One long vs. two short sessions? Physiological and perceptual responses to low-intensity training at self-selected speeds in cross-country skiers

Original investigation

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Abstract

Purpose: To compare self-selected speeds and corresponding physiological responses and perceived training stress between one long session vs. two shorter sessions of low-intensity training (LIT) in one day among cross-country skiers. **Methods:** Thirteen national-level skiers performed two different LIT types during classical roller-skiing matched for the same distance in a counterbalanced order. The training consisted of either one long (~3 hours) session (1LIT) or two shorter (~1.5 hour each) sessions (2LIT) with 7 hours of recovery in between. Speed, heart rate (HR), rating of perceived exertion (RPE), and blood lactate concentrations (Bla) were measured, and perceived training stress (1-10) assessed after sessions. **Results:** 2LIT was performed at mean (SD) 1.9% (2.0%) higher speeds vs. 1LIT ($P \leq 0.01$). Higher speeds were also found in the second vs. first session of 2LIT and the second vs. first part of 1LIT (1.9% [3.2%] and 3.2% [3.6%], respectively, both $P \leq 0.01$). There were no significant differences between LIT types in HR, although RPE increased in the second vs. first part of 1LIT (0.9 [0.8]-point $P \leq 0.01$). Bla was reduced in the second vs. first session/part of both LIT types (~0.16 [0.20] $mmol \cdot L^{-1}$, $P \leq 0.05$). There were no differences in perceived training stress between LIT types 7 and 23 hours after training, although higher perceived muscular exertion (2.0 [1.1]-point $P \leq 0.01$) was found directly after 1LIT. **Conclusion:** Compared to a distance-matched long session, skiers perform two shorter sessions of LIT at slightly higher self-selected speeds with the same physiological responses elicited although minor differences in perceived training stress were observed.

Keywords: duration, endurance training, intensity, physiological drift, LIT, XC skiing.

Introduction

Cross-country (XC) skiing is an endurance sport performed over varied terrain inducing interval-based fluctuations in external and internal intensity, as well as frequent changes between sub-techniques.[1-3] To accommodate these demands, skiers perform high annual training volumes (~750-950 hours) consisting of ~90% endurance training.[4-7] Although XC skiing competitions are performed at high intensities with an interaction between aerobic and anaerobic energy systems,[1] ~90% of the endurance training (~600-800 hours) is performed as low-intensity training (LIT).[4-7] For example, the world's most decorated female skier of all time performed on average 784 LIT hours during her most successful seasons, with 24% of the sessions distributed as "long sessions" (>150 min) and 17% as "short sessions" (<90 min) in the general preparation period. The remaining 59% of LIT sessions were between 90–150 min.[6]

XC skiers perform substantial parts of their LIT volume in varied terrain and competition-specific racecourses, leading to terrain-dependent intensity fluctuations, as evident during competitions.[8-10] These large volumes of LIT lead to high overall training volumes and are an important stimulus both for physiological and technical development.[3] Here, an important feature is to perform LIT at speeds relevant to the higher competition-specific speeds, in which previous studies have found the largest speed differences between LIT and competition-specific speeds (i.e., high intensity [HI]) in uphill terrain.[8-10] However, these studies are limited by their use of short LIT sessions (~20 min) since both overall and terrain-specific speeds might differ between LIT sessions of different duration.

Once-a-day vs. twice-a-day training ("doubles") are frequently discussed in endurance training optimization.[11] For example, performing the same LIT work or distance as either one long session or two shorter sessions in one day might elicit differences in self-selected speeds, physiological responses and thereby influence adaptive signaling, as well as recovery times differently.[11] However, the majority of studies today have only investigated twice-a-day training as a strategy to perform the second session in a more glycogen depleted state (i.e., "train-low").[12] In this context, it is also likely that longer sessions elicit duration-dependent "drifts" in rating of perceived exertion (RPE) and heart rate (HR). This has recently been referred to as "durability", and defined as deterioration in physiological characteristics over time during prolonged exercise.[13] These changes in physiological responses associated with longer sessions may induce a different physiological stimulus compared to performing two shorter sessions, but may also increase training stress and recovery demands. Consequently, a better understanding of the influence of performing one long vs. two shorter sessions of LIT in one day on physiological and perceptual responses, as well as the associated training stress and recovery in endurance athletes is needed.

Therefore, the purpose of this study was to compare self-selected speeds and corresponding physiological responses and perceived training stress between performing one long vs. two shorter sessions of LIT in one day among XC skiers. It was hypothesized that the skiers would perform two shorter sessions at higher speeds due to the reduced duration of each session, whereas the long session would be associated with a duration-dependent drift in physiological and perceptual responses and thus influence subjective markers of training stress more negatively.

Methods

Participants

Thirteen male skiers volunteered to participate in the study (participant characteristics are shown in Table 1). The participants were classified as highly trained/national level athletes according to the classification framework developed by McKay et al.[14] The study is done in accordance to the institutional ethical requirements, and approval for data security and handling was obtained from the Norwegian Centre for Research Data. The study was conducted in accordance with the Declaration of Helsinki, and all participants signed an informed consent prior to the experimental trials.

[Table 1]

Design

The two experimental trials were performed in a counterbalanced order, consisting of either one long (~3 hours) LIT session (1LIT) or two shorter (~1.5 hour each) LIT sessions (2LIT) with 7 hours of recovery in between. The 1LIT and 2LIT was matched for the same distance and performed over two consecutive days. The experimental trials were performed in a roller-skiing racecourse using the classical technique during the skier's late preparation period (October). Speed and HR were continuously monitored for all sessions, whereas subjective markers of training stress and recovery were determined at two different time points after sessions. The participant's diet was monitored, and fluid and carbohydrate (CHO) intake standardized during all sessions (see nutritional protocol). After the experimental trials on day three, a simulated competition (~34 min HI session) was performed in the same racecourse to compare terrain-specific external and internal intensities during LIT with competition-specific values.

Protocols and measurements

Experimental trials

The participants training loads were standardized over the last two days before the experimental trials consisting of one moderate-intensity training (MIT) session (~45-min total work duration) in roller-ski skating the penultimate day and one LIT session (~1.5-hour duration) in running the last day before the trials. Both the experimental trials and the simulated competition were performed in a 4.5-km roller-skiing racecourse. Course and elevation profiles of the racecourse (Figure 1) were measured with an integrated global positioning system (GPS) and barometer (Garmin Forerunner 920 XT [Garmin Ltd., Olathe, KS, USA]) using a methodology previously described.[15] The racecourse was further divided into four different terrain sections: S1 (uphill: distance, 1140 m; climb, + 65 m; gradient, 6%), S2 (flat: distance, 400 m; climb, +7 m; gradient, 0%), S3 (downhill: distance, 1770 m; climb, -71 m; gradient, -3%), and S4 (flat: distance, 970 m; climb, +2 m; gradient, 0%). A small part (flat: distance, 220 m; climb, 0 m; gradient; 0%) at the start and finish of the racecourse was excluded from the analyses because the participants reduced their speed and stopped during this part in connection to measurements and fluid intake. The exact distance of the racecourse analyzed was therefore 4280 m. The participants were blinded for all measures of external and internal intensity during the experimental trials. The participants started with a 1-min starting interval in a randomized order. The participants were further instructed not to draft behind each other to establish valid comparisons. Weather conditions were similar and stable during all three days being partly cloudy, with ambient air temperatures of 12-15 °C, a low and stable wind (3-4 $m \cdot s^{-1}$), and relative humidity varying between 60% and 65%.

[Figure 1]

Low-intensity training types. Seven and six of the participants started with 2LIT and 1LIT on day 1, respectively. The two LIT types were distance-matched, consisting of two sessions of 6 laps for 2LIT (25.7 km) and one session of 12 laps for 1LIT (51.4 km), respectively. Every second lap was interspersed with a ~2-min recovery period to determine blood lactate concentrations (Bla), RPE using the 6–20-point Borg scale,[16] and to provide fluid and CHO intake. The participants were instructed to perform all LIT sessions according to their own self-selected LIT speeds but to target an intensity corresponding to RPE = 8-12.[16] The two sessions constituting 2LIT were separated by 7 hours of recovery, in which the participants rested at home according to their self-selected recovery procedures (including fluid and dietary intake) used in connection with twice-a-day training sessions.

Simulated competition. The simulated competition was an individual time-trial consisting of 3 laps in the same racecourse (12.8 km). The distance was chosen based on its relevance for the group of skiers. The participants were instructed to perform ~30 min of self-selected warm-up prior to the start of the competition. The participants started with a 1-min starting interval in a randomized order. Performance times were recorded as previously described by Talsnes et al.[17]

Nutritional protocol. In an attempt to standardize nutritional status, breakfast before sessions and lunch between/after sessions were provided to the participants. The participants were instructed to replicate their dietary intake across the experimental trials and the simulated competition. The content of all meals was self-reported under supervision of the researchers conducting the study. Between lunch and the start of the 2. session during 2LIT, the participant recorded their fluid and nutritional intake. No differences in dietary intake between the experimental trials were found (see supplementary Table 1 for detailed description). During the experimental trials, the participants consumed 0.3 dl of sports drink (High 5 Sports Nutrition., Brighton, United Kingdom) every second lap. The total intake during 6 laps was 0.9 L (0.6 L/h). Fluid and CHO intake were matched between 2LIT and 1LIT. The amount of sports drink and CHO intake (40 g/h) were in accordance with the ACSM guidelines on CHO intake during endurance exercise.[18]

Measurements and equipment

The participants used the same type (category two wheels) and pair of roller skis (IDT Sports, Lena, Norway) during the experimental trials and the simulated competition. HR was monitored continuously during all sessions using a wrist-worn Garmin Forerunner 920 XT/935 watch. Due to measurement error, HR data was missing on four of the participants and are therefore presented as n=9. Bla of 5-μL samples were taken from the fingertip and analyzed using a Lactate Scout 4 kit (EKF diagnostics., Cardiff, United Kingdom). Speed was continuously monitored using an integrated global navigation satellite system (10 Optimeye S5 [Catapult Sports, Melbourne, Australia] and 3 Admos [Advanced Sport Instruments, Lausanne, Switzerland]). The Catapult sensors has previously been validated against a geodetic, multi-frequency receiver by Gløersen et al.,[19] and the Admos sensors included the same specifications.

Training stress and recovery. The participants were asked to rate and report their sleep quality the previous night, general mental and physical wellbeing, readiness to train, muscle soreness, fatigue, and attractiveness to the training day, using a visual analogue scale (VAS) from 1 to 10. These subjective markers were reported 7 hours (POST-1) and 23 hours (POST-2) after the start of the first session for both 2LIT and 1LIT. Moreover, the participants answered a questionnaire on their acute perceived muscular and ventilatory exertion directly after each session. For comparison of these variables, the average of the two sessions constituting 2LIT was compared to the corresponding values for 1LIT.

Statistical analyses

All statistical analyses were carried out using SPSS 26.0 (SPSS Inc, Chicago, IL, United States). Data are reported as mean (standard deviation [SD]) for continuous variables and assumptions of normality verified using a Shapiro–Wilk test. Ordinal data are reported as median (interquartile range [IQR]). Analyses of variances (ANOVA) for repeated measures was applied to compare speed and physiological responses between the experimental trials. Initially, main effects of LIT type (2LIT vs. 1LIT) and session/part within LIT type (first vs. second session [2LIT] and first vs. second part [1LIT], respectively) were examined. Further, possible interaction effects between LIT type and LIT session/part were evaluated. In cases of significant interaction effects, pairwise comparisons were applied using the paired-sample t-test procedure. The strength of the main analyses was quantified by effect size (ES) calculated as partial eta square (partial eta^2) with 0.01, 0.06, and 0.14 interpreted as small, medium, and large effects, respectively.[20] The non-parametric Wilcoxon signed-rank test was applied to compare subjective markers of training stress and recovery between LIT types. For all comparisons, alpha levels of $P \leq 0.05$ were considered statistically significant.

Results

Speed characteristics. Descriptive data for time and speed between and within LIT types, as well as the HI session (simulated competition) are shown in Table 2 and supplementary Table 2. There was a main effect of both LIT type (F=10.5, P=0.008, partial eta^2=0.488) and LIT session/part (F=11.5, P=0.006, partial eta^2=0.511) on speed. Analyses revealed 1.9% (2.0%) higher speeds in 2LIT vs. 1LIT (Figure 2), as well as higher speeds in the second vs. first LIT session/part (1.9% [3.2%] and 3.2% [3.6%] for 2LIT and 1LIT, respectively, Figure 2). Similar main effects of LIT type and LIT session/part were found comparing speed in %HI. Time differences between and within LIT types for each lap are displayed in Figure 3.

[Table 2]

[Figure 2]

[Figure 3]

There was a significant main effect of LIT type in S2 (F=7.06, P=0.021, partial eta^2=0.370) and S4 (F=6.7, P=0.024, partial eta^2=0.359), as well as a tendency towards main effect in S3 (F=4.04, P=0.058, partial eta^2=0.268). There was a significant main effect of LIT session/part in S1 (F=10.1, P=0.008, partial eta^2=0.456), S2 (F=14.3, P=0.003, partial eta^2=0.544), S3 (F=15.9, P=0.002, partial eta^2=0.570), and S4 (F=4.8, P=0.049, partial eta^2=0.286). All main effects revealed higher speeds in 2LIT vs. 1LIT, and higher speeds in the second vs. first LIT session/part within LIT types.

Physiological and perceptual responses. Descriptive data on physiological responses between and within LIT types are shown in Table 2 and Figure 4. There were no significant main effects of LIT type or LIT session/part on HR, $\%HR_{max}$, and HR in %HI. There was a main effect of LIT session/part on Bla (F=4.9, P=0.047, partial eta^2=0.290), revealing lower Bla during the second session/part within both LIT types (~0.16 [0.20] $mmol \cdot L^{-1}$, both $P \leq 0.05$). There was an interaction effect found between LIT type and LIT session/part on RPE (F=12.7, P=0.004, partial eta^2=0.514). Analyses revealed higher RPE during the second vs. first part of 1LIT (2.0 [1.1]-point P=0.011). Although not significant, large interaction effects (ES=0.230-0.240) between LIT type and LIT session/part on HR were found. However, pairwise comparisons demonstrated no significant differences (P=0.112 and P=0.321) for the second vs. first session of 2LIT and the second vs. first part of 1LIT, respectively. There was a significant interaction between LIT type and LIT session/part on HR in S1 (F=4.6, P=0.046, partial eta^2=0.410). Analysis revealed reduced HR in the second vs. first session of 2LIT (P=0.013). However, no significant main effects of LIT type or LIT session/part on HR in the different terrain sections were found. Similar findings were found for $\%HR_{max}$ and HR in %HI.

[Figure 4]

Perceived training stress and recovery. There were no significant differences in any of the VAS markers of training stress and recovery between LIT types at POST-1 and POST-2 (Table 3). However, higher acute perceived muscular (2.0 [1.1]-point, P=0.012) and ventilatory (1.0 [1.0]-point, P=0.023) exertion were found for 1LIT vs. 2LIT.

[Table 3]

Discussion

The purpose of this study was to compare self-selected speeds and corresponding physiological responses and perceived training stress between performing one long vs. two shorter sessions of LIT in one day among XC skiers. The main finding was that skiers perform two shorter sessions at higher self-selected speeds compared to one long session. Higher speeds were also observed in the second session of 2LIT and the second part of 1LIT. However, no significant differences in average physiological and perceptual responses were found between LIT types, although RPE increased in the second part of 1LIT. Lastly, higher acute perceived muscular and ventilatory exertion were found in connection to 1LIT, although perceived training stress and recovery were not significantly different between LIT types 7 and 23 hours after training.

This is the first study to investigate differences in external and internal intensity between different LIT manipulations in XC skiing and to compare these intensities to competition-specific values. In accordance with the hypotheses, skiers perform two shorter sessions in one day at higher self-selected speeds compared to one long LIT session. However, significant main effects of LIT type were only found during the two flat terrain sections, with a tendency toward significant main effect in the downhill section. This implies that the observed speed differences between 1LIT and 2LIT were mostly due to differences in flat and downhill terrain at relatively high speeds, whereas no differences were found in uphill terrain at lower speeds. Although the observed speed differences were statistically significant, their practical relevance (only ~2% speed or ~3 min time difference) may be questioned. However, it cannot be ignored that these findings may have implications for skiers' technical training by allowing more competition-relevant speeds in flat and downhill terrain sections. It could also be speculated that such speed differences would be more evident in racecourses involving larger terrain variations (i.e., speed fluctuations and sub-technique changes) than the racecourse used in the present study, with only 4 terrain sections and a ~4-min downhill section. Therefore, future studies including data on sub-technique selection and associated kinematical patterns are needed to further understand technical responses to different LIT manipulations in XC skiing.

The overall LIT speeds were ~82-83% of competition speeds, and were somewhat higher than those previously reported among male skiers.[8,10] However, contrary to the present study, these studies were performed on snow using the skating technique with similar distances for LIT and HI. This may indicate that LIT are performed closer to competition speeds while roller-skiing compared to actual on-snow skiing. However, independent of LIT type, skiers performed both short and long LIT sessions relatively close to their competition speeds (~83% and ~90% in flat and downhill terrain sections, respectively). Relative to competition-specific values, the largest speed differences were found in the uphill terrain section (~73-74% of competition speed), in accordance with previous findings.[8,10] Altogether, the present findings indicate a large potential for performing high volumes of LIT at competition-relevant speeds in XC skiing.

Interestingly, there was a significant main effect of LIT session/part on speed, revealing higher speeds in the second session of 2LIT and the second part of 1LIT, which was consistent across the different terrain sections investigated. The reason for these findings is not known but may imply better “performance” in the afternoon during 2LIT, possibly explained by circadian variations (i.e., time-of-day effects)[21] and/or positive precondition-effects from the first session.[22] However, more surprising were the higher speeds found during the second part of 1LIT, indicating a “pacing strategy” with increasing speeds throughout the long LIT session. In particular, the first 3 laps of 1LIT were slower and the first 2 laps of the second session of 2LIT were faster than the average time for all laps. Whether this observation is only a consequence of the distance-matched design or a deliberate “pacing practice” employed during different LIT sessions among skiers remains unknown and requires attention in future studies.

There were no significant main effects of LIT type on average HR responses, indicating that the two LIT types elicited somewhat similar physiological loads. However, interaction effects (large ES) between LIT type and LIT session/part on HR were found, which did not reach significance due to the reduced statistical power on HR data. These interaction effects indicated reduced HR in the second vs. first session of 2LIT (particularly the first 4 laps) and *vice-versa* in the second vs. first part of 1LIT (particularly the last 4 laps), although the pairwise comparisons did not reach statistical significance. These indications were further strengthened by the significant interaction effects on HR found in S1 (uphill terrain), revealing significantly lower HR in the second vs. first session of 2LIT. These findings coincided with an interaction effect between LIT type and LIT session/part on RPE, revealing higher RPE in the second vs. first part of 1LIT. Altogether, the observed physiological and perceptual responses were partly in accordance with the hypotheses, implying a small duration-dependent HR and RPE “drift” in connection to the long LIT session.[13] However, considering the experimental design using self-selected speeds, and the higher speeds found during the second part of 1LIT, the reasons for these physiological and perceptual changes cannot be established. Lastly, there was a significant main effect of LIT session/part on Bla, revealing reduced Bla in the second vs. first session/part of both LIT types. These findings are likely explained by glycogen depletion, and reduced CHO availability,[12] which were somewhat surprising, particularly during 2LIT, considering the amount of exogenous CHO provided. Altogether, future studies using laboratory designs under more standardized conditions should further investigate physiological responses and potential "drifts" in HR and RPE (i.e., internal-to-external workload ratio) between long vs. short LIT sessions.

There were no significant differences between LIT types in the subjective markers of training stress and recovery (VAS) measured at two different time points after sessions. This implies somewhat similar training-induced stress and recovery demands from performing one long session vs. two shorter sessions of LIT in one day. However, higher perceived muscular and ventilatory exertion, assessed directly after each session was found in connection to 1LIT, revealing some inconsistency in the training stress data. Therefore, training stress and associated recovery times for different LIT manipulations should be further investigated using objective markers of hormonal and/or autonomic disturbance. When considering the optimal ratio between signaling and stress of performing one long vs. two shorter LIT sessions, the question is probably not whether one or the other are needed, and most likely, both are relevant for maximizing responses from endurance training. For example, one long session might elicit a greater magnitude of molecular signaling, but induce a higher stress response, whereas two shorter sessions might elicit higher external intensities, different signaling and a lower stress response.[11] However, these topics are only speculative, and intervention studies on the actual training effects of different LIT manipulations are warranted to elucidate these questions.

Practical applications

Two shorter LIT sessions are performed at slightly higher self-selected speeds than one long LIT session, particularly on flat and downhill terrain during skiers LIT training. However, the practical significance of these findings can be questioned as the average speed difference was only ~2%. Still, this may have implications for the technical training of skiers by allowing sub-technique selections and kinematical patterns closer to competition-specific values. Therefore, such features should be considered when programming LIT sessions, constituting ~90% of the endurance training volume among skiers. However, performing a longer LIT session may elicit higher acute training stress, thereby inducing a different physiological stimulus, although perceived training stress and recovery one day after were the same as after performing two shorter sessions.

Conclusions

Compared to a distance-matched long session, skiers perform two shorter sessions of LIT in one day at slightly higher self-selected speeds, particularly on flat and downhill terrain. These findings coincided with average similar physiological responses, although minor differences in perceived training stress were observed between the two LIT types.

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Table 1. Participant characteristics of the thirteen national-level male cross-country skiers participating in the study.

Variables	
Age (y)	19 (1)
Body height (cm)	180.2 (5.2)
Body mass (kg)	73.2 (6.8)
Body mass index ($kg \cdot m^{-2}$)	22.3 (1.5)
VO_{2max} ($L \cdot min^{-1}$)	4.99 (0.36)
VO_{2max} ($mL \cdot min^{-1} \cdot kg^{-1}$)	68.4 (3.5)
HR_{max} ($beats \cdot min^{-1}$)	201 (8)
Annual training volume ($h\ y^{-1}$)	566 (52)
Distance FIS points	223 (43)

VO_{2max}, maximal oxygen uptake obtained during incremental running in the laboratory; HR_{max}, maximal heart rate obtained during incremental running in the laboratory; FIS, International Ski Federation. Data are presented as mean (standard deviation).

Table 2. Descriptive data on speed, physiological, and perceptual responses to one long vs. two short sessions of low-intensity training, as well as a simulated competition (high intensity) in national-level male cross-country skiers.

	1LIT		**2LIT**		**1LIT**	**2LIT**	**HI**
Variables	**1.Part**	**2.Part**	**1. Session**	**2.Session**	**Total**	**Total**	**Total**
Total							
Time (min:sec)	86:28 (03:28)	83:38 (02:55)	84:34 (02:33)	82:51 (03:24)	170:05 (06:01)	167:24 (05:13)	33:47 (00:32)
Speed ($m \cdot s^{-1}$)	5.17 (0.21)	5.34 (0.17)	5.29 (0.14)	5.40 (0.18)	5.26 (0.18)	5.34 (0.14)	6.43 (0.13)
HR ($beats \cdot min^{-1}$)	139 (7)	140 (8)	142 (5)	139 (8)	140 (6)	140 (7)	178 (5)
HR in %HR_{max}	69.4 (3.4)	70.0 (4.3)	70.6 (3.0)	69.1 (4.4)	69.8 (3.6)	69.7 (3.8)	88.9 (1.9)
Bla ($mmol \cdot L^{-1}$)	0.8 (0.1)	0.7 (0.0)	0.9 (0.3)	0.7 (0.1)	0.8 (0.2)	0.8 (0.2)	7.8 (2.7)
RPE (6-20)	11.2 (0.4)	12.0 (0.3)	11.3 (0.8)	11.3 (1.0)	11.3 (0.9)	11.3 (0.8)	18.0 (2.5)
Speed in %HI	80.5 (3.6)	83.1 (2.7)	82.3 (2.8)	83.9 (3.2)	81.8 (3.0)	83.1 (2.7)	NA
HR in %HI	78.1 (2.9)	78.7 (4.0)	79.4 (2.1)	77.7 (4.0)	78.5 (2.9)	78.4 (3.4)	NA
Segment 1							
Time (min:sec)	06:06 (00:18)	05:53 (00:17)	05:58 (00:13)	05:50 (00:22)	06:00 (00:17)	05:54 (00:16)	04:23 (00:05)
HR ($beats \cdot min^{-1}$)	143 (6)	144 (7)	146 (5)	143 (6)	144 (7)	144 (6)	181 (5)
HR in %HR_{max}	71.5 (3.0)	72.0 (3.8)	72.9 (2.9)	71.1 (4.2)	71.8 (3.4)	72.0 (3.5)	90.2 (2.2)
Speed in %HI	72.0 (3.4)	74.6 (3.3)	73.5 (2.6)	75.3 (4.3)	73.3 (3.2)	74.4 (3.1)	NA
HR in %HI	79.3 (2.0)	79.7 (3.0)	80.8 (1.9)	78.8 (3.7)	79.5 (3.4)	79.8 (2.7)	NA
Segment 2							
Time (min:sec)	01:34 (00:05)	01:30 (00:04)	01:31 (00:03)	01:29 (00:04)	01:32 (00:04)	01:30 (00:03)	01:10 (00:02)
HR ($beats \cdot min^{-1}$)	144 (7)	145 (9)	146 (6)	143 (8)	144 (7)	145 (7)	184 (6)
HR in %HR_{max}	71.6 (3.5)	72.4 (4.6)	73.0 (3.4)	71.5 (4.6)	72.0 (4.0)	72.3 (3.9)	91.7 (1.8)
Speed in %HI	75.3 (3.9)	78.6 (3.7)	77.8 (3.2)	79.4 (3.9)	77.0 (3.6)	78.6 (3.2)	NA
HR in %HI	78.0 (3.1)	78.9 (4.2)	79.5 (2.7)	78.0 (4.3)	78.4 (3.6)	78.8 (3.4)	NA
Segment 3							
Time (min:sec)	03:54 (00:10)	03:47 (00:07)	03:49 (00:05)	03:45 (00:07)	03:51 (00:09)	03:47 (00:05)	03:24 (00:04)
HR ($beats \cdot min^{-1}$)	132 (8)	133 (9)	134 (6)	132 (9)	133 (8)	133 (7)	174 (7)
HR in %HR_{max}	65.8 (4.1)	66.5 (4.7)	66.9 (3.0)	66.0 (4.7)	66.2 (4.3)	66.4 (3.6)	86.7 (2.2)
Speed in %HI	87.0 (3.6)	89.6 (2.3)	90.0 (2.4)	90.8 (2.4)	88.3 (2.9)	90.0 (2.0)	NA
HR in %HI	75.9 (4.5)	76.7 (5.2)	77.1 (2.5)	76.1 (4.7)	76.3 (4.7)	76.6 (3.2)	NA
Segment 4							
Time (min:sec)	02:50 (00:07)	02:46 (00:05)	02:47 (00:05)	02:45 (00:07)	02:48 (00:05)	02:46 (00:06)	02:19 (00:04)
HR ($beats \cdot min^{-1}$)	138 (7)	139 (9)	139 (6)	136 (9)	138 (8)	138 (7)	177 (7)
HR in %HR_{max}	68.6 (3.8)	69.4 (4.9)	69.5 (3.3)	67.7 (5.1)	69.0 (4.2)	68.6 (4.1)	88.3 (2.0)
Speed in %HI	81.8 (4.5)	83.9 (3.2)	83.2 (4.0)	84.5 (4.2)	82.8 (3.7)	83.9 (3.7)	NA
HR in %HI	77.7 (4.3)	78.5 (4.7)	78.7 (2.7)	76.6 (4.7)	78.1 (4.0)	77.6 (3.4)	NA

1LIT, one long low-intensity training session; 2LIT, two short low-intensity training sessions; HI, high-intensity obtained from a simulated-competition; HR, heart rate; HR_{max}, maximal heart rate; Bla, blood lactate; RPE, rating of perceived exertion; NA, not available. Data are presented as mean (standard deviation).

Table 3. Descriptive data on subjective markers of training stress and recovery between one long vs. two short sessions of low-intensity training in national-level male cross-country skiers.

	1LIT	**2LIT**		
Variables	**Session**	**1. Session**	**2.Session**	**Total**
Perceived muscular exertion (1-10)	6.0 (3.0)	4.0 (1.5)	4.0 (1.5)	4.0 (1.0)
Perceived ventilatory exertion (1-10)	4.0 (1.5)	3.0 (1.5)	3.0 (1.5)	3.0 (1.5)
Perceived technical quality (1-5)	4.0 (0.5)	4.0 (1.0)	4.0 (1.0)	4.0 (1.3)
	1LIT		**2LIT**	
Variables	**POST-1**	**POST-2**	**POST-1**	**POST-2**
Sleep quality (1-10)	7.0 (1.0)	7.0 (2.0)	7.5 (2.0)	6.0 (2.5)
General mental wellbeing (1-10)	7.0 (2.0)	8.0 (3.0)	8.0 (2.0)	8.0 (2.5)
General physical wellbeing (1-10)	7.0 (2.0)	7.0 (2.0)	7.0 (2.0)	7.0 (2.0)
Readiness to train (1-10)	7.0 (2.0)	6.0 (2.0)	7.0 (2.0)	7.0 (3.0)
Muscle soreness (1-10)	6.0 (2.0)	7.0 (1.5)	7.0 (2.5)	7.0 (0.5)
Fatigue (1-10)	6.0 (2.0)	6.5 (1.0)	7.0 (2.5)	7.0 (2.5)
Attractiveness to the training day (1-10)	7.0 (2.0)	8.0 (2.0)	8.0 (2.5)	8.0 (1.5)

1LIT, one long low-intensity training session; 2LIT, two short low-intensity training sessions; POST-1, seven hours after the start of low-intensity training session; POST-2, twenty-three hours after start of low-intensity training session. Data are presented as median (interquartile range).

Figure captions

Figure 1 - (A) two-dimensional and (B) three-dimensional map of the 4.3-km racecourse divided into 4 different terrain sections.

Figure 2 - Speed difference between (upper panel) and within (lower panel) 1LIT and 2LIT among thirteen national-level male cross-country skiers. 2LIT-1, first session of two short low-intensity training sessions; 2LIT-2, second session of two short low-intensity training sessions; 1LIT-1, first part of one long low-intensity training session; 1LIT-2, second part of one long low-intensity training session.

Figure 3 - Time differences per lap compared to average lap time for 1LIT and 2LIT among thirteen national-level male cross-country skiers. 2LIT-1, first session of two short low-intensity training sessions; 2LIT-2, second session of two short low-intensity training sessions. 1LIT-1, first part of one long low-intensity training session; 1LIT-2, second part of one long low-intensity training session.

Figure 4 - Heart rate differences (percent-point of maximal heart rate) between (upper panel) and within (lower panel) 1LIT and 2LIT among nine national-level male cross-country skiers. 2LIT-1, first session of two short low-intensity training sessions; 2LIT-2, second session of two short low-intensity training sessions; 1LIT-1, first part of one long low-intensity training session; 1LIT-2, second part of one long low-intensity training session.

Supplementary Table 1. Fluid and nutritional intake across the experimental trials and the simulated competition in national-level male cross-country skiers.

	1LIT		2LIT			HI
Variables	**Breakfast**	**Lunch**	**Breakfast**	**Lunch**	**Snack**	**Breakfast**
Fluid, ml/kg body mass	4.9 (1.4)	10.4 (3.7)	4.7 (1.1)	9.7 (3.2)	6.5 (0.8)	4.8 (1.8)
Energy, kcal/kg body mass	7.7 (1.5)	13.8 (3.4)	8.0 (1.5)	12.8 (1.7)	6.4 (2.6)	7.4 (1.8)
Carbohydrate, g/kg mass	1.1 (0.2)	1.5 (0.4)	1.2 (0.2)	1.4 (0.2)	1.2 (0.2)	1.1 (0.2)
Fat, g/kg body mass	0.2 (0.0)	0.6 (0.2)	0.2 (0.1)	0.6 (0.1)	0.1 (0.1)	0.2 (0.0)
Protein, g/kg body mass	0.3 (0.1)	0.5 (0.2)	0.3 (0.1)	0.5 (0.1)	0.2 (0.1)	0.2 (0.1)

1LIT, one long low-intensity training session; 2LIT, two short low-intensity training sessions. Snack represents fluid and nutritional intake between the lunch and the start of the second session of 2LIT. Data are presented as mean (standard deviation).

Supplementary Table 2. Individual data on speed and speed differences between one long vs. two short sessions of low-intensity training in national-level male cross-country skiers.

	1LIT		**2LIT**		**1LIT**	**2LIT**	**Speed difference**
	1.Part	**2.Part**	**1. Session**	**2.Session**	**Total**	**Total**	**1LIT vs. 2LIT**
Participant 1	5.35	5.51	5.26	5.44	5.43	5.35	-1.58
Participant 2	4.73	4.91	4.97	5.03	4.82	5.00	3.69
Participant 3	5.26	5.30	5.26	5.33	5.28	5.30	0.82
Participant 4	4.75	4.86	4.96	5.18	4.80	5.07	5.56
Participant 5	5.03	5.03	5.24	5.11	5.03	5.18	2.95
Participant 6	4.86	5.01	5.02	4.98	4.94	5.00	1.50
Participant 7	4.97	5.18	5.05	5.42	5.08	5.23	3.50
Participant 8	5.05	5.10	5.23	5.26	5.08	5.24	3.23
Participant 9	4.95	5.12	5.16	5.26	5.04	5.21	3.45
Participant 10	4.79	5.09	4.89	4.72	4.94	4.80	-2.74
Participant 11	5.20	5.27	5.13	5.36	5.24	5.25	0.90
Participant 12	4.73	4.91	4.90	4.90	4.82	4.90	1.74
Participant 13	4.79	5.31	4.80	5.27	5.05	5.03	-0.40
Mean (SD)	5.17 (0.21)	5.34 (0.17)	5.29 (0.14)	5.40 (0.18)	5.26 (0.18)	5.34 (0.14)	1.90 (2.6)

1LIT, one long low-intensity training session; 2LIT, two short low-intensity training sessions; SD, standard deviation.

Figure 1

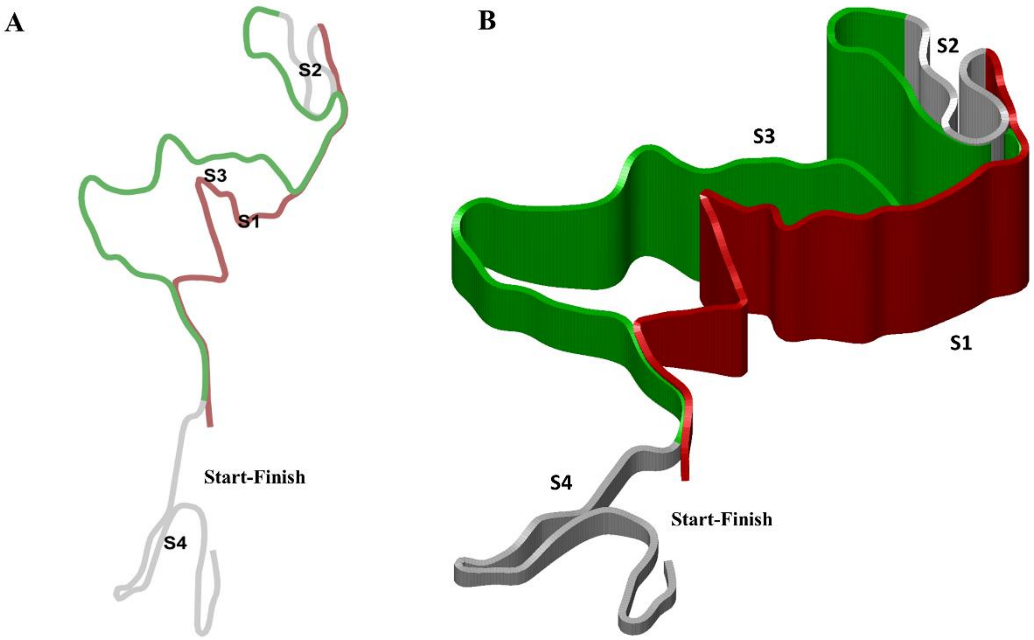
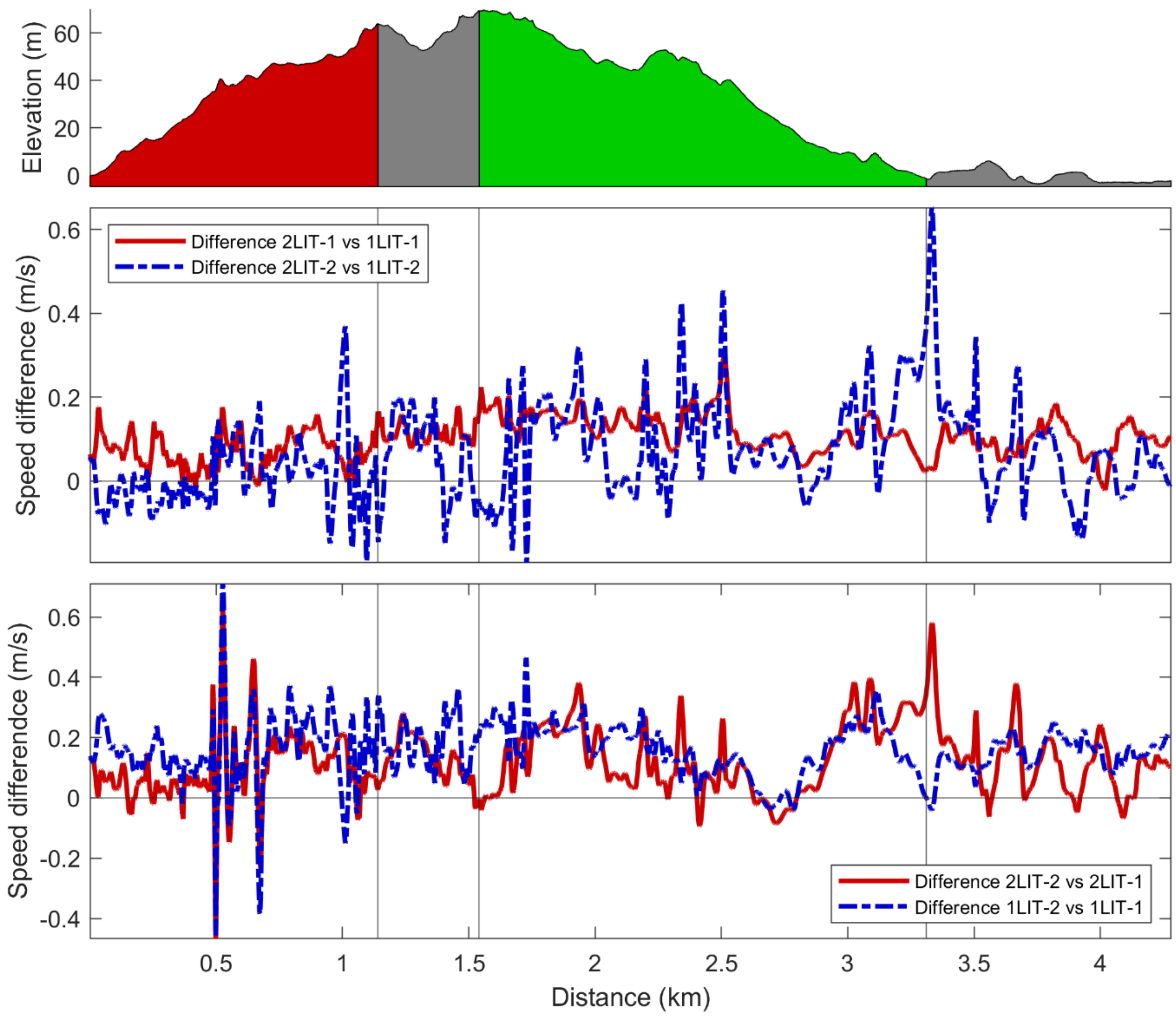
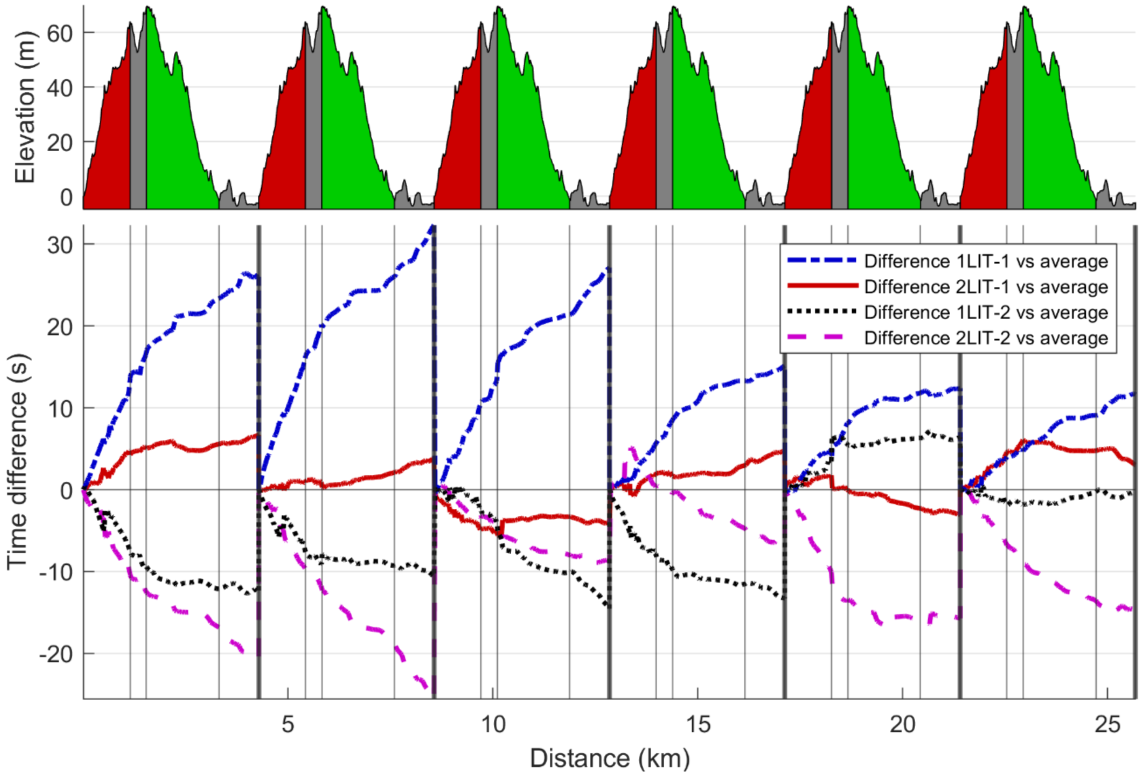


Figure 2



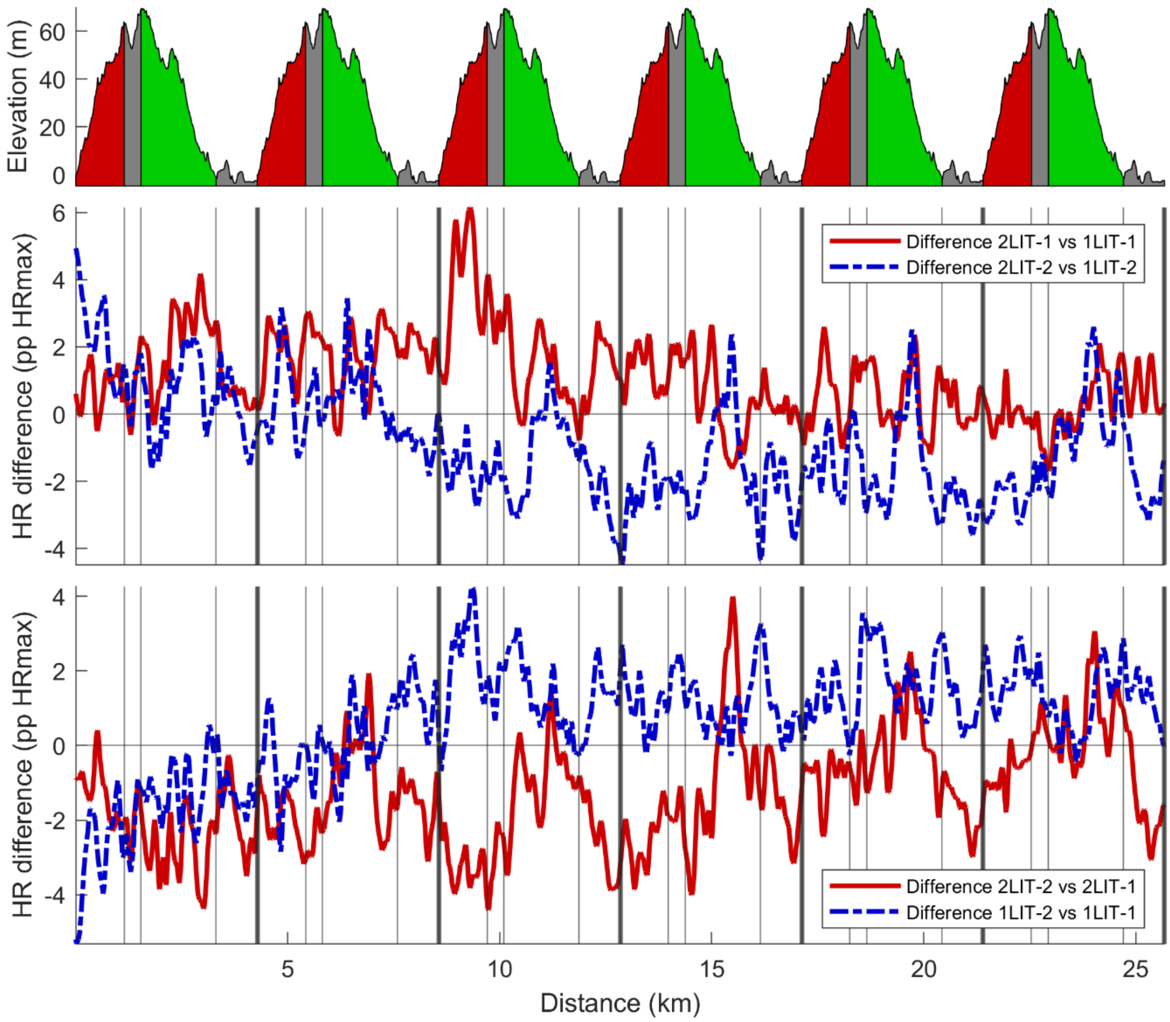
Elevation (m)
60
40
20
0
Speed difference (m/s)
0.6
0.4
0.2
0
Difference 2LIT-1 vs 1LIT-1
Difference 2LIT-2 vs 1LIT-2
Speed differendce (m/s)
0.6
0.4
0.2
0
-0.2
-0.4
Difference 2LIT-2 vs 2LIT-1
Difference 1LIT-2 vs 1LIT-1
0.5
1
1.5
2
2.5
3
3.5
4
Distance (km)

Figure 3



Elevation (m)
60
40
20
0
Time difference (s)
30
20
10
0
-10
-20
Difference 1LIT-1 vs average
Difference 2LIT-1 vs average
Difference 1LIT-2 vs average
Difference 2LIT-2 vs average
5
10
15
20
25
Distance (km)

Figure 4



Elevation (m)
60
40
20
0
HR difference (pp HRmax)
6
4
2
0
-2
-4
Difference 2LIT-1 vs 1LIT-1
Difference 2LIT-2 vs 1LIT-2
HR difference (pp HRmax)
4
2
0
-2
-4
Difference 2LIT-2 vs 2LIT-1
Difference 1LIT-2 vs 1LIT-1
5
10
15
20
25
Distance (km)