosen. Between-group comparisons were done with 1-way ANOVA. When ANOVA showed statistically significant group differences, Tukey's *post-hoc* test analysis was used to compare differences. Correlations between selected sections and overall race time, or speed were calculated using the Spearman's rank test. The interpretation of the magnitude of linear association between the variables were evaluated according to Hopkins et al. (2009) as trivial: $r < 0.1$, small: $0.1 \leq r < 0.3$, moderate: $0.3 \leq r < 0.5$, large: $0.50 \leq r < 0.7$, very large: $0.7 \leq r < 0.9$, and extremely large: $0.9 \leq r < 1.0$. The level of statistical significance was set at $\alpha = 0.05$. The statistical

analysis was performed using IBM SPSS Statistics Version 27 and Microsoft Excel for Mac Version 16.59.

2 Results

2.1 Description of race development

How time difference to the skier who achieved rank 1 develops in the 34 following skiers over the analysed race distance of 21.7 km is provided in **Figure 2**. The number out of a group of 45 skiers that were within certain time differences up to 120 s to the current leader over the race distance is presented in **Figure 3**, and formation of packs, including number of packs over the race in the same 45 skiers is displayed in **Figure 4**. Based on the power balance model, it was estimated that when skiing in a pack, a skier can save ~1.5% propulsive power in S 2, 1.2% in S 4, 0.3% in S 5, 0.7% in S8, 0.8% in S11, and 0.9% in S13. During the race, the skiers spent an average 53% racing uphill, 20% downhill, and 27% on flat terrain.

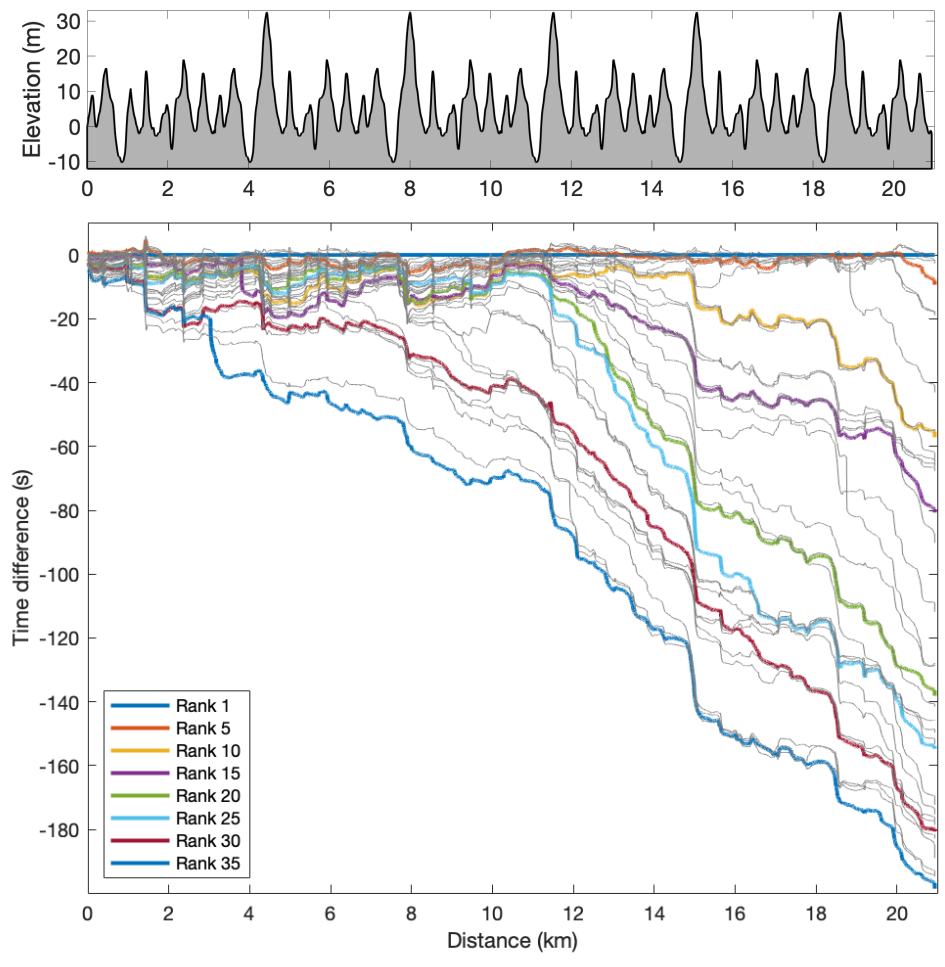


Figure 2 | Time difference vs Rank 1 in 34 skiers over the race distance. Every fifth rank accentuated with colours.

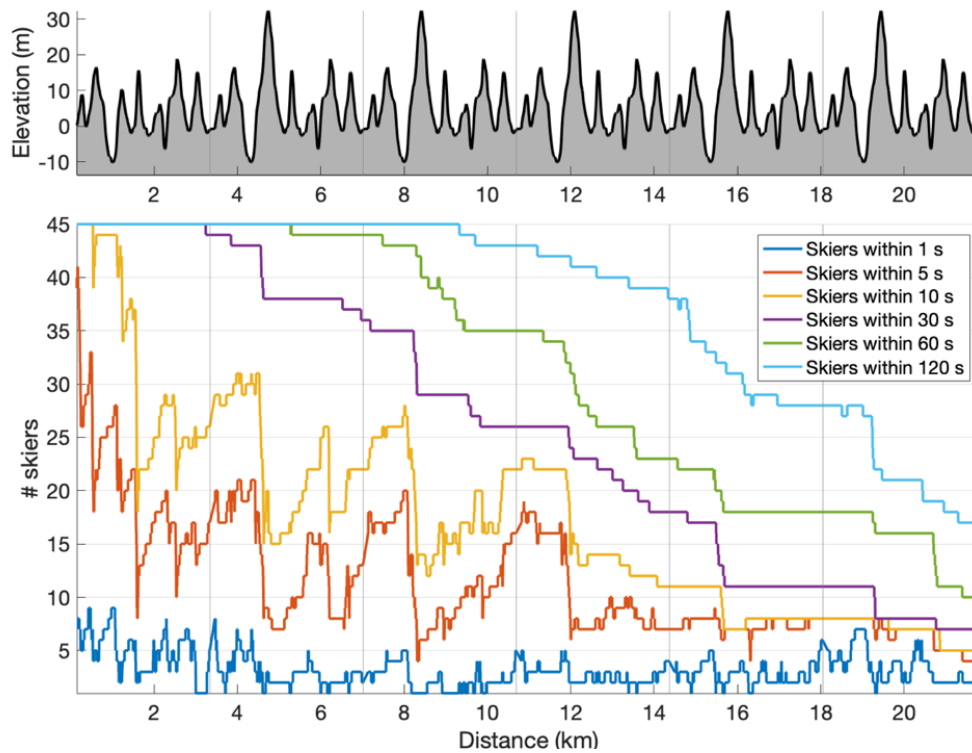


Figure 3 | Number of skiers within different time differences to current leader over race distance.

Visualization of the number of skiers (45 total) who lie within 1, 5, 10, 30, 60, and 120s behind the current leader over the race distance of 20.92 km and in relation to elevation.

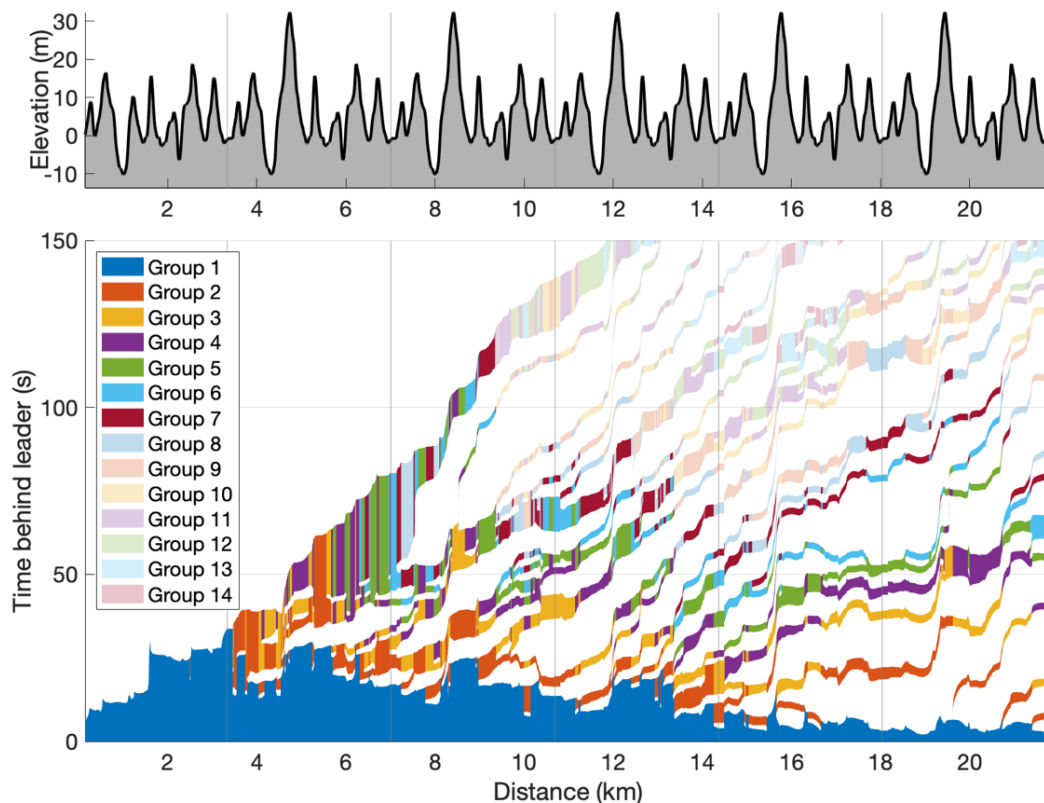


Figure 4 | Formation of packs of 45 skiers over race distance. Visualization of number of packs and the range of time behind the current leader within the packs over race distance (20.02 km) and in relation to elevation. Only packs within 150 seconds behind the current leader are presented.

The last kilometre of the race consisted of S12-14, and the final sprint over 109 m. The distance was divided into sections of 100 m. Speed over the first four 100 m sections showed a large significant correlation with mean overall race speed ($r = .55, .54, .62, .62$, respectively, $p < .01$ for all), and the fifth 100 m section showed moderate significant correlation with mean overall race speed ($r = .38, p > .05$), while the following showed no significant correlation. Speed differences of Groups 2, 3 and 4 against Group 1 are presented in **Figure 5** and time differences of the Top 5 and Top 10 ranked skiers against rank 1 is shown in **Figure 6**. Speed in the final 109m sprint was significantly faster than average speed in the last lap and in the 900m before the final sprint. The 35 skiers increased speed on average 13.6% (± 8.1) ($p < .001$), Group 1 14.0% (± 3.6) ($p < .001$), Group 2 8.8% (± 3.9) ($p < .001$), Group 3 19.5% (± 8.7) ($p < .001$), and Group 4 12.5% (± 10.0) ($p = .003$). Within Group 1, speed in the final sprint (109 m) showed no significant correlation with rank or average overall speed.

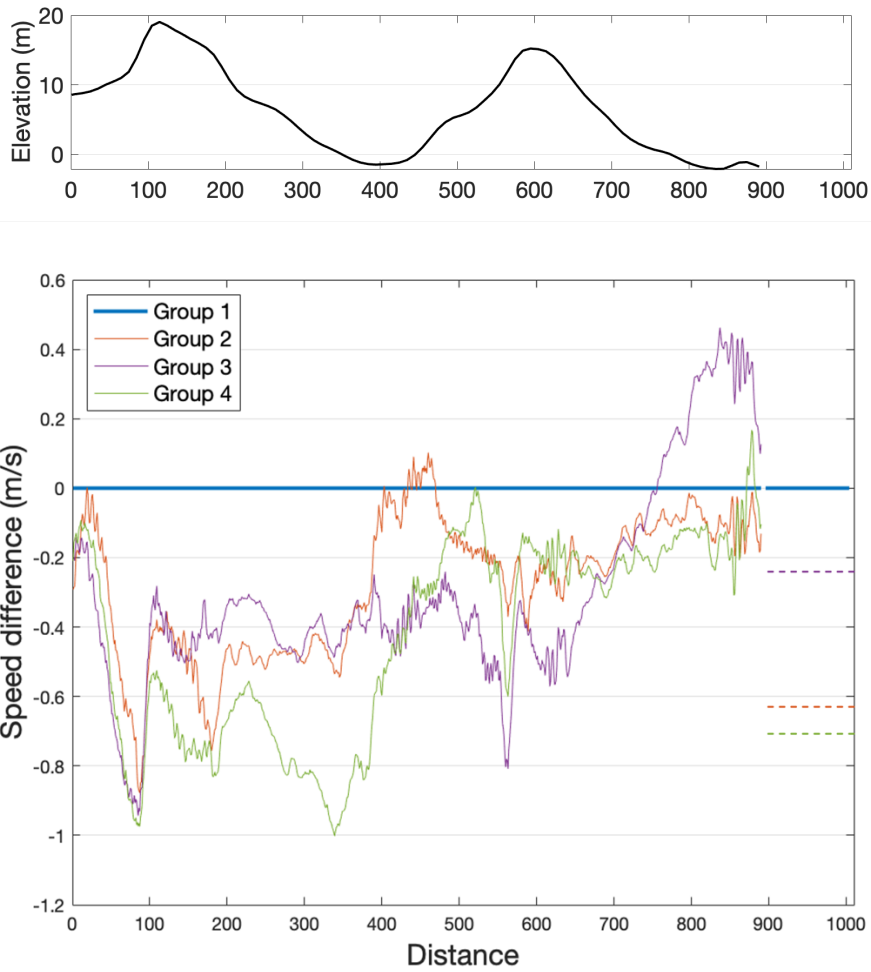
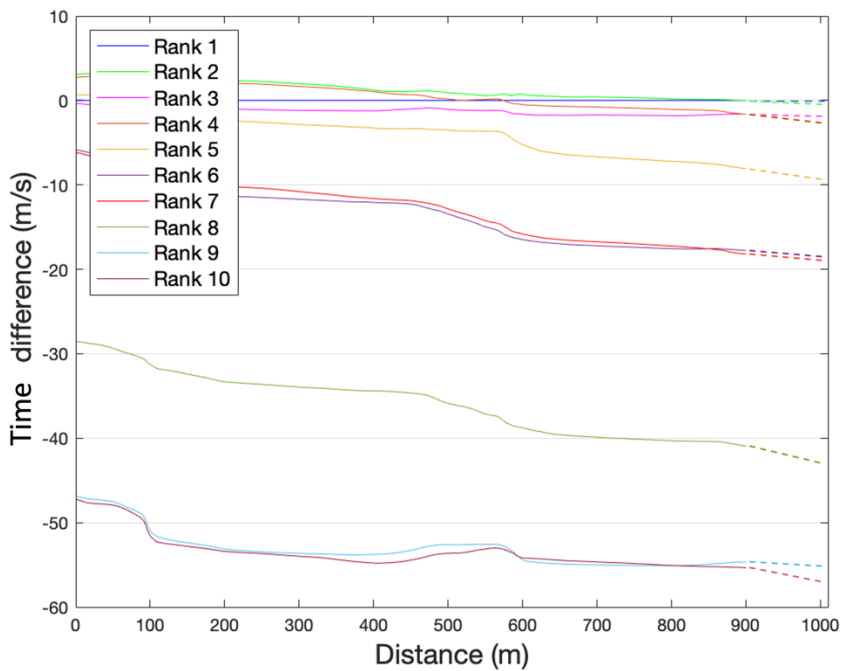
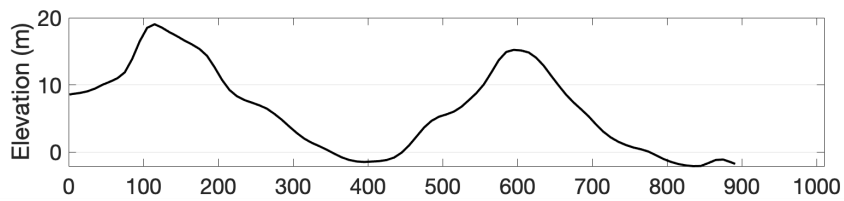
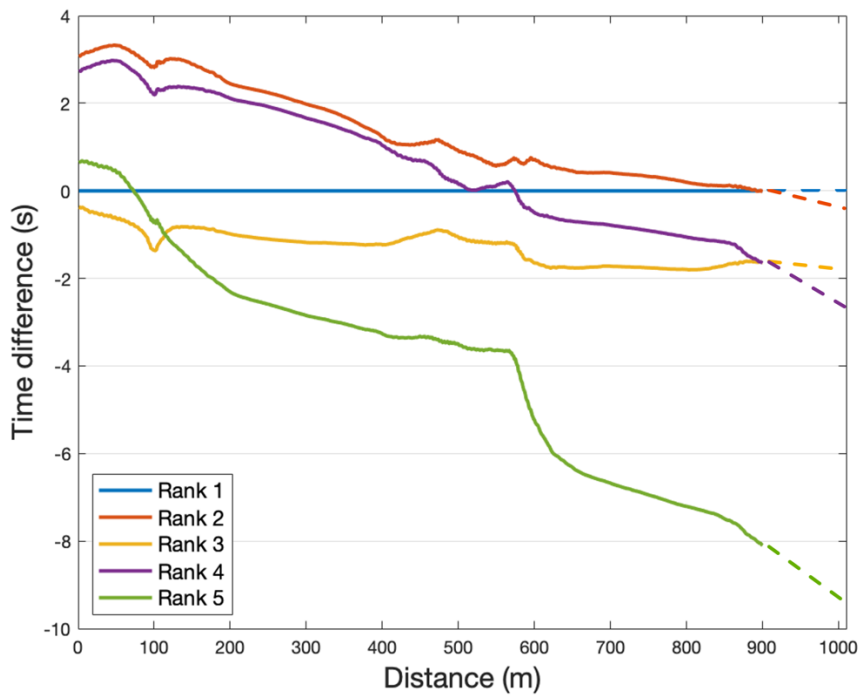


Figure 5 | Speed difference to Group 1 over the last kilometre in $\text{m}\cdot\text{s}^{-1}$. Continuous speed data represented with solid line, the average speed difference to Group 1 in the final sprint represented with a dashed line. Elevation data for the final sprint was not available. Group 1: final rank 1-10; Group 2: final rank 11-20; Group 3: final rank 21-30; Group 4: final rank 31-40.



A



B

Figure 6 | Time difference of top 10 (A) and top 5 (B) ranked skiers against rank 1 in final kilometre. Continuous speed data represented with solid line, the average speed difference to rank 1 in the final sprint represented with a dashed line. Elevation data for the final sprint was not available.

2.2 Speed profile

The 35 skiers used a positive speed profile indicated by a higher speed over the first three laps compared with their average speed over the whole race ($p < .001$) (Table 2).

Table 2 | Pacing shown as speed over the first three laps presented as % (\pm SD) of mean speed over the whole race for each group

All skiers ($n = 35$)	Group 1 ($n = 7$)	Group 2 ($n = 9$)	Group 3 ($n = 9$)	Group 4 ($n = 10$)
+3.65 (± 1.41)	+1.47 (± 0.22)	+3.24 (± 0.41)*	+4.94 (± 0.58)*	+4.39 (± 0.97)*

*Lap 1 was shorter than the other 5 laps (3170 m and 3550 m. respectively).
Positive values indicate positive pacing (i.e., the athletes were slower in the second three laps.
Group 1: final rank 1-10; Group 2: final rank 11-20; Group 3: final rank 21-30; Group 4: final rank 31-40
* significantly different from Group 1 ($p < .01$)*

2.2.1 Lap & sections analyses (3)

The average speed of the group of all skiers during the race was $6.55 (\pm 0.13) \text{ m}\cdot\text{s}^{-1}$. When comparing average lap speed lap-by-lap (Table 3), all groups were fastest in lap 1 and were significantly slower in lap 2. The average speed of the 35 skiers in lap 2 was 7.3% ($p < .001$) slower than their average speed in lap 1. It has to be noted that the first lap had 200 m less uphill, and 180 m less downhill sections than all other laps. Over the following laps 3-5, the speed decreased in comparison to the previous lap on average 2.8% ($p < .001$), 2.0% ($p = .03$), 1.9% ($p = .053$), respectively. From the 5th to the last lap, speed increased again (1.5%, $p = .235$). Only Group 1 increased speed in an additional lap, which was from lap 3 to lap 4 (1.3%, $p = .021$).

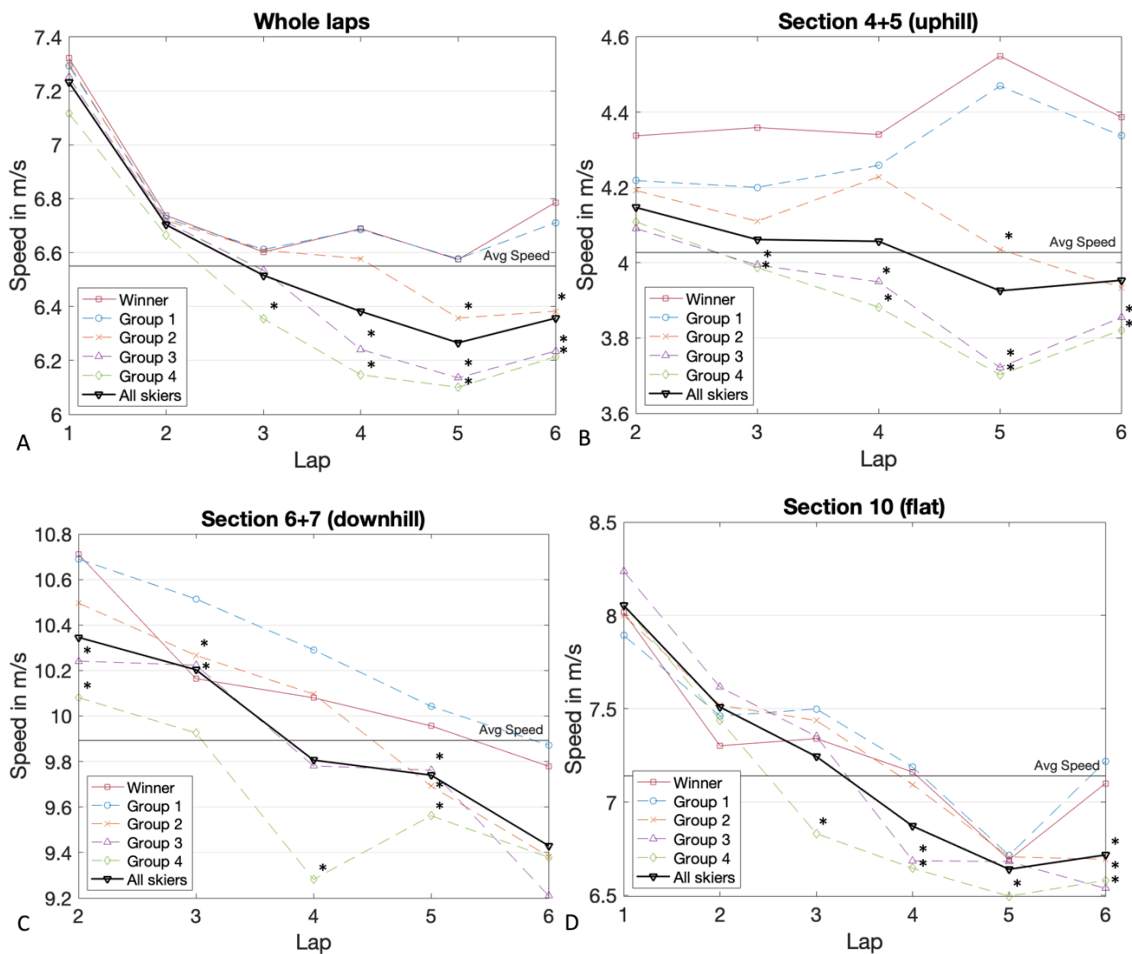


Figure 7 | Mean speed (m·s⁻¹) in different sections for each group lap-by-lap (lap 1 shorter than laps 2-6). (A) Mean speed within whole lap; (B) Mean speed within S4 and 5 together (longest uphill), including only laps 2-6, because lap 1 did not have S5; (C) Mean speed within S6+7 (longest downhill), including only laps 2-6, because lap 1 did not have S6; (D) Mean speed within S10 (longest flat section). * Statistical significant difference ($p < 0.05$) to Group 1. Group 1: final rank 1-10; Group 2: final rank 11-20; Group 3: final rank 21-30; Group 4: final rank 31-40

2.1 Differences in speed profile & important sections

Between groups, Group 1 showed statistically significant less % difference between the first three laps and the whole race ($p < .001$ for all). Group 3 ($p < .001$) and Group 4 ($p = .003$) both had significantly higher % differences between first and last 3 laps than Group 2. There was no significant difference between Group 3 and Group 4. (**Table 1**).

The average speed in each terrain type was highest in Group 1. The average difference in speed against Group 1 in uphill terrain was 2.02%, 5.48%, 5.98%, for Groups 2, 3 and 4, respectively (all $p < .001$), and in flat terrain 1.02% ($p = .113$), 2.34% ($p < .001$), 3.75% ($p < .001$) for Groups 2, 3 and 4, respectively. The differences in

downhills were 1.73% ($p = .009$), 2.01% ($p = .002$), 4.55% ($p < .001$), for Group 2, 3 and 4, respectively.

Time spent in uphill terrain had the highest correlation with finish time ($r = .964$, $p < .001$), followed by very high correlations with finish time of time spent in flat terrain ($r = .852$, $p < .001$) and time spent in downhill terrain ($r = .811$, $p < .001$). Correlations of speed in individual sections over laps are presented in **Table 4**.

Table 3 | Speed in different sections for each group lap by lap presented as % difference (\pm SD) to lap 2

(A) Whole lap						
Lap	Rank 1	Group 1	Group 2	Group 3	Group 4	All skiers
1 ^Δ	8.7	8.4 (± 0.3)	8.7 (± 1.0)	8.0 (± 0.8)	6.8 (± 1.5)	7.9 (± 1.2)
2	-	- *	- *	- *	- *	- *
3	-2.0	-1.7 (± 0.4)*	-1.6 (± 1.1)*	-2.7 (± 1.2)*	-4.6 (± 1.8)*	-2.8 (± 1.8)*
4	-0.7	-0.6 (± 0.3)*	-2.1 (± 1.3)	-7.0 (± 2.4)*	-7.8 (± 1.6)*	-4.8 (± 3.4)*
5	-2.4	-2.2 (± 0.4)*	-5.4 (± 1.4)*	-8.6 (± 1.7)	-8.5 (± 1.2)*	-6.5 (± 2.8)
6	0.7	-0.2 (± 1.2)*	-5.0 (± 1.9)	-7.1 (± 2.4)	-6.8 (± 2.9)	-5.2 (± 3.4)
(B) Section 4+5 (uphill)						
Lap	Rank 1	Group 1	Group 2	Group 3	Group 4	All skiers
1 ^Δ	-	-	-	-	-	-
2	-	-	-	-	-	-
3	0.5	-0.4 (± 1.7)	-2.0 (± 2.1)	-2.4 (± 2.2)	-3.0 (± 2.9)	-2.1 (± 2.4)
4	0.1	1.0 (± 1.8)	0.9 (± 3.4)	-3.5 (± 3.7)	-5.5 (± 3.6)	-2.2 (± 4.2)
5	4.9	6.0 (± 2.8)*	-3.8 (± 4.5)	-9.0 (± 2.4)*	-9.9 (± 3.8)*	-5.3 (± 6.9)
6	1.1	2.8 (± 2.4)	-6.2 (± 2.7)	-5.8 (± 2.4)	-7.0 (± 5.8)	-4.7 (± 5.2)
(C) Section 6+7 (downhill)						
Lap	Rank 1	Group 1	Group 2	Group 3	Group 4	All skiers
1 ^Δ	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-5.1	-1.6 (± 2.7)	-2.2 (± 2.5)	-0.2 (± 2.5)	-1.6 (± 1.9)	-1.4 (± 2.4)
4	-5.9	-3.7 (± 2.1)	-3.8 (± 2.8)	-4.5 (± 3.0)	-8.0 (± 7.4)*	-5.2 (± 4.6)*
5	-7.1	-6.1 (± 1.9)	-6.1 (± 1.9)	-4.7 (± 3.3)	-5.2 (± 2.4)	-5.9 (± 2.9)
6	-8.7	-7.7 (± 2.0)	-7.7 (± 2.0)	-10.1 (± 10.9)	-7.0 (± 2.3)	-8.9 (± 7.3)

(D) Section 10 (flat)						
Lap	Rank 1	Group 1	Group 2	Group 3	Group 4	All skiers
1 ^Δ	9.8	5.8 (± 2.2)	6.3 (± 3.2)	8.2 (± 1.1)	8.3 (± 3.1)	7.2 (± 2.7)
2	-	- *	- *	- *	- *	- *
3	0.5	0.5 (± 1.5)	-1.1 (± 2.9)	-3.5 (± 2.8)*	-8.2(± 3.8)*	-3.5(± 4.3)*
4	-1.9	3.7 (± 1.5)*	-5.7(± 2.2)*	-12.2(± 4.1)*	-10.7 (±2.6)	-8.5(± 4.3)*
5	-8.4	-10.0 (± 1.7) *	-10.8 (± 2.1)*	-12.3 (±2.4)	-12.7 (± 2.5)	-11.6 (± 2.4)*
6	-2.8	-3.3 (± 2.0)*	-11.0 (± 4.7)	-14.2 (± 1.7)	-11.6 (± 4.1)	-10.6 (± 5.1)

Positive number: higher speed than in lap 2

Group 1: final rank 1-10; Group 2: final rank 11-20; Group 3: final rank 21-30; Group 4: final rank 31-40

* Statistical significant difference ($p < .05$) to previous lap

^ΔLap 1 was shorter and did not include S 5&6. Therefore, (B) Section 4+5 and (C) Section 6+7 do not include lap 1.

Table 4 | Correlation between section speed with average race speed for 35 cross-country skiers during a mass-start race in the skating style.

Lap	S1 (F)	S2 (U)	S3 (D)	S4 (U)	S5 (U)	S6 (D)	S7 (D)	S8 (U)	S9 (D)	S 10 (F)	S11 (U)	S12 (D)	S13 (U)	S14 (D)	Com- plete lap
1	0.58*	0.49*	-0.17	0.42*			-0.14	0.74*	-0.36*	-0.33	0.56*	0.06	-0.30	0.57*	0.75*
2	-0.16	-0.26	0.19	-0.00	0.60*	0.55*	0.60*	-0.17	0.23	0.05	-0.10	0.34*	-0.22	0.58*	0.48*
3	0.03	0.41*	0.32	0.11	0.77*	0.61*	0.54*	0.20	0.42*	0.73*	0.37*	0.64*	-0.20	0.41*	0.82*
4	-0.26	0.64*	0.74*	0.74*	0.86*	0.78*	0.81*	0.88*	0.61*	0.77*	0.80*	0.63*	0.82*	0.80*	0.88*
5	0.69*	0.75*	0.68*	0.83*	0.83*	0.42*	0.69*	0.61*	0.45*	0.55*	0.39*	0.71*	0.13	0.18	0.86*
6	0.60*	0.32	0.06	0.37*	0.69*	0.26	0.61*	0.36*	0.39*	0.48*	0.51*	0.63*	0.34*	0.25	0.66*
All laps	0.61*	0.84*	0.58*	0.69*	0.88*	0.61*	0.73*	0.83*	0.52*	0.86*	0.79*	0.84*	0.47*	0.82*	

Lap 1 did not include S 5 and S6. Significant correlations highlighted with colours. Colours based on the magnitude of linear association between the variables trivial: $r < 0.1$. small: $0.1 < r < 0.3$. moderate: $0.3 < r < 0.5$. large: $0.50 < r < 0.7$. very large: $0.7 < r < 0.9$. and extremely large: $0.9 < r < 1$. * $p < .05$

2.2 Qualitative & quantitative data from the questionnaire

A summary of the most relevant answers within all groups to the qualitative questions is given in Table 5. On average, the entire group of 35 skiers had an agreement of 8.3/10 before the race, and 8.2/10 after the race with the statement “I had decided to open as hard

as the lead, and to try to keep up as long as possible/ I did open as hard as the lead, and tried to keep up as long as possible “. Furthermore, agreement with the statement “To what extent were you able to complete the competition according to the strategies you had planned beforehand?” was significantly different between Group 4 and Group 1 ($p < .01$) (**Figure 8**). For that statement, there was a high correlation between agreement and rank ($r = 0.57, p < .01$). For figures regarding agreement within groups with further questions, see Appendix B.

Table 5| Summary of statements by the skiers answering the open questions of the questionnaire

Group 1	Group 2	Group 3	Group 4	Quotes (all translated from Norwegian original)
Strategies planned before the race				
↑ Lie far ahead to avoid accordion effect	↑↑ stay far in front of the field & keep up as long as possible	↑↑↑ keep up with main group as long as possible	↑↑ keep up with main group as long as possible	Group 1 <i>“Had a clear plan to be patient until the last kilometre”</i>
↑↑ stay behind for most of race, speed up in last kilometre	↑ overtake before narrow sections	↑↑ open fast for good positioning and avoid accidents	↑ offensive start to get good positioning & reduce accordion effect	Group 3 <i>“I was determined to keep up as long as I could and used zero energy to assess whether this was too hard“</i>
↑ stay a bit behind in uphill, make up for it easier terrain				
Challenges experienced during the race				
↓ accordion effect	↓↓↓ accordion effect especially further back in the field and in beginning of race	↓↓↓ accordion effect in the back of the field and in beginning of race	↓↓↓ risk of accidents	Group 3: <i>“Mad accordion effect for us that were further behind in the group, plus better ranked skiers in front that therefore can have a more even pacing/intensity”</i>
↓ difficult to overtake	↓↓↓ difficult to overtake	↓↓↓ demanding snow conditions	↓ difficult to overtake	
	↓↓↓ risk of accidents		↓ accordion effect	
	↓↓ narrow track sections	↓ narrow track sections		

Drafting position – experienced benefits and disadvantages

↑↑↑ save energy because less air resistance in easy terrain	↑↑↑ save energy because less air resistance in easy terrain ↑ motivational factor ↓↓↓uneven speed ↓↓ risk of pole breaking	↑↑↑ save energy because less air resistance ↑↑↑ skiers in front of the field, or in a stretched field, can benefit from drafting ↓↓↓ uneven speed ↓↓↓ risk of accidents and breaking poles ↓↓ forced to copy cycle pattern	↑↑↑ save energy because of less air resistance in easy terrain ↑ motivation ↓uneven speed ↓ risk of accidents and breaking poles ↓ forced to copy cycle pattern	Group 3: „Benefit from staying behind if you are among the top 10. Stress and uneven skiing further back. Easier to keep a steady speed when the field is stretched.”
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Copying the cycle pattern of the skier in front – experienced benefits and disadvantages

↑ makes skiing easier when being close to other skiers ↑ relaxing	↑↑ mentally comfortable, easy if skier in front has similar cycle pattern as oneself ↓↓↓ difficult if cycle pattern is different to own	↑ easy to copy pattern ↓↓↓ difficult if cycle pattern is different to own	↑↑ save energy, don't have to think ↓↓↓ difficult & stressful if cycle pattern is different to own	Group 1: „Can relax more with the same rhythm of movement“ Group 3: “Some go big and others with much frequency, this is even more amplified during a mass-start where the stress level is enormous. Runners fall and break poles, so the main focus is on skiing narrowly and keeping poles/skis away.”
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↑↓ arrows indicate direction of statement (positive or negative experience) and number of skiers making the statement (↑/↓ = Statement by one skier, ↑↑/↓↓ = Statement by two skiers, ↑↑↑/↓↓↓ = Statement by two or more skiers). Representative quotes selected to present experiences of skiers in further detail. Group 1: final rank 1-10; Group 2: final rank 11-20; Group 3: final rank 21-30; Group 4: final rank 31-40.

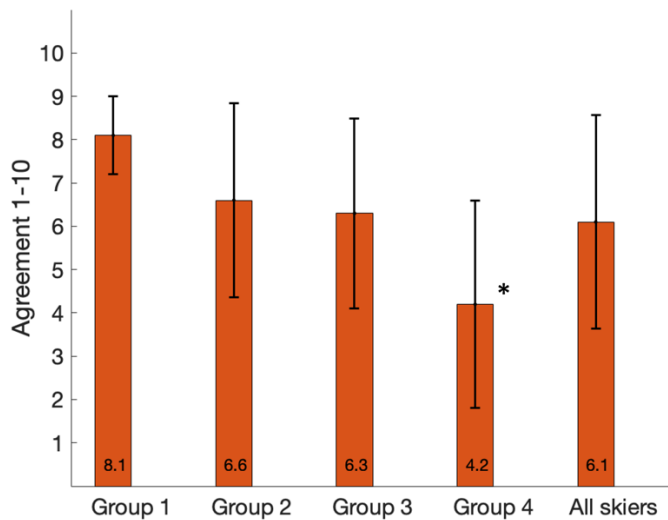


Figure 8 | Agreement on a scale of 1-10 (1: do not agree at all, 10: completely agree) in the four groups based on rank with the statement “To what extent were you able to complete the competition according to the strategies you had planned beforehand?”. Group 1: final rank 1-10; Group 2: final rank 11-20; Group 3: final rank 21-30; Group 4: final rank 31-40. *Statistical significant difference ($p < .05$) to Group 1.

3 Discussion

The present study compared speed profiles and tactical choices between skiers of different performance levels in a skating style mass-start competition in cross-country skiing by (1) describing the race development and speed profiles over the whole race and different terrain sections, (2) identifying differences in speed profiles, and (3) the tactical choices distinguishing skiers on different performance levels.

The main findings were

- (1) In the group of all skiers, an overall positive pacing pattern was observed where skiers decreased speed in the second half of the race.
- (2) Better performing skiers showed a more even pacing profile, with the largest differences in performance between Group 1 and the other groups being observed in uphill terrain, where speed also showed the highest correlation with overall performance.

- (3) Most skiers, independent of performance in this specific race, had the tactic to follow the lead as long as possible. However, higher ranked skiers were able to follow their personal strategy better than their counterparts.

3.1 General race development and speed profiles

An overall positive speed profile was observed, meaning the skiers were slower in the second part of the race than in the first part. The largest change in speed between laps was the decrease from lap 1 to lap 2, and speed decreased more in the first part of the race than in the second. In 10 -50 km XC-ski time trials, a positive pacing pattern has been observed as well, but in contrast to this study, speed decreased more steadily and the difference from the first to the second lap was less pronounced (Ardigò et al., 2020; Stöggl et al., 2018). An explanation is that in a mass-start, skiers start aggressively to achieve good positioning from the start of the race to enable skiing at ones best abilities, because position change over the race is difficult due to changing terrain (Sandbakk & Holmberg, 2017).

Over the course of the race, time difference against rank 1 increased and an increasing number of skiers lost the lead (**Figures 2 & 3**) and formed multiple packs of different size, likely with similar performance level within the packs (**Figure 4**). It could be expected that new packs form mostly during challenging sections such as uphill, or after a specific time point in the race, but that was not the case. Skiers stayed together as one group for the first lap, and then divided first into two and later more smaller packs, likely due to difference in performance level. The pack formation is fluent, meaning that skiers form new packs, but also re-join a pack they have previously been in. This formation of packs with large gaps in between presumably creates difficulties to advance in the field later, as skiers in Groups 3 and 4 reported.

3.2 Differences in speed profiles distinguishing skiers on different performance level

Between the groups, faster skiers decreased speed less over the whole course of the race compared to overall slower skiers. While Groups 2, 3 and 4 reduced speed between lap 2 and 5, speed in group 1 fluctuated within a narrower range ($0.2 \text{ m}\cdot\text{s}^{-1}$). This is similar to findings on a mass-start in mountain biking, where top performing athletes showed a more even speed profile, and less fluctuation in speed than their counterparts (Abbiss et al.,

2013). In theory, fluctuations in velocity require a higher energy cost because when increasing velocity, a large amount of energy is used to overcome drag instead of production of forward motion (Abbiss & Laursen, 2008; Sundström et al., 2013). Therefore, from a theoretical perspective, an even speed profile with fluctuations in power output are advised (Abbiss & Laursen, 2008; Sundström et al., 2013). This is supported by the model for XC-skiing created by (Sundström et al., 2013) and models for cycling (Atkinson & Brunskill, 2000; Swain, 1997). The larger decrease in speed in Groups 2, 3 and 4 occurred probably because skiers tried to keep up with the faster skiers in front as long as possible to keep their position, and to benefit from drafting. Ultimately, they likely fatigued and lost the leading group, either as a single skier or as a newly formed pack.

Even speed profiles with high speeds have been explained by greater endurance capacity in faster skiers. This enables to keep a higher power output over the race (Stögggl et al., 2018). Naturally, physical ability is of utmost in a mass-start as well. An additional reason for speed differences in a mass start may be the accordion effect. As skiers in this race reported, and supported by findings in cycling (Trenchard, 2010), congestion due to the accordion effect is more pronounced further back in the field. Starting order in a XC-ski mass-start is based on FIS points from previous races. Hence, better performing skiers are further in front and therefore are less at risk of facing the accordion effect which gives them further advantage.

In concordance with previous research on time trials, skiers spent ~50% of the race time skiing uphill (Bolger et al., 2015; Sandbakk & Holmberg, 2017), and the time spent in uphill sections correlated most strongly with finish time (Bilodeau et al., 1996; Bolger et al., 2015; Rundell & McCarthy, 1996; Sandbakk, Losnegard, et al., 2016). Related to that, the largest differences in speed between Group 1 and other groups was in uphill terrain, with larger differences in less performing groups. Additionally, analysis of speed difference against the current leader showed that in the longer uphills, the number of skiers within a certain time difference decreases, but then increases afterwards in easier sections (**Figure 3**), so skiers are able to catch up there. In the longest uphill (S 4 + 5), Group 1 increased speed between the second and last lap while all other groups decreased speed (**Figure 7**). Furthermore, speed in individual uphill sections in the second part of the race showed a higher correlation with overall performance (**Table 4**). These are indicators that the top ranked skiers had the physical ability to sustain high work rates

needed in uphill over the race while the others did not. This supports previous findings that faster skiers have more physical capacity left at the end of the race and the ability to employ longer cycles (Seeberg et al., 2021), a decisive factor in uphill velocity (Rundell & McCarthy, 1996).

In some laps in the longest downhill (S6+7), there were significant differences in speed between groups compared with Group 1, but not in the uphill before (S4+5). Possibly, skiers slowed down towards the end of the long uphill section due to fatigue and therefore started the downhill section with less speed. This is supported by a high correlation between S5, the second part of the longest uphill, and performance, while S4, the first part, was less important. In the last kilometre of the race, the first part was more important for performance than the last part as shown by higher correlations. That may be because at that point, skiers fatigued and were not able to change the ranking anymore. Group 1 was the fastest in the final sprint, followed by Group 3, Group 2, and then Group 4. This may indicate that Group 2 was more fatigued due to skiing at higher intensity before when they tried to keep up with the lead. It is also possible, that within Group 3, skiers were next to each other and sprinted for final positions over the last final sprint, whereas skiers in Group 2 did not. Among the top ranked skiers, speed in the final sprint had no significant correlation with rank or performance. This is likely because the distances between most of the skiers were too large for skiers to change position in the final sprint. Within the top 10 ranked skiers, several pairs of skiers raced for final position. Hence, performance in the final sprint was decisive for ranking within a group of skiers skiing close together. It can be concluded that performance difference are mainly decided by uphill performance and the ability to maintain speed in uphill terrain, while performance within individual groups of skiers are decided in the final sprint.

3.3 Tactical choices

The overall faster speed in better performing skiers and how they are able to maintain it has been explained by physical parameters. However, the observed more even speed profile in contrast to overall slower skiers is related to strategy of the skiers. In a group of skiers, the ones in front can choose the speed, and the following skiers can either overtake, keep up, or let go of the group.

Studies on time trials have suggested that weaker skiers could benefit from a slower start with lower personal intensity, and a more even speed profile afterwards

(Losnegard et al., 2016; Stöggl et al., 2020). Losnegard et al. (2022) found that skiers who choose a faster start than their counterparts can improve performance if pacing more evenly. In a mass-start, it is more difficult to implement this strategy. Based on the questionnaire, skiers in all groups had the tactic to start as hard as the lead and keep up as long as possible. After the race, all groups felt that they had been able to follow that strategy. Skiers in Groups 3 and 4 named achieving good positioning, reducing the risk of accidents as well as the accordion effect as reasons for an offensive start. They also reported that later during the race, it was more difficult for them to advance in the field. The same reasoning has been found in mountain bike races (Abbiss et al., 2013; Impellizzeri & Marcora, 2007). It can be assumed that due to higher physical capacity, skiers in Group 1 were able to follow the leading skier at a lower relative intensity than Groups 2, 3 and 4, who likely skied at a less ideal personal speed.

One advantage of skiing close to skiers in front is to benefit from skiing in a drafting position. Skiers stated that thereby, they had less air resistance (drag) and could therefore save energy. It was calculated that in the steepest segment (S5), a skier saves around 0.3% propulsive power in a drafting position compared to the skier in front, while in S4, which is less steep, they can save ~1.2% propulsive power and in S2, which is even less steep, they can save ~1.5%. The reason for this is that the effect is higher at higher speed. This is in line with previous findings on the effect of drafting on heart rate, which is dependent on power output. They showed a significant difference in heart rate in leading and drafting position while double poling (Ainegren et al., 2022) and skating (Bilodeau et al., 1994).

However, while all groups of skiers agreed about the possibility to save energy, negative effects of skiing in a pack were experienced. Skiers in Group 3 stated that the benefit of drafting was mainly reserved for the skiers in front of the field, or in a stretched field. In Groups 2, 3 and 4, skiers struggled with uneven speed related to skiing behind other skiers, as well as risk of accidents and breaking poles. Furthermore, when skiing close behind another skier, it is difficult to keep one's own cycle rhythm and one is forced to copy the cycle rhythm of the skier in front. Even though in all groups, skiers stated that they found it easier to ski and comfortable to copy someone else's pattern, skiers in Groups 2, 3 and 4 did also report difficulties doing so if the pattern deviated from their own preferred cycle pattern. Skiers who are flexible and have the ability to adapt to

someone else's cycle rhythm likely have a benefit in mass-starts. Additionally, skiers across groups reported difficulties to overtake in the narrow track sections and the accordion effect as a challenge that resulted from skiing in a large group, especially further back in the field.

After the race, skiers in Group 1 felt that they were able to implement their previously planned strategies to a higher extent than skiers in Group 4 did (**Figure 10**), and agreement correlated highly with ranking. It can be assumed that they have more race-experience and therefore had more realistic strategies. Overall slower skiers reported more about challenges such as the accordion effect, difficulties to overtake due to narrow track sections, accidents, and challenging snow conditions. It is possible, as some skiers stated, that these aspects are more pronounced further back in the field. Furthermore, better performing skiers may be able to handle obstacles and unforeseen challenges better in the given moment.

3.4 Strengths and Limitations

This study is the first to analyse speed profiles and tactics in a real-life mass-start event. This study design has the advantage that is in real conditions on snow, and most importantly, with all skiers starting at the same time which makes factors such as tactics and drafting possible, but also creates challenges that would not arise in the lab or in individual time trials such as the need to copy another skiers' cycle pattern and the accordion effect. Additional to objective measurements, subjective information about personal tactics of the skiers before and during the race as well as experiences during the race was collected. One disadvantage compared to a study performed in the lab is that it was not possible to measure physiological values, which could have added information about the internal load, without disturbing the skiers too much from the race.

Unfortunately, the first lap was different than all following five laps, which made it difficult to compare it to the rest. However, since skiers were much faster in the first lap, it would have been interesting to be able to do so. Furthermore, only male participants were included. It would be interesting to see if the findings can be directly transferred to female athletes, or if there are differences.

3.5 Conclusion

The present study showed that in a mass-start cross-country skiing competition on national level, an overall positive speed profile can be observed. However, better performing skiers showed a more even pacing pattern over the race, with lower fluctuation in speed between laps. The largest differences in performance were found in uphill terrain, that also showed a close to perfect association with overall performance, and therefore was the terrain most decisive for overall performance. This is likely because uphill performance is most related to physical and technical abilities and therefore differentiates groups of skiers within the top 40. However, within groups of skiers skiing together, sprint abilities in the final part of the race, especially the final sprint, are important for the final outcome. In general, all the examined skiers started at a relatively similar pace and seemed to keep up as long as possible. However, over the race skiers were split into packs and performance difference between these gradually increased. Skiers experienced being in this position close to other as skiers as easier and less stressful if the field is not too tight, which might have been due to saving of energy by drafting, especially in easier terrain at higher speed. Additionally, in a tight field with many skiers, the accordion effect arises which forces skiers to slow down. There were no differences between groups regarding tactics for the race, but higher ranked skiers felt more able to implement their strategies, likely due to better planning beforehand.

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Appendix A: Questionnaire in original language (Norwegian) and English translation

Spørsmål om strategiene før konkurransen

(Questions about strategies before the competition)

Hvor godt stemmer følgende utsagn med strategien din for dagen konkurranse på en skala fra 1 til 10:

(How well do you agree with the following statements about your strategies for today's competition on a scale of 1 to 10:)

Jeg hadde bestemt meg for å gå i et tempo som er optimalt for meg personlig.

(I had decided to ski at a speed that is optimal for me personally.)

Jeg hadde bestemt meg for å åpne like hardt som teten, og prøve å henge på så lenge som mulig.

(I had decided to open as hard as the lead, and try to keep up as long as possible.)

Jeg hadde bestemt meg for å åpne i et tempo jeg visste jeg kunne holde hele veien til mål uten å sprekke.

(I had decided to open at a speed I knew I could sustain all the way to the finish line without hitting the wall.)

Jeg hadde bestemt meg for å åpne i et tempo jeg visste var litt for hardt, men valgte allikevel dette for å få hjelp av utøverne rundt meg.

(I had decided to open at a speed I knew was a bit too fast, but chose it anyways to get help of the athletes around me.)

Jeg hadde bestemt meg for å holde igjen farten i de bratteste oppoverbakkene selv om dette innebar å falle bakover i feltet, for så å prøve å avansere i feltet i lettpartier.

(I had decided to keep lower speed in the steepest uphill even if it meant that I fall behind in the field, and to then try to advance in easier sections.)

Jeg hadde bestemt meg for å kun ligge bak andre utøvere for å spare krefter, og ikke dra en meter selv.

(I had decided to only stay behind other athletes to save energy and not stay in front at all.)

Hadde du noen andre strategiene du hadde bestemt deg for før konkurransen? – Eventuelt tempo i start, mål, eller andre seksjoner, når å forbikjøre eller ligge bak andre skiløpere, team strategiene...

(Did you have any other strategies you had decided on before the competition? – Maybe speed in the start, finish, or other sections, when to overtake or stay behind other skiers, team strategies...)

Spørsmål om konkurransedagen

(Questions about the competition day)

Hvordan var dagsformen din på konkurransedagen på en skala fra 1 (veldig dårlig form) til 10 (veldig god form)?

(How was your daily form on competition day on a scale of 1 (very bad form) to 10 (very good form)?)

I hvilken grad klarte du å gjennomføre konkurransen i henhold til strategiene du hadde planlagt før konkurransen? - Ranger fra 1 (ikke i det hele tatt) til 10 (i svært store grad).

(To what extent were you able to complete the competition according to the strategies you had planned beforehand?)

Hvilke avvik hadde du eventuelt, og hvorfor ble de ikke som planlagt?

(What deviations did you have possibly, and why did it not go as planned?)

Hvor godt stemmer følgende utsagn med strategien din under konkurransen på en skala fra 1 til 10:

(How well do you agree with the following statements about your strategies during today's competition on a scale of 1 to 10:)

Jeg gikk i et tempo som var optimalt for meg personlig.

(I did ski at a speed that was optimal for me personally.)

Jeg åpnet like hardt som teten, og prøvde å henge på så lenge som mulig.

(I did open as hard as the lead, and tried to keep up as long as possible.)

Jeg åpnet i et tempo jeg visste jeg kunne holde hele veien til mål uten å sprekke.

(I did open with a speed I knew I could sustain all the way to the finish line without hitting the wall.)

Jeg åpnet i et tempo jeg visste var litt for hardt, men valgte allikevel dette for å få hjelp av utøverne rundt meg.

(I did open with a speed I knew was a little too fast, but chose it anyways to get help from other athletes around me.)

Jeg holdt igjen farten i de bratteste oppoverbakkene selv om dette inne bar å falle bakover i feltet, for så å prøve å avansere i feltet i lettpartier.

(I did keep lower speed in the steepest uphill even if it meant that I fell behind in the field, and then tried to advance in easier sections.)

Jeg lå bak andre utøvere for å spare krefter, og dro ikke en meter selv.

(I did stay behind other athletes to save energy and did not stay in front at all.)

Hvilke fordeler og/ eller ulemper opplevde du ved å ligge i rygg på andre skiløpere under konkurransen?

(Which advantages and/ or disadvantages did you experience when skiing close behind another skier during the competition?)

I hvilken grad kopierte du bevegelsesrytmen til skiløperen foran deg når du gikk bak andre skiløpere?

Ranger fra 1 (ikke i det hele tatt) til 10 (i svært store grad).

(To what degree did you copy the movement pattern of the skier in front when you skied behind other skiers?)

Hvis du koperte bevegelsesrytmen til utoveren som gikk foran, hvilke fordeler og/ eller ulemper opplevde du?

(If you copied the movement pattern of the skier in front, which advantages and/ or disadvantages did you experience?)

Hadde du noen uhell under konkurransen, evt hvilke type uhell når skjedde det?

(Did you have any accidents during the competition, which type of accident and how did it happen?)

Hvordan var gliden på skiene under konkurransen, sammenlignet med de rundt deg? - Ranger fra 1 (svært dårlig) til 10 (svært god).

(How was the glide of your skis during the competition compared with those around you? - Answer from 1 (very bad) to 10 (very good).

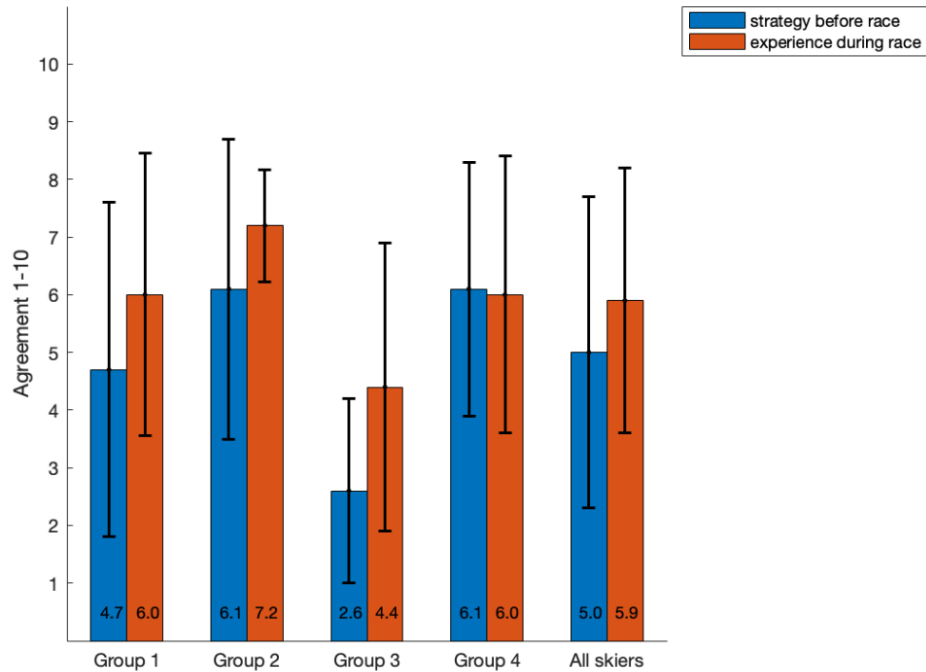
Hvor fornøyd er du med din prestasjon i dag på en skala fra 1 (veldig dårlig prestasjon) til 10 (veldig god prestasjon)?

(How satisfied were you with your performance today on a scale of 1 (very poor performance) to 10 (very good performance)?)

Har du noen andre kommentater om dine opplevelser i konkurransen i dag?

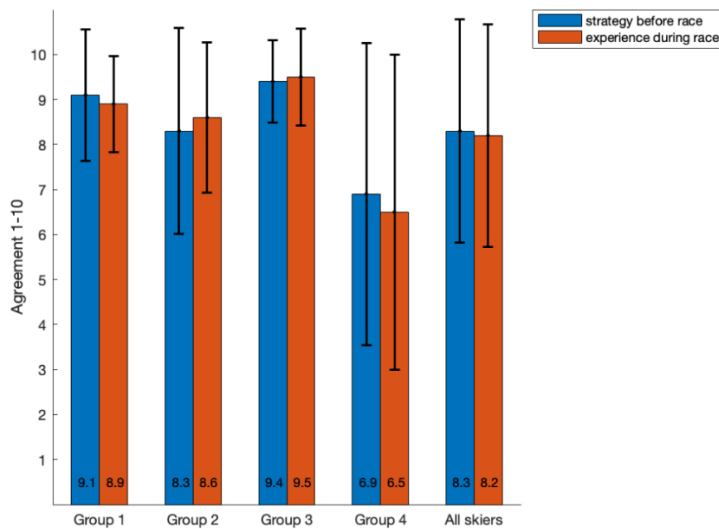
(Do you have any other comments about your experiences during the competition today?)

Appendix B: Agreement in groups based on ranks with statements in the questionnaire



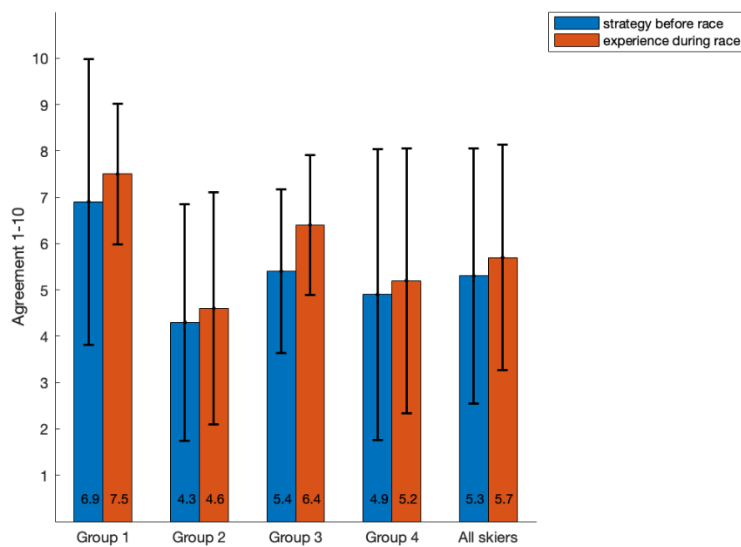
Agreement on a scale of 1-10 (1: do not agree at all, 10: completely agree) in the four groups based on rank with the statement “I had decided to ski at a speed that is optimal for me personally/ I did ski at a speed that was optimal for me personally“

Group 1: final rank 1-10; Group 2: final rank 11-20; Group 3: final rank 21-30; Group 4: final rank 31-40



Agreement on a scale of 1-10 (1: do not agree at all, 10: completely agree) in the four groups based on rank with the statement “I had decided to open as hard as the lead, and to try to keep up as long as possible/ I did open as hard as the lead, and tried to keep up as long as possible“

Group 1: final rank 1-10; Group 2: final rank 11-20; Group 3: final rank 21-30; Group 4: final rank 31-40



Agreement on a scale of 1-10 (1: do not agree at all, 10: completely agree) in the four groups based on rank with the statement “I had decided to keep lower speed in the steepest uphill, even if it meant that I fall behind in the field, and to then try to advance in easier sections / I kept lower speed in the steepest uphill, even if it meant that I fall behind in the field, and to then try to advance in easier sections”

Group 1: final rank 1-10; Group 2: final rank 11-20; Group 3: final rank 21-30; Group 4: final rank 31-40

