The Evolvement of Session Design from Junior Age to Senior Peak Performance in World-Class Cross-Country Skiers

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This is an original investigation with 2 figures and 4 tables. The abstract consists of 247 and the text of 3488 words.

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Abstract

Purpose: To compare designs of training sessions applied by world-class cross-country (XC) skiers during their most successful junior and senior season. ***Methods:*** Retrospective analysis of self-reported training characteristics (i.e., training form, intensity and exercise mode) among eight male and seven female world-class XC-skiers was conducted. ***Results:*** Total number of sessions (441±71 vs 519±34, p<.001, large effect) and mean duration (1.5±0.1h vs 1.7±0.1h, p<.001, moderate effect) increased from junior to senior age. More double sessions days were performed at senior age (124±50 vs 197±29 days, p<.001, large effect). The number (310±64 vs 393±64, p<.001, large effect) and duration (1.3±0.1h vs 1.5±0.1h, p<.001, moderate effect) of low-intensity training sessions increased from junior to senior age. Regarding intensive training, most emphasis was put on high-intensity training sessions lasting 20-39 min with <5 min intervals at junior age, while 40-59 min moderate-intensity training with 5-9 min intervals was predominant at senior age. More MIXED (combined moderate- and high-intensity) sessions (9±7 vs 14±7, p=.023, moderate) and longer races (0.5±0.1h vs 0.6±0.1h, p=0.29, moderate effect) compensated for fewer high-intensity training sessions at senior age (36±17 vs 25±10, p=.027, moderate effect). Duration of strength training sessions increased significantly (0.6±0.1 vs 0.8±0.2h, p=0.30, moderate effect) while other training forms remained unchanged. ***Conclusion:*** World-class XC-skiers increased their training volume from junior to senior age primarily by more and longer low-intensity training sessions, and training more often performed twice per day. Concurrently, the most frequent intensive sessions were modified from high-intensity to moderate-intensity training, lasted longer and contained longer intervals.

Keywords: long-term development, training characteristics, endurance sports, training intensity distribution, sex differences

Introduction

Reaching a world-class level in endurance sports requires many years of systematic training. A substantial body of research has been devoted to describing fundamental training variables such as training volume, forms, modes, and intensity distribution (TID) in senior world-class XC-skiers. Here, a total training volume of 750-950 h, including ~90% endurance training and ~10% strength and speed training, has been reported.[1–3] According to "time-in-zone" analyses, their endurance training is commonly distributed as ~90% low-intensity training (LIT), 4-6% moderate-intensity training (MIT) and 4-6% high-intensity training (HIT), including 60-70% specific exercise modes.[1–3]

In a recent paper, we investigated the progression of fundamental training variables from junior age to senior peak performance in world-class XC-skiers of both sexes.[3] Except for women who included more strength training than men at senior age, the study revealed almost identical training patterns across sexes, with an increase in training volume of ~200 h, mostly due to higher volumes of LIT. While higher proportions of HIT than MIT were conducted during junior age, the opposite was the case at senior age. Still, information regarding the progression of training load variables (i.e., session duration and design, as well as once-a-day vs. twice-a-day training) remains inconclusive. Detailed descriptions of the sessions comprising the large LIT volume performed by endurance athletes are particularly underrepresented in research literature.[4,5] However, a case study on the most successful female XC-skier reported that 42% of the LIT sessions lasted 90-150 min, 23% lasted ≥150 min, 21% were spent on warm-ups and cool-downs, 10% lasted 50-90 min, and 4% lasted <50 min.[2] Similar distributions of LIT are reported for a male XC-skier's return to world-class level, showing most of the LIT time being performed as sessions lasting 90-150 min.[6] Detailed information regarding prescription of interval-training sessions is also underreported, including intensity, accumulated work duration, interval time, number of repetitions, recoveries between repetitions, and exercise modes. Knowledge about the evolvement of session design and distribution from junior to senior in world-class XC-skiers is crucial for facilitating long-term development of talented athletes coping with gradual escalations of training volume.

Indeed, more research is needed regarding distribution of training sessions across days and the design and duration of different sessions applied by world-class XC-skiers at different stages of their career. Based on the substantial differences in training characteristics from junior to senior age at the macro level,[3] it is reasonable to expect significant differences also on session designs. Therefore, the aim of this study was to compare the designs and distribution of training sessions applied by world-class XC-skiers during their most successful junior and senior season.

Materials and Methods

Participants

Fifteen senior world-class XC-skiers (eight men and seven women) were recruited from the researchers' network. Inclusion criteria were as follows: (1) medalist in either World Championships or Olympic Games, or repeatedly on the podium in World-Cup races, (2) detailed training log data of their most successful junior and senior season. The included skiers were born between 1972 and 1998 and had altogether gathered 36 Olympic medals, 62 senior World Championship titles, 283 World-Cup victories and 22 junior World Championship titles. Mean age was 19.9±0.4 y in the analyzed junior season and 28.1±2.8 y in the peak performing senior season. All participants gave their written informed consent about their participation in this study. The Regional Committee for Medical and

Health Research Ethics waived the requirement for ethical approval for this study. The ethics of the project was performed according to the institutional requirements at the Department of Neuromedicine and Movement Science, Norwegian University of Science and Technology, Norway. Approval for data security and handling was obtained from the Norwegian Centre for Research Data (reference number 419807).

Study design

A retrospective study design was used to compare self-reported training characteristics between the most successful junior and senior seasons. The most successful senior season of each athlete was selected holistically based on several pre-defined performance parameters. The parameters were assessed in the following order with available training data assumed: 1) number of individual medals in World Championships and Olympic Games, 2) number of World-Cup podiums, 3) number of team medals in World Championships and Olympic Games, and 4) calculated peak age. For the selection of junior season, the following order was applied: 1) number of individual medals in junior World Championships, 2) number of team medals in junior World Championships, 3) number of podium spots in national junior races. Age was defined in accordance with the competition rules of the International Ski Federation (FIS), while peak age was calculated based on individual FIS point trajectories according to Walther et al.[7]

Training data

All participants reported their training including information about duration, training form, intensity, and the exercise modes for the endurance and speed training in a training diary designed by the Norwegian Top Sport Centre (Olympiatoppen). Prior to the introduction of the web-based diary, the older participants had used a non-web-based version (Microsoft Excel) or written diaries designed by the Norwegian Ski Federation. Distributions of training forms, intensities and modes were analyzed as previously described.[3] In terms of intensity quantification, a three-zone scale (LIT, MIT and HIT) and the modified session goal approach were employed, as previously described.[3] For analyses of intensive sessions, the session goal approach was used, meaning that sessions were categorized as MIT or HIT, respectively, if the core part of the sessions consisted of this intensity.[8] Warm-up and active recovery periods were recorded as LIT. Since athletes may apply several intensities within the same session, and to gain a more detailed comprehension, TID was categorized as either LIT, MIT, HIT, MIXED, races, or performance tests. MIXED included all sessions where both MIT and HIT were conducted within the same session and either portion was ≥33.3% of the intensive core part of the session. Sessions were defined as LIT if neither MIT, MIXED, HIT, races nor performance tests were included in this session. For detailed analyses of sessions spent as LIT, training was defined as warm-up if executed together with MIT, MIXED or HIT. Similarly, ≤30 min LIT sessions prior to strength or speed training were classified as warm-up. As for the endurance training, speed and strength training were also registered time-based. For speed training within endurance sessions, 2 min per bout were registered. For strength training, total duration of the session (including recovery periods) was recorded. All recorded training was checked session by session for correct registration, and distribution and details about session design were gathered from diary comments. Consistency in reporting of training and correct intensity classification were verified via a semi-structured interview with each participant during the data-analysis phase of this study.

Statistical analyses

All data is presented as mean±standard deviation (SD). Normality of the data was tested by visual inspection of histograms and Shapiro-Wilk test (a=0.05). Statistical comparisons between junior and senior seasons were assessed using paired sample t-test or its nonparametric counterpart Wilcoxon test. For sex comparisons unpaired t-test and Mann-Whitney-U test as its nonparametric counterpart were applied. P was set to <.05. Pearson's product coefficient was applied for effect sizes (ESs) of nonparametric tests and was interpreted according to Hopkins as r<0.1=trivial, 0.1-0.3=small, 0.3-0.5=moderate, 0.5-0.7=large, 0.7-0.9=very large and >0.9=extremely large.[9] ESs for parametric tests were calculated as Cohen d, and criteria for interpretation were 0.0-0.2=trivial, 0.2-0.6=small, 0.6-1.2=moderate, 1.2-2.0=large and >2.0=very large.[9]

Results

Total training

Time spent across training forms, modes and intensities at both stages is presented in Table 1. The annual number of sessions increased by 78±69 (21±24%, r=0.9, p<.001) from junior to senior season. Detailed information about the total number and mean duration of sessions across forms, modes, and intensities as well as the corresponding sex-differences are presented in Table 2.

Table 1 and 2 about here

Distribution of training sessions

The number of training days did not change significantly from junior to senior (311±26 vs 317±12, r=0.1, p=.802) and neither did the number of rest days (55±26 vs 49±12, r=0.1, p=.842). While the number of days with two or more sessions increased by 72±50 (r=0.9, p<.001) from junior (124±50 days) to senior age (197±29 days), the number of days with only one session dropped from 187±41 to 120±26 days (d=1.6, p<.001) in the corresponding period. Table 3 exemplifies the weekly distribution of training across different sessions at junior and senior age during the general preparation period and competition period.

Endurance training

The percentage distribution of executed sessions across intensities for junior vs. senior seasons was 72 vs. 77% LIT, 5.7 vs. 7.4% MIT, 2.0 vs. 2.7% MIXED, 8.8 vs. 5.0% HIT, 8.5 vs. 6.4% races and 2.7 vs 1.4% tests. Figure 1 shows the annual distribution of LIT sessions categorized by durations. The annual number of specific LIT sessions increased from 167±37 to 210±28 sessions (d=1.0, p<.001), while unspecific LIT sessions increased from 143±38 to 182±30 (d=1.0, p=.003). Mean duration of both specific (1.6±0.1 vs 1.7±0.1 h, d=1.2, p<.001) and unspecific (1.0±0.2 vs 1.2±0.1 h, d=1.0, p=.003) LIT sessions was higher at senior compared to junior age.

Figure 1 about here

Figure 2 presents the annual number of MIT, MIXED and HIT sessions at junior and senior age across different total work and interval durations. The number of MIT sessions in specific (21±9 vs 30±8 sessions, d=1.0, p=.001) and unspecific modes (4±3 vs 7±4 sessions, d=0.6, p=.045) increased from junior to senior age, but only the mean duration of the latter was extended by 0.2±0.1 h (d=1.2, p<.001). Also, the number of specific MIXED sessions increased (7±6 vs 11±5 sessions, d=1.0, p=.003), whereas the number of unspecific sessions (2±3 vs 3±2) and duration remained unchanged and equal across modes. Specific HIT sessions were downsized from 23±11 sessions at junior age to 14±7 sessions at senior age (d=0.7, p=.019), however, the change in unspecific sessions was not significant (13±7 vs 10±5 sessions). HIT session duration also remained unchanged and equal across modes. Table 4 shows most frequently applied designs of MIT, MIXED and HIT sessions at junior and senior age during general preparation period and competition period. The number of ski and roller-ski races (specific mode) remained unchanged from junior (30±7 races) to senior (29±7 races), but the number of unspecific races was reduced from 6±4 to 3±3 races (d=0.8, p=.009).

Figure 2 about here

Discussion

This is the first study to provide detailed insights into world-class XC-skiers' distribution and design of sessions from their most successful junior to senior season. The main changes from junior to senior age were as follows: 1) total number and mean duration of sessions increased by ~20 and ~10%, respectively; 2) the number of training days remained unchanged, but the number of days with double sessions increased; 3) a higher proportion of the endurance sessions was conducted as LIT, and particularly the number of sessions lasting ≥90 min increased; 4) while most typical intensive sessions during junior age were HIT sessions with 20-39 min total work duration and intervals of <5 min, the most typical intensive sessions during senior age were MIT sessions of 40-59 min and intervals of 5-9 min duration.

Total training

The overall training volume, number and duration of sessions reported during senior season in the current study are consistent with previously reported training characteristics in world-class XC-skiers and biathletes, highlighting the need of approximately >500 annual sessions and >800 h of training to perform on a world-class level.[1–3] However, information related to junior training is limited in previous research, and the ~440 sessions distributed across ~310 days at junior age provide new reference values for talents that ultimately achieved senior world-class level. The changes in number of sessions (20%) and total training volume (35%) from junior to senior age observed in this study are at the lower end of previous case studies reporting as much as 50% more sessions and 80% more training volume during corresponding transitions.[2,10] While we suspect individual training background, especially training volume at junior age, to cause these discrepancies, it is important to highlight that this longitudinal change (8.3 y on average) in total training volume was achieved by both increased number and duration of sessions. While the number of sessions increased with large effect, the duration increased moderately. Seemingly, the former plays a more important role when increasing training load at these age stages. This assumption is further reinforced by the increased number of days with double sessions (large effect). Several plausible explanations may underline this strategy. First, the effects of endurance and strength training may interfere if conducted within the same session.[11–13] Second, double sessions may provide better possibilities for nutritional intake, recovery, and variation in modes. Third,

implementation of two daily sessions may induce lower perceived exertion and potentially higher mitochondrial efficiency.[14,15] Last, higher professionalization with more days on training camps and less school/education obligations make it possible to train twice a day at senior age. However, more research is needed regarding the organization of daily training load and how the distribution across different sessions influences the elicited strain and adaption to training.

Training forms

World-class XC-skiers increased the number of endurance sessions significantly in the transition from junior to senior, whereas the number of strength, speed and other sessions did not change significantly. However, both endurance and strength training sessions lasted longer at senior age. While a more nuanced view on the changes in endurance training is provided below, the increased duration of strength sessions is mainly caused by changes in women's strength training routines as both duration and number of sessions were clearly higher in senior women than in men.

Low-intensity training

At senior age, the number and percentage of endurance sessions devoted to LIT were similar to previous case studies on world-class skiers.[2,6,10] The high number of LIT sessions at junior age stresses the importance of such training, also when training less. This importance of LIT is further emphasized by the fact that nearly the entire rise in training volume was explained by more LIT sessions. Aligned with previous case reports, we found 90-149 min LIT sessions to be most frequently applied at both age stages.[2,6] Interestingly, only sessions lasting ≥90 min increased significantly from junior to senior. We can only speculate for reasons to the more frequently application of longer sessions. However, the most likely explanation is that senior skiers can tolerate longer sessions at sufficiently high speeds to develop their aerobic capacity and technique without accumulating too much strain. Previous literature have also suggested that such long lasting sessions in specific modes are effective for developing underlying performance factors such as work economy and the fractional utilization of maximal oxygen uptake (VO_{2max}).[16] This assumption is further supported by the fact that longer LIT sessions were mostly performed on (roller) skies, while short LIT sessions (<50 min) were typically performed in unspecific modes (e.g., running). In general, LIT sessions in XC-skiing can be performed over relatively long durations due to high variation in terrain, styles, and sub-techniques and due to gentle locomotion modalities in terms of muscular impact compared to e.g., running.[17,18] This enables athletes to manage long sessions frequently while keeping the risk of injuries low. Future research should investigate the interplay of duration and mode, as well as frequency and intensity of LIT sessions for optimal load management within micro-cycles.

Moderate- and high-intensity training

The distribution of intensive sessions at senior age found here lay somewhere in between previous reports where a substantial overweight of HIT sessions was reported for a female XC-skier and biathlete, while an overweight of MIT was reported for a male XC-skier.[2,6,10] In the current study, we observed a slight predominance of MIT and a substantial number (20%) of MIXED sessions, providing a new and more nuanced analysis of TID patterns. Notably, the TID patterns were clearly different at junior age, where the number of MIT and MIXED sessions were considerably lower (large and moderate effect) and the number of HIT sessions was higher (moderate effect). Hence, HIT was more prioritized than MIT at junior age, both in terms of volume and number of sessions across intensities. Despite the trends towards fewer HIT sessions at senior age and no changes in mean duration, total time of HIT was relatively similar at both age stages. This was mainly achieved by more MIXED

sessions and longer races at senior age. Although it remains speculative, there might be several reasons to apply MIXED sessions. First, such sessions can last longer than pure HIT sessions and stimulate several adaptations at once in world-class athletes who, theoretically, are able to work at high fractions of their VO_{2max} and thus high speeds also during MIT. Furthermore, a conservative start of the intensive session may induce lower perceived exertion (RPE) compared to fast starts, and lastly, such sessions might be used to simulate pacing strategies with harder finishes.[19]

This study revealed explicit changes in interval loading variables from junior to senior age and illustrates how frequently different session designs were applied. The most frequently used intensive sessions at junior age were HIT sessions with 20-39 min total accumulated working duration and <5 min intervals. Such sessions have been shown to have a great impact on VO_{2max}, which is also reflected by the exceptionally high VO_{2max} at junior age in the investigated athletes.[20–22] On the other hand, the most frequently used intensive sessions at senior age were MIT intervals with 40-59 min total accumulated working duration and 5-9 min duration. Similar session designs have been described as typical MIT sessions in previous case reports on XC-skiers.[2,6] Although the scientific evidence for physiological benefits of MIT intervals in highly trained endurance athletes is limited, there is some evidence that advocates positive effects of the rise in MIT shown here.[23] First, the high level of senior world-class athletes allows them to conduct MIT at high speeds, making it relevant from a technical perspective. This technical relevance is also reflected by the fact that most of such sessions were performed in specific modes. Second, MIT allows much time on relatively high intensities that stimulate key performance factors, like work economy and fractional utilization of maximal oxygen uptake VO_{2max}, without inducing the same amount of stress as HIT.[16,24]

Races and tests

The annual number of ~35 races performed by world-class XC-skiers did not change significantly from junior to senior and matched the number of HIT sessions, emphasizing the large contribution of races to the total amount of HIT. The mean duration of races increased from junior to senior, and races lasted longer than HIT sessions at both stages. This highlights the role of races as specific stimuli with continuous efforts, complementing intensive interval sessions.

Practical Applications

The present study provides unique insights regarding the design and distribution of training sessions applied by world-class XC-skiers during their most succesful junior and senior season. Such knowledge is important for athletes, coaches and sports federations when planning and evaluating for long-term development. Our findings suggest that escalations in training volume should be performed by increasing both duration and number of sessions, with most emphasis on the latter. Almost the entire rise in training volume can be related to more LIT, which is mainly achieved by an increased number of ≥90 min sessions mostly executed in specific modes. Relatively more HIT was prioritized when training less volumes at junior age, with the most frequently applied sessions lasting 20-39 min, including intervals of <5 min. Contrary, MIT became more pronounced at senior age, with sessions of 40-59 min duration and 5-9 min being the most common interval duration.

While our findings provide invaluable lessons learned from the long-term athelete development of 15 male and female world-class skiers, care should be taken when interpreting the present data. Indeed, the executed training might have been influenced by the culture-specific training philosophy in Norway. A further source of error might be recall bias, especially among older participants. Also, six athletes had their best senior season during the Covid-19 pandamic, in which changes in race calender

and traveling routines might have influenced their training. Lastly, future research should also include athletes at lower performance levels since this dimension has not been covered in the current study.

Conclusions

World-class XC-skiers increase their total training volume from junior to senior age by executing 20% more sessions. This is mainly due to larger amounts of days with double sessions in addition to 10% longer session duration. The fact that nearly the entire increase in training volume was derived from LIT sessions highlights the importance of such training to progress from talented junior to elite senior athlete. The rise in long LIT sessions performed in specific modes underlines the need for large amounts of specific training to achieve world-class level. The shift from shorter HIT sessions with shorter interval durations to more emphasis on longer MIT (and MIXED) sessions with longer interval durations reflects how TID progresses over XC skiers' career stages on their road towards world-class level. Finally, the high number and relatively large duration of races, which matches the annual number of HIT sessions at both stages, confirm the important contribution of races to the total training load and their importance as specific stimuli.

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Tables

Table 1 Maximal aerobic power (VO_{2max}) and distribution of training time (mean±SD) across forms, intensities, and modes in world-class XC-skiers during most successful junior and senior season-

	Junior	**Senior**
Total training (h)	668±111	860±78
Endurance (h)	591±103	778±65
Strength (h)	50±14	57±23
Speed (h)	17±7	19±8
Other (h)	11±7	6±5
LIT (h)	537±97	714±62
MIT (h)	20±8	33±8.9
HIT (h)	34±9	31±6
Specific (h)	412±82	532±58
Unspecific (h)	195±39	263±50
VO_{2max} ($L \cdot min^{-1}$) men	5.7±0.2	6.0±0.3
VO_{2max} ($L \cdot min^{-1}$) women	4.3±0.4	4.5±0.3
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) men	76.2±2.7	79.1±0.4
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) women	66.9±4.0	71.3±4.4

LIT, Low-intensity training; MIT, Moderate-intensity training; HIT, High-intensity training

Table 2 Annual training distribution (mean±SD) and sex-differences (mean±SE) of sessions across training forms, modes, and intensities in world-class XC-skiers during most successful junior and senior season.

	Number of sessions					Mean duration of sessions (h)				
	Junior	**Senior**	***p***	**Effect size**	**Sex-diff. w against m**	**Junior**	**Senior**	***p***	**Effect size *d***	**Sex-diff. w against m**
Total training										
	441±71	519±34	<.001	*r*=0.9		1.5±0.1	1.7±0.1	<.001	*d*=1.2	
Training forms										
Endurance	427±77	508±39	<.001	*d*=1.1		1.4±0.1**	1.5±0.1	<.001	*d*=1.3	-0.1 ±<0.1
Strength	77±18	73±17*	.529	*d*=0.1	16.8±7.7	0.6±0.1	0.8±0.2**	.030	*d*=0.6	0.3±0.1
Speed	74±30	78±30*	.618	*d*=0.1	29.0±14.0	0.2±0.1	0.2±0.1	.745	*d*=0.1	
Other	24±26	13±16	.258	*r*=0.3		0.7±0.3	0.7±0.5	.530	*r*=0.2	
Exercise modes										
Specific	253±49	299±33	.002	*d*=1.0		1.6±0.1**	1.8±0.1	<.001	*d*=1.2	-0.1±0.1
Unspecific	174±40	210±32	.005	*d*=0.9		1.1±0.2	1.3±0.1	.059	*d*=0.5	
Intensity distribution										
LIT	310±64	393±39	<.001	*d*=1.2		1.3±0.1**	1.5±0.1	<.001	*d*=1.1	-0.1±<0.1
MIT	25±10	38±10	<.001	*d*=1.2		0.6±0.2	0.7±0.1**	.087	*d*=0.5	-0.1±<0.1
MIXED	9±7	14±7	.023	*d*=0.7		0.5±0.2**	0.5±0.1	.998	*d*<0.1	-0.2±0.1
HIT	36±17	25±10	.027	*d*=0.6		0.4±0.1*	0.4±0.1	.091	*d*=0.5	-0.1±<0.1
Races	36±6	32±9	.089	*d*=0.5		0.5±0.1	0.6±0.1**	.029	*d*=0.6	-0.1±<0.1
Tests	12±4	7±3	.004	*d*=0.9		0.36±0.1	0.45±0.2	.028	*d*=0.6	

*w, women; m, men; LIT, Low-intensity training; MIT, Moderate-intensity training; HIT, High-intensity training; * significant sex-difference (p>0.05) with moderate effect; ** significant sex-difference (p>0.05) with large effect*

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Table 3 Typical training weeks of world-class XC-skiers during general preparation (May-October) and competition period (November-April) at junior and senior age.

Day		**General preparation period**		
		Junior		**Senior**
Mon	M	Free/school	M	120 min roller-ski classical LIT
	E	100 min roller-ski skating incl. MIT interval 5-6×7-8 min	E	60 min running
Tue	M	90 min roller-ski classical LIT	M	105 min roller-ski skating incl. MIT interval 6-7×8 min
	E	60 min running LIT and 30 min strength training	E	30 min running LIT and 30 min strength training
Wed	M	90 min roller-ski skating LIT incl. speed training	M	180 min running LIT
	E	60 min running LIT	E	120 min roller-ski classical LIT
Thu	M	95 min roller-ski classical incl. HIT interval 5-6×4 min	M	105 min roller-ski skating LIT incl. speed training
	E	30 min running LIT and 30 min strength training	E	Free
Fri	M	Free/school	M	105 min roller-ski classical incl. MIT interval 5-6×10 min
	E	90 min roller-ski classical LIT	E	60 min running LIT
Sat	M	150 min running LIT	M	120 min roller-ski skating LIT
	E	Free	E	40 min running LIT and 40 min strength training
Sun	M	120 min roller-ski skating LIT	M	120 min running LIT
	E	Free	E	Free
Sum		15.3 hours, 10 sessions		20.6 hours; 12 sessions
Day		**Competition period**		
		Junior		**Senior**

Mon	M	Free/school	M	120 min ski skating LIT incl. speed training
	E	60 min ski classical LIT incl. speed training	E	40 min running LIT and 30 min strength training
Tue	M	120 min ski skating LIT	M	150 min ski classical LIT
	E	60 min ski classical and 30 min strength training	E	Free
Wed	M	Free/school	M	105 min ski skating incl. MIT interval 4-5×7-8 min
	E	95 min ski skating incl. HIT interval 4-5×3-4 min	E	75 min ski classical
Thu	M	Free/travel	M	Free/travel
	E	30 min running LIT	E	40 min running LIT
Fri	M	75 min ski classical incl race recon HIT 4×3-4 min	M	75 min ski classical incl. race recon MIT 1×10 min
	E	30 min running LIT	E	30 min running LIT
Sat	M	80 min ski classical including 5-10 km race	M	90 min ski classical including 10-15 km race
	E	30 min running LIT	E	30 min running LIT
Sun	M	80 min ski skating including 5-10 km race	M	90 min ski skating including 10-15 km race
	E	Free/travel	E	Free/travel
Sum		11.5 hours; 10 sessions		14.6 hours, 11 sessions

LIT, Low-intensity training; MIT, Moderate-intensity training; HIT, High-intensity training

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Table 4 The most frequently applied intensive session designs by world-class XC skiers during general preparation (May-October) and competition period (November-April) at junior and senior age.

	Junior	**Senior**
General preparation period		
MIT	5×8 min, R: 2 min, roller-skiing on tracks or combined with uphills	6×8 min, R: 2 min, roller-skiing on tracks or combined with uphills
	2×20 min, R: 2min, roller-skiing on tracks	5×10 min, R: 2 min, roller-skiing on tracks
	1×40 min, roller-skiing on tracks	5×8 min, R: 2 min, roller-skiing on tracks or combined with uphills
	4×8 min, R: 2 min, roller-skiing on tracks or combined with uphills	4×10 min, R: 2 min roller-skiing on tracks
MIXED	5×7 min, R: 2 min, roller-skiing on tracks or combined with uphills	4×12 min, R: 2 min, roller-skiing on tracks
	6×5 min, R: 2 min, uphill running or roller-skiing on tracks	5×8 min, R: 2 min, roller-skiing on tracks or combined with uphills
	5×5 min, R: 2 min, uphill running or roller-skiing on tracks	6×6 min, R: 2 min, uphill running or roller-skiing on tracks
	6×4 min, R: 2 min, uphill running or roller-skiing on tracks	6×5 min, R: 2 min, uphill running or roller-skiing on tracks
HIT	5×5 min, R: 2 min, uphill running or roller-skiing on tracks	6×6 min, R: 2 min, uphill running or roller-skiing on tracks
	6×4 min, R: 2 min, uphill running or roller-skiing on tracks	6×5 min, R: 2 min, uphill running or roller-skiing on tracks
	5×4 min, R: 2 min, uphill running or roller-skiing on tracks	5×5 min, R: 2 min, uphill running or roller-skiing on tracks
	4×3 min, R: 2 min, roller-skiing on tracks, sprint simulation	4×3 min, R: 2 min, roller-skiing on tracks, sprint simulation
Competition period		
MIT	5×8 min, R: 2 min, skiing on racecourses	5×10 min, R: 2 min, skiing on racecourses
	4×8 min, R: 2 min, skiing on racecourses	6×8 min, R: 2 min, skiing on racecourses
	3×10 min, R: 2 min, skiing on racecourses	5×8 min, R: 2 min, skiing on racecourses
	1×15 min, R: 2 min, skiing on racecourses	1×10 min, R 2 min, racecourse recon
MIXED	5×5 min, R: 2 min, uphill running or skiing on racecourses	6×5 min, R: 2 min, uphill running or skiing on racecourses
	6×4 min, R: 2 min, skiing on racecourses	5×6 min, R: 2 min, skiing on racecourses
	5×4 min, R: 2 min, skiing on racecourses	5×4 min, R: 2 min, skiing on racecourses
	4×4 min, R: 2 min, skiing on racecourses	2×5 min, R: 2 min, racecourse recon
HIT	5×5 min, R: 2 min, skiing on racecourses	6×6 min, R: 2 min, skiing on racecourses
	6×4 min, R: 2 min, skiing on racecourses	6×5 min, R: 2 min, skiing on racecourses
	5×4 min, R: 2 min, skiing on racecourses	5×5 min, R: 2 min, skiing on racecourses

	4×4 min, R: 2 min, skiing on racecourses	6×4 min, R: 2 min, skiing on racecourses

LIT, Low-intensity training; MIT, Moderate-intensity training; HIT, High-intensity training; R, rest interval

Figure captions

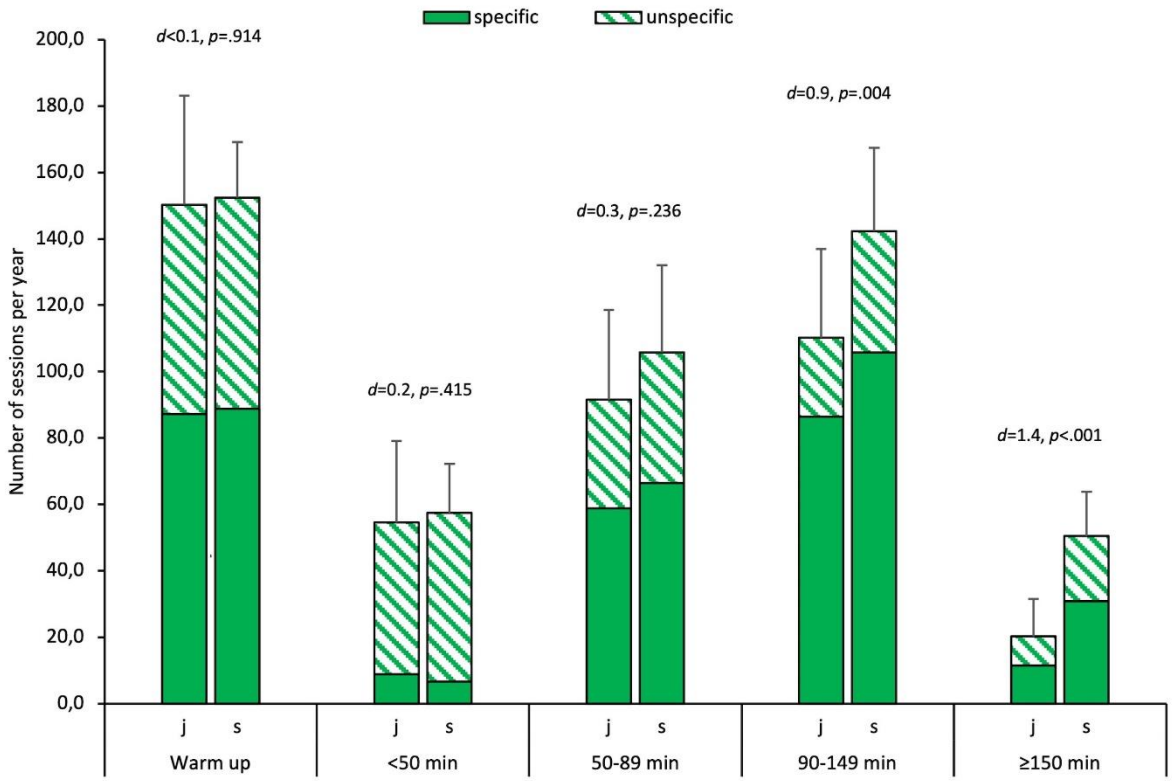
Figure 1

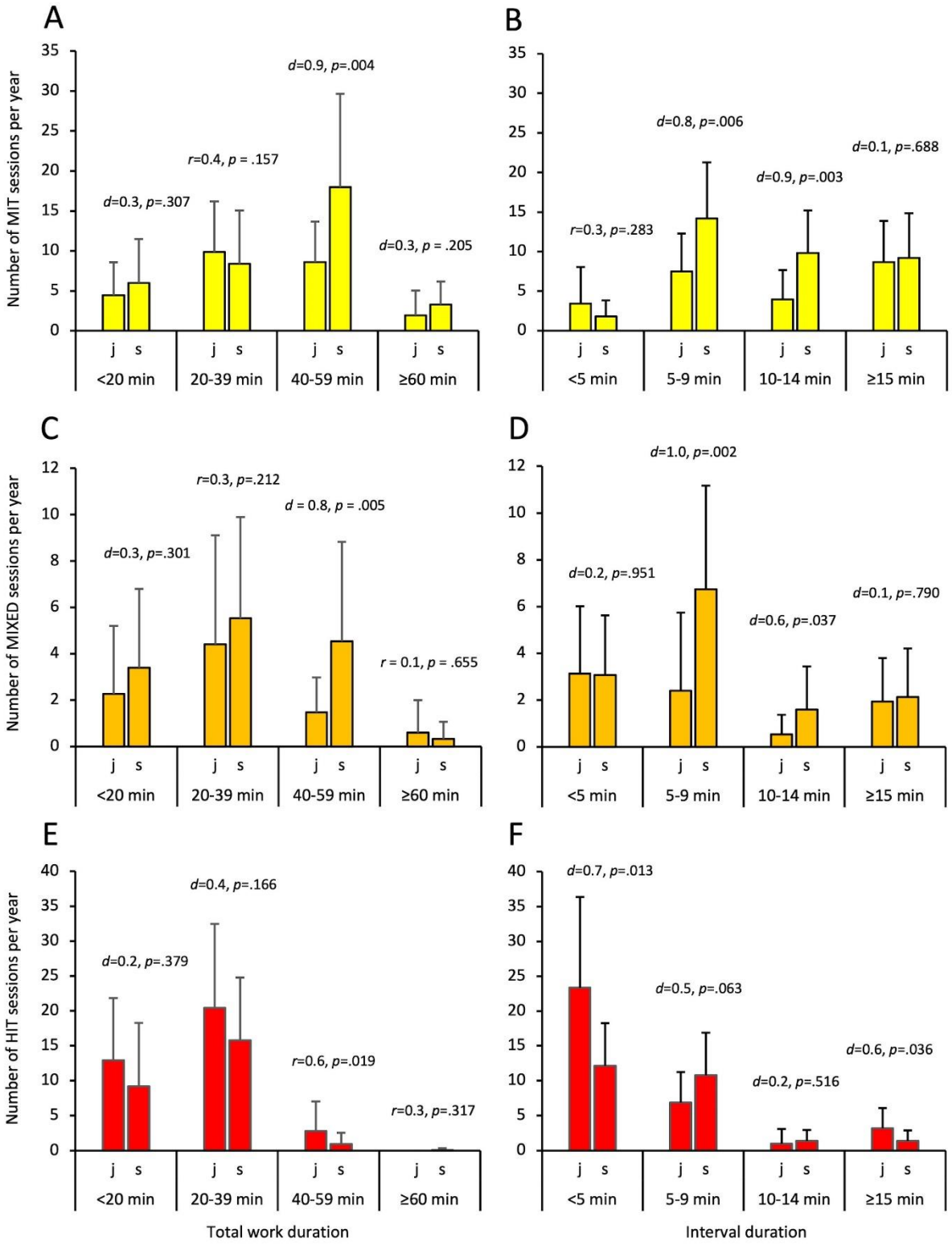
Distribution of annual LIT sessions performed by world-class XC-skiers during their most successful junior (j) and senior (s) season categorized by duration and exercise mode.

Figure 2

Distribution of total work (left) and interval duration (right) across MIT (A, B), MIXED (C, D) and HIT (E, F) sessions performed by world-class XC-skiers during their most successful junior (j) and senior (s) season.

Figures




A
B
C
D
E
F
Number of MIT sessions per year
Number of MIXED sessions per year
Number of HIT sessions per year
d=0.3, p=.307
r=0.4, p = .157
d=0.9, p=.004
d=0.3, p = .205
r=0.3, p=.283
d=0.8, p=.006
d=0.9, p=.003
d=0.1, p=.688
d=0.3, p=.301
r=0.3, p=.212
d = 0.8, p = .005
r = 0.1, p = .655
d=0.2, p=.951
d=1.0, p=.002
d=0.6, p=.037
d=0.1, p=.790
d=0.2, p=.379
d=0.4, p=.166
r=0.6, p=.019
r=0.3, p=.317
d=0.7, p=.013
d=0.5, p=.063
d=0.2, p=.516
d=0.6, p=.036
j s
<20 min
20-39 min
40-59 min
≥60 min
<5 min
5-9 min
10-14 min
≥15 min
Total work duration
Interval duration

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