Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

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Analysis of race-preparation strategies, performance-development, and physiological responses during an entire sprint competition in cross-country skiing

Master's thesis in Physical Activity and Health
Supervisor: Øyvind Sandbakk
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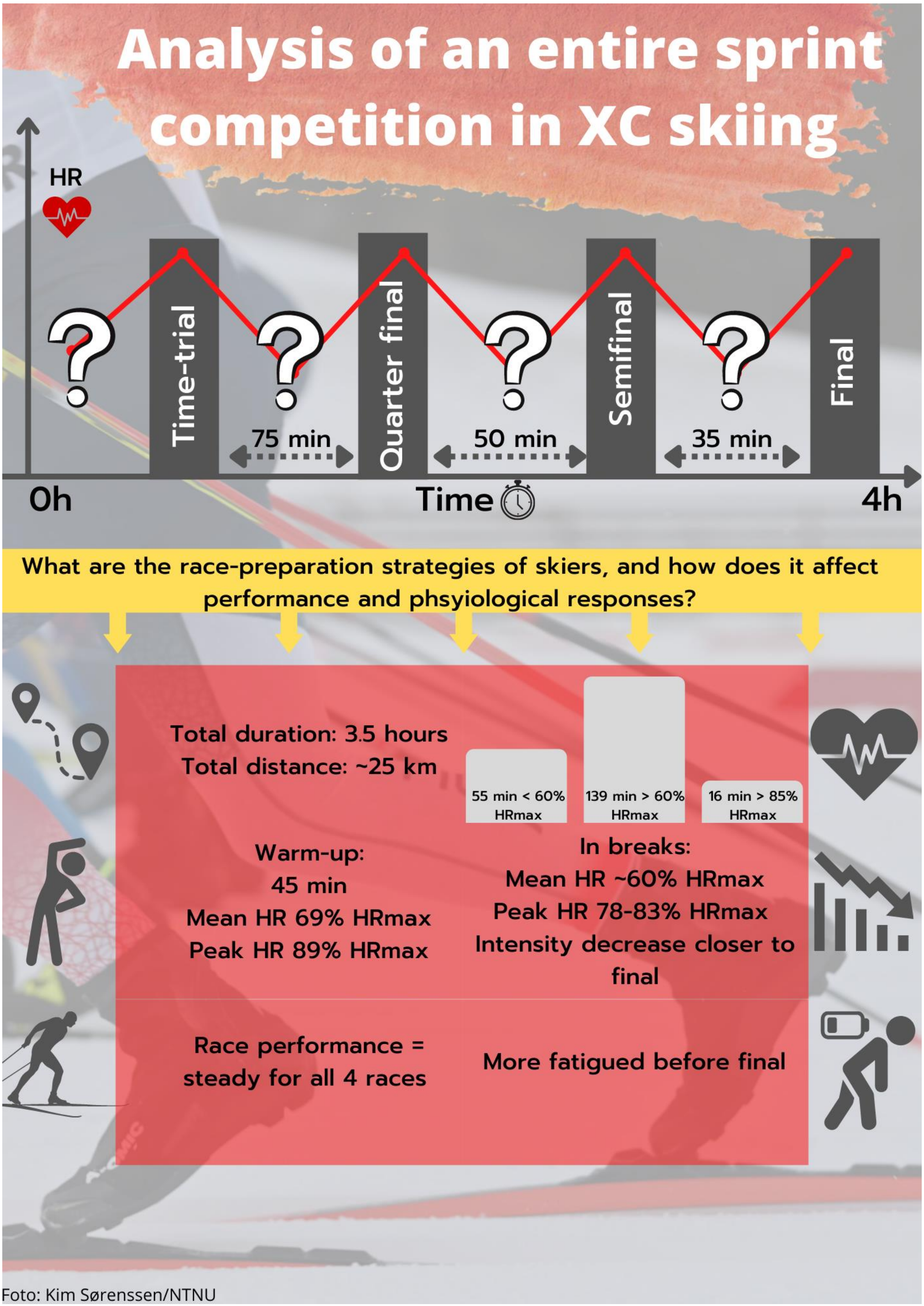
Infographic



Abstract

Purpose: To describe race-preparation strategies, performance-development and physiological responses during an entire cross-country (XC) skiing sprint competition, and to compare skiers of different performance levels.

Methods: 20 male junior XC skiers participated in a simulated sprint competition in XC skiing, consisting of an individual time-trial (TT), quarter final (QF), semifinal (SF) and final (F). The competition followed procedures employed in real-world competitions. During warm-up and recovery, skiers could use their own preferred strategies of activity, recovery and nutrition. Heart rate (HR), speed and distance were measured from warm-up until end of the competition using HR monitor and global navigation satellite system (GNSS) units. Blood lactate concentration (BLa) as well as subjective feeling of readiness (RED) and exertion (RPE) were measured before and after each race.

Results: On average, 139 of the total 210 minutes were spent at above 60% of maximum HR (HR_{max}), 16 minutes above 85% of HR_{max}, and skiers covered an average distance of ~25 km. Race time was relatively stable across heats, with race time in the SF being faster than all other heats (all $P < 0.05$). Peak (HR_{peak}) and mean (HR_{mean}) HR during TT was 92.2 and 89.2, respectively, but decreased gradually to 90.2 and 86.9% of HR_{max} in F, respectively. BLa before and after F was higher than for other heats (all $P < 0.05$), except after TT ($P = 0.09$). HR_{mean}, HR_{peak} and peak 1-minute average (HR_{1min}) HR during warm-up was 69.3, 89.4 and 86.6% of HR_{max}, respectively. The intensity in breaks decreased when approaching the F, with HR_{mean} HR_{peak} and HR_{1min} being reduced from 58.7 to 59.3, 83.4 to 78.1 and 81.1 to 76.1% of HR_{max}, respectively, in the break after TT compared to before F. No significant differences were found in race-preparation strategies in terms of intensity between high and low performers, although the fastest skiers were less affected by fatigue before the F.

Conclusion: The present data illustrated current race-preparation strategies, performance-development and the physiological responses during an entire sprint XC competition. The sprint event is long-lasting (3.5 hours), includes > 25 km of movement and is physiological demanding with skiers having long periods of elevated HR and repeated all-out efforts leading to close-to-maximum HR and BLa values. While better skiers seem to maintain performance better than less performing skiers, no difference in race-preparation strategies between groups were found.

Sammendrag

Formål: Beskrive rennforberedelser, utvikling av prestasjon og fysiologiske responser under en hel sprintkonkurranse i langrenn.

Metode: 20 mannlige junior langrennsutøvere deltok i en simulert langrennssprint, bestående av prolog (P), kvartfinale (KF), semifinale (SF) og finale (F). Konkurransen fulgte rennprosedyrer basert på ekte konkurranser. Under oppvarming og pauser mellom løp valgte utøverne sine egne foretrukne strategier med tanke på aktivitet, restitusjon og næringsinntak. Hjerterate (HR), hastighet og distanse ble mål fra start av oppvarming til målgang F ved bruk av HR-måler og global navigasjon satellittsystem. Blodlaktatkonsentrasjon (BLa) og subjektive mål av om hvor klar man var til start og utmattelse ble målt før og etter hvert løp.

Resultat: I gjennomsnitt ble 139 av total 210 minutter tilbrakt på en intensitet over 60% av maksimal HR (HR_{maks}), 16 minutter over 85% av HR_{max}, og en tilbakelagt distanse på 25 km. Løpstider var relativt stabil, med løpstid i SF som raskest ($P < 0.05$ for alle løp). Peak (HR_{peak}) og gjennomsnittlig (HR_{snitt}) HR under P var 92,2 og 89,2% av HR_{maks}, respektivt, og ble redusert 90,2 og 86,9% av HR_{maks}, respektivt, i F. BLa før og etter F var høyere enn andre løp ($P < 0.05$ for alle), unntatt etter P ($P = 0.09$). HR_{snitt}, HR_{peak} og høyeste 1-minutt gjennomsnittlig HR (HR_{1min}) under oppvarming var 69,3, 89,4 og 86,6% av HR_{maks}, respektivt. Intensiteten i pauser gikk ned jo nærmere man kom F, med HR_{snitt}, HR_{peak} og HR_{1min} redusert fra 58,7 til 59,3, 83,4 til 78,1 og 81,1 til 76,1% av HR_{maks}, respektivt, i pausen etter P sammenlignet med før F. Ingen signifikante forskjeller ble funnet i rennforberedelser i form av intensitet mellom de raskeste sammenlignet mot tregere utøvere, men de raskeste var mindre utmattet før F.

Konklusjon: Denne studien viser utøveres rennforberedelser, utvikling av prestasjon og fysiologiske responser under en hel langrennssprint. En sprint varer i 3,5 time, man beveger seg 25 km og er fysisk krevende i form av lange perioder med forhøyet HR og flere maksanstrengelser som fører til svært høye HR og BLa verdier. De beste utøverne klarer å opprettholde prestasjon bedre enn dårligere utøvere, men ingen forskjell ble funnet i strategier for rennforberedelser.

Acknowledgements

I would like to thank my supervisors Øyvind Sandbakk and Jan Kocbach for excellent guidance through my master project, and for always being helpful and available for supervision. A special thanks also to PhD. candidates Rune Kjøsen Talsnes and Trine Seeberg for superb guidance during planning and data collection for this project. Thank you also to my fellow master students Jan-Magnus Brattebø and Hanna Leona Wolf for co-working during our projects.

I would also like to thank the athletes that participated in my study. By your commitment for giving your best during the competition, as well as following the protocol for testing gave great insight to how a XC ski sprint competition is conducted by athletes. I hope that the sprint competition was a great event for the athletes as well, and that they made some experiences they could take benefit from later in the season.

At last, I would like to thank all employees at Senter for Toppidrettsforskning and Olympiatoppen Midt-Norge for advising me and taking time to answer all my questions. I have really enjoyed the past year and could not have chosen a better place to write my thesis!

Thank you,

Tore Berdal

Abbreviations

XC = cross-country

TT = time-trial

QF = quarter final

SF = semifinal

F = final

FIS = International Ski Federation

VO_{2max} = maximal oxygen uptake

VO_{2peak} = peak oxygen uptake

V_{max} = maximal velocity

HR = heart rate

HR_{max} = maximum heart rate

HR_{mean} = mean heart rate

HR_{peak} = peak heart rate

HR_{1min} = highest average heart rate over 1 minute

BLa = blood lactate concentration

GNSS = global navigation satellite system

RED = rate of perceived readiness

RPE = rate of perceived exertion

HI = high performance group

LOW = low performance group

Introduction

Cross-country (XC) skiing is a winter endurance sport where the World Cup athletes compete in distances from sprint (~1.5 km) to 30 and 50 km for women and men, respectively. In modern XC skiing, sprint XC skiing is a vital part of the competition program, and in the 2021/2022 season 13 out of 37 scheduled competitions in World Cup and Olympics were individual sprints (1). A sprint in XC skiing consists of a 2-4 min time-trial (TT), where the 30 fastest skiers qualify for the finals. The finals include three rounds of head-to-head knock out heats: quarter finals (QF), semifinals (SF), and final (F). In each head-to-head heat there are 6 skiers, where the two fastest from each heat, plus the two fastest runners-up across heats, qualify for the next round. This leads to 12 skiers in the SF and 6 in the F (see Fig. 1 for overview of the race format in XC skiing sprint competitions). There is a break of 1.5 to 2.5 hours between TT and QF and breaks between 20 and 50 minutes between each round of knock out heats. In total, a competition day in sprint XC skiing sprint may last for three to four hours, including four races of two to four minutes with warm-up and breaks preceding each race.

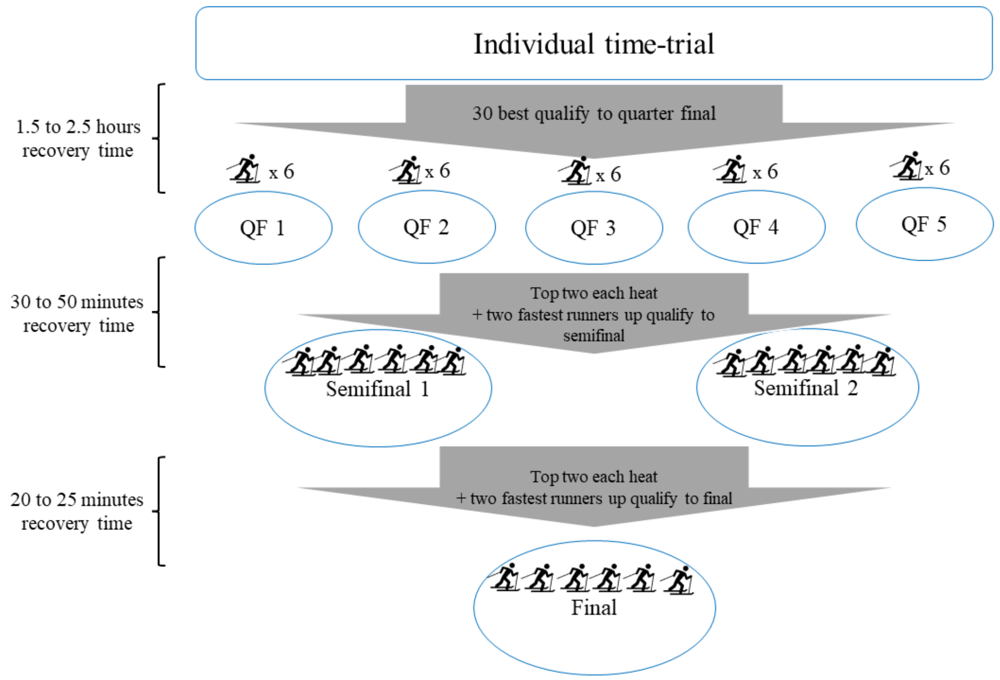


Fig. 1. Overview of the race format of a XC skiing sprint in FIS-competitions. QF = quarter final.

Most research on XC skiing has so far focused on the TT. Previous research has shown that the varying terrain in XC skiing leads to large fluctuations in work rate, with work rates as high as 160% of maximal oxygen uptake (VO_{2max}) in short steep uphills (2-4). However, this is compensated by reduced work rates in flat and downhill terrains. Whereas this also leads to large fluctuations in energy supply, most of the energy come from aerobic pathways during a TT, with an average of ~75-80% (5, 6). Additionally, the anaerobic contribution plays a vital role in the TT, with ~20-25% of the energy supply coming from anaerobic pathways (5, 6).

In simulated sprint including repeated heats, the mean intensity of each heat is above 90% of VO_{2max}, with heart rate (HR) approaching close to maximum, highlighting the maintenance of large aerobic turnover (7). Additionally, blood lactate concentration (BLa) repeatedly reaches above 12 mmol/L, indicating high supplementation of anaerobic contribution (7, 8). Despite the high demands of work rate in XC skiing sprint, athletes are still able to maintain relatively similar race times over repeated heats (7-9). Velocity in the finish-sprint, on the other hand, may decrease during heats due to peripheral fatigue when resting periods are as short as 12 min (9). To what extent these findings apply when conducting a XC ski sprint competition on snow, more similar to real-world competition, should be looked into.

Due to the aerobic contribution during sprint competitions, including the ability to recover between heats, elite performance in XC sprint skiing demands high VO_{2max} values (10). Also, sprint performance correlate well with aerobic characteristics, such as VO_{2max} and oxygen uptake at ventilatory threshold (11, 12) and world class sprinters in XC skiing have higher VO_{2max} compared to national class sprinters (13). However, if athletes have similar VO_{2max}, anaerobic components and sprint abilities could play a bigger role in sprint performance (6). For example, previous research has also shown that TT performance to correlate well with high maximal velocity (V_{max}) (12, 14). In sprint XC skiing, better athletes also reach higher peak values of BLa than slower athletes (7), and may have faster lactate recovery after a TT, which could be an important factor in a XC ski sprint (13). However, it is not known if the best skiers use different strategies during a sprint competition for enhancing their performance.

Two main strategies to improve sprint performance are appropriate warm-up and recovery strategies in relation to the competition, which due to the repeated heats with inconsistent recovery time between are more or less interrelated. Currently, the procedures employed by sprint skiers have not yet been described. The warm-up prior to a XC ski competitions normally consists of a long-traditional warm-up, with increasing intensity (15). Recent research looked into the warm-up strategies of XC skiers before sprint races, which support the use of a long-traditional warm-up before both race types (16). However, no difference in TT performance was found between traditional warm-up when compared to short-specific warm-up, consisting of 8x100 m with increasing intensity up to V_{max} (17). Research done on repeated heats in sprint XC skiing did not always include the long irregular breaks that occurs during a competition. The breaks between heats should be at least 20 minutes to maintain performance (18). How to optimize the recovery time between two maximal efforts have been investigated in XC skiing, cycling and running (19-21), where they investigated the effect of active versus passive recovery. Active recovery at intensity close to lactate threshold is superior in terms of lactate removal. However, there was little difference in performance of two subsequent TT's after active versus passive recovery in XC skiing and cycling (19, 20). Additionally, to optimize performance in a competition, a precondition exercise can be used by athletes. Research have looked into if exercise in the morning can affect performance later in the day, however this has not shown any benefits for endurance sports (22, 23). What race-preparations used by sprint skiers have only been briefly described in warm-up, and how different strategies can be applied before each race in a full competition in XC skiing, is unknown. Additionally, it is not known if these strategies vary between the best athletes and their inferior counterparts.

To my knowledge there are no previous studies investigating the race-preparations strategies used by athletes during a full sprint competition in XC skiing. Therefore, the primary aim of this study is do describe race-preparation strategies, performance-development and physiological responses during an entire competition day in XC sprint skiing, including possible impact of warm-up and recovery strategies. The secondary aim is to compare these factors between skiers of different performance levels.

Methods

Participants

Twenty national-level male junior XC athletes recruited from a regional high school participated in the study. The performance level of the group was relatively heterogenous, including two participants who competed in the junior World Championships later in the season, and VO_{2max} ranging from 58.4 mL·min^{-1} ·kg^{-1} to 76.8 mL·min^{-1} ·kg^{-1}. The mean characteristics of the group were: age 18.3 ± 0.7 years, height 181.5 ± 5.2 cm, body mass 75.3 ± 7.9 kg, VO_{2max} 67.6 ± 5.7 mL·min^{-1} ·kg^{-1}, maximal HR (HR_{max}) 202.3 ± 8.3 beats·min^{-1}. All participants were informed about the protocol and aim of the study before the race and signed a written consent the same morning or at a previous laboratory test. The study was pre-approved by the Norwegian Centre for Research Data.

Design and procedures

Overall design of the study

The study consisted of a simulated on-snow sprint competition in the freestyle technique, in mid-December 2021. An International Ski Federation (FIS) regulated racecourse, with a length of 1311 m was used (see Fig. 2 for track profile). The race format was designed to simulate a real-world XC skiing competition, including four races: TT, QF, SF and F, and appropriate recovery time between. Speed, position, HR and BLa were measured during the full competition, and subjective measurements were collected. A full competition is in the current study defined as start of warm-up to finish of the F. A laboratory test was conducted ± 3 weeks to the sprint competition to collect information about characteristics of the participants, including VO_{2max}, HR_{max}, height and body mass.

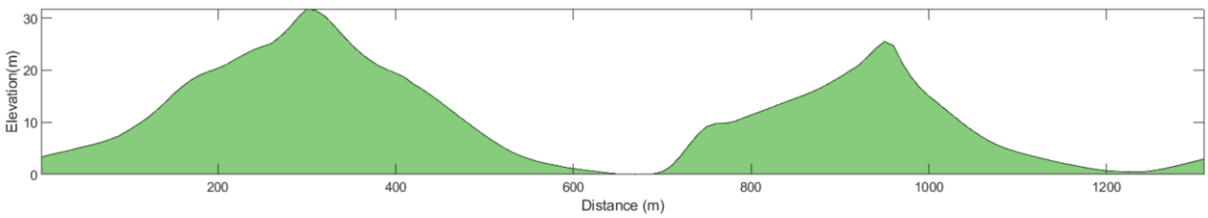


Fig. 2. Track profile of the 1311 m racecourse.

Laboratory testing

VO_{2max} data was collected in a maximal incremental test to exhaustion on roller skis in the laboratory on a 3-by-5m treadmill (Forcelink S-mill, Motekforce Link, Amsterdam, The Netherlands). Respiratory variables were continuously measured through open-circuit indirect calorimetry (Oxycon Pro, Erich Jaeger GmbH, Hoechberg, Germany). The rolling coefficient was measured to 0.018 µ before and after data collection, with the method described in Sandbakk, Holmberg (24). Roller skis were standardized for all participants (IDT Sports, Lena, Norway), while participants used their own boots and poles with mounted carbide tips. Warm-up to the maximal incremental test consisted of low-intensity skiing followed by a submaximal lactate profile test. During the maximal incremental test, the incline of the treadmill was locked at 7%, with starting speed at 12 $km \cdot h^{-1}$, increasing with 1 $km \cdot h^{-1}$ every min. The test ended when the participants could not keep up with the speed of the treadmill, or at the participants own wish to stop the test. VO_{2max} was defined as highest one minute average of VO_2 uptake. HR was measured during the test by the athletes wearing their own sports watch and HR sensor. HR_{max} was defined by taking peak HR (HR_{peak}) from the laboratory test, plus 5 $beats \cdot min^{-1}$, following Ingjer (25). Three athletes did not participate in the laboratory test. Data from previous testing in the same laboratory is included for these athletes. HR_{max} for these three athletes was later defined as HR_{peak} from race day, plus 13 $beats \cdot min^{-1}$, as 13 $beats \cdot min^{-1}$ was the mean difference between HR_{max} and HR_{peak} from the race day.

Race day data collection

The simulated sprint consisted of a TT followed by three heats simulating QF, SF and F. During warm-up and breaks between TT and QF (break 1), QF and SF (break 2), and SF and F (break 3), the athletes followed their self-selected procedures for warm-up, recovery and nutritional intake. They were instructed to do what they thought would be best for their performance. The racecourse was machine groomed in the morning before race start, and snow condition was stable with fast and dry snow throughout the whole competition. The snow in the track was a combination of artificial and natural snow. The weather was stable with cloudy skies. Weather characteristics were measured at three different times; before TT, before QF and after F. The mean snow temperature was -2.8 degrees Celsius, ranging from -1.7 to -3.7 degrees Celsius, mean air temperature -2.1 degrees Celsius, ranging from -1.6 to -2.4 degrees Celsius, and air humidity 78%, ranging from 77 to 79%. See Fig. 3 for weather and snow conditions.

Fig. 3. Start of quarterfinal heat A, showing weather and snow conditions that were stable through the whole day.

The athletes met at the stadium at 8:00 in the morning for information and receiving starting bibs. The TT started at 09:15 and the athletes started the warm-up when they wanted to. Time between each individual start was 1 min. The start list was ranked after expected performance level based on results from last season in combination with the laboratory testing conducted in advance of the simulated competition. Based on results from the TT, the athletes were divided into three separate QF's. The six best athletes were placed in heat A, the seven next in heat B and the seven last in heat C. In contrast to a real sprint competition in XC skiing, this simulated competition did not include the knock-out system used in FIS regulated competitions. Instead, a promotion-relegation system was developed to secure that a high number of athletes completed the whole competition. This secured that the competition element was kept, and that the athletes were motivated to perform their best. The two best athletes in each heat advanced to a higher-ranked heat for the next round of finals, whereas the two last athletes in each heat were relegated to lower-ranked heat. See Fig. 4 for a visualization of the race format and starting time for each race. Race times in the TT was measured manually by using the Race Splitter app (Makalu Logistics Inc, Fontana, California, USA) to get results from the TT quickly. Finishing positions in finals were also taken manually, to control which athlete got promoted and relegated.

The breaks between TT, QF, SF and F were 75, 50 and 35 minutes, respectively, inspired by FIS rules (26, 27). The break between TT and QF was shortened from the usual 1.5 - 2.5 hours, to 75 min due to limited time availability for the athletes. The break between SF and F in this competition was longer than in real competitions for practical reasons during data collection, such as avoiding athletes waiting in line for reporting subjective data and BLa measurements. The break between each heat in every final were seven minutes, instead of the five minutes used in FIS competitions, again for practical reasons during measurements. Heat A started first in every round of finals, followed by heat B, then heat C.

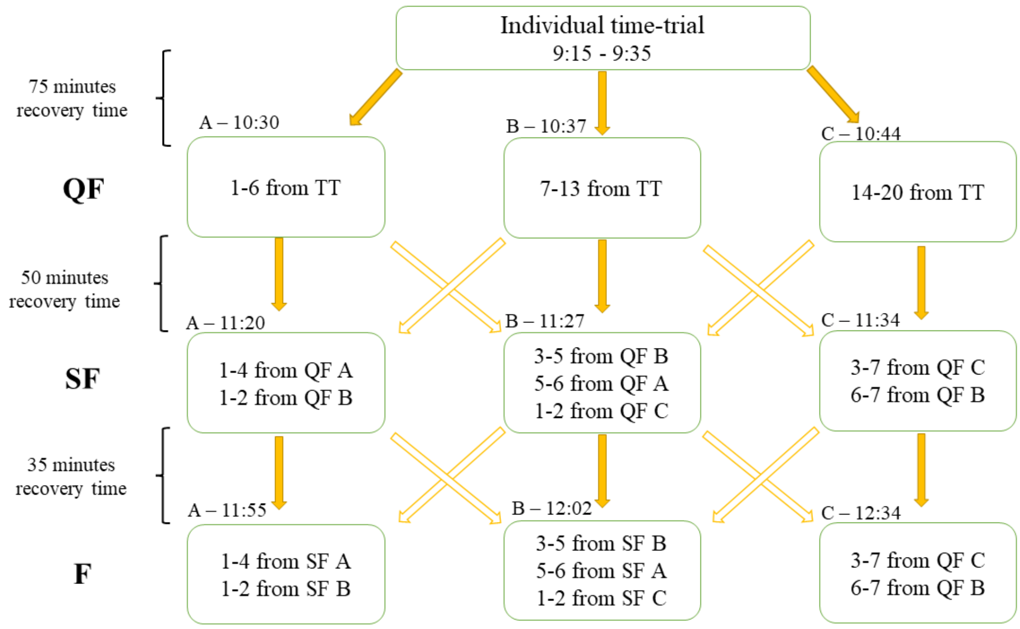


Fig 4. Overview of start times and race format in the simulated competition. TT = time-trial, QF = quarter final, SF = semifinal, F = final. A, B and C represent each heat in each round of finals.

During each race a Catapult Optimeye S5 (Catapult Innovations, Melbourne, Australia) sensor was carried in a small pocket in a customized bib under the starting bib to collect information about speed and position data (see Fig. 5 for attachment for Catapult sensor). This sensor contains an integrated Global Navigation Satellite System (GNSS) and IMU and has previously been validated for speed and positions measurements in XC skiing (28). The sensor has a sampling frequency of 10-Hz for GNSS data. 30 minutes before start of TT and QF, the sensors were taken outside and placed on the ground in an open area to ensure GNSS fix. The sensors were taken inside after the TT for charging. After QF the sensors were stored outside between heats. HR data was measured from the start of the warm-up until the end of the competition by using Garmin Forerunner 920XT/935 (Garmin Ltd., Olathe, United States) with a sampling rate of 1-Hz. The Garmin Forerunner also measured speed and distance from start of warm-up until end of competition by using a GNSS system with 1-Hz sampling rate, to collect data from warm-up and breaks. Approximately five minutes before each start, BLa were taken from the athlete's fingertip, using a Lactate Pro 2 device (Arkray Europe B.V, Amstelveen, the Netherlands). They were also asked about their rating of perceived readiness (RED) on a scale from 1-10, modified from Nurmekivi, Karu (29). Explanation of the RED scale was given to athletes before the start of the race. 1-3 minutes after each finish BLa was again taken, together with a rate of perceived exertion (RPE), using the Borg scale, rating from 6-20 (30). All athletes were familiar with the Borg scale. See Fig. 6 for visual overview of the data collection. To get more descriptive data from each athlete, a questionnaire was handed out in the morning before the race. This gave more information on what the athletes did before and during the race in terms of preparations, activity, recovery, and nutritional intake, and was a supplement to the quantitative data. See Appendix 1 for detailed information about questions. To get an overview of energy intake before and during competition, food and drinks were roughly calculated to calories and carbohydrate estimates. For drinks, the nutrient content on the sports drink served in athlete's area was the standard. For other food, the software Dietist Net (Kost og Ernæringsdata, Stockholm, Sweden) was used for estimation of calories and carbohydrates, a software used by Olympiatoppen in Norway.

Fig. 5. Sensor placed in a pocket of a customized bib before each race.

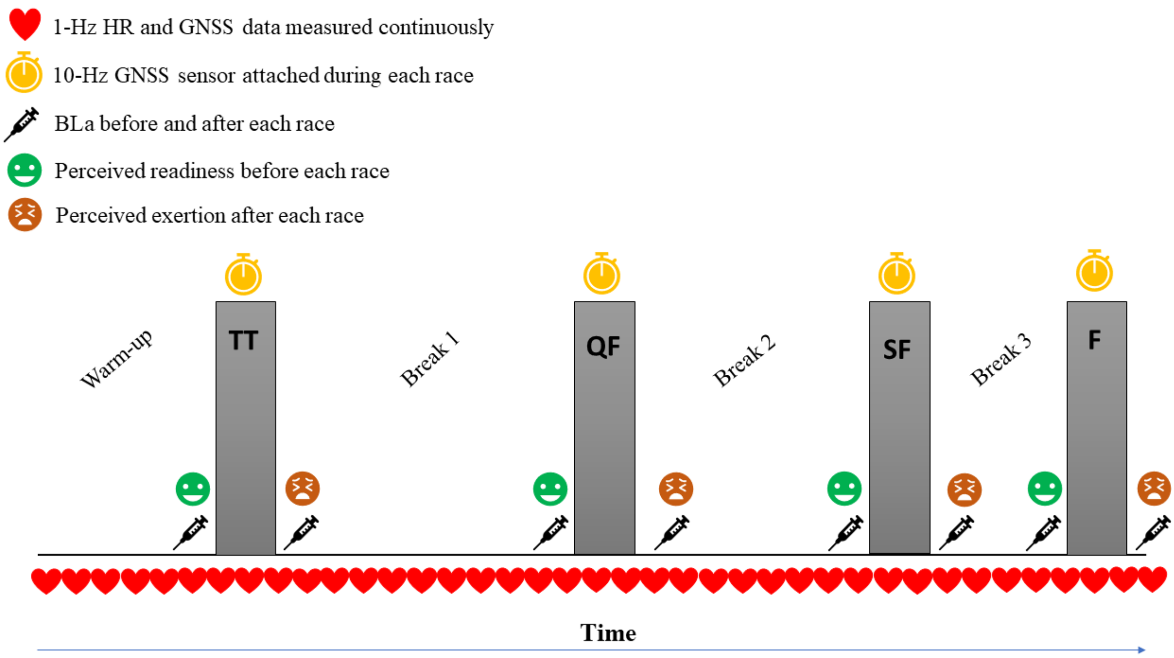


Fig. 6. Measurements taken at different time points during the competition. HR = heart rate, GNSS = global navigation satellite system, BLa = blood lactate concentration, TT = time-trial, QF = quarter final, SF = semifinal, F = final.

The participants were instructed to only do low-intensity training the last day prior to the simulated competition. They were also instructed to eat breakfast in the morning and bring extra clothes and nutrition, but no caffeinated nutrition should be taken during the competition. Like in real competitions, an athlete's area was set up indoors so the athletes could rest and stay warm between each race. To make sure all athletes had the opportunity to get the nutrition needed during the competition, ad libitum sports drink, energy bars and bananas were provided inside in the athletes' area. The athletes used their own racing equipment including skis, poles, and boots, and were encouraged to use the same skis they would use in a competition. Additionally, they were asked to glide their skis with CH6 glide wax (Swix, Lillehammer, Norway) or similar low-fluorine products to minimize the effect of glide differences.

Statistical analysis

All data was first visually inspected. Data was checked for normal distribution using Shapiro-Wilk test, together with visual inspection of histogram and Q-Q plots in SPSS. For data that was assumed normal distributed, a paired samples t-test was used to check for differences between each race, and differences between warm-up and each break. For data that was assumed non-normal distributed, a non-parametric test was used. P-values were very similar when using parametric vs non-parametric tests, and therefore the cases where data deviated from a normal distribution are not specified further. Differences were considered significant if P-value < 0.05. Data are presented as mean ± SD unless anything else is specified. Data was analyzed using MATLAB 9.10.0. (R2021a; MathWorks Inc., Natick, MA), IBM SPSS Statistics version 27 (SPSS Inc., Chicago, IL, United States) and Excel 2016 (Microsoft Corporation, Redmond, United States). Signal errors for GNSS and HR was fixed by interpolation in Excel. To divide athletes into sub-groups, final rank was taken into account. The six athletes that ended in final A were defined as high-performers (HI), and the six that ended in the C final were defined as low-performers (LOW). To check for statistical differences between sub-groups, one-way ANOVA test was used, with sub-groups as factor variable

Results

Race day characteristics

Total duration of the full competition, including warm-up, was 210 ± 6.2 min. Total distance covered was 25.2 ± 2.9 km. The athletes spent on average 139.1 ± 26.5 min above 60% of HR_{max} and 16.1 ± 4.3 min above 85% of HR_{max}. 13 of 20 athletes answered the questionnaire, where three were from the HI group, three from the LOW group, and six that didn't represent any if these. Results from the questionnaire are presented in Table 1.

Table 1. Answers from the 13 athletes that completed the questionnaire. Answers gives information about preparations prior to the competition and nutritional intake during competition.

Question	Answer
Hours of sleep (h)	7.6 ± 0.7
Sleeping quality (1-10)	7 ± 1.5
Morning exercise (yes/no)	Yes = 1, No = 12
Breakfast time (time)	$06{:}45_{AM} – 7{:}30_{AM}$
Energy intake breakfast (kcal·kg body mass $^{-1}$)	4.8 ± 2.5
Intake of carbohydrate during breakfast (g·kg body mass $^{-1}$)	0.6 ± 0.3
Energy intake during competition (kcal·kg body mass $^{-1}$)	6.1 ± 3.0
Intake of carbohydrate during competition (g·kg body mass $^{-1}$)	1.1 ± 0.5
Total fluid intake during competition (dl)	9.5 ± 3.9
Perceived day shape (1-10)	6.3 ± 1.2
Satisfaction with performance (1-10)	6.3 ± 2.0

Values are presented as mean ± SD, except for breakfast time (range), and morning exercise (yes/no). h = hours, kcal = kilo calories, g = gram, dl = deciliter

To visualize continuous HR from the full competition, HR curve for the winner is displayed as an example (Fig. 7). Mean values for the whole group can be seen in Table 3. The winner started the warm-up 56 minutes before he started his TT. According to his answers in the questionnaire, the warm-up included some short high-speed and high-intensity bouts of ~30 seconds. During the warm-up HR_{peak} was 90% of HR_{max} and the highest 1-min average HR (HR_{1min}) was 86% of HR_{max}. Mean HR (HR_{mean}) of the warm-up was 73% of HR_{max}. During the full competition the winner spent 7.4% of the time (16 mins) at an intensity above 85% of HR_{max}. During the longer break 1 and break 2, the winner's strategy was to have 5-10 minutes of low intensity, before some time with passive recovery, followed by active recovery of low to moderate intensity. In these breaks the winner did not exceed 81% of HR_{max}. In the shorter break 3, the winner was trying to keep himself active with jogging, to get rid of lactate, as he describes in the questionnaire.

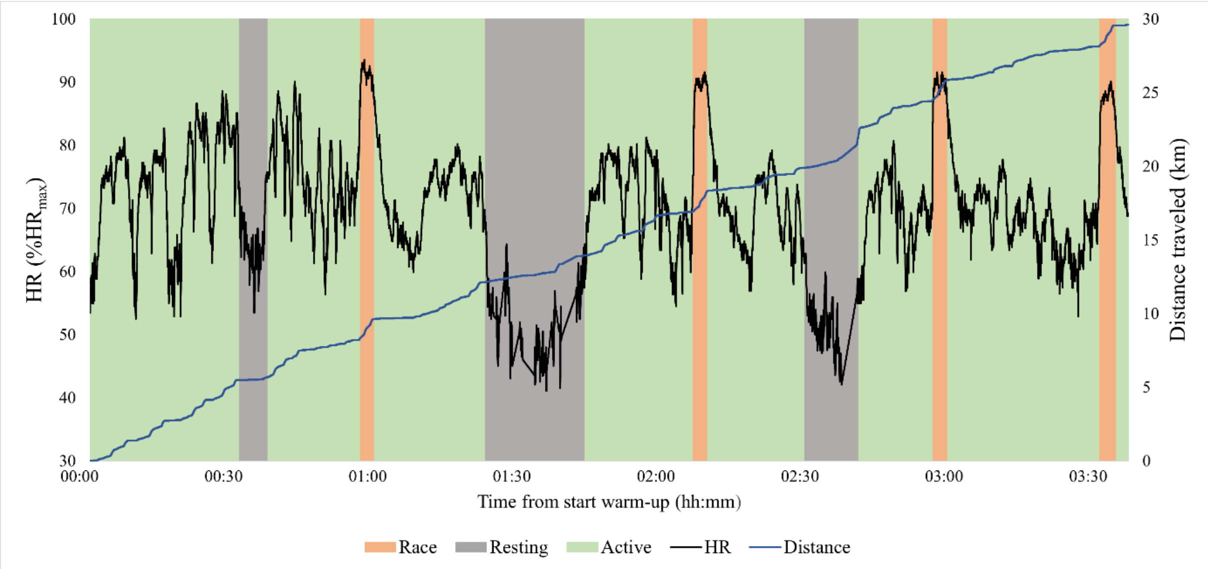


Fig: 7. Continuous heart rate (HR) and distance traveled for the winner of the competition. Colors visualizing if the athlete is racing, passive or active.

Performance-development and physiological responses

The fastest race time was in SF, which was faster than TT (P = 0.002), QF (P = 0.003), and F (P = 0.012). A small, yet significant difference was found between QF and F, with QF being faster (P = 0.026). The finish-sprint was slower in TT than QF (P = 0.025) and F (P = 0.002), but not than SF (P = 0.270). Finish-sprint time in the F tended towards being faster than SF (P = 0.070). Both HR_{peak} and HR_{mean} decreased from TT to F, as HR_{mean} in F was lower than TT and QF (both p = 0.001). HR_{peak} in F was lower than TT (P = 0.001), QF (P = 0.001) and SF (P = 0.005). HR_{peak} in SF was lower than TT (P = 0.019) and QF (P = 0.036). BLa after race decreased from TT to SF, and reached its peak after F. BLa was higher before F than before TT (P = 0.022), QF (P = 0.023) and SF (P = 0.001). RED was lower before F than before TT (P = 0.006), QF (P = 0.007) and SF (P = 0.44). RPE was highest in TT and was statistically different from QF (P < 0.001), SF (P = 0.003) and F (P = 0.013). RPE was lowest in QF and differed from SF (P = 0.003) and F (P = 0.015). Results are presented in Table 2.

Race-preparation strategies

Intensity in warm-up was significantly higher than in the breaks, with HR_{mean}, HR_{peak} and HR_{1min} being higher in warm-up (all p-values < 0.001). In the warm-up the athletes reached a HR_{peak} of 89.4 ± 3.0%, HR_{1min} 86.6% ± 3.7% and HR_{mean} 69.3 ± 3.3% of HR_{max}. Break 1 and 2 only differed in HR_{mean} (P = 0.001) and distance (P < 0.001). Break 3 had lower intensity than both break 1 and break 2, with lower HR_{mean} (P =0.031 and p = 0.306), HR_{peak} (P = 0.010 and p = 0.001), and HR_{1min} (P = 0.010 and p = 0.004) compared to break 1 and break 2, respectively. BLa removal was lower in break 3 than break 1 (P = 0.003) and break 2 (P = 0.004). Table 3 includes data from warm-up and all three breaks between races. HR curves for the first 20 minutes and last 20 minutes of each break are shown in Appendix 2 and Appendix 3, respectively. A large variation in individual differences was observed, where the HR of each individual fluctuates from the HR_{mean} curve, and a variation of time at high intensities. There seem to no clear pattern of when athletes reached their HR_{peak} before start.

Group differences

There was a difference between HI and LOW groups in race time for all races (P < 0.005), and finish-sprint time in all races (P < 0.05) except SF (P = 0.105). No difference was found in HR values during each race, but HI group tended to have higher HR_{mean} during F (P = 0.069). For subjective measurements, RED was significantly higher in the HI group before F (11.2 ± 0.5 vs 10.2 ± 1.0, P = 0.046), but not significantly higher before TT (P = 0.260), QF (P = 0.124) and SF (P = 0.355). For BLa measurements the only significant difference between groups was found after F (11.2 ± 0.5 vs 10.2 ± 1.0, p = 0.046). The HI group had higher BLa removal in the breaks, however not significant. No significant differences were found between groups in HR values in warm-up and breaks, but it was a tendency that HI group had higher HR_{1min} during warm-up (P = 0.075), and higher HR_{peak} during break 3 (P = 0.093). Table 4 present data from sub-groups. Development of BLa and subjective data for each group are found in Fig. 8 and Fig. 9, respectively.

Table 2. Development of speed, heart rate, blood lactate concentration and subjective measurements from race to race

Variable	**TT**	**QF**	**SF**	**F**
Mean time (s)	177.4 ± 6.9 ^{SF}	176.9 ± 8.7 $^{SF\ F}$	173.5 ± 7.7 $^{TT\ QF\ F}$	176.9 ± 7.9 $^{QF\ SF}$
Mean velocity (m/s)	7.40 ± 0.28 ^{SF}	7.43 ± 0.36 $^{SF\ F}$	7.57 ± 0.33 $^{TT\ QF\ F}$	7.43 ± 0.32 $^{QF\ SF}$
Finish-sprint time (s)	9.6 ± 0.5 $^{QF\ F}$	9.3 ± 0.7 ^{TT}	9.5 ± 0.7	9.1 ± 0.5 ^{P}
HR_{mean} ($\%HR_{max}$)	89.2 ± 2 ^{F}	88.7 ± 2.0 ^{F}	87.8 ± 3.4	86.9 ± 3.0 $^{TT\ QF}$
HR_{peak} ($\%HR_{max}$)	92.2 ± 1.7 $^{SF\ F}$	91.8 ± 1.9 $^{SF\ F}$	91.3 ± 2.4 $^{TT\ QF\ F}$	90.2 ± 2.8 $^{TT\ QF\ SF}$
BLa PRE (mmol/L)	2.8 ± 1.3 ^{F}	3.1 ± 2.0 ^{F}	2.5 ± 1.3 ^{F}	4.6 ± 2.0 $^{TT\ QF\ SF}$
BLa POST (mmol/L)	9.9 ± 1.6 $^{QF\ SF}$	9.1 ± 1.8 $^{TT\ F}$	8.8 ± 1.7 $^{TT\ F}$	10.8 ± 1.4$^{QF\ SF}$
RED (1-10)	7.9 ± 1.0 ^{F}	7.5 ± 1.1 ^{F}	7.3 ± 1.4 ^{F}	6.6 ± 1.4 $^{TT\ QF\ SF}$
RPE (6-20)	17.9 ± 0.9 $^{QF\ SF\ F}$	15.3 ± 1.9 $^{TT\ SF\ F}$	16.5 ± 1.1 $^{TT\ QF}$	16.6 ± 1.9 $^{TT\ QF}$

Values are presented as mean ± SD
^{TT} = significant difference from time-trial (P<0.05).
^{QF} = significant difference from quarter final (P<0.05).
^{SF} = significant difference from semifinal (P<0.05).
^{F} = significant difference from final (P<0.05).
TT = time trial, QF = quarter final, SF = semifinal, F = final, HR = heart rate, LA^- = blood lactate concentration, PRE = before race, POST = after race, RED = perceived readiness, RPE = perceived exertion

Table 3. Overview of characteristics in warm-up and breaks between races

Variable	**Warm-up**	**Break 1**	**Break 2**	**Break 3**
Time (min)	46.1 ± 10.2 $^{1\ 3}$	70.9 ± 5.7 $^{WU\ 2\ 3}$	46.5 ± 4.9 $^{1\ 3}$	32.5 ± 5.3 $^{WU\ 1\ 2}$
Distance (km)	6.88 ± 1.13 $^{2\ 3}$	6.29 ± 1.59 $^{2\ 3}$	4.43 ± 1.51 $^{WU\ 1\ 3}$	2.25 ± 0.9 $^{WU\ 1\ 2}$
HR_{mean} (% HR_{max})	69.3 ± 3.3 $^{1\ 2\ 3}$	58.7 ± 3.7 $^{WU\ 2}$	61.8 ± 2.6 $^{WU\ 1\ 3}$	59.3 ± 4.0 $^{WU\ 2}$
HR_{peak} (% HR_{max})	89.4 ± 3.0 $^{1\ 2\ 3}$	83.4 ± 3.4 $^{WU\ 3}$	83.1 ± 2.7 $^{WU\ 3}$	78.1 ± 5.9 $^{WU\ 1\ 2}$
HR_{1min} (% HR_{max})	86.6 ± 3.7 $^{1\ 2\ 3}$	81.1 ± 3.1 $^{WU\ 3}$	80.5 ± 2.8 $^{WU\ 3}$	76.1 ± 5.4 $^{WU\ 1\ 2}$
BLa removal (mmol/L)	NA	6.8 ± 2.2 ^{3}	6.6 ± 1.8 ^{3}	4.1 ± 2.1 $^{1\ 2}$
Nutritional intake	NA	12/13	7/13	6/12$^{\#}$
Sprints close to V_{max}	8/13	5/13	5/13	4/12$^{\#}$
High-intensity bout	10/13	4/13	1/13	0/12$^{\#}$

Variables presented as mean ± SD. Nutritional intake, sprint and HIT are based on questionnaire, and presented as 1 = yes, 0 = no.
^{WU} = significant difference from warm-up ($P<0.05$).
^{1} = significant difference from break 1 ($P<0.05$).
^{2} = significant difference from break 2 ($P<0.05$).
^{3} = significant difference from break 3 ($P<0.05$).
Break 1 = break between TT and QF, break 2 = between QF and SF, break 3 = between SF and F.
HR = heart rate, HR_{1min} = 1 minute heart rate with highest mean. BLa removal = BLa after finish – BLa before next start. $^{\#}$ = one of the 13 athletes that answered questionnaire left after SF.

Table 4: Overview of data from races, warm-up and breaks for sub-groups.

Variable	HI group	LOW group	p-value
Anthropometric			
Height (cm)	182.7 ± 5.0	181.5 ± 5.1	0.710
Body mass (kg)	80.2 ± 9.0	70.0 ± 3.9	0.044 *
VO_{2max} ($mL \cdot min^{-1} \cdot kg^{-1}$)	70.0 ± 6.4	62.7 ± 2.8	0.070
Full competition data			
Total distance (km)	26.4 ± 2.2	25.2 ± 3.4	0.556
Total time (min)	207.5 ± 5.3	210.9 ± 6.8	0.394
Total HR over 85% of HR_{max} (min)	14.8 ± 1.6	15.7 ± 5.1	0.709
Total HR over 60% of HR_{max} (min)	139.5 ± 24.5	138.0 ± 39.6	0.945
Minutes warm-up (min)	45.0 ± 6.8	45.1 ± 7.2	0.973
Race data			
TT time (s)	170.5 ± 2.9	184.5 ± 6.4	0.001 **
QF time (s)	169.5 ± 1.5	187.0 ± 1.5	0.002 **
SF time (s)	165.7 ± 2.6	181.2 ± 5.4	0.000 **
F time (s)	171.8 ± 1.1	189.0 ± 1.1	0.000 **
TT finish-sprint (s)	9.3 ± 0.4	10.0 ± 0.5	0.020 *
QF finish-sprint (s)	8.9 ± 0.4	10.0 ± 0.7	0.007 **
SF finish-sprint (s)	9.2 ± 0.6	10.0 ± 1.0	0.105
F finish-sprint (s)	8.7 ± 0.2	9.4 ± 0.3	0.004 **
TT HR_{mean} (% HR_{max})	89.2 ± 1.9	88.6 ± 2.1	0.677
QF HR_{mean} (% HR_{max})	88.6 ± 2.1	88.2 ± 1.3	0.688
SF HR_{mean} (% HR_{max})	89.1 ± 1.3	86.0 ± 5.2	0.234
F HR_{mean} (% HR_{max})	87.8 ± 1.4	85.3 ± 1.4	0.069
Warm-up and breaks data			
Warm-up distance (km)	7.6 ± 0.4	6.3 ± 0.7	0.009 **
Break 1 distance (km)	6.2 ± 0.9	6.7 ± 2.4	0.698
Break 2 distance (km)	4.3 ± 1.1	4.6 ± 2.0	0.762
Break 3 distance (km)	2.4 ± 0.2	2.0 ± 0.9	0.331
Warm-up HR_{mean} (% HR_{max})	68.7 ± 3.3	70.2 ± 4.2	0.543
Break 1 HR_{mean} (% HR_{max})	59.1 ± 3.6	58.3 ± 5.5	0.801
Break 2 HR_{mean} (% HR_{max})	60.5 ± 2.0	62.5 ± 3.6	0.306
Break 3 HR_{mean} (% HR_{max})	60.7 ± 1.7	57.5 ± 5.7	0.261

Table 4 continued

Warm-up HR_{peak} (% HR_{max})	89.6 ± 0.7	87.8 ± 3.3	0.253
Break 1 HR_{peak} (% HR_{max})	81.8 ± 4.2	83.6 ± 2.9	0.432
Break 2 HR_{peak} (% HR_{max})	82.8 ± 2.4	82.1 ± 2.9	0.670
Break 3 HR_{peak} (% HR_{max})	80.4 ± 2.0	74.7 ± 6.5	0.093
Warm-up HR_{1min} (% HR_{max})	87.2 ± 1.4	84.4 ± 2.8	0.075
Break 1 HR_{1min} (% HR_{max})	79.2 ± 3.7	82.0 ± 2.0	0.182
Break 2 HR_{1min} (% HR_{max})	79.3 ± 2.7	80.0 ± 2.7	0.701
Break 3 HR_{1min} (% HR_{max})	77.9 ± 1.8	73.1 ± 5.8	0.146
Break 1 BLa removal (mmol/L)	7.6 ± 2.2	5.9 ± 2.9	0.292
Break 2 BLa removal (mmol/L)	7.2 ± 3.0	6.1 ± 1.7	0.471
Break 3 BLa removal (mmol/L)	4.8 ± 2.6	3.2 ± 2.1	0.288

HI = high-performers group, LOW = low-performers group, TT = time-trial, QF = quarter final, SF = semifinal, F = final, HR = heart rate, BLa = blood lactate concentration, BLa removal = BLa after race – BLa before the following race, PRE = before race, POST = after race, * = statistical difference between groups ($P < 0.05$), ** = statistical difference between groups ($P < 0.01$).

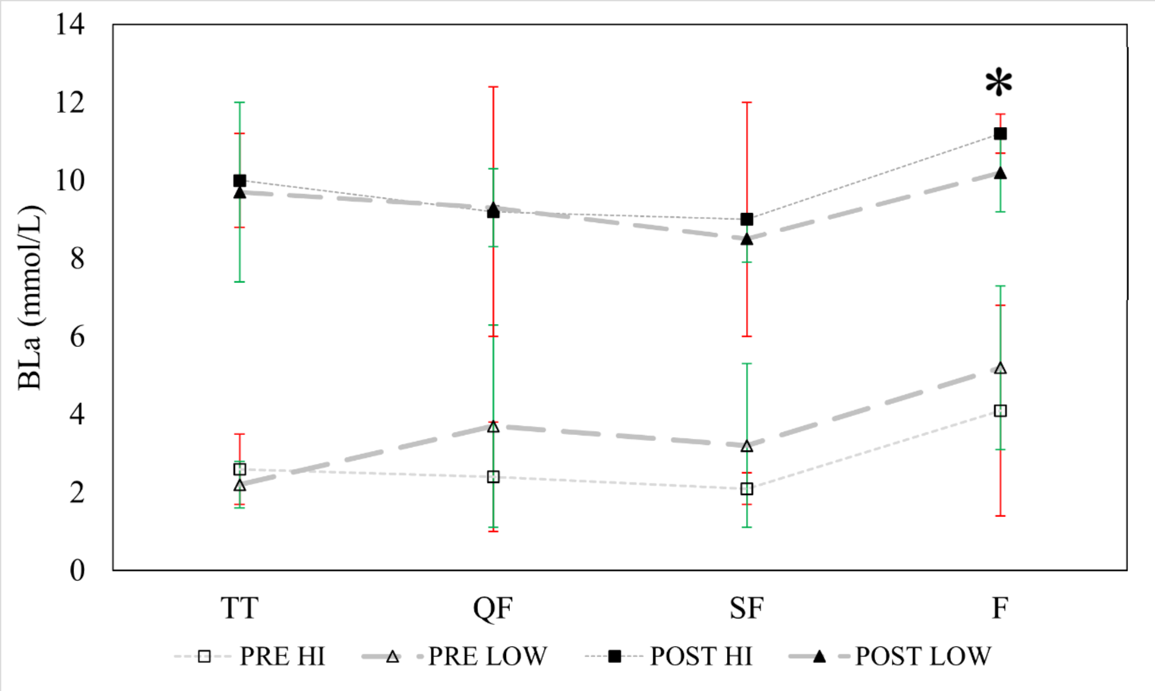


Fig. 8: Blood lactate concentration (BLa) values for high- and low-performers groups before and after each race, presented as mean ± SD. Red error bars = high performance group (HI), green error bars = low performance group (LOW). TT = time-trial, QF = quarter final, SF = semifinal, F = final, PRE = before race, POST = after race, ■ = high performers group, ▲ = low performers group, open symbols = PRE race, filled symbols = POST race, * = statistical difference between groups ($P < 0.05$).

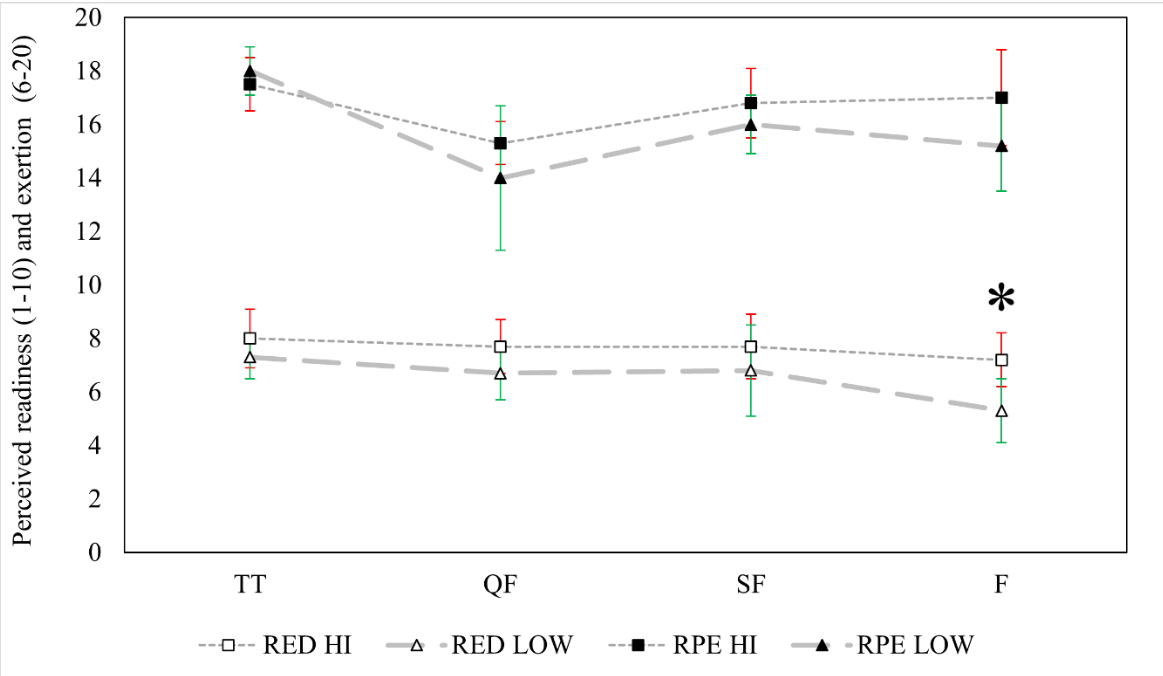


Fig. 9. Perceived readiness (RED) and perceived exertion (RPE) values high- and low-performers groups before and after each race, presented as mean ± SD. Red error bars = high performance group (HI), green error bars = low performance group (LOW). TT = time-trial, QF = quarter final, SF = semifinal, F = final, ■ = high performers group, ▲ = low performers group, open symbols = perceived readiness, filled symbols = perceived exertion, * = statistical difference between groups ($P < 0.05$)

Discussion

The aim of the current study was to describe race-preparation strategies, performance-development and physiological responses during an entire sprint competition in XC skiing. The secondary aim was to compare these factors between skiers of different performance levels. Main findings of this study were 1) during the 3.5 hour of an entire sprint competition in XC skiing, athletes covered a distance of ~25 km, spent 139 minutes above 60% of HR_{max} and 16 minutes above 85% of HR_{max}, 2) maintained their performance levels of stable race time and finish-sprint time 3) HR_{peak} and HR_{mean} decreased from TT to F, 4) intensity based on HR-data and traveled distance decreases from warm-up to breaks closer to the F, 5) the skiers reported lowest RED and highest BLa before F, but this did not affect race time and 6) no differences was found between groups of different performance levels in intensity during race-preparation, but the best skiers were less influenced by fatigue closer to the F.

Description of full race day in sprint

During the full sprint competition, the athletes covered a distance of ~25 km, in a combination of skiing and running, and almost 2.5 hours were spent at an intensity above 60% of $HR_{max.}$ Training sessions with similar duration is a part of the normal training routine for XC skiers (15), but the sprint is much more demanding due to the repeated bouts of high intensity races and moderate to high intensity during warm-up and breaks. The group average of 16 minutes at an intensity above 85% HR_{max} indicates that athletes rarely go above these intensities in periods beyond the four races. Total race time of four races would give less than 12 minutes, i.e., outside the races only 4 minutes were spent at high intensity, where most came in warm-up, or immediately after finish, during HR recovery.

To get insight in the race-preparation of athletes in the morning prior the race, answers from the questionnaire were analyzed. The athletes reported an average of 7.5 hours of sleep the night before the competition, which is same as this age group of endurance athletes report in general (31). In this group of skiers only one athlete reported morning activity, consisting of a short low-intensity run. Due to the early starting time of this simulated competition, it was limited time for this in the morning, and the number of athletes who did this could have been different if the competition had started later in the day as most XC competitions do. The mean energy intake for the group during competition was 6.l kcal·kg body mass $^{-1}$, and 1.1 g carbohydrates·kg body mass^{-1}. A previous study reported the same intake of carbohydrates during a XC ski sprint competition for Swedish junior and senior athletes (32). These values do not meet the recommended nutritional intakes during exercise, which should be 30-60 g carbohydrates per hour (33). Based on the body mass characteristics of the participants in this study, that corresponds to 0.4 to 0.8 g carbohydrates·hour^{-1}·kg body mass^{-1}. These are recommendations for exercises up to 2.5 hours. A sprint in XC skiing lasts for 3.5 hours including inactivity in breaks, thus the nutritional intake seems to be lower than optimal. However, it should be mentioned that nutritional intake are estimates based on answers from the athletes, and that the true energy intake deviates from this number. Even though the athletes do not reach the recommended nutritional intake during the competition, this does not seem to affect the performance negatively. Getting enough intake of food during strenuous activity could be challenging. Based on this data, it seems like the nutritional intake during competition is not a limiting factor. It could be hypothesized that the intake prior to the competition is just as important, so secure full liver glycogen stores before the competition. It is therefore uncertain what effect low versus high nutritional intake has during a sprint.

Performance-development and physiological responses

The race time in this competition was relatively stable in all races, with race time in SF being faster than the others. This strengthens the theory that XC skiing athletes can maintain their mean velocity over four repeated races in sprint (7-9, 34, 35). The non-normal distribution of race time in QF, SF and F is caused by the athletes racing in groups. This could be due to the effect of drag, as explained in Andersson, Govus (35). By looking at mean speed curves for all races (see Appendix 4), the downhill speed for TT seems to be lower than QF, SF and F, which strengthen the theory of taking advantage of drag. However, a more likely explanation is higher motivation and effort to keep up with the skier in front during head-to-head heats, to be able to fight for a good finishing position. To get a good finishing position the finish-sprint is important, as first-to-finish wins the race. This can explain why the finish-sprint time was highest in F and lowest in TT. The athletes' ability of increasing their finish-sprint velocity during repeated heats is in resemblance with other studies on XC skiing sprint (8, 35), but in contrast with the findings of Zory, Millet (9). However, in the study of Zory, Millet the recovery time was only 12 minutes, which could highlight the need of enough recovery time in XC skiing sprint. In this simulated competition, where the breaks between races are similar to real-world competitions, and athletes can choose their own racing tactics, they can maintain their performance in total race time and finish-sprint time.

HR values, both peak and average, during races decreased from TT to F. However, the decrease in HR does not affect the race time. This conflicts with other studies done on repeated heats, which report a stable heart rate through all heats, as well as a steady VO_2 uptake (7, 8, 34, 35). Why a decrease in HR in subsequent races occurred in the current study, is uncertain. One explanation could be that it is easier to race in groups, where you can stay behind another skier. However, it is likely to believe that many athletes gave maximum effort to keep up with the skier in front when racing in groups, which should not lead to decreased HR. Another explanation is that the athletes were more fatigued later in the competition, and thereby could not keep the same intensity. Still, they were able to maintain performance. Based on the findings of this study it is hard to tell what caused the decrease in HR from TT to F. BLa after races was highest after F. The peak BLa values of 10.8 mmol/L in this study is slightly lower than what is observed in other studies on XC skiing sprint (7, 8, 34, 36). BLa before start was higher before F than the other races. The same pattern has been seen in previous research (8), where BLa was lower in the first race compared to the following ones. In the current study the significant increase in BLa at start did not occur until the F. It could be hypothesized that in competitions where the athletes choose their own preferred race-preparation strategies, and with longer breaks between races, they are capable of a high BLa removal until the break before the F, where the BLa removal is lower. However, in another study by Andersson, Holmberg (36) there was no increase in BLa at start over four subsequent TT's on the treadmill. In this study the break between each trial was 45 min, which could prevent an increase in BLa before the last TT. Even though the athletes can maintain their performance, the physiological responses vary between races, were the higher BLa values occur closer to the end of the competition, possibly due to shorter breaks and a last all-out effort in the F.

Race-preparation strategies

This group of skiers used a traditional orientated warm-up strategy, with a mean warm-up time of 46 minutes, starting at low intensity, followed by some time at higher intensity. Some focused more on longer bouts of high intensity, such as 2-3 minutes, while some focused more on shorter and faster bouts, for example the winner who had bouts of ~30 seconds. This is to some extent similar to what Swedish elite XC skiers reported in the warm-up before a sprint race (16). The HR_{mean} during warm-up is lower in the current study, but it did not exclude the lower HR in the transition periods, that includes changing to race equipment etc., as Jones, Govus (16). An interesting approach is how a shorter specific warm-up, as described in Strom Solli, Kocbach (17), would affect the performance. In two separate TT's they did not find any difference in performance between short-specific and long-traditional warm-up. The same findings was found in a warm-up study in running (37). How this warm-up strategy would affect performance in repeated races over a time period of 3-4 hours, is not known, and it should be investigated if this is an effective way of reducing the total load of a XC ski sprint competition.

The intensity in the breaks was lower than in the warm-up, with the lowest intensity in the break before F. During the longer recovery time in break 1 and 2 the athletes used a combination of active and passive recovery, where athletes had some activity straight after the race, followed by an inactive period, and then an active period with moderate to high intenisty before next race. In break 3, the intensity was significantly lower, with lower HR_{peak} and HR_{1min}. During break 3 the athletes used mostly active recovery, by keeping themselves active towards the F, but had less moderate to high intensity. If this is a planned strategy for saving energy to the F, or if it happens due to a lack of energy to do bouts of higher intensity is not known. Research done on recovery strategies in different sports have found little difference in performance after active versus passive recovery but agrees that active recovery has better effect on lactate removal, and especially when intensity during active recovery reaching ventilatory threshold (19-21). In the current study, the BLa removal was lower in break 3 than break 1 and 2 possibly due to the combination of less recovery time and lower intensity in break 3, which led to a higher BLa before start of the F. However, this did not affect the performance in the F. It should be highlighted that it is debated if initial lactate level has an impact on the subsequent performance (38, 39). Findings of Choi, Cole (40) implies a higher resynthesis of muscle glycogen during passive recovery compared to active recovery. The study by Monedero and Donne (20) concluded that a combination of active and passive recovery was better, potentially due to the effect of both BLa removal and muscle glycogen resynthesis. A typical recovery strategy in sprint in XC skiing seem to be somewhat similar, with a combination of active and passive recovery. Nevertheless, if this is the optimal strategy for performance during the full competition, and if the same strategy should be used in each break, should be further investigated.

Differences between sub-groups

The HI and LOW performance group differed in performance in the races, and BLa and subjective measures in the F, but no significant differences were found in HR values during race-preparation. An interesting finding was before and after F, where the HI group reported higher RED at start, followed by higher BLa levels after F. An explanation for this could be that the HI group were more motivated at this point, as they were fighting for the podium. However, a more likely explanation could be that the HI group had more energy towards the end of the competition. When looking at HR values in break 3, the tendency of higher HR_{peak}

in the HI group could be an indicator that they still had the capacity to reach higher intensity in the break, which may make them more prepared for the F. Even though not significant, there is a trend that the HI group have lower BLa values at start before each race (Fig. 8), which may be due to the activity in the breaks, which again can lead to higher RED before start, which is also a trend for the HI group (Fig. 9). Previous research have also shown that better sprinters in XC skiing can recover faster than the slower ones (13), which could also be explained by higher aerobic capacity. The HI group also tend to have higher HR in the F, and combined with higher BLa after F, an explanation may be that the LOW group do not have the (aerobic) capacity for maintaining their effort and performance as good as the HI group. Even though this study gives no clear evidence on difference in race-preparation strategies between high- and low-performers, there is an indication that better athletes have the capacity to be more prepared toward the end of competition, and perform better in the F.

Methodological considerations

This study gives insight to an entire on-snow competition in XC skiing, and which race-preparations athletes apply. Due to the ongoing COVID-19 pandemic, competitions for this age group were cancelled at the time when this simulated competition was conducted, which could strengthen the athlete's motivation to perform at their best. During the laboratory testing athletes used their own sports watches, and HR_{max} was defined from HR_{peak} in the laboratory. As HR data is a central part of this study, a limitation is that the sport watch was not standardized, and a HR_{max} test was not conducted. However, following Ingjer (25), an acceptable way of defining HR_{max} is adding 5 beats·min^{-1} to the HR_{peak} in a maximal incremental test to exhaustion. At last, all athletes were recruited from the same high school. It is reasonable to believe that this group of skiers to some extent have the same strategies in warm-up and breaks, as they have received tips and advice from their coaches. Therefore, these findings may not be generalizable to other groups or nations of skiers. By recruiting athletes with different coaches, one may see more differences in race-preparation.

Practical implications

The findings of this study give insight into the physiological demands of sprint XC skiing and XC skiers race-preparations during an entire sprint competition. The long duration and distance covered, along with spent at elevated HR highlights that a sprint in XC skiing is much more than just one TT as studied in most previous studies on sprint skiing. This indicates that athletes should focus also on long training sessions to be able to maintain performance throughout the whole competition. Additionally, as the intensity in the breaks decreases over time, it should be questioned if the race-preparation before SF and F is not good enough, or if the best solution is to save energy for the last races. Future research should focus on which race-preparation strategies that are most advantageous for performance in four subsequent races in XC skiing sprint.

Conclusion

The current study illustrates race-preparation strategies, performance-development and physiological responses during a sprint competition on XC skiing. The competition lasts for 3.5 hours, including warm-up, and skiers travel a distance of 25 km. Together with the long periods of elevated HR, including four races with HR and BLa values to maximum, this highlights the high physiological demand of a sprint competition in XC skiing. Still, the performance levels of these well-trained sprint skiers were maintained during four subsequent races. However, better skiers are better at maintaining performance throughout the whole competition, but no difference was found in intensity during race-preparations or races. The race-preparation strategies were not influenced by performance level and were modified to fit the gradually shorter recovery times and increasing levels of fatigue during the competition day.

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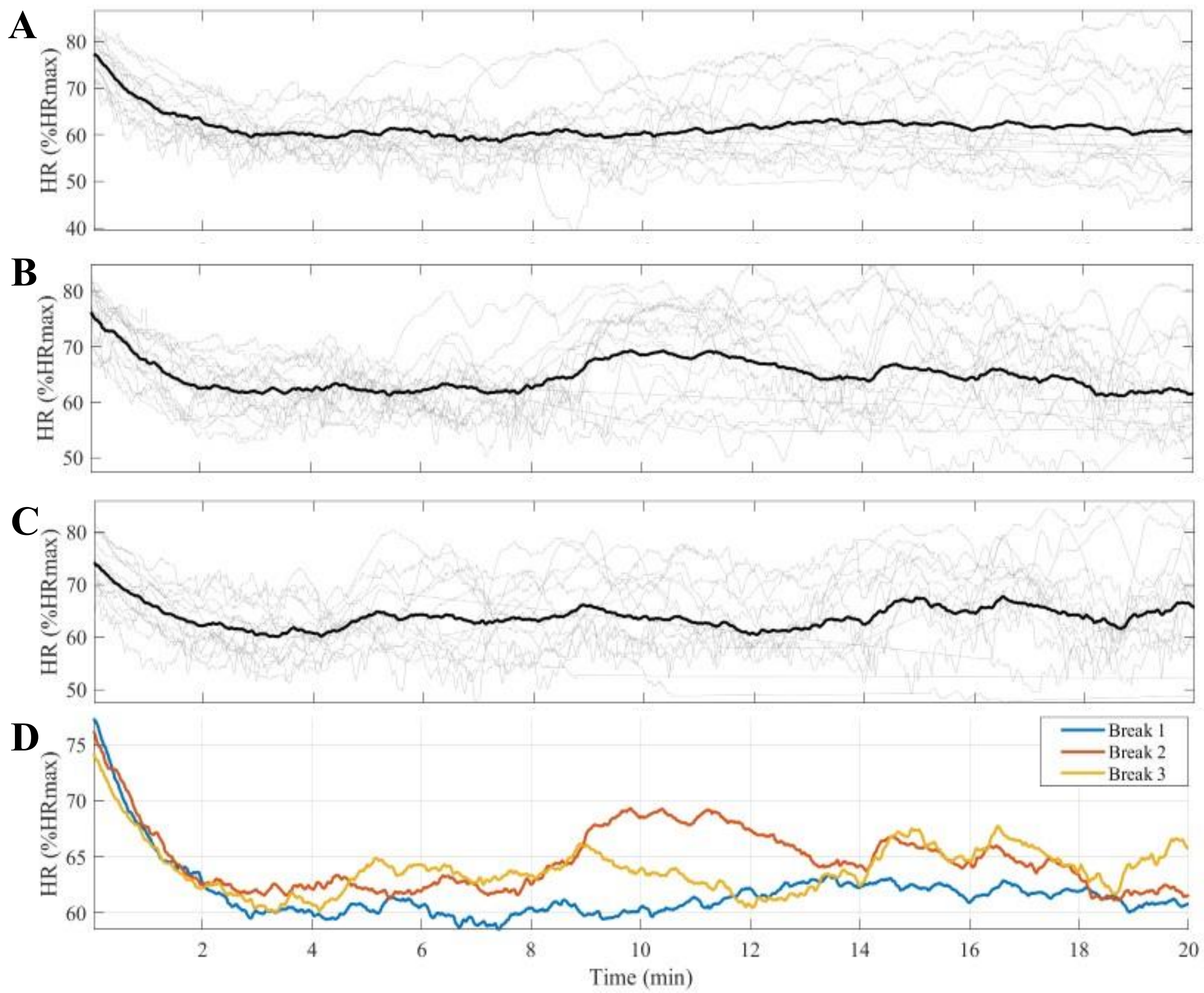
Appendix

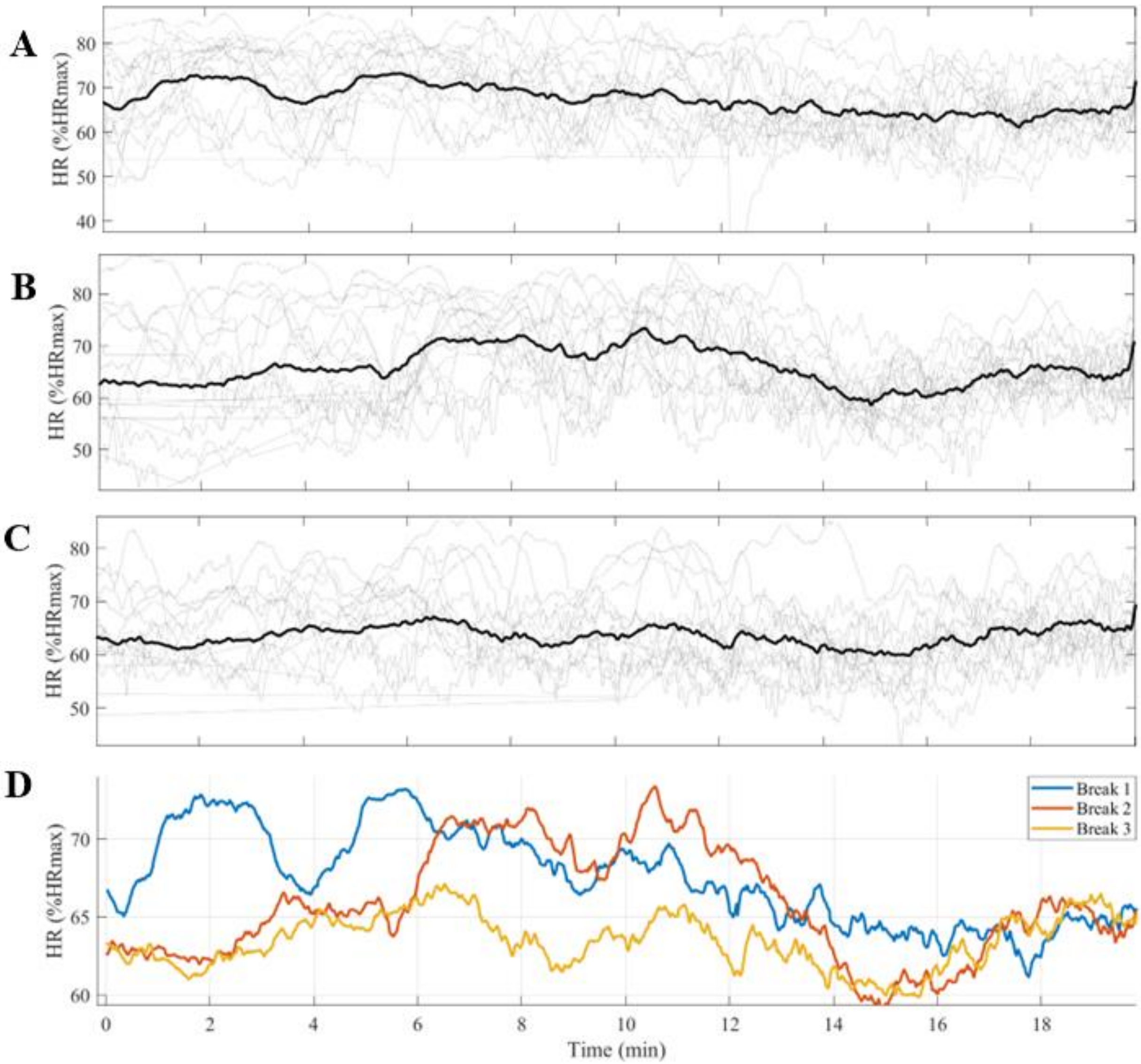
Appendix 1: Questionnaire for the athletes that was handed out before start of the warm-up.

Questionnaire on race day
What is your maximal heart rate?
How many hours did you sleep tonight?
Rate your sleep quality on a scale from 1-10
When did you eat breakfast?
What did you eat for breakfast? Specify
Did you perform any types of activities before warm-up? Specify (running, stretching, strength, etc.)
What else did you do before the race? Specify (Relaxing, school work, house work, etc.)
How many minutes before the start did you start your warm-up?
Describe your warm-up as detailed as possible (how much, time in intensity zones, maximum speed, skiing, running etc)
Describe what you did between the heats as detailed as possible. Include time inactive, times in different intensities, maximal speed etc.) **a. Between time-trial & quarter final** **b. Between quarter finale and semi final** **c. Between semifinal and final**
What tactical considerations did you do in the: **a. Quarter final** **b. Semifinal** **c. Final**
Nutrition: What did you eat between the: **a. Time trial & quarter final** **b. Quarter finale and semifinal** **c. Semifinal and final**
How much liquid did you drink throughout the competition? (water and sports drink)
Rate your perceived day shape on a scale from 1-10
Rate your satisfaction with your performance on a scale from 1-10

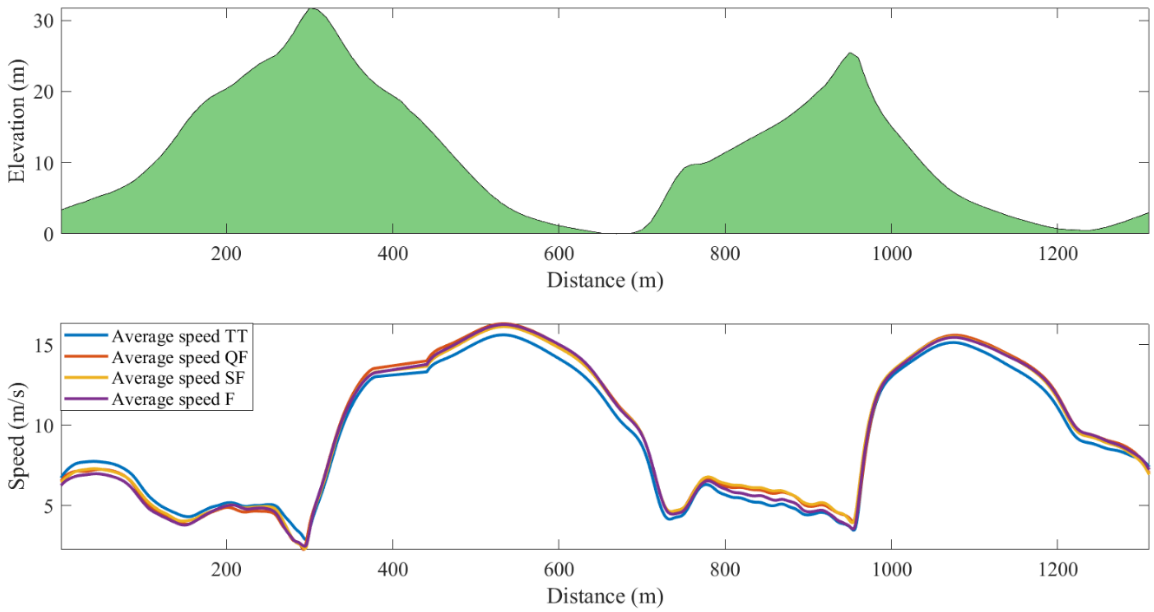
Appendix 2: Heart rate (HR) curves during the first 20 minutes of after finish of A) time-trial B) quarterfinal C) semifinal D) mean values during break 1, 2 and 3 respectively. Grey curves = HR for each individual, black = mean HR for the group.



Appendix 3: Heart rate (HR) curves during the last 20 minutes before start of A) quarterfinal B) semifinal C) final D) mean values for break 1, 2 and 3 respectively. Grey curves = HR for each individual, black = mean for the group.



Appendix 4: Mean velocity for each race in different parts of the track. Note that the track passed through a tunnel at 400 m where signal was lost and restored with interpolation.



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