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Title: Cross-country skiers with a fast-start pacing pattern increase time-trial performance by use of a more even pacing strategy

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ABSTRACT

Purpose: To investigate whether skiers with a fast-start pacing pattern increase time-trial performance by use of a more even pacing strategy. **Methods:** Thirty-four skiers (~17 yrs., 16 males) performed an individual 7.5 (3x2.5) km free technique race on snow with a self-selected pacing strategy (Day 1). Based on the starting pace the first ~2 min (Lap 1 first 600-m segment pace·7.5 km pace^{-1}), subjects were ranked into two groups; an intervention group with the fastest start pace (INT, n=17) and a control group with a more conservative pace (CON, n=17). On Day 2, INT were instructed to reduce their start pace based on their average Lap 1-3 segment pace from Day 1, while CON were instructed to maintain their Day 1 strategy. **Results:** INT increased their time-trial performance more than CON from Day 1 to Day 2 (Effect size; ES=0.87, P<0.05). From Day 1 to Day 2, INT slowed their start pace (mean±CI; 7.7±2.0%, ES=2.00), with lowered heart rate (HR) (83±2 to 81±2% of HR_{max}) and 1-10 ratings of perceived exertion (RPE) (5±1 to 4±1), but finished with a faster overall 7.5 km time (-1.9±0.9%, ES=0.99) (all P<0.05). For CON, no change was found for starting pace (-0.7±2.0%, P=0.47), overall 7.5 km time (-0.2±1.4%, ES=0.02, P=0.81), RPE or HR between days. No differences were found for end-RPE (9±1) or average HR between Day 1 and 2 for either group**. Conclusion:** Skiers with a pronounced fast-start pattern benefit by using a more even pacing strategy to optimize time-trial distance skiing performance.

Key Words: *Cross-country skiing; GNSS; Intermittent exercise, Heart rate, Performance; Rate of perceived exertion*

INTRODUCTION

The distribution of energetic resources during a race – i.e. pacing – is widely accepted to have a substantial influence on performance in various endurance sports such as running, cycling, swimming, rowing and speed skating [1-6]. The overall goal is to use all energy sources before the finishing line, but without large homeostatic disturbances early in an event, to avoid a substantial slowdown. As energy released through aerobic oxidation is the only metabolic pathway that is sustainable [7], an even distribution of speed seems advantageous for performance in endurance sports held on constant course inclinations with durations of >2-4 min [2,8].

In intermittent endurance sports with uneven metabolic distribution, such as cross-country (XC) skiing, biathlon or mountain bike cycling, athletes repeatedly choose work rates in excess of their maximal aerobic power [9-11]. Thus, the pacing patterns impose repeated oxygen deficits that when accumulated are several times higher than the athlete's maximal accumulated oxygen deficit [11]. Hence, the nature of these sports demands that different energy systems work in concert to satisfy rapid changes in metabolic power, which clearly challenges athletes' ability to prescribe their exercise intensity and thereby their pacing strategy.

In XC skiing, no objective internal or external markers (such as heart rate (HR), speed and power output) can be used continuously during a race to plan, adjust or evaluate exercise intensity and thereby the pacing strategy. A component that appears to integrate many variables during whole-body exercise is subjective internal markers such as rating of perceived exertion (RPE) [12]. It has been suggested that the athlete uses previous experience, anticipation of exercise duration/distance and information about the course profile, as well as knowledge of his/her current physiological and psychological state, to adjust pacing [1]. The athlete then creates a "template" for the increase in RPE and selects an initial work rate based on the duration of the event [1,13,14]. However, how RPE is related to changes in pacing strategy with intermittent energy demand is currently not known.

Despite the relatively long duration of a XC distance skiing race (~15-120 min), skiers typically apply a fast-start/positive pacing pattern (i.e. reducing speed) on a lap-to-lap basis [15,16]. Better and more experienced skiers demonstrate less reduction in speed between laps than lower-ranked and younger athletes [16,17]. More specifically, it has been recently found that young skiers demonstrate a higher exercise intensity during the initial phases of the time trial than elite skiers, and thereby a more pronounced positive pacing pattern [17]. This implies that the start pace could serve as an important aspect of the overall pacing pattern in XC skiing. However, to date, no experimental data have been provided on how the pacing pattern in general, and the starting pace specifically, influences distance skiing performance.

Although several studies have described pacing patterns in XC skiing [10,15-18], the only experimental study investigating the effect of pacing strategy in XC-skiing focused on sprint skiing [19], and limited information is available on distance skiing. In a preliminary study **[see Appendix, Supplemental Digital Content 1]**, we investigated group differences between a "Fast-start pacing strategy" and an "Even pacing strategy" on 10-km roller ski performance in high-level junior skiers. We randomly assigned skiers into the two groups based on a time-trial with the use of a self-selected pacing strategy and found no significant differences between the pacing strategies in overall distance skiing performance. In line with others [20,21], we concluded that changes in pacing strategies in highly trained athletes should be individualized. We further hypothesized that the most pronounced fast-start athletes could benefit from a more conservative start pace, but due to the methodology, these assumptions could not be confirmed.

Therefore, our aim was to investigate whether reducing the starting pace in athletes with the most pronounced fast-start pacing pattern, and thereby targeting a more even lap-to-lap pacing strategy, would increase overall 7.5 km skiing time-trial performance on snow in highly trained junior skiers.

METHODS

Subjects. Eighteen female (age 17 ± 1 yrs., body height 168 ± 5 cm, body mass 61 ± 7 kg, self-selected pole length skating 91% ± 1% of body height) and 16 male (age 17 ± 1 yrs., body height 180 ± 4 cm, body mass 70 ± 7 kg, self-selected pole length skating 91% ± 1% of body height) skiers were recruited to the project. Their maximal oxygen uptake during running (females (n=15); 56.4 ± 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$, males (n=15); 70.2 ± 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) was determined on a separate day ± 2 months from the test day (for protocol see Losnegard, Schafer, Hallen [22]). All skiers were highly trained regional-level junior athletes. The study was approved by the ethics committee at the Norwegian School of Sport Sciences (ref 135-180620), found advisable by the Norwegian Centre for Research Data, and conducted according to the Declaration of Helsinki. All subjects gave their oral and written consent to participate, with parental consent for those under the age of 18 years.

Design. The subjects performed two time trials on two days separated by 24 hrs. At Day 1, subjects performed an individual 7.5 (3x2.5) km free technique race (~25 min) with a self-selected pacing strategy (Day 1) on a cross-country skiing course in Geilo (Geilo, Norway, altitude 760 m asl). The distance of 7.5 km is used in competitions for this group of skiers. The track profile is shown in Figure 1. Based on the ranking of their relative starting pace over the first ~2 min (Lap 1 first 600 m segment pace·7.5 km $pace^{-1}$), the subjects were assigned into two groups; an intervention group with the fastest starting pace (INT, n=17, 10 men) and a control group with a more conservative start pace (CON, n=17, 6 men). At Day 2, the subjects were informed of their experimental grouping before the warm-up (40 min before start). INT were instructed to target their Day 1 individualized average 600 m segment pace from Lap 1-3 in Lap 1 at Day 2 and they were informed how many seconds slower they should ski the first 600 m segment relative to Day 1. CON were instructed to keep to the same starting pace and overall pacing strategy as Day 1. All skiers were very familiar with the race track, as they used this during daily training.

[Figure 1 near here]

Methodology. A 30 s starting interval between each subject was used based on a ranking, where the potentially fastest skiers started first and the starting order was identical on both days. Each start group was limited to 12 subjects due to the number of available GNSS units and to reduce the number of skiers on the track at the same time. During the race, the skiers wore an integrated IMU and GNSS unit on their backs (between thoracic vertebrae 4 and 5), to capture speed continuously. Heart rate was measured during all tests with personal monitors and heart rate max (HR_{max}) was reported based on their highest heart rate during the latest year. Prior to the trials, the skiers performed a self-selected warm-up on skis. The warm-up consisted of 30 min of primarily low intensity skiing incorporating 1-3 moderate intensity sets of 1-3 min and 2-3 progressive sprints (>15 sec). Subjects were instructed to perform the warm-up identically on Day 1 and Day 2, including the use of the same terrain.

RPE using a 1-10 scale [23] was reported orally during the race (600 m, 3100 m, 5600 m) and ~30 s after crossing the finish line (7500 m) [**Figure 1**]. A poster illustrating RPE levels 1-10 was visible to the skiers and they reported a number to a testing staff, who registered the rating. All skiers were familiar with the RPE 1-10 system from regular training and testing. The RPE Hazard score, which is the product of the momentary RPE and the fraction of race distance remaining (%), was calculated. This score defines the likelihood that athletes will change their effort during the competition and is associated with the need to reduce the speed to values at which homeostatic disturbances stay within acceptable limits [13]. Summated HS was calculated by adding the HS values from each segment.

Apparatus. All skiers used their own skis, boots and poles, which were identical for both days. All skis were prepared identically for each test day. Speed and movement data were collected using an integrated Inertial Measurement Unit (IMU) and Global Navigation Satellite System (GNSS) unit (Optimeye S5, Catapult Innovations, Melbourne, Australia), validated by Gløersen, Kocbach, Gilgien [24]. The unit consisted of a 10Hz GNSS-receiver, tracking both GPS and GLONASS data, a 3D accelerometer (100Hz), a 3D magnetometer (100Hz) and a 3D, 2000 deg·sec^{-1} gyroscope (100Hz). VO_{2max} during running was measured at Geilo (760 m asl) on a treadmill (Woodway ELG, GmbG, Weil am Rein, Germany) and oxygen consumption was measured using an automatic ergo-spirometry system (Oxycon Pro, Jaeger Instrument, Hoechberg, Germany).

Conditions. The study was conducted in mid-January. Snow and weather conditions were similar on both competition days (sunny, hard-packed snow, air temperature -10 to -15ºC, snow temperature -18 to -22 ºC, air pressure 1022 to 1030hPa and wind 2 to 3 m·s^{-1} from NW). Snow friction was not measured throughout the test, but based on the results [**Figure 2**] combined with personal communication with the subjects, we estimate a slightly lower friction coefficient for high speeds (downhill) and slightly higher friction coefficient for low speeds (uphill) on Day 2 compared to Day 1.

Data analyses. Segment times and overall times were recorded using synchronized watches and a Racesplitter timekeeping system (Makalu Logistics Inc., Fontana, CA, USA). The course profile along the track was calculated for each athlete and lap, based on the IMU-GNSS sensors and averaged to obtain a standard course with an accompanying elevation profile. Data from the IMU-GNSS sensors and from the HR monitors carried by the athletes were adapted to the standard course, and subsequently used to illustrate the speed and HR of each athlete along the course. For 8 athletes, GNSS data from personal 1Hz GNSS receivers were used due to missing data from the 10Hz GNSS receivers. This does not influence the results since timing was based on the Racesplitter system and GNSS is used only to illustrate the development of time differences. Speed was calculated from changes in GNSS position data per unit of time.

Statistical Analysis. Data are presented as mean ± standard deviation (SD), except for relative differences between test days and between groups, which are presented as means ± 95% confidence intervals (CI). Paired sample t-tests were used to calculate the differences within groups from Day 1 to Day 2, while an unpaired t-test was conducted between groups for the relative differences from Day 1 to Day 2. A P-value ≤ 0.05 was considered statistically significant. Statistical analyses were performed using Microsoft Office Excel 2013 (Microsoft, Redmond, WA, USA). The magnitude of change in the score between groups was expressed as standardized mean differences (Cohen's *d* effect size; ES) with the formula $((M1–M2)/(\sqrt{(SD^2{}_1+SD^22)/2}))$ and for the within group comparison $((M1–M2)/(\sqrt{(SD^2{}_1+SD^22-2rS^1S^2)}))$. All figures were created using Sigmaplot (version 13.0; Systat Software Inc, San Jose, CA) or MATLAB R2018a (MathWorks, Inc., Natick, MA, United States).

RESULTS

Pacing strategy and Performance

The relative time differences between Day 1 and Day 2 for INT and CON are shown in **Figure 2,** and individual differences within the two groups are shown in **Figure 3**. INT reduced their Lap 1 600 m segment time and overall 7.5 km time more than CON from Day 1 to Day 2 (Effect size; ES=2.00 and 0.87, P<0.05). On Day 1, the overall time (min:ss) for INT was 24:18 ± 2:22 (men, n=11: 22:45 ± 0:44 and women, n=6: 27:09 ± 1:21), while for CON this was 25:58 ± 2:37 (men, n=5: 22:56 ± 1:06 and women, n=12: 27:14 ± 1:54). On Day 1, there were no significant differences in overall time between groups when separated into male and females, respectively (P>0.05). On Day 2, the overall time for INT was 23:51 ± 2:19 min and was thus a faster overall 7.5 km time compared to Day 1 (mean±CI; -1.9±0.9%, P<0.001, ES = 0.99) while CON had an overall time of 25:59 ± 3:16 min, which was not significantly different from Day 1 (-0.2±1.4%, P=0.81, ES=0.02). Changes in performance from Day 1 to Day 2 in INT were accompanied by changes in all types of terrain (downhills: 1.5%, undulating: 2.5% and uphill: 1%).

Figure 4a shows the Pacing Index for the first 600 m from each lap for the two groups. INT increased the Lap 1 600 m segment time, but reduced the Lap 2 and Lap 3 600 m segment time from Day 1 to Day 2 (P<0.05). At Day 1, the ratio between Lap 1 600 m segment time and 7.5 km time was significantly different for INT and CON (8.4±0.4 versus 9.3±0.3%, P<0.01). On Day 2, INT slowed their Lap 1 600 m time compared to Day 1 (7.7±2.0%, P<0.001) while no change was found in CON (-0.7±2.0%, P=0.47) resulting in no differences in Lap 1 600 m segment time between the two groups (9.2±0.5 versus 9.1±0.2%, P>0.05, INT and CON respectively). The Pacing Index between laps is presented in **Figure 4b.** INT had a more even pacing distribution on Day 2 compared to Day 1, with a reduction in the Lap 1 Pacing Index (Lap 1 relative to average lap time) from -4.1±0.7 to -1.7±0.7%, Lap 2 from 2.0±0.4 to 0.6±0.5% and Lap 3 from 1.8±0.5 to 1.0±0.4% (all P<0.05). No significant changes were found for CON.

Heart rate

The HR-response for INT and CON on Day 1 and Day 2 are shown in **Figure 5**. INT reduced their relative HR on Lap 1 for the first 600 m from Day 1 to Day 2 (83±2 vs. 81±2% of HR_{max}, P<0.05), with no changes in CON (81±2 vs. 81±2% of HR_{max}, P=0.73). The average HR during the race was not different between Day 1 and Day 2 for either INT (90±2 vs. 90±1 % of HR_{max}) or CON (92±1 vs. 91±% of HR_{max}) (all P>0.05).

RPE, RPE Hazard Score and Summated RPE Hazard Score

The RPE, RPE-Hazard Score (HS) and Summated RPE-HS during the race is shown in **Figure 6A-C**. No differences were found for end-RPE between Day 1 and 2 in either INT or CON (all 9±1). However, INT had a lower RPE and RPE-HS at 600 m for Day 2 compared to Day 1 (4.1±0.9 vs. 5.1±1.0 and 3.7±0.8 vs. 4.7±0.9, respectively, both $P<0.05$) and at 3100 m for Day 2 compared to Day 1 (6.5±0.9 vs. 7.2±0.7 and 3.8±0.5 vs. 4.2±0.4, respectively, both $P<0.05$). The summated RPE-HS was lower in INT on Day 2 than Day 1 (9.6±1.3 vs. 11.1±1.3, $P<0.05$). No significant changes were found in CON (10.7±1.1 vs. 10.3±1.3). On Day 1, the RPE-HS was higher at 600 m than 3100 m for both groups ($P<0.05$). On Day 2, the RPE-HS at 600 m compared to 3100 m was only higher for CON ($P<0.05$), but not INT.

[Figure 2-6 near here]

DISCUSSION

The present study showed that high-level junior skiers with a fast-start pacing strategy can increase their time-trial 7.5 km distance skiing performance on snow with the use of a more even pacing strategy. The increased performance was accompanied with reduced summated RPE Hazard Score, implying less discomfort during the race.

XC skiers typically apply a fast-start/positive pacing pattern (i.e. reducing speed) on a lap-to-lap basis with a typical decrease in speed of 2-12% during competitions [15,16]. This magnitude of decrease in speed was also found in INT on Day 1; they showed a ~6% time-reduction from Lap 1 to Lap 3. This was reduced to ~3% after adjusting the starting pace on Day 2, which was similar to what CON accomplished on both days (~2%) **[Figure 6]** and thus at the lower end of what is typically found in “real-life races”. Thus, skiers with a fast-start pacing pattern benefitted from adopting a more conservative start strategy to optimize performance. The present finding seems independent of the level of the skiers as the two groups were similar in performance at Day 1. Thus, the performance gain in INT should be attributed to other factors.

The track profile **[Figure 1]** contains a rather long uphill after just ~30 s of skiing, where the exercise intensity typically reaches ~120-150% of VO_{2max} [10,11,17]. Therefore, delayed O_2-kinetics were expected, where skiers acquired substantial oxygen deficits [11]. This was likely higher in INT than CON on Day 1 due to their higher relative speed and similar performance level. A high O_2-deficit could imply a reduced ability to recover during the race. This partial recovery of anaerobic work capacity is possible when the aerobic metabolic rate is higher than the total required metabolic rate, and closely related to the magnitude of the difference and the duration [11]. By reducing this O_2-deficit from Day 1 to Day 2, which was indicated by lowered heart rate, INT were potentially able to better maintain speed on a lap-to-lap basis without inducing an early substantial homeostatic disturbance. Thus, this indicates that INT moved to a more even energy distribution to optimize performance, which is in agreement with results from other endurance sports with durations >3 min [2]. In addition, it has been demonstrated that gross efficiency is negatively affected by high intensity work and that the recovery of gross efficiency after anaerobic work is relatively slow [25-27]. Thus, a slower start at Day 2 in INT could maintain gross efficiency better compared to the faster start at Day 1 with consequently lower RPE and Hazard Score.

Competition courses in XC skiing consist of approximately one-third ascending, one-third flat and one-third descending terrain. About 50% of the total time is used in uphill skiing [28] and the uphill is the terrain that provides the greatest discrimination between levels of skiers [17,29,30]. In the present study, the performance gains in INT from Day 1 to Day 2 can be attributed to all types of terrain when snow conditions were taken into consideration. The cause of the increased speed in downhill terrain is not known; however, it could be suggested that INT were less fatigued before the downhills on Day 2 than on Day 1, as reflected by their lower RPE. The skiers might therefore have been able to implement better "micro pacing strategies" than on Day 1, such as more efficient transitions between techniques or more aerodynamic downhill positions. Although the focus on such "micro pacing strategies" has increased in recent years [31], not much is known in this area and it should be highlighted in future studies investigating pacing strategies.

The highest risk of premature fatigue, based on the "RPE Hazard Score" (RPE-HS), was at 600 m for both groups on Day 1. On Day 2, INT reduced their RPE-HS at both 600 m and 3100 m from ~4.5 to ~3.8 points and thereby had a lower and more evenly distributed RPE-HS curve in the first half of the race. Interestingly, this resulted in a lower summated RPE-HS for INT on Day 2 than on Day 1. We did not collect the session RPE; however, a recent study found a very strong correlation between session RPE and summated RPE-HS [14]. Taken together, this implies that the skiers performed better, with less discomfort, which could be important for recovery aspects when races are held on consecutive days. This is a novel finding that to the authors' knowledge, has rarely been investigated in intermittent endurance sports. Moreover, in sports such as XC skiing, no external markers can be used continuously, and athletes must use their previous experience to adjust pacing. To optimize pacing strategy and performance, we propose that the "RPE template" [1] needs to be calibrated with the use of objective data such as segment or lap times. The present study demonstrates a simple but practical tool, by combining split times and the RPE/RPE Hazard Score, which could provide useful objective and subjective data on athletes' pacing strategies in intermittent endurance sports.

Limitations

A potential limitation of the present study is that only the INT group received instructions on Day 2, which may have resulted in more motivated athletes. However, CON used almost the same total time at Day 2 as Day 1 (difference of 0.2%) implying the same performance as the conditions were similar between days. Moreover, INT only got instructions on pacing the first ~2 min of the ~25 min race and no lap-to-lap strategy or "micro pacing strategies" were given. In both groups, the skiers were not informed about the instructions given to the other group. Also, average HR and end RPE was not different between days for either group, implying that the internal workload was similar. Taken together, we believe that the methodical aspects of feedback have limited influence on the conclusion in the present study.

A potentially more robust design could be to provide instructions for an additonal group of skiers to increase start speed. However, as presented in the preliminary study **[see Appendix, Supplemental Digital Content 1],** we found no significant differences between the pacing strategies in overall distance skiing performance when randomly assign skiers to a "Fast-start pacing strategy" or an "Even pacing strategy". Therefore, the current study was designed to individualize pacing strategies, i.e. make all skiers adapt a "Even pacing strategy" (on lap-to-lap basis), which seems as the best choice based from other similar sports [2,8]. Our research design was based on this experience from the preliminary study, practical experience working with high level skiers and previous research[20,21] were pacing strategies should be individualized.

Practical Application

Coaches and athletes must be aware of the length and intensity of the "fast-start pacing strategy" that is traditionally used in XC skiing at all levels. Thus, the course profile and snow conditions will play a significant role in the pacing strategy, which should be taken into consideration when interpreting the present findings. In addition, we found a clear effect of starting pace on overall performance despite no training being provided on this strategy. As pointed out in previous research, it is logical to assume that practice and learning pacing strategies would be beneficial to performance [21].

CONCLUSION

Cross-country skiers with a pronounced fast-start pacing pattern benefit by using a more even pacing strategy to optimize time-trial distance skiing performance. With such a strategy, an increased overall performance can be accompanied by less discomfort during the race.

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Conflict of Interest

The authors declare no professional relationships with companies or manufacturers who will benefit from the results of the present study. We declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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Supplemental digital content 1. docx

Figure legends

Figure 1: A) Profile of the 3x2.5 km course, the Lap 1 600 m segment (brown area) and where subjects reported their 1-10 Rate of Perceived Exertion (RPE). B) 3-dimensional map of the course. Green = Downhills, Red = Uphill and Grey is undulating terrain.

Figure 2: The relative time difference between Day 1 and Day 2 for INT = intervention (n=17), CON = Control (n=17) and when "corrected" differences between groups. The "corrected" INT time difference is found by treating the CON time difference as a reference, and subtracting the CON time difference from the INT time difference.

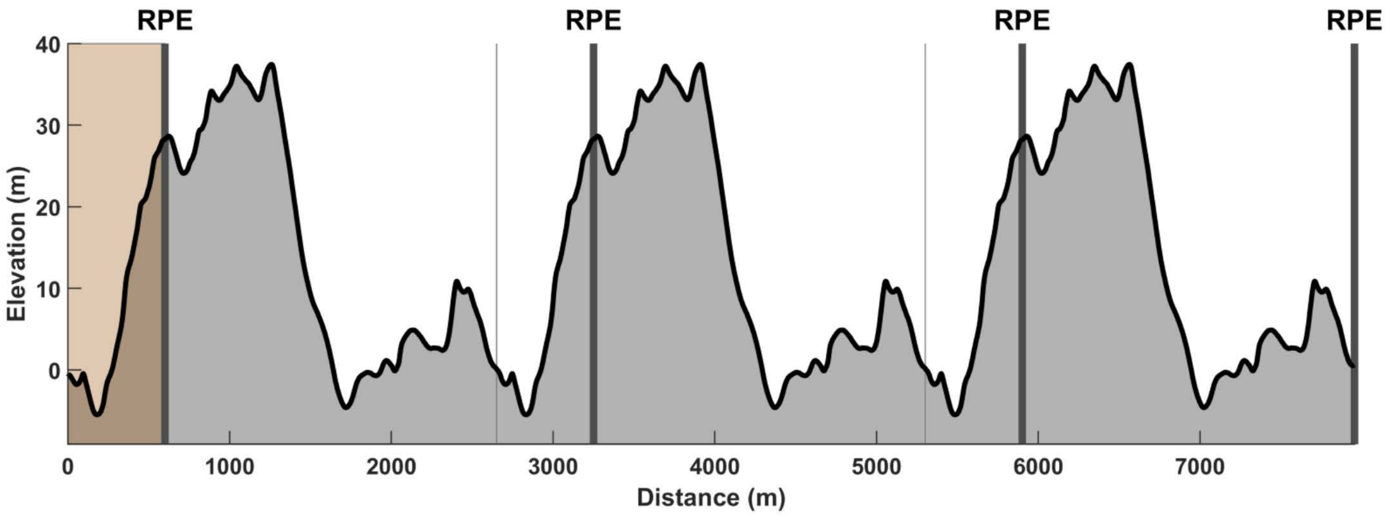
Figure 3: The individual relative time difference between Day 1 and Day 2 for INT = intervention (n=17) and CON = Control (n=17). Brown area marks the Lap 1 600 m segment.

Figure 4: The Pacing Index for the first 600 m segment for each lap (upper) and the different laps (lower). The Pacing Index is calculated as segment time/average segment time. INT = intervention (n=17), CON = Control (n=17). * Significantly different to INT Day 1 ($P<0.05$)

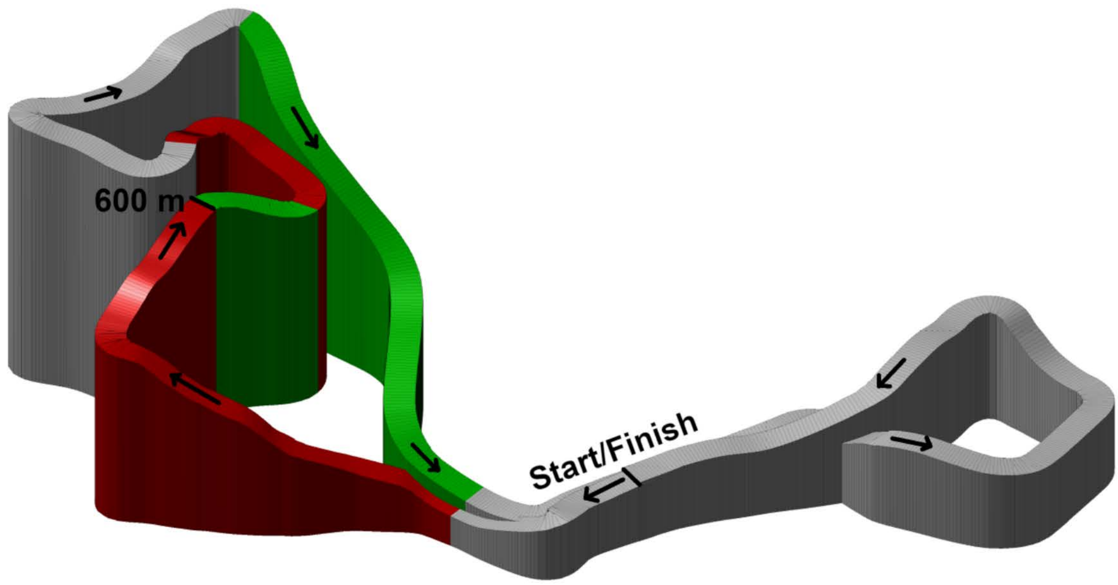
Figure 5: Day 1 and Day 2 heart rate relative to the subjects' maximal heart rate in INT = intervention (n=17) and CON = Control (n=17). Brown area marks the Lap 1 600 m segment.

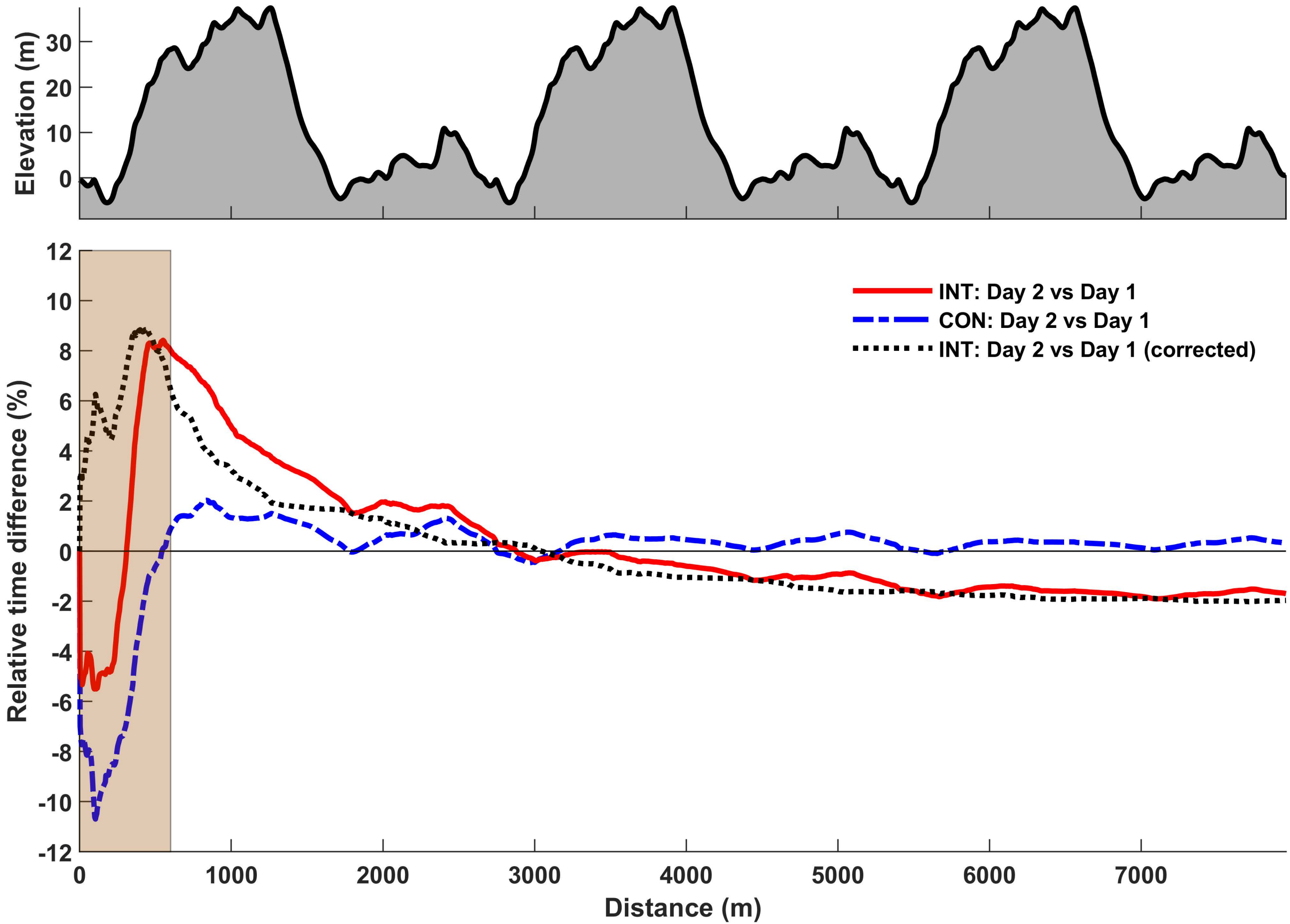
Figure 6: 1-10 Rate of perceived exertion (RPE) (upper), RPE Hazard Score (middle) and RPE summated Hazard Score (lower) at 600 m, 3100 m, 5600 m and finish (7500 m) for INT = intervention (n=17), CON = Control (n=17) at Day 1 and Day 2. The RPE Hazard score is the product of the momentary RPE and the fraction of race distance remaining (%). Summated RPE Hazard score is the accumulated RPE Hazard score. * Significantly different to INT Day 1 ($P<0.05$)

A)

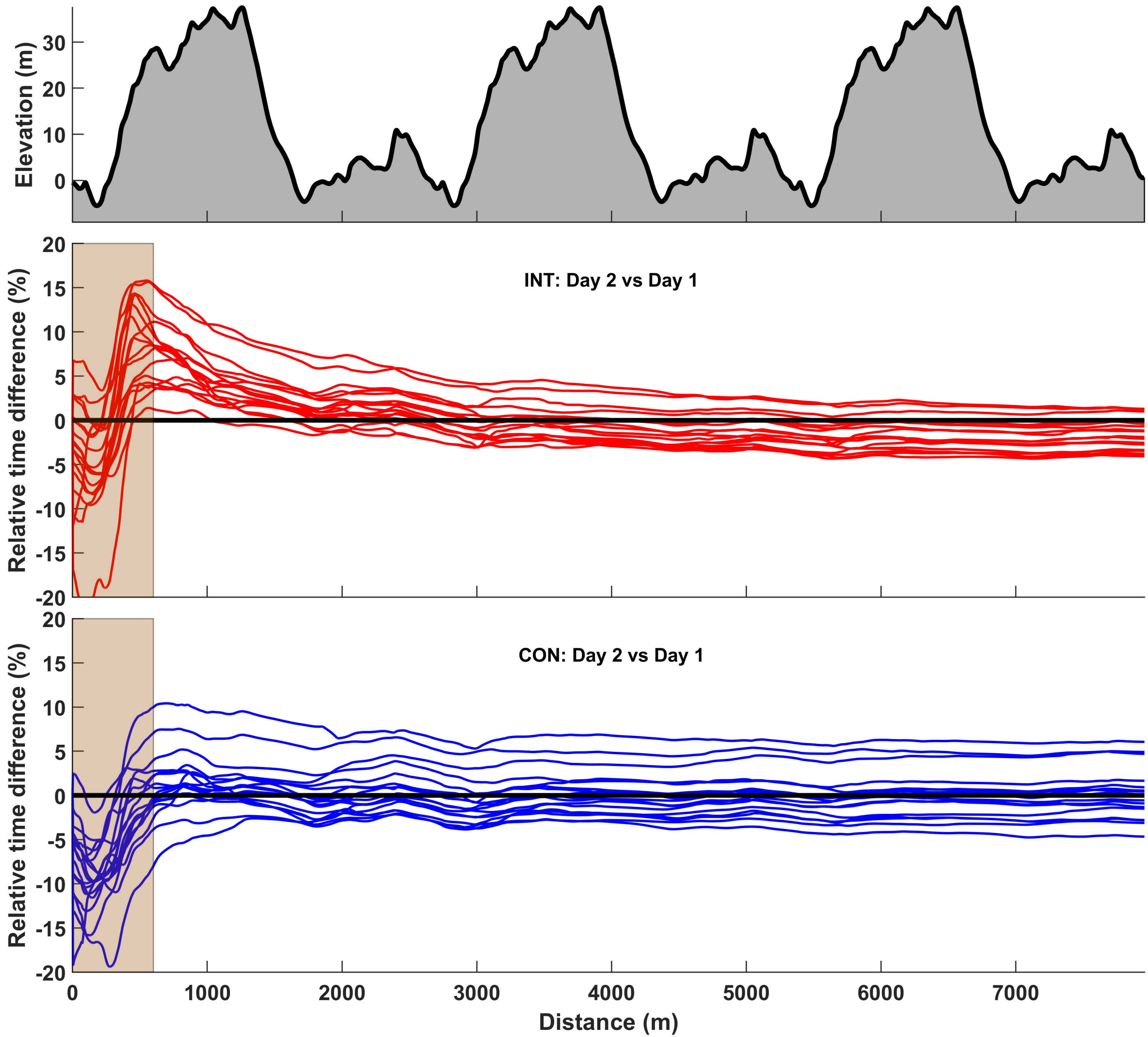

RPE
RPE
RPE
RPE
40
30
20
10
0
Elevation (m)
0
1000
2000
3000
4000
5000
6000
7000
Distance (m)

B)

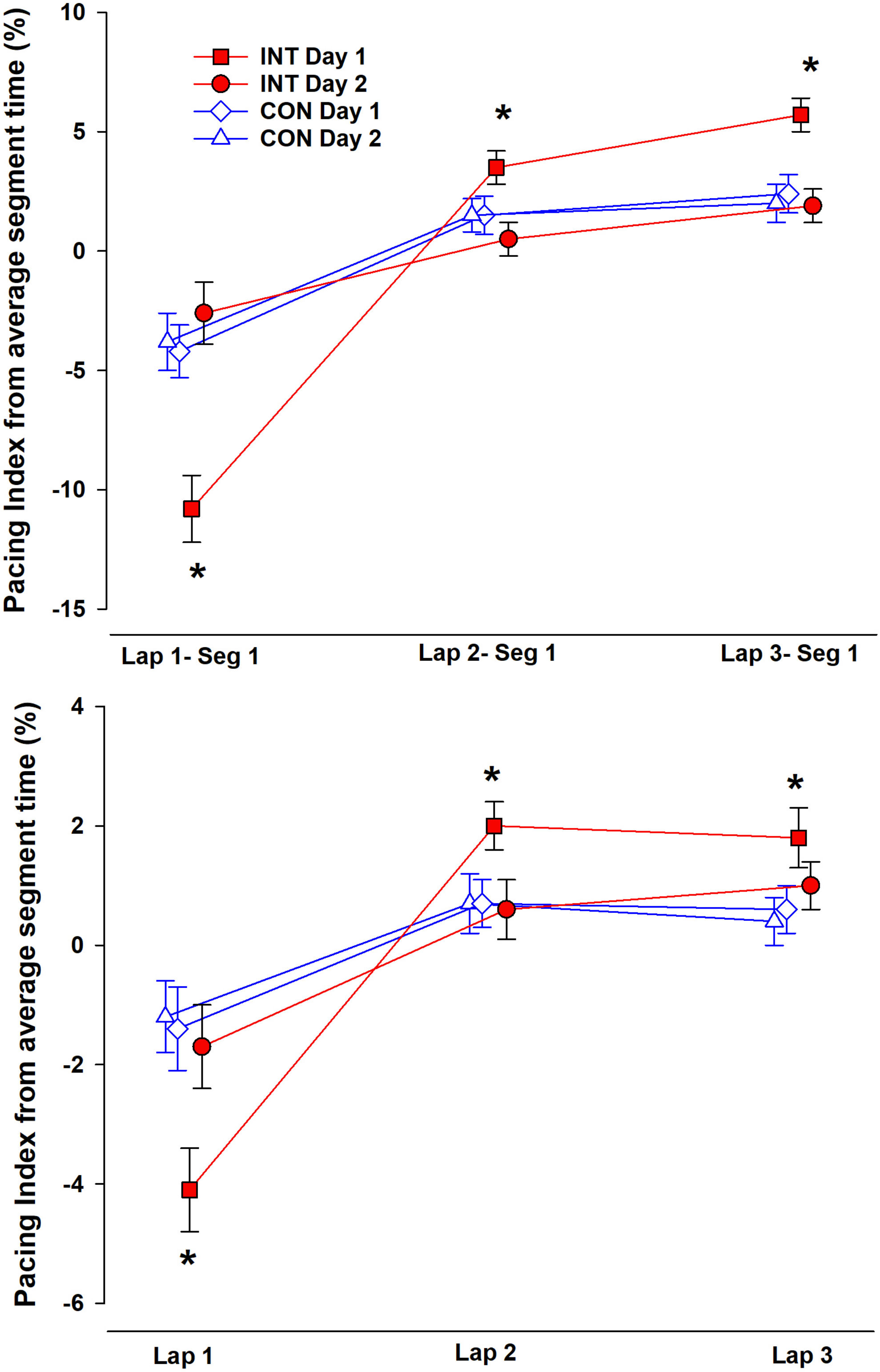

600 m
Start/Finish



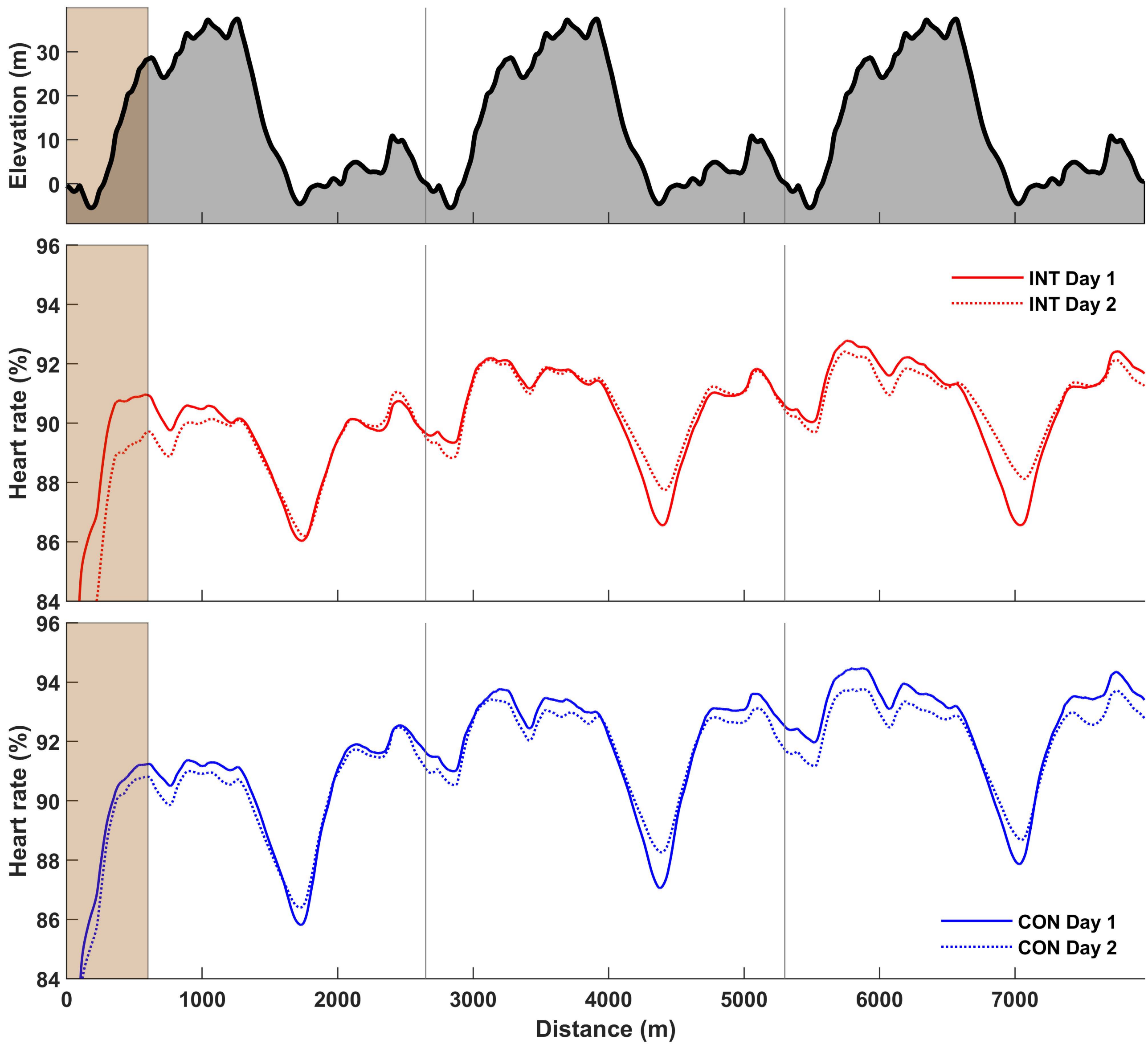
Elevation (m)
30
20
10
0
Relative time difference (%)
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
INT: Day 2 vs Day 1
CON: Day 2 vs Day 1
INT: Day 2 vs Day 1 (corrected)
0
1000
2000
3000
4000
5000
6000
7000
Distance (m)



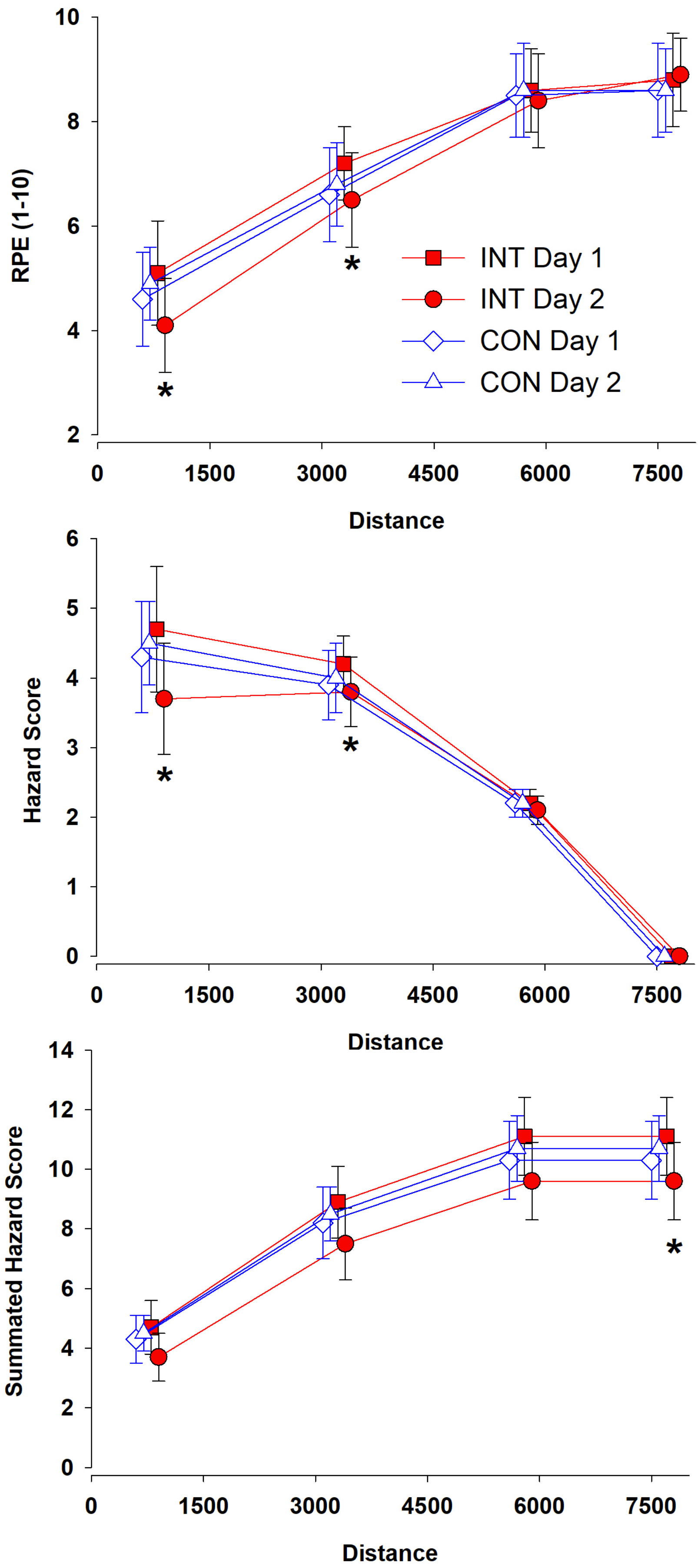
Elevation (m)
30
20
10
0
INT: Day 2 vs Day 1
CON: Day 2 vs Day 1
Relative time difference (%)
20
15
10
5
0
-5
-10
-15
-20
0
1000
2000
3000
4000
5000
6000
7000
Distance (m)



Pacing Index from average segment time (%)
10
5
0
-5
-10
-15
INT Day 1
INT Day 2
CON Day 1
CON Day 2
*
*
*
Lap 1- Seg 1
Lap 2- Seg 1
Lap 3- Seg 1
Pacing Index from average segment time (%)
4
2
0
-2
-4
-6
*
*
*
Lap 1
Lap 2
Lap 3



Elevation (m)
30
20
10
0
Heart rate (%)
96
94
92
90
88
86
84
INT Day 1
INT Day 2
Heart rate (%)
96
94
92
90
88
86
84
CON Day 1
CON Day 2
0
1000
2000
3000
4000
5000
6000
7000
Distance (m)


RPE (1-10)
10
8
6
4
2
0
1500
3000
4500
6000
7500
Distance
INT Day 1
INT Day 2
CON Day 1
CON Day 2
*
Hazard Score
6
5
4
3
2
1
0
0
1500
3000
4500
6000
7500
Distance
Summated Hazard Score
14
12
10
8
6
4
2
0
0
1500
3000
4500
6000
7500
Distance

The influence of a "Fast-start pacing strategy" versus an "Even pacing strategy" on roller ski performance in highly trained junior skiers

I. Purpose

Despite the relatively long duration of a cross-country (XC) distance skiing race (~15-120 min), skiers typically apply a fast start/positive pacing pattern (i.e. reducing speed) on a lap-to-lap basis irrespective of distance, technique or sex, with a typical decrease in speed of 2-12% during competitions [1,2]. This contrasts with most other endurance sports with >3 min duration, which implies that performance could be optimized with a more conservative race strategy. However, to date no experimental data has been provided on how pacing patterns influence distance skiing performance. Therefore, we investigated the differences between a fast-start (**FAST**), and thereby a "positive pacing", versus an "even pacing strategy" (**EVEN**) in 10 km roller ski performance in highly trained junior skiers.

II. Methods

17 female (age 16.6±0.8 yrs, body height 170±4 cm, body mass 62±5 kg, self-selected pole length skating; 91 ± 1 % of body height) and 5 male (age 17.2 ±0.9 years, body height 182 ±7 cm, body mass 71 ± 4 kg, self-selected pole length skating; 90 ± 1% of body height) skiers were recruited to the project. All skiers were competitive and highly trained regional-level junior athletes recruited from a sport school. The study was approved by the ethics committee at the Norwegian School of Sport Sciences, found advisable by the Norwegian Centre for Research Data, and conducted according to the Declaration of Helsinki. All subjects gave their oral and written consent to participate, with parental consent for those under the age of 18 years.

III. Design

Subjects performed an individual 5 lap x 2 km free technique race with a self-selected pacing strategy (Day 1) on a roller skiing course at Geilo (Geilo, Norway, altitude 760 m above sea level, 8-10 ºC both testing days). The track profile is shown in [**Figure 1**]. The subjects were counterbalanced into two groups based on the overall ranking on Day 1; a fast start (FAST, total ranking 1,3,5 etc., n=12, 3 men) and a group with a more conservative start pace targeting an even pacing (EVEN, total ranking 2,4,6 etc., n=11, 2 men). At Day 2, FAST were instructed to target a 4% faster Lap 1 time than their individual average Lap times from Day 1. This was based on the typical strategy observed in World cup races [2]. EVEN were instructed to target their individual average lap pace from Day 1 on Lap 1. To help the skiers to adjust the Lap 1 pace, a split time was given at 600 m at both warm-up and the first lap on Day 2, based on the time from Day 1. After the first lap on Day 2, the pacing strategy was self-selected for both groups. The skiers performed the two time trials with a 24 hr. interval between them and the starting order was identical both days. During the race, each skier wore an integrated IMU and GNSS unit on their back (for details, see main article). Segment times and total 600 m times were recorded using synchronized watches and the Racesplitter timekeeping system (for details, see main article)

IV. Statistical Analysis

Data are presented as mean ± standard deviation (SD), except for relative differences between test days and between groups, which are presented as means ± 95% confidence intervals (CI). Paired sample t-tests were used to calculate the differences within groups from Day 1 to Day 2, while an unpaired t-test was conducted between groups for the relative differences from Day 1 to Day 2. A P-value ≤ 0.05 was considered statistically significant and P-values ≤ 0.10 were considered tendencies. Statistical analyses were performed using Microsoft Office Excel 2013 (Microsoft, Redmond, WA, USA).

V. Results

The split times and overall times are shown in Table 1**.** On Day 2, FAST increased their Lap 1 pace relative to their average Lap pace from Day 1 (mean±CI; 4.4±1.1%, P<0.001), with no difference in EVEN (0.3±1.3%, P<0.001). Lap 1 paces relative to average paces from Day 1 to Day 2 were significantly different between groups (P<0.05). No difference was found for overall performance from Day 1 to Day 2 for either FAST or EVEN.

<<Table 1 near here>>

VI. Discussion

The result of this preliminary experiment showed no group differences between a fast-start, and thereby a positive pacing, versus an even pacing on 10 km rollerski performance in highly trained junior skiers.

Our hypothesis was that an even pacing strategy would increase performance in highly trained skiers. We managed to adjust the starting pace (first lap) in both groups according to the goal (0.3% of average pace from Day 1 in EVEN and -4.4% of average lap pace from Day 1 in FAST). The 4% faster strategy was based on findings from World Cup races where this is a typical strategy performed by elite skiers [2]. As stated by Hettinga, De Koning, Schmidt, Wind, Macintosh, Foster [3], experienced athletes do not always follow the theoretical optimal pace as there are several important determinations of performance. However, EVEN did not change their performance relative to their self-selected strategy conducted on Day 1 or the fast start strategy group. Based on the current methods, we cannot conclude that an even strategy is more beneficial than a fast start strategy used in present study. Importantly, highly trained athletes seem to manage a very robust system for choosing their pacing strategy, including previous experience and physical performance level. Hence, large deviations from this template may result in negative performance outcomes [3]. In the present study, we chose a method to test different pacing strategies and not to optimize pacing strategies for individual skiers. These aspects seem important when evaluating the effect of pacing strategies in the literature and implementing data in practical settings.

VII. Conclusion

We found no group differences between a fast start strategy versus a more conservative pacing on 10 km roller ski performance in highly trained junior skiers.

VIII. References

1. Stoggl T, Pellegrini B, Holmberg HC. Pacing and predictors of performance during cross-country skiing races: A systematic review. *J Sport Health Sci.* 2018;7(4):381-393.
2. Losnegard T, Kjeldsen K, Skattebo O. An Analysis of the Pacing Strategies Adopted by Elite Cross-Country Skiers. *J Strength Cond Res.* 2016;30(11):3256-3260.
3. Hettinga FJ, De Koning JJ, Schmidt LJ, Wind NA, Macintosh BR, Foster C. Optimal pacing strategy: from theoretical modelling to reality in 1500-m speed skating. *Br J Sports Med.* 2011;45(1):30-35.

Appendix 1. Supplemental Digital Content 1

Table 1: Total time and lap times during Day 1 (self-selected pacing strategy; SS) and during Day 2 (fast pacing strategy; FAST or Even pacing strategy; EVEN).

	FAST		**EVEN**	
	Day 1: SS	**Day 2: FAST**	**Day 1: SS**	**Day 2: EVEN**
Lap 1	6:15±0:36	6:11±0:33	6:17±0:34	6:28±0:36*
Lap 2	6:31±0:38	6:27±0:34	6:27±0:34	6:30±0:39
Lap 3	6:31±0:34	6:30±0:34	6:32±0:36	6:29±0:37
Lap 4	6:34±0:31	6:33±0:33	6:33±0:33	6:32±0:39
Lap 5	6:28±0:33	6:26±0:35	6:25±0:30	6:24±0:39
Total	32:18±2:49	32:07±2:44	32:15±2:48	32:24±3:08

Note: min:ss, data are mean±SD. * Significant difference to Day 1 within group (P<0.05)