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Title: Highly trained biathletes with a fast-start pacing pattern improve time-trial skiing performance by pacing more evenly

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ABSTRACT

Purpose: In sprint biathlon a J-shaped pacing pattern is commonly used. We investigated whether biathletes with a fast-start pacing pattern increase time-trial skiing and shooting performance by pacing more evenly. **Methods:** Thirty-eight highly trained biathletes (~21 yrs., 26 men) performed an individual 7.5 km (3x2.5 km for women) or 10 km (3x3.3 km for men) on roller skis with a self-selected pacing strategy (Day 1). Prone (after lap 1) and standing shooting (after lap 2) stages were performed using paper targets. Based on their pacing strategy in the first time-trial (ratio between the initial ~800-m segment pace on lap 1 and average ~800-m segment pace on laps 1-3), participants were divided into an intervention group with the fastest starting pace (INT, n=20) or a control group with a more conservative starting pace (CON, n=18). On Day 2, INT were instructed to reduce their starting pace, while CON was instructed to maintain their Day 1 strategy. **Results:** INT increased their time-trial skiing performance more than CON from Day 1 to Day 2 (mean±95CI; 1.6±0.8% vs -0.4±0.9%, P=0.04). From Day 1 to Day 2, INT reduced their starting pace (5.0±1.5%, P<0.01), with reduced ratings of perceived exertion (RPE) during lap 1 (P<0.05). For CON, no change was found for starting pace (-0.8±1.2%) or RPE between days. No differences were found for shooting performance for either group. **Conclusion:** Highly trained biathletes with a pronounced fast-start pattern improve skiing performance without any change in shooting performance by pacing more evenly.

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

INTRODUCTION

Biathlon is an Olympic winter endurance sport that combines ski skating in hilly terrain with high-precision rifle shooting. There are four individual competition formats; sprint, pursuit, individual, and mass start. The sprint and individual competitions are both time-trial events, in which an athlete's distribution of energetic resources, i.e., their "pacing strategy," has a substantial influence on performance.[1-4]

In biathlon sprint, the most common pacing pattern is a "J-shaped" pacing strategy [1] with a relatively fast first lap (before prone shooting), a slower second lap (before standing shooting) and then a faster third lap. In contrast to most other endurance sports, pacing strategy in biathlon does not only influence endurance performance, but also the preparations to the precise task of rifle shooting.[2] In sprint competitions, the laps are interspersed by a prone and a standing shooting each consisting of 5 shots. Each target missed results in a penalty loop of ~150 m (~25 s), with penalty time explaining 31-35% of the difference between placing in the top 10 or placing between 21-30 in World Cup sprint races.[3]

To achieve a medal in international championships, biathletes must perform better than their season average and have a hit rate above 95%.[2,5] Skiing intensity and degree of fatigue may especially influence standing shooting through changes in body movement and vertical rifle sway [6] and thereby shooting performance. Previously, the effect of increasing exercise intensity has also been shown to negatively influence the movement of the rifle in prone shooting, but not the dichotomous variable "hit" or "miss".[7] Vertical movement of the rifle in prone shooting was related to shooting performance in a race simulation but not during rest [6]. Moreover, a simulated roller-skiing race negatively affected stability of hold in both horizontal and vertical directions and aiming accuracy and cleanness of triggering in standing shooting in both elite and junior athletes, when compared with shooting in a rested state.[8] A detailed analysis of a sprint competition using GPS-devices also indicated that better performing athletes slow down relatively more before standing shooting.[1] Overall, the above information indicates that pacing strategy could influence shooting performance.

In biathlon World Cup sprint competitions, faster skiing speed on laps 2 and 3 differentiates medalists from other top 20 finishers.[4] Furthermore, the 10 highest ranked biathletes in World Cup have lap times closer to their average pace than 21-30 ranked biathletes, indicating that they employ a more even pacing pattern.[3] Recently, we found that cross-country skiers with a fast start pacing pattern improved skiing performance by reducing their starting pace.[9] These observations allow us to hypothesize that a more conservative pacing strategy would also be beneficial for skiing performance in highly trained biathletes with a fast-start pacing pattern. However, the possible impacts on shooting performance have not yet been examined.

This study tested the hypothesis that biathletes with a fast-start pacing pattern would improve time-trial skiing and shooting performance by using more even pacing during a simulated sprint biathlon competition. More specifically we investigated how this change in pacing strategy influences a) time-trial roller ski performance, b) hit rate and precision of prone and standing shooting and c) rate of perceived exertion and heart rate responses.

METHODS

Participants. Twelve women (age 20 ± 1 yrs., body height 1.70 ± 0.54 m, body mass 65.7 ± 5.5 kg, self-selected pole length skating 91% ± 1% of body height) and 26 men (age 22 ± 1 yrs., body height 1.83 ± 0.51 m, body mass 76.9 ± 5.3 kg, self-selected pole length skating 91% ± 1% of body height) biathletes were recruited to the project. The participants were classified as "Highly trained" (Tier 3) [10] and competed on a national and regional level in Norway. 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 participants gave their oral and written consent to participate.

Design. All participants performed two time-trials separated by 72 h. The participants performed an individual sprint 7.5 km (3x2.5 km) for women or 10 km (3x3.3 km) for men in the freestyle technique on a roller ski track at an international racecourse at Birkebeiner ski area (Lillehammer, Norway). The track profile is shown in Figure 1. Prone shooting (after lap 1) and standing shooting (after lap 2) were performed on standardized paper targets for 0.22 caliber on a 50 m outdoor shooting range, with scoring rings from 1-10 (10 is maximum point per shot, 0 is a miss on standing shooting and 8-10 is considered a hit in prone shooting when converted to hit or miss in biathlon). There were 5 paper targets per shooting with the same aiming area (black part of the circular target) as in competitions. A maximum of 50 points could be obtained per shooting.

The design were based on our recent study [9] in cross-country skiing showing that cross country skiers are able to reproduce a given starting pace first ~3 min of a race between days with the following requirements; 1) the conditions are similar between days, 2) experienced participants that are well familiar with the track and that 3) the participants test the starting pace as a part of their warm up. On Day 1, participants performed an individual biathlon sprint race with a self-selected pacing strategy. Based on the ranking of their relative starting pace over the first ~800-m segment on Lap 1 in relation to their average ~800-m segment pace on Lap 1-3, the participants were assigned into two groups; an intervention group with the fastest starting pace (INT, n=20, 14 men) and a control group with a more conservative start pace (CON, n=18, 12 men). On Day 2, the participants were informed of their assigned group before the warm-up (40 min before start). INT were instructed to target their Day 1 average ~800 m segment pace from Lap 1-3 at Lap 1, and they were informed how many seconds slower they should ski the first 800 m segment relative to Day 1. The men in INT were also told to prolong their adjusted start pace for the first ~1500-m (top of the hill, Fig 1) of Lap 1 due to the topography of their racetrack. CON was instructed to maintain the same starting pace and overall pacing strategy as Day 1. All participants were familiarized with the racetrack, as they used this during their daily training.

[Figure 1 near here]

Procedure. During the race, the participants wore an integrated Inertial Measurement Unit (IMU) and Global Navigation Satellite System (GNSS) unit on their back (between thoracic vertebrae 4 and 5), to capture position and speed continuously. The participants were placed into 3 start groups, separated by 1 h. Each start group was limited to 12 participants because of the number of available GNSS units, and to reduce the number of participants on the track at the same time. Within each group, participants started at 30 s intervals, with the same starting order on both days.

Before the trials, the participants performed zeroing on paper targets and warm-up on skis. Each group started zeroing approximately 1 h before the test start. Participants were given as many series as they wanted, to mirror zeroing in competition. The weather remained consistent from zeroing until the start of the competition. The warm-up consisted of 30 min of primarily low intensity (<70 % of heart rate max, HR_{max}) skiing incorporating one moderate intensity (80-90% of HR_{max}) effort of 3-5 min and 2-3 progressive sprints (>15 s, interspersed by 1 min). For the moderate intensity 3-5 min effort, participants skied from the start of the track. On day 2 participants used this same segment to calibrate their starting pace using their own stopwatch, based on the target time they were given for the first ~800-m. Participants were instructed to perform the warm-up identically on day 1 and day 2, including the use of the same terrain. Rate of perceived exertion (RPE) using a 6-20 scale [11] was reported verbally during the race (after ~800 m of each lap, before (~150 m) and after 1st shooting (~50 m), before and after 2nd shooting, ~200 m before the finish) and ~30 s after crossing the finish line [**Figure 1**]. Participants were familiar with the RPE scale and the values they reported were recorded. Because of low quality of heart rate data from many of the participants, only data from 7 (3 men) in the intervention group and 9 (6 men) in the control group could be used. Moreover, since the women and men performed different distances, only the heart rate from the first ~800 m of each lap and the last ~300 m before shooting is shown. The study was conducted in mid-October. Surface and weather conditions were similar on both test days (sunny, air temperature 5-10ºC and wind 2 to 3 $m \cdot s^{-1}$ from Northwest).

Apparatus. All biathletes used their own ski boots and poles and a pair of Swenor Skate rollerskis (Swenor, Sarpsborg, Norway) with wheel type 2 selected from a fleet of matched roller skis. Kinematic data were collected using an integrated IMU and GNSS unit (Optimeye S5, Catapult Innovations, Melbourne, Australia), validated by Gløersen, Kocbach and Gilgien [12]. The unit consisted of a 10 Hz GNSS-receiver, tracking both GPS and GLONASS data, a 3D accelerometer (100 Hz), a 3D magnetometer (100Hz) and a 3D, 34.9 $rad \cdot s^{-1}$ gyroscope (100 Hz). Heart rate was measured using Polar Verity Sense heart rate monitors (Polar Electro Oy, Kempele, Finland).

Data analyses. Segment times (first 800 m of each lap, pre- and post-shooting of each lap to exclude shooting times, Figure 1) and overall times (including shooting 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. Timing from the IMU/GNSS sensors were used to calculate timing excluding shooting. For 8 athletes, GNSS data from personal 1 Hz GNSS receivers were used because of missing data from the 10 Hz GNSS receivers. 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). All figures were created using Sigmaplot (version 13.0; Systat Software Inc, San Jose, CA) or MATLAB R2022a (MathWorks, Inc., Natick, MA, United States).

RESULTS

Overall Performance and Pacing strategy

On Day 1, the overall time (min) for INT was 28:06 ± 1:31 (women, n=6: 26:27 ± 0:51 and men, n=14: 28:49 ± 1:08), while the corresponding time for CON was 26:42 ± 1:28 (women, n=6: 24:59 ± 1:05 min and men, n=12: 27:23 ± 0:52). There were significant differences in overall time between groups where CON performed better than INT (*P*=0.001). On Day 2, the overall time for INT was 27:42 ± 1:31 (women, n=5: 24:25 ± 00:57 and men, n=12: 28:28 ± 00:58) while CON recorded an overall time of 26:43 ± 1:45 (women, n=6: 26:27 ± 0:51 and men, n=14: 27:36 ± 1:00). INT slowed their starting pace for the first ~800-m by 5.0 ± 1.5% (*P*<0.01) from Day 1 to Day 2, with no significant differences for CON (-0.8 ± 2.7%). INT increased their overall time-trial performance more than CON from Day 1 to Day 2 (mean ± 95CI; 1.5 ± 0.7% vs. 0.0 ± 0.9%, *P*=0.02).

Skiing Performance and Pacing strategy excluding shooting time

The pacing index for skiing performance for both days is shown in **Figure 2** while the relative time differences in skiing time between Day 1 and Day 2 for INT and CON are shown in **Figure 3 and 4**. INT improved time-trial performance more than CON (mean ± 95CI; 1.6 ± 0.8% vs -0.4 ± 0.9%, *P*=0.04). When analyzing male and female athletes separately, only the men in INT showed greater performance improvement from Day 1 to Day 2 compared with CON. No differences were found in change from Day 1 to Day 2 between INT and CON for the female athletes. Changes in performance from Day 1 to Day 2 in INT reflected changes in skiing speed in all types of terrain [**Figure 3**].

[Figure 2-4 and Table 1-2 near here]

Shooting performance

No differences in shooting performance were found within or between groups. INT performed prone shootings on Day 1 and Day 2 of 42.1 ± 3.8 and 41.8 ± 2.8 points (*P*=0.74) while the standing shootings resulted in 25.4 ± 6.0 and 24.2 ± 8.0 points (*P*=0.57). CON performed prone shootings on Day 1 and Day 2 of 42.4 ± 3.2 and 42.1 ± 3.2 points (*P*=0.70) while the standing shootings resulted in 28.6 ± 6.0 and 24.9 ± 6.2 points (*P*=0.07).

Heart rate

The HR-response for the first ~800 m and the last ~300 m segment before shooting on lap 3 for INT (n=8) and CON (n=9) on Day 1 and Day 2 are shown in **Table 1.** Both groups displayed a lower HR on Day 2 compared with Day 1 for all the segments analyzed. No significant differences were observed between the two groups.

RPE

The RPE during the race is shown in **Table 2**. On Day 1, there were no between-group differences in RPE for any segments. From Day 1 to Day 2, INT reduced their RPE for all segments on Lap 1, and all segments on Lap 2 except before standing shooting. INT increased their Finish RPE on Day 2 compared with Day 1. In total, INT had a lower summated RPE during the race (all RPE except finish) at Day 2 compared with Day 1 (126 ± 7 vs. 131 ± 5, $P<0.05$). CON had no significant difference in summated RPE at Day 2 compared with Day 1 (131 ± 6 vs. 130 ± 5, $P>0.05$). INT reduced their summated RPE more from Day 1 to Day 2 compared with CON ($P<0.05$).

DISCUSSION

The current experimental study investigated whether highly trained biathletes with a fast-start pacing pattern would improve their overall performance by using more even pacing. The main finding was that changing to a more even pacing strategy resulted in improved time-trial performance, without influencing shooting performance. The improved skiing performance was accompanied by reduced summated RPE, implying less psychological discomfort during the race.

On Day 1, INT used a self-selected "J-shaped" pacing strategy commonly used in sprint biathlon competitions.[1,3] By reducing the starting pace in INT on Day 2, the pacing index became more even and similar to the pattern observed in CON on both days [**Figure 2**]. Moreover, CON was faster than INT on Day 1, which is in line with findings from international races where the best performing biathletes tend to have lap times closer to their average pace compared with lower performing athletes.[3,4] Taken together, these two main findings indicate that an even pacing strategy is the best choice for biathlon performance in the sprint event.

The improved performance in INT compared with CON was only evident in men, and not in women. For women, both INT and CON improved their skiing performance to a similar extent. The reason for this is not known, but men had a hillier track profile with a longer uphill section, in which the changes from a fast-start to a more even pacing pattern could have a larger performance impact. Moreover, it should be noted that only 5 (CON) and 6 (INT) women participated in the project, which did not provide sufficient statistical power to validly compare sexes.

Interestingly, the improved performance in the current study is attributed to increased skiing speed on laps 2 and 3 in all types of terrain **[Figure 3],** including the downhills. Although speculative, it could be assumed that INT were able to maintain their gross efficiency throughout the race better on Day 2 compared with Day 1, resulting in lower RPE. Moreover, in sports such as cross-country skiing and cycling, the ability to efficiently glide or roll when power output is low (e.g., during downhills) is an important factor for the overall result.[9,13,14] This ability is likely linked to maintenance of an efficient technique (e.g., neuromuscular performance which may deteriorate with fatigue) and thereby also influences pacing.[13]

We did not find any changes between groups in heart rate for the analyzed segments at the start and finish of each lap. Although INT reduced their heart rate similarly to what we have found in previous studies with cross-country skiers,[9] CON also displayed similar heart rate changes in the present study. As demonstrated in previous research,[15] heart rate alone may not validly reflect changes in intensity or pacing strategy in sports with highly variable heart rate during races such as cross-country skiing and biathlon.

Performance in biathlon is determined by the combination of skiing speed and the number of targets hit during high-precision rifle shooting. A novel finding in the present study is that shooting performance is not influenced by reducing the starting pace in biathletes with a fast start pacing pattern. From a practical perspective, athletes and coaches have observed that changes in starting pace is challenging for mental preparations before shooting and could have a negative influence at first. For example, a start that is too slow might induce a passive mental state of shooting, whereas a too fast strategy could result in greater physical fatigue, thereby impairing shooting accuracy. Notably, a possible limitation of the analyses of shooting performance is that the athletes shot at paper targets. Although this provides a more accurate measure of shooting performance than “hit” or “miss” on original metal biathlon targets, these paper targets do not provide instant feedback to the athlete. Normally the first shot during both prone and standing shooting are the most missed targets in the World Cup,[3] indicating the difficulty of shooting with a higher heart rate (heart rate drops during shooting) but also the fact that athletes might adjust their aiming strategy if they miss the first shot, thereby increasing the chances of success on the second shot if they missed the first.

Practical Application

The varying terrain in skiing, with corresponding changes in energetic demands [16], requires a continuous decision-making process based on anticipation of effort. As there are no valid objective measures that provide athletes with continuous feedback during races, skiing requires well-calibrated subjective sensations of intensity (e.g., RPE). Interestingly, no differences in RPE were observed between groups on Day 1. Although such comparisons in RPE between athletes should be interpreted with caution, it implies that both groups had the same sensation of the starting pace, despite the relatively faster start pace in INT. This finding is in line with our recent data from cross-country skiers [9] implying that RPE needs to be calibrated individually through objective data during training and competitions. Evaluating competitions based on objective data, such as split-times or GPS patterns combined with self-reported subjective ratings, therefore, is a practical and efficient tool for competitive biathletes and cross-country skiers. When working with highly trained athletes, the methods for modifying pacing patterns used in the present study could be used as a framework for coaches and athletes to enhance training sessions and performance in skiing sports.

CONCLUSIONS

Biathletes with a pronounced fast-start pacing pattern benefit from using a more even pacing strategy to optimize time-trial distance skiing performance. The improved performance was reflected by faster skiing speed in all types of terrain, with no effect on shooting performance. In addition, the use of a more even lap-to-lap pacing strategy led to lower perceived exertion 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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Table 1: Heart rate (HR; beat·min^{-1}) as the average value for the first ~800 m and last ~300 m for each lap. Data are mean and SD. *Significant different from day 1 ($P < 0.05$). INT = intervention (n=8), CON = Control (n=9).

	INT Day 1	INT Day 2	CON Day 1	CON Day 2
Lap 1				
HR First ~800 m	174±10	170±11*	176±10	173±5*
HR Last ~300 m before shooting	182±9	178±8*	179±10	175±11*
Lap 2				
HR First ~800 m	185±9	182±8*	183±9	179±10*
HR Last ~300 m before shooting	183±9	181±10*	181±9	176±10*
Lap 3				
HR First ~800 m	185±8	182±9*	184±9	181±9*
HR Last ~300 m before finish	185±8	183±9	185±10	181±9*

Table 2. Rate of perceived exertion (RPE) using a 6-20 scale during the time-trial and at the finish. Women performed 3 laps of 2.5 km (7.5 km) while men performed 3 laps of 3.3 km (10 km). Pre and Post shooting RPE was recorded ~150 m before and ~50 m after shooting on each lap. Pre-finish was recorded ~200 m from finish. *Significant different from day 1 ($P < 0.05$)

Lap	Position	INT Day 1	INT Day 2	CON Day 1	CON Day 2
1	~800-m	14.9 ± 1.4	13.7 ± 1.6*	15.5 ± 1.3	15.2 ± 1.2*
	Pre-shooting Prone	15.9 ± 1.1	15.0 ± 1.4*	16.0 ± 1.2	15.9 ± 1.1
	Post-Shooting Prone	13.3 ± 1.1	12.7 ± 1.7*	13.4 ± 1.1	13.3 ± 1.1
2	~800-m	17.4 ± 0.7	16.4 ± 0.9*	17.4 ± 1.0	17.0 ± 1.0
	Pre-shooting Standing	16.9 ± 0.9	16.7 ± 0.7	17.0 ± 1.1	16.8 ± 0.8
	Post-Shooting Standing	15.2 ± 1.3	14.7 ± 1.3*	14.7 ± 1.6	14.5 ± 1.2
3	~800-m	18.2 ± 0.8	18.1 ± 0.8	18.1 ± 0.8	18.2 ± 1.0
	Pre-finish (200-m to finish)	18.9 ± 0.8	19.2 ± 0.6	19.3 ± 0.7	19.1 ± 0.6
	Finish	19.4 ± 0.8	19.7 ± 0.6*	19.6 ± 0.5	19.6 ± 0.6

Figure legends

Figure 1: Racetrack including where RPE was reported. Men did 3 laps of 3.3 km and women 3 laps of 2.5 km with prone and standing shooting between laps. Red = uphills, grey = flat, green = downhills.

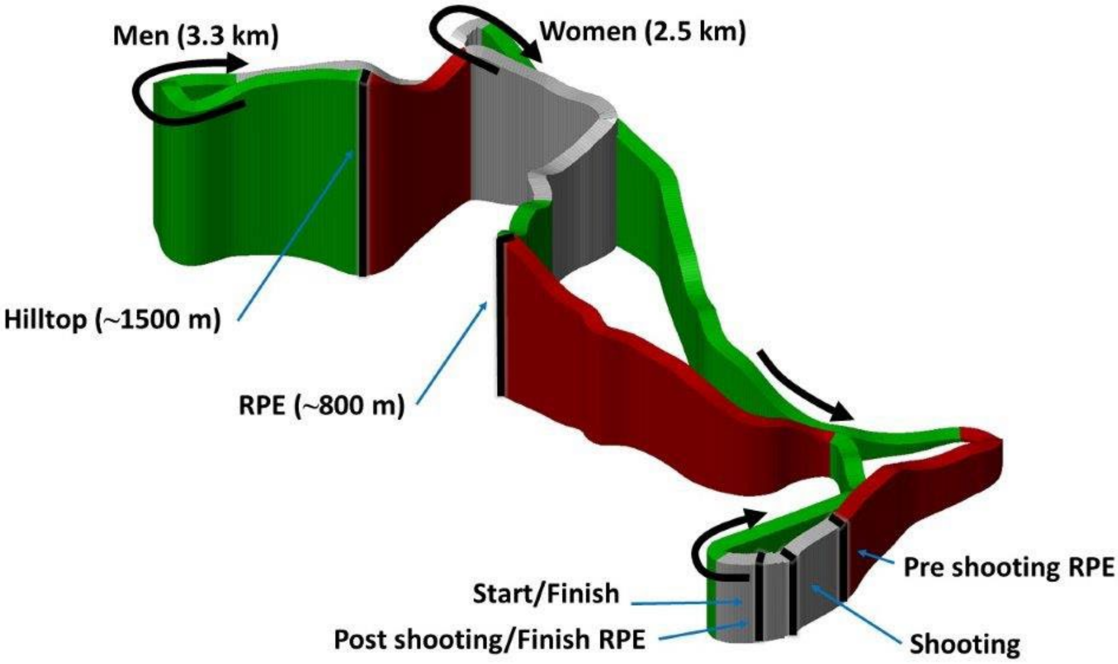

Figure 2. The Pacing Index for the different laps, extracting the shooting time. The Pacing Index is calculated as (segment time - average segment time) / segment time. *Significantly different between Day 1 and Day 2 for the Intervention group (INT) ($P < .05$). CON indicates control; INT, intervention. The bars indicate CI 95%.

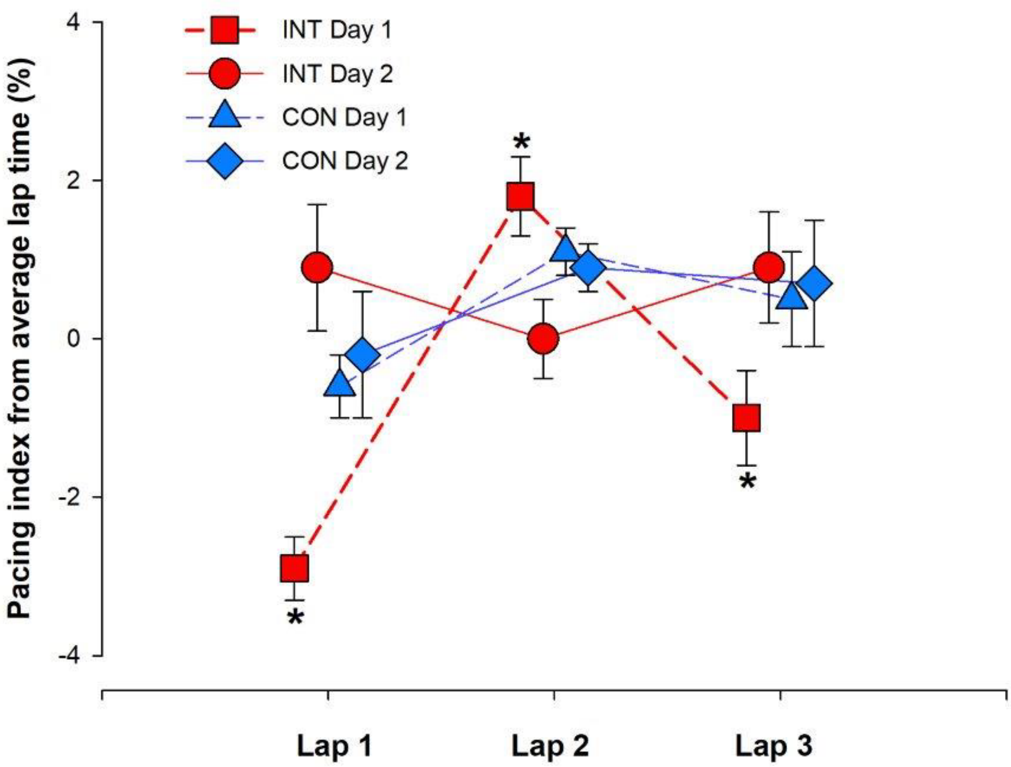

Figure 3: Relative skiing time differences (excluding shooting) from Day 1 to Day 2 for INT (Intervention) in red and CON (Control) in blue. The thin dotted lines illustrate the segments were only the men skied. Women performed 7.5 km and men 10 km. The brown area indicates the segment where INT were instructed to target their Day 1 average ~800 m segment pace from Lap 1-3 at Lap 1.

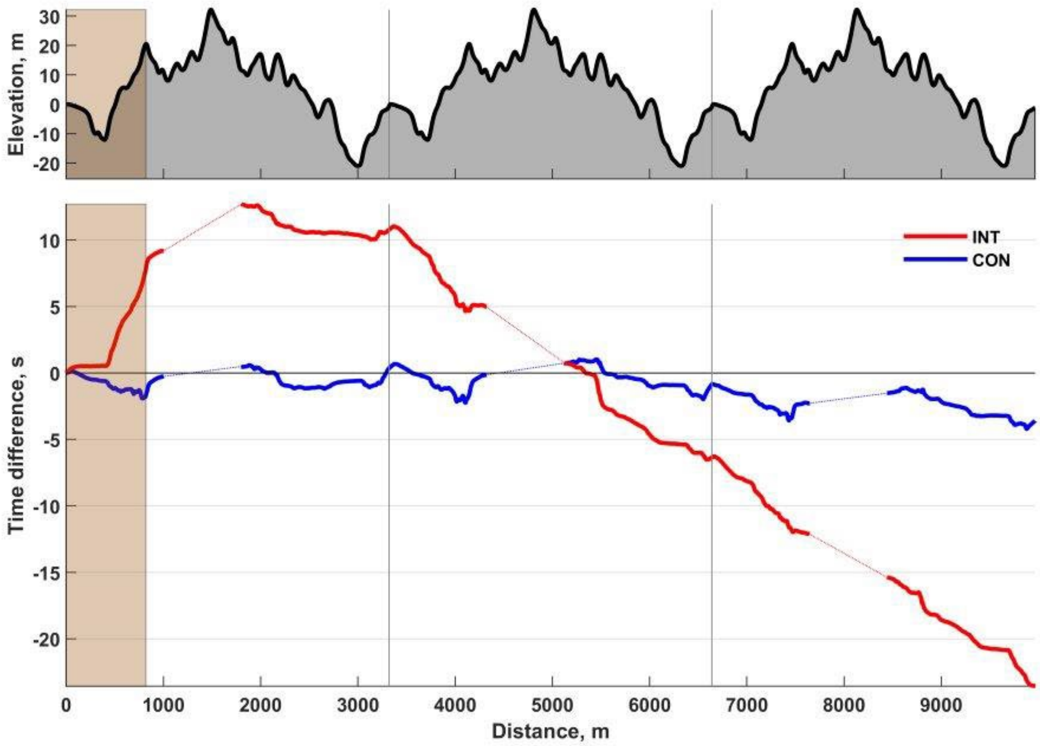

Figure 4: Individual relative time differences from Day 1 to Day 2 for INT (Intervention) in red and CON (Control) in blue. The thin dotted lines illustrate the segments were only the men skied. Women performed 7.5 km and men 10 km. The brown area indicates the segment where INT were instructed to target their Day 1 average ~800 m segment pace from Lap 1-3 at Lap 1. The men in INT were also told to prolong their more "controlled" pace over the first ~1500-m (green area) of Lap 1.