Title

Annual volume and distribution of physical training in Norwegian female cross-country skiers and biathletes: a comparison between sports, competition levels, and age categories - the FENDURA project.

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Original investigation

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Annual training of female XC skiers and biathletes

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Abstract

Purpose

To describe and compare the annual physical training characteristics between Norwegian female cross-country (XC) skiers and biathletes across competition levels and age categories.

Methods

Daily training sessions for one year were recorded for 45 XC skiers and 26 biathletes, comprising international/national-team [inter(national)] and non-national/regional-team members (non-national) of both junior and senior age. Endurance, strength, flexibility, speed, and power training sessions were recorded. Data included exercise modality, intensity, and duration. Data were analysed using linear mixed-effects models.

Results

The total annual physical training volume consisted of ~90% endurance training for both groups, although XC skiers had significantly higher total volumes (~10%; p=.003; d=0.78) than biathletes. Senior XC skiers performed more training hours of skiing and/or roller skiing compared to biathletes over the season. However, biathletes compensated for this lower volume by more skating, and higher proportion of endurance training as skiing (81±17%), compared to XC skiers (68±16%; p<.001; d=0.94). Overall, (inter)national level athletes completed a higher annual training volume than non-national level athletes (740±90 h vs 649±95 h; p=.004 d=0.81). Although juniors reported less endurance volume than seniors, they maintained a relatively stable level of endurance training across the preparatory and competition period, unlike senior athletes.

Conclusion

The higher annual physical training volume by XC skiers compared to biathletes is likely caused by the different demands of the two sports; XC skiing necessitates training for two

skiing styles, while biathlon requires additional shooting practice. However, biathletes compensate with a higher proportion of ski training, particularly in the skating technique.

Keywords

skiing, endurance training, strength training, intensity distribution, training periodization

Introduction

Cross-country (XC) skiing and biathlon are two demanding winter endurance sports. Both necessitate a highly developed aerobic energy delivery capacity and skiing efficiency, combined with anaerobic capacity, to cross varying terrain with the simultaneous use of upper- and lower-body musculature.[1,2] The primary differences between the two sports are the smaller range of competition times and formats, the exclusive use of the skating technique and the inclusion of shooting in biathlon, with the added requirement of rifle carriage.[3]

The physiological demands of these sports are met by high endurance training volumes of 700–950 $h \cdot year^{-1}$ for world-class XC skiers and biathletes, with a typical training intensity distribution of 88–91% low-intensity training (LIT), 3–7% moderate intensity training (MIT), and 5–8% high intensity training (HIT).[2–4] The inclusion of shooting practice within the training program of biathletes appears to reduce endurance training volume by ~19–30% when compared to world-class XC skiers.[5–7] Studies about the periodisation pattern in elite XC skiers and biathletes have reported a high volume of LIT during the preparatory phases, followed by a reduction in LIT volume, an increase in HIT volume, and a greater proportion of ski training prior to, and during, the competition phase.[2,8,9] However, despite the popularity of these winter endurance sports, only a handful of studies have specifically reported the longer-term (i.e., annual) training characteristics of female XC skiers and/or biathletes. Apart from a recent study by Myakinchenko et al.[6], the majority of previous research has examined small samples (i.e., $n \leq 12$)[2,5,10,11] or case studies.[9] As such, there is a clear need for additional research describing the annual training characteristics of female XC skiers and biathletes, using a larger and more robust sample. Similarly, previous studies including female biathletes have focused exclusively on elite athletes,[5,6] and thus additional research is required to compare the annual training characteristics between biathletes of different competition levels.

Further, there remains a dearth of data regarding training similarities or differences between age categories within these sports, i.e., junior compared to senior female athletes. Junior athletes are likely to have a lower annual training volume and different training intensity distribution compared to seniors, due to the requirement of gradual training progression for optimal development, as well as their delayed competition schedule and requirement of school attendance. Karlsson et al.[10] previously described the difference in training between junior and senior level XC skiers (e.g., increased endurance training volume from ~470 $h \cdot year^{-1}$ to ~730 $h \cdot year^{-1}$, primarily as skiing LIT). However, this was a longitudinal cohort study and thus did not compare different age categories at the same time point. Likewise, there appears to be limited scientific evidence describing the training distribution of junior and senior female biathletes. Therefore, additional comparative research is needed to better understand the differences in training characteristics in female cross-country skiers and biathletes competing at different competition levels and in different age categories.

This study aimed to describe and compare the annual training characteristics (i.e., volume, modality, and intensity distribution) of Norwegian female XC skiers and biathletes, and compare between competition levels and age categories.

Methods

This study was part of The Female Endurance Athlete (FENDURA) project. The overall objective of the FENDURA project is to conduct novel female-specific research and contribute to developing and improving the exercise performance, training and health of female athetles.[12]

Participants

A group of 71 highly trained Norwegian female endurance athletes, consisting of XC skiers (n = 45) and biathletes (n = 26), were included in this study. All athletes were competing at either a Norwegian regional/non-national level (i.e., 'non-national'; Tier 3) or at a national/international level (i.e., '(inter)national'; Tier 4/5).[13] Athletes were classified into their respective performance tiers using the 6-tier guidelines by McKay et al.[13], using their current competition level (e.g., member of the national team, previous year's results) and agreement between two investigators with specific expert-insights (GSS and TPE). Athletes were considered either junior or senior, depending on their athletic age category recorded at the start of the season. Information regarding hormonal contraceptive use (or lack thereof) was also collected for cohort description and to permit comparison by future studies. However no further analysis of this data was undertaken and is only displayed for informative purposes. See Table 1 for group anthropometric, demographic, and hormonal contraceptive use information. All participants were fully informed about all study procedures and requirements before they agreed to provide written informed consent. This study was approved by the Norwegian Social Science Data Services (Project Number: 409326) and assessed by the Norwegian Regional Committees for Medical and Health Research Ethics (Project ID: 135555).

Table 1. Anthropometric characteristics of 71 female XC skiers and biathletes, split by sport, competition level and age category.

Variable	All Athletes	Sport		Competition Level		Age Category	
	N = 71	XC Skiers (n = 45)	Biathletes (n = 26)	Non-National (n = 50)	(Inter)national (n = 21)	Senior (n = 36)	Junior (n = 35)
Age (years)	20.9 ± 2.7	21.1 ± 3.0	20.5 ± 2.1	20.2 ± 2.3	22.5 ± 2.9	23.0 ± 2.1	18.7 ± 0.7
Body mass (kg)	62.2 ± 4.8	61.6 ± 4.7	63.2 ± 4.9	61.8 ± 4.7	63.0 ± 5.1	61.5 ± 4.6	62.9 ± 5.1
Stature (cm)	169 ± 6	169 ± 5	170 ± 7	169 ± 6	169 ± 5	168 ± 6	170 ± 6
(Inter)national (n)	21	14	7	-	21	15	6
Non-National (n)	50	31	19	50	-	21	29
Senior (n)	36	22	14	21	15	36	-
Junior (n)	35	23	12	29	6	-	35
Hormonal contraceptive use							
Combined OCP (n)	17	11	6	11	6	9	8
Progestin-only OCP (n)	6	2	4	5	1	4	2
Implant (n)	9	7	2	8	1	4	5
IUS (n)	14	11	3	8	6	11	3
No hormonal contraception (n)	25	14	11	18	7	8	17

Data presented as mean ± standard deviation. Note: XC = cross country; OCP = oral contraceptive pill; IUS = intrauterine system.

Design

A prospective cohort study design was employed, with athletes systematically recording all their day-to-day training sessions across the annual season of 2020/2021, from 1st May 2020 to 30th April 2021. This data collection period coincided with the worldwide outbreak of the COVID-19 virus, and as such, may not be representative of a normal athletic training year.

Training Data

Daily training data were recorded in an electronic training diary, either using software developed by the Norwegian Top Sport Centre (Olympiatoppen) or Bestr (Bestr, Oslo, Norway). All recorded parameters were identical, regardless of the software developer. Athletes reported session duration, training form (i.e., endurance, strength, flexibility, speed and power), modality (i.e., on-snow or roller skiing [classic or skating], running, cycling, other) and the perceived training intensity for the session using the Borg CR10 scale, ranging from 1 "extremely easy" to 10 "maximum intensity".[14] Data on biathlete shooting training (number of shots fired or time spent shooting) were not included in the original data collection of the FENDURA project, and thus were not included in the analysis. Competition and benchmark testing sessions were also excluded from the data analysis due to the unusual situation of the COVID-19 pandemic, which restricted the possibility for many of the athletes to undertake laboratory-based testing and saw the cancelation of many competitive events. Total training time was considered the cumulative time of endurance, speed, power, strength, and flexibility training. Endurance training intensity was initially categorised using a 5-zone model, with duration of training in each zone recorded in minutes and then converted to a standardised 3-zone model, as previously described for similar data:[2,9,15–17] LIT (zones 1–2; below the first lactate threshold), MIT (zone 3; between the first and second lactate threshold) and HIT (zones 4–5; above the second lactate threshold). Duration of time spent in all modalities other than endurance training, i.e., speed, power, strength, and/or flexibility, were recorded to the nearest minute.

Annual Training Phase Definition

For data systematization and analysis, the annual training season was split into five distinct training phases: general preparatory 1 (GP1: 1st May–31st July), general preparatory 2 (GP2: 1st August–30th October), specific preparatory phase (SP: 1st November–31st December), competitive phase (CP: 1st January–31st March), and transition/recovery phase (REC: 1st April–30th April), as previously described.[9]

Data analysis

All analyses were undertaken using R (R Core Team 2021). Data were modelled using linear mixed effects (package: *lme4*)[18] with a random intercept for each athlete. All models included training phase (levels: GP1; GP2; SP; CP; REC), sport (levels: XC; biathlon), level of competition [levels: (inter)national; non-national] and age category (levels: junior; senior) as fixed factors, with interactions included between all fixed factors. Fit and convergence were checked with the DHARMa package.[19] Post-hoc testing, effect sizes (Cohen's *d*), and marginal means were produced using the *emmeans* package,[20] with Tukey correction for multiple comparisons. Statistical significance was assumed to $\alpha = 5\%$. Data are provided as means and variance reported as standard deviations (± SD) or 95% confidence intervals [95% CI], unless otherwise noted.

Results

Annual training time and periodisation

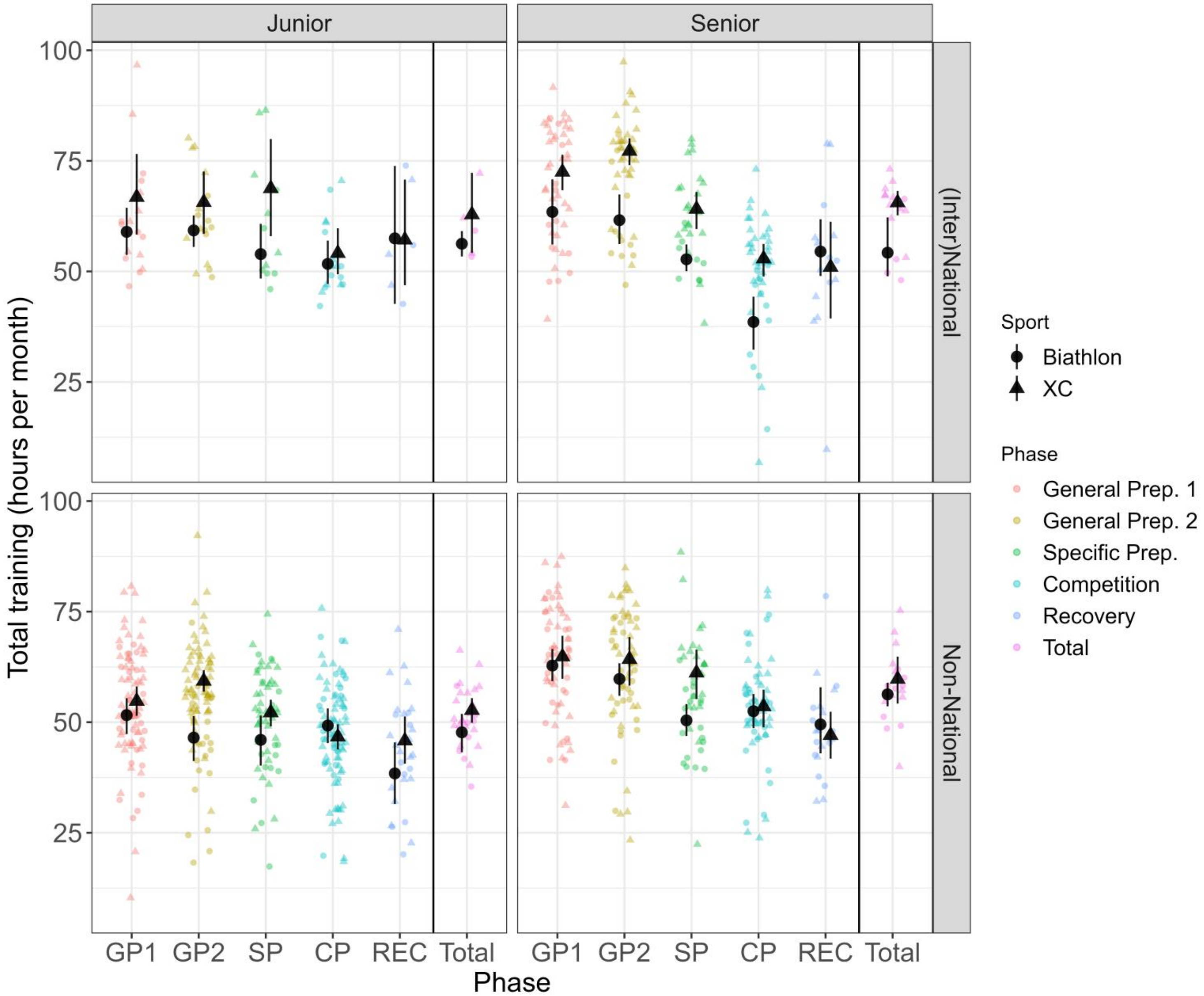
Total annual training time for all XC skiers and biathletes was 676 ± 102 h·year^{-1} (range: 425 – 902 h·year^{-1}) distributed across 434 ± 58 training sessions. XC skiers completed 10% more total annual training time (699 ± 105 h·year^{-1}) compared to biathletes (636 ± 83 h·year^{-1}; p = .003; d = 0.78). Differences were also found between competition levels ((inter)national: 740 ± 90 h·year^{-1}; non-national: 649 ± 95 h·year^{-1}; p = .004; d = 0.81) and for age categories (senior: 719 ± 95 h·year^{-1}; junior: 631 ± 90 h·year^{-1}; p < .001; d = 0.91), independent of sport. No interaction effects were found between sport, competition level or age category. See Table 2 for details.

Endurance training accounted for 89.2 ± 4.0% of total training time for all athletes, with an additional 7.0 ± 2.6% used for strength training, and the remainder (3.8 ± 2.2%) as flexibility, speed, and power training. Split by sport, endurance training comprised 90.9 ± 3.4% of total training time for biathletes, and 88.3 ± 4.0% for XC skiers. On average, most endurance training was completed as LIT (90.5 ± 2.6%; 546 ± 90 h·year^{-1}), with approximately equal proportions of MIT (4.5 ± 1.8%; 28 ± 12 h·year^{-1}) and HIT (4.9 ± 1.8%; 29 ± 10 h·year^{-1}). See Figure 1 for the total monthly training time per training phase, for sport, competition level and age category. No significant differences were found between sports for either the total annual MIT and HIT training time or the number of sessions for MIT or HIT (p = .160 to .476). XC skiers completed higher monthly total training volumes during GP1, GP2 and SP (p = .001 to .027; d = 0.48 to 0.94) than biathletes. XC skiers also reported significantly more annual strength training than biathletes (p = .011; d = 0.78; Table 2), and specifically, senior XC athletes had higher monthly strength training during the preparatory phases (p = .001 to 005; d = 0.51 to 0.75; Figure 2) when compared to senior biathletes.

Table 2. Annual training time across the 2020/21 annual season for female XC skiers and biathletes.

	XC				Biathlon			
	Junior	**Senior**	**Non-National**	**(Inter)national**	**Junior**	**Senior**	**Non-National**	**(Inter)national**
Annual training (h·year^{-1}: *, $, #)	648 ± 89	752 ± 96	662 ± 71	780 ± 99	598 ± 84	668 ± 69	627 ± 74	661 ± 86
Endurance (h·year^{-1}: *, $, #; % total: *)	566 ± 79; 87.3 ± 3.1	672 ± 92; 89.3 ± 3.1	583 ± 94; 87.9 ± 4.3	695 ± 66; 89.2 ± 3.4	537 ± 73; 90.0 ± 2.9	612 ± 60; 91.7 ± 3.8	564 ± 75; 90.1 ± 3.4	614 ± 69; 92.9 ± 2.9
Strength (h·year^{-1}: *; % total: $)	53 ± 14; 8.2 ± 1.9	49 ± 22; 6.6 ± 3.2	51 ± 19; 7.8 ± 2.9	51 ± 17 $; 6.5 ± 2.1	45 ± 15; 7.4 ± 1.9	37 ± 18; 5.4 ± 2.5	42 ± 16; 6.6 ± 2.3	37 ± 19 $; 5.5 ± 2.8
Speed & power (h·year^{-1}; % total: *)	20 ± 8; 3.0 ± 1.1	22 ± 10; 2.8 ± 1.2	18 ± 8*#; 2.8 ± 1.1	26 ± 11*#; 3.2 ± 1.3	9 ± 7; 1.4 ± 1.2	9 ± 7; 1.4 ± 1.0	10 ± 7*; 1.6 ± 1.1	7 ± 6*; 1.0 ± 0.8
Mobility (h·year^{-1}; % total: *)	10 ± 10; 1.6 ± 1.3	10 ± 12 #; 1.3 ± 1.6	11± 10; 1.1 ± 1.5	9 ± 12; 1.6 ± 1.4	7 ± 9; 1.2 ± 1.6	11 ± 11 #; 1.6 ± 1.6	11 ± 12; 1.7 ± 1.7	4 ± 3; 0.6 ± 0.6

XC = cross country skiers. Data presented as mean ± standard deviation. Statistical difference ($p < .05$) in annual training between groups: * = sport difference; $ = age category difference; # = competition level difference.


Junior
Senior
(Inter)National
Non-National
Total training (hours per month)
100
75
50
25
GP1 GP2 SP CP REC Total
GP1 GP2 SP CP REC Total
Phase
Sport
Biathlon
XC
Phase
General Prep. 1
General Prep. 2
Specific Prep.
Competition
Recovery
Total

183

Figure 1. Distribution of monthly training per phase for XC and biathlon, split by competition level and age category. Group data for each sport are presented as total training hours per month, annually and per phase, with the mean indicated as a black shape (XC = circle; biathlon = triangle) and black vertical lines indicating 95% confidence intervals. Individual athlete data points are shown for each sport, with the shape indicating sport and point colour indicating phase (GP1 = red; GP2 = gold; SP = green; CP = aqua; REC = blue; Total = pink). Note: XC = cross country skiers; GP1 = general preparatory phase 1; GP2 = general preparatory phase 2; SP = specific preparatory phase; CP = competition phase; REC = recovery phase.

Annual periodization of endurance training

LIT volume for (inter)national athletes was significantly higher than non-national athletes for all phases (*p* < .001 to .006; *d* = 0.60 to 0.98) apart from CP. Within competition level, decreased LIT volume was reported from GP2 to SP for non-national athletes (*p* = .007 *d* = 0.38) and decreased LIT and MIT was observed from SP to CP for national athletes (*p* < .001 to .016; *d* = 0.51 to 0.80).

The volume of LIT was stable in GP1 and GP2, before decreasing to SP (*p* = .002 to .003; *d* = 0.59 to 0.86) for seniors of both sports and decreasing again to CP for senior XC skiers (*p* = .001; *d* = 0.62; see Figure 2). Conversely, volume remaining relatively consistent across all phases for juniors of both sports. Accordingly, the volume of LIT during GP1 and GP2 was higher in seniors of both sports, compared to juniors (*p* = .002 to .011; *d* = 0.81 to 0.89), with no differences from SP onwards. The proportion of LIT was higher in seniors compared to juniors during GP2 and REC (*p* = .011 to .025; *d* = 0.49 to 0.54), with no other significant differences in LIT proportion across consecutive phases for all athletes. Seniors reported a reduction in proportion and volume of MIT (*p* < .001 to .012; *d* = 0.51 to 0.64) and a simultaneous increase in proportion and volume of HIT from GP1 to GP2 (*p* < .001 to .003; *d* = 0.44 to 0.53), while juniors had no significant differences between phases, apart from REC. Senior athletes also had a higher proportion and volume of MIT (p < .001 to .015; *d* = 0.59 to 1.09) and lower volume of HIT for GP1 (*p* = .016; *d* = 0.56), as well as lower proportions of HIT for GP1 and GP2 (*p* = .001 to .005; *d* = 0.66 to 0.76), when compared to juniors.

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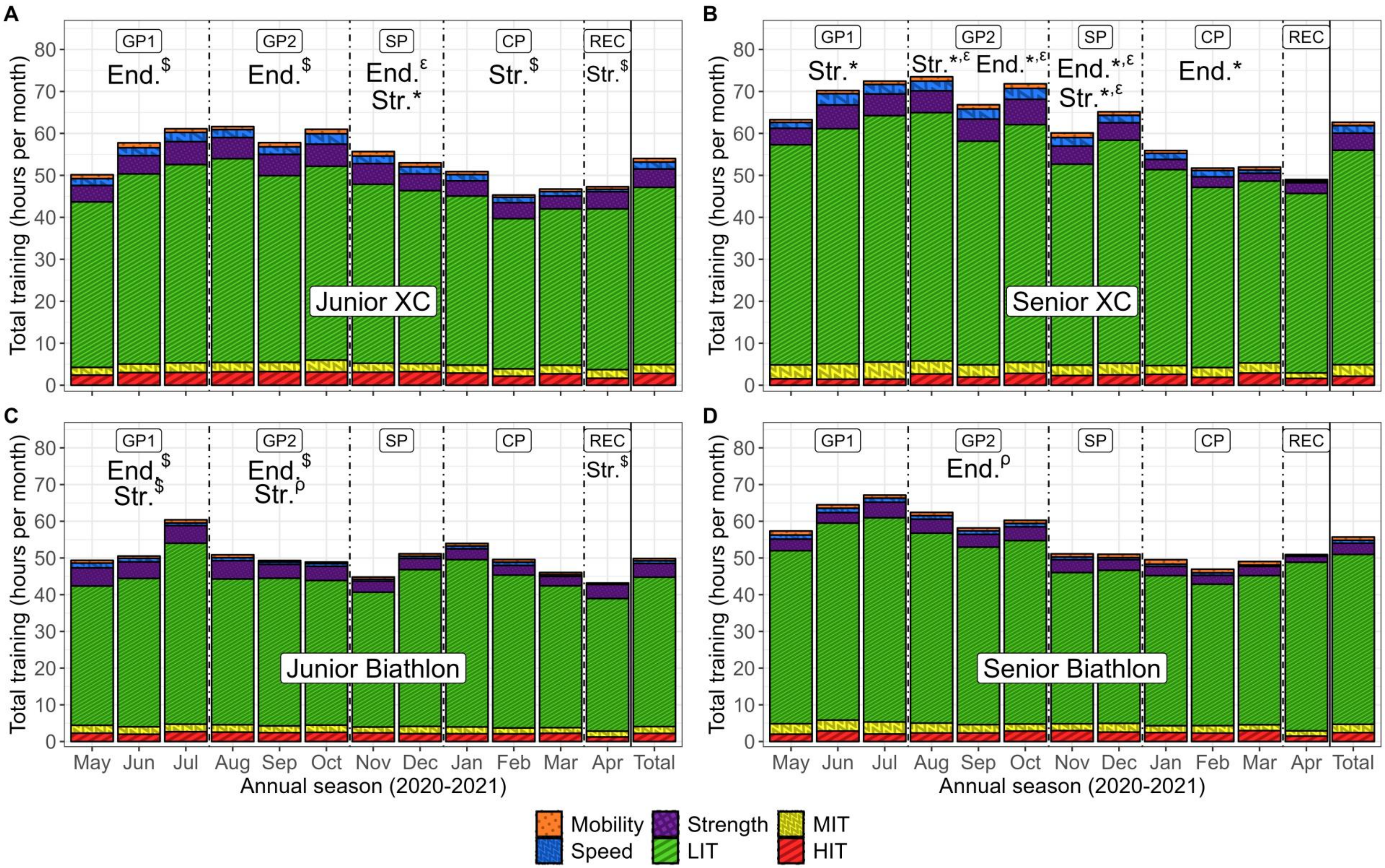
A
B
C
D
GP1
GP2
SP
CP
REC
End.$
End.$
End.ε
Str.*
Str.$
Str.$
Str.*
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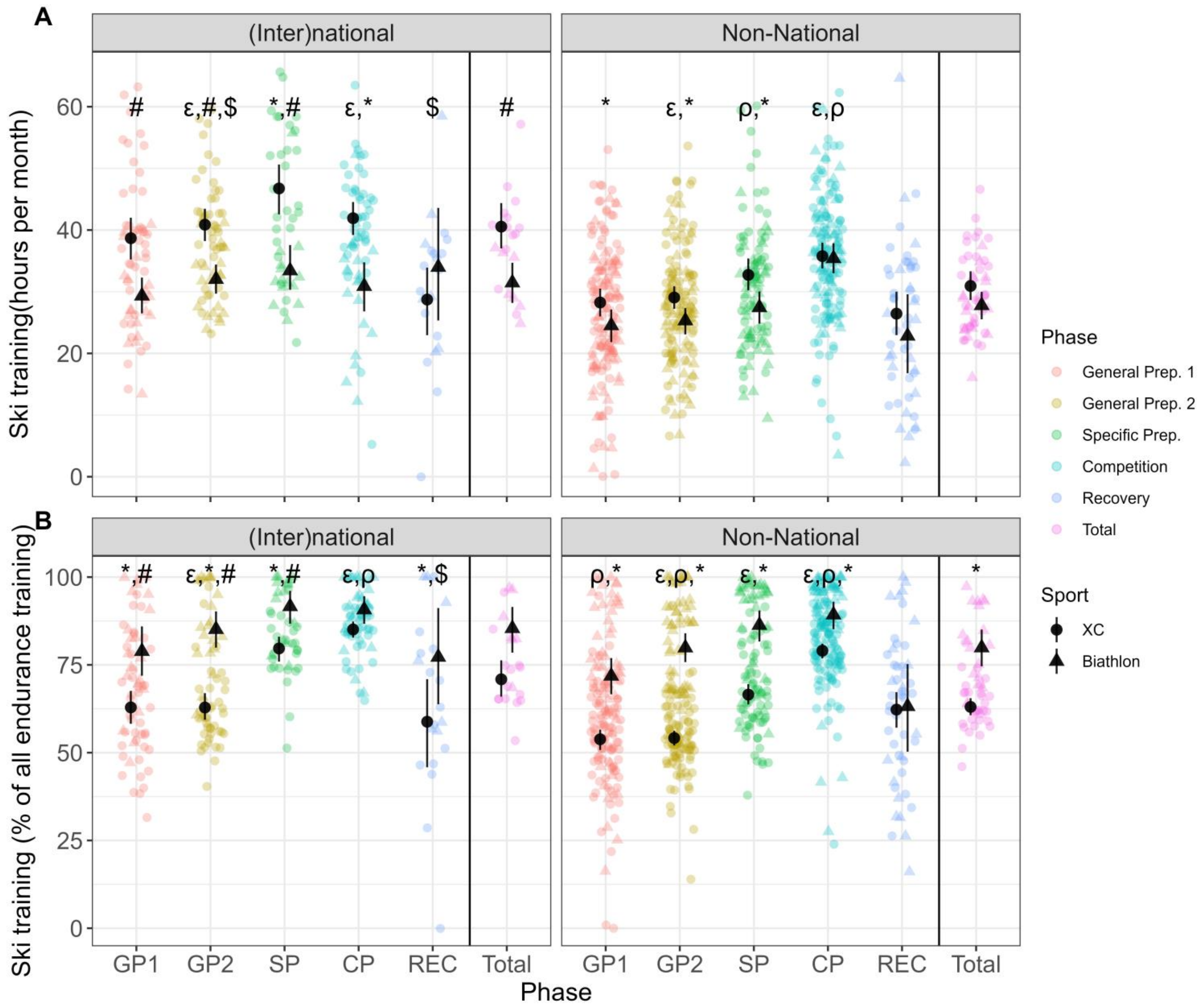
End.*
End.$
Str.$
End.$
Str.ρ
Str.$
End.ρ
Junior XC
Senior XC
Junior Biathlon
Senior Biathlon
Total training (hours per month)
May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr Total
Annual season (2020-2021)
Mobility
Speed
Strength
LIT
MIT
HIT

Figure 2. Annual training distribution per month and phase for XC and biathletes of different age categories. (A) junior XC; (B) senior XC; (C) junior biathlon; and, (D) senior biathlon. Data are presented as mean monthly training hours per modality (indicated by bar colour). Months are grouped per phase, as indicated by the dashed separator lines, with phases abbreviated: GP1 = general preparatory phase 1; GP2 = general preparatory phase 2; SP = specific preparatory phase; CP = competition phase; REC = recovery phase; Total = annual mean. Note: XC = cross country skiers; LIT = low-intensity training; MIT = medium-intensity training; HIT = high-intensity training; End. = cumulative LIT, MIT and HIT endurance training; Str. = strength training. Comparisons are within and between sports and age categories, for End and Str. Statistically different ($p < .05$) from subsequent phase, within the same sport and competition level: ε = XC; ρ = Biathlon. Statistically different ($p < .05$) within the same phase: * = sport difference compared to BI, within age category; $ = age category difference compared to senior, within the sport.

Annual periodization of exercise modes

Ski training (i.e., on-snow skiing or roller skiing) comprised 72.2 ± 18.7% of all endurance training time, with the remainder consisting of alternative endurance activities, such as running (18.7 ± 16.8%) or other sports (9.1 ± 13.7%). Split by sport, biathletes completed significantly lower monthly ski volume but a higher proportion of endurance training as skiing (29 ± 10 $h \cdot month^{-1}$ and 81 ± 17%), when compared to XC skiers (34 ± 12 $h \cdot month^{-1}$ and 68 ± 16; $p <$ .001 to .005; d = 0.47 to 0.94). Senior XC skiers reported higher volumes of ski training during all phases (p < .001 to .009; d = 0.72 to 1.29) apart from REC, and lower proportions in all phases apart from CP (p < .001 to .033; d = 0.74 to 1.59), when compared to senior biathletes. Junior XC skiers had a higher volume than biathletes only during GP1 and GP2 (p = .031 to .037; d = 0.56 to 0.58) but were proportionally lower than biathletes for all phases apart from REC (p < .001 to .003; d = 0.83 to 1.61). See Figure 3 for differences in ski training proportion, within and between sports and competition levels.

When total ski-training time was separated into the two ski techniques (skate and classic), it was found that biathletes spent a significantly greater proportion of training time using the skating technique (56–66% of total ski training), compared to XC skiers (45–48% of all ski training), during all phases (p < .001; d = 0.79 to 1.31) apart from during REC (p = .059). However, when compared to absolute training time, there was no sport difference for skating time (p = 0.542).



A
(Inter)national
Non-National
Ski training(hours per month)
#
ε,#,$
*,#
ε,*
$
#
*
ε,*
ρ,*
ε,ρ
B
Ski training (% of all endurance training)
*,#
ε,*,#
*,#
ε,ρ
*,$
ρ,*
ε,ρ,*
ε,*
ε,ρ,*
*
GP1
GP2
SP
CP
REC
Total
Phase
Phase
General Prep. 1
General Prep. 2
Specific Prep.
Competition
Recovery
Total
Sport
XC
Biathlon

239

Figure 3. Annual distribution of ski training (on-snow and roller-ski) per phase for XC and biathletes of different competition levels. (A) monthly ski training per phase in hours; (B) proportion of monthly endurance training as ski training per phase. Group data for each sport are presented per phase and annually, with the mean indicated as a black shape (XC = circle; biathlon = triangle) and black vertical lines indicating 95% confidence intervals. Individual athlete data points are shown for each sport, with the point colour indicating phase and shape indicating sport (XC = circle; biathlon = triangle; GP1 = red; GP2 = gold; SP = green; CP = aqua; REC = blue; Total = pink). Note: XC = cross country skiers; GP1 = general preparatory phase 1; GP2 = general preparatory phase 2; SP = specific preparatory phase; CP = competition phase; REC = recovery phase. Statistically different ($p < .05$) from subsequent phase within the same sport: ε = XC; ρ = Biathlon. * = statistically different ($p < .05$) between sports, within the same phase and competition level. Statistically different ($p < .05$) from non-national competition level within the same phase: # = XC; $ = Biathlon.

Discussion

The purpose of this observational study was to describe and compare the annual training characteristics of Norwegian female XC skiers and biathletes across competition levels and age categories. The main findings from this study were: 1) XC skiers completed a ~10% higher annual physical training volume than biathletes (shooting excluded) and ~24% higher annual volume of strength training; 2) XC skiers reported a higher volume of overall ski training but similar volumes of skating compared to biathletes; 3) biathletes trained higher proportions of ski training and skating compared to XC skiers; 4) (inter)national level XC skiers performed higher volumes and proportions of ski training than non-national level XC skiers during the preparatory phases (i.e., GP1, GP2, SP); and, 5) the annual periodization of endurance training was different between senior and juniors, with seniors performing significantly higher volumes during GP1 and GP2 than juniors.

High annual training volumes have been associated with international athletic success in endurance sports, with previous literature reporting a range from ~700–900 $h \cdot year^{-1}$ for mixed-sex cohorts of senior elite XC skiers[2] and world-class biathletes.[3] Similar values were also observed in the present study, with (inter)national senior XC skiers and biathletes completing 787 ± 62 and 651 ± 100 $h \cdot year^{-1}$, highlighting the importance of a large training volume to remain competitive at the elite level. Biathletes reported ~10% lower annual training volumes (636 ± 83 $h \cdot year^{-1}$) compared to XC skiers (699 ± 105 $h \cdot year^{-1}$); a smaller difference than the ~30–35% lower training volumes of biathletes compared to XC skiers in previous research.[4,6,7,21] The exact reason(s) for this difference in training volume between the sports is unclear, however, one reason may be due to the time spent in shooting practice. Shooting accuracy is estimated to explain 35–50% of race performance in biathlon and is thus a critically important skill for success.[3] Therefore, it is logical that biathletes' training time may be reallocated for shooting practice, from time spent on other types of (physical) training. This is supported by previous research on elite biathletes which noted that ~30–40% of annual shots were fired during 'at-rest' shooting-only training, with the remainder of shots undertaken during endurance training of various intensities.[3,7,21] Unfortunately, the volume and content of shooting training were not recorded in the presented study and should therefore be investigated in future research. An additional reason for the observed training differences may be due to the different ski technique requirements during competitions: biathletes exclusively use the skating technique, whilst XC skiers utilise both skating and classic techniques.

Total volume of annual strength training was significantly higher (~+24%) for XC skiers compared to biathletes (~51 vs 41 h·year^{-1}). This finding aligns with recent research indicating that XC skiers perform almost double the volume of strength training compared with biathletes.[6,21] Similar to previous studies[2,9], senior XC skiers performed more strength training during the preparatory phases, followed by decreased volumes towards CP. In contrast, biathletes reported a relatively flat periodisation, with less strength training performed during the preparatory phases. One reason for the different emphasis and periodization of strength training between the sports may be the different competitive demands: XC skiers utilize both the classic and skate skiing techniques, and also compete in knock-out style sprint races, which necessitates strength training for acceleration and sprint performance development; components which are arguably of lower importance in biathlon.[3,22] The requirement of rifle carriage in biathlon is known to biomechanically influence skiing technique due to the rifle weight (e.g., increased cycle rate and reduced cycle length at a given speed),[23] which could necessitate a higher demand for strength training. However, the observed lower strength training volume of biathletes, when compared to XC skiers, might be an effect of training prioritization around shooting. Specifically, shooting practice may reduce the time allocated to other forms of training, resulting in the prioritization of endurance training over strength training for biathletes. While sport differences may potentially influence strength training requirements, there is currently a lack of empirical evidence supporting this hypothesis. Alternatively, another reason for this strength training difference could be due to tradition and/or training philosophy within each sport. More research investigating the detailed content and periodization of strength training in elite biathletes is needed.

A high proportion of training time (~89%) was completed as endurance training for both sports, which aligns with similar values reported by other studies of elite endurance athletes.[2,4] Senior XC skiers trained higher volumes of ski-specific training (38 ± 12 vs 31 ± 9 $h \cdot month^{-1}$, respectively), but similar volumes of skating compared to senior biathletes. However, the overall proportion of ski training (Biathletes: 81 ± 17%; XC skiers: 68 ± 16%; Figure 3) and proportion of skating (56–66%) were higher in biathletes compared to XC skiers, who reported a more even distribution between the two technique styles. These identified training differences are likely caused by the distinct demands of the two sports (i.e., both the classic and skating technique styles used in XC skiing compared to the singular use of skating in biathlon). Still, this finding indicates that biathletes may ‘compensate’ for their lower endurance training volumes with higher proportions of ski training in the skating style.

Irrespective of sport, (inter)national level athletes reported significantly higher annual total training volumes (740 ± 90 $h \cdot year^{-1}$) compared to non-national level athletes (649 ± 95 $h \cdot year^{-1}$), further supporting the importance of a large training volume to compete at the highest level in endurance sports.[22,24] This finding is further supported when considering ski training volumes, where (inter)national level XC skiers reported significantly higher monthly training during the preparatory phases (i.e., GP1, GP2 and SP) and overall (Figure 3) when compared to non-national skiers. In contrast, a competition-level difference in ski training time for biathletes was only found for GP2 and REC. The reason for this finding is uncertain, and more data on the periodization of biathlon athletes' training, including shooting data, is necessary to understand the differences in periodization patterns between XC skiers and biathlete training.

A significant difference was observed between the pattern of endurance training for junior and senior athletes, with the former group reporting lower endurance training across the two general preparatory phases (~48–49 $h \cdot month^{-1}$) that was maintained during SP and CP (~44–46 $h \cdot month^{-1}$; Figure 2). Conversely, senior athletes reported a higher training volume during the GP phases (~59–60 $h \cdot month^{-1}$), before significantly tapering towards SP and CP (47–52 $h \cdot month^{-1}$). The model of endurance training found for senior athletes in this study is similar to the volume distribution previously described for senior biathletes[5] and XC skiers.[2,9] This is likely explained by increased specialization as a senior athlete, implying the capacity and time to perform higher training volumes during the preparatory phases, while more frequent traveling and competitions make it less possible to perform high training volumes during CP. The attenuated training taper for junior athletes may also be due to the later start of the competitive season in juniors and the reduced number of competitive international events, thus allowing more time spent training, rather than travelling. Alternatively, or simultaneously, the maintenance of junior athletes' training volume may also be prioritized over tapering for competition, as maintenance of training for the development of aerobic and technical capacities could be considered more beneficial over the longer term.

Volume and proportion of HIT were found to be lower for seniors compared to juniors during the general preparatory phases (i.e., GP1 and GP). This result is initially surprising, as previous research has emphasized the importance of increasing HIT to further develop aerobic capacity.[25] Still, similar developments in intensity distribution have previously been observed in the world's most successful female XC skier, emphasizing more HIT during the early stages of her senior career but then higher LIT and MIT during the later years.[9,26] Furthermore, analyses of endurance athletes have demonstrated that increases in training volume are primarily due to a rise in LIT,[15] and it has been speculated that the quality of HIT sessions might be of more importance than quantity. Longitudinal research has also highlighted a progressive improvement in skiing economy as athletes transit from the late teenage period (juniors) to adulthood (seniors), potentially due to a larger training volume arising from an increase in low-intensity training volume as they age.[27] Overall, the present data indicate that increasing endurance volume during the general preparatory phases with higher volumes of LIT and MIT might assist an athlete in successfully transitioning from junior to senior level, regardless of sport.

The training data for the present study was collected during the worldwide outbreak of the COVID-19 virus, which limited the number of competitive events and laboratory testing sessions that athletes were able to attend. Personal communication with a representative group of coaches and athletes indicated that training characteristics and periodization patterns were the same as before COVID-19. In most groups, training plans were made before COVID-19 began, and the decreased number of competitions was offset by test races and high-intensity sessions, to maintain the planned intensity distribution. Still, care should be taken when evaluating the results from this study, since pandemic-induced changes may have occurred. For example, there are indications that athletes reported reduced sickness, had fewer travel days, and focused less on tapering than in pre- and post-COVID years, thereby allowing more time for training and possibly higher training volumes. While it is difficult to determine the true effect of the pandemic on the present study, the similarity of data to previous research[2,3] that has reported annual training volume and load distribution, suggests there was, at most, a limited influence.

Practical Applications

The present study described how the different loading factors were balanced across the annual cycle to meet the sports-specific demands in XC skiing and biathlon. While XC skiers on average performed ~10% higher endurance and ~24% higher strength training volumes, biathletes ‘compensated’ with higher proportions of ski-specific training in the skating style. The lower training volumes in biathlon likely reflect the additional demands of shooting practice, which is essential for success in this sport. In addition, our data demonstrated differences in training between competition levels that could highlight potential improvement areas for lower-level athletes. The differences found between junior and senior athletes, with overall less volume but greater maintenance of training throughout the competitive period in juniors, align with their training development and competitive schedule.

Conclusions

This study describes and compares the training characteristics of highly-trained (regional-level to world-class) female XC skiers and biathletes, across the junior and senior age categories. The higher annual training volume by XC skiers compared to biathletes is likely caused by the different demands of the two sports; XC skiing balances training time for the two different skiing styles while biathlon requires additional shooting practice. To compensate for their lower ski-training volume, biathletes spend a higher proportion of their total endurance time as ski training, particularly in the skating technique. A high training volume, particularly during the preparatory phases, seems to be an important differentiating factor between competition levels of XC skiers. However, this volume difference was not significant in biathletes, possibly due to greater focus on shooting practice as this is an additional performance-differentiating factor. Clear differences were observed in the annual periodization between junior and senior athletes. While senior athletes demonstrated a traditional periodization pattern with a reduction in training volume from the preparatory phases towards the competitive phase, junior athletes had a relatively consistent training volume across the annual phases. Future studies should investigate the sophisticated interplay of physical training and shooting practice performed by biathletes at different ages and performance levels.

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References

1. Sandbakk Ø. The Evolution of Champion Cross-Country-Skier Training: From Lumberjacks to Professional Athletes. *Int J Sports Physiol Perform*. 2017;12(2):254-259. doi:10.1123/ijspp.2016-0816

2. Tønnessen E, Sylta Ø, Haugen TA, Hem E, Svendsen IS, Seiler S. The Road to Gold: Training and Peaking Characteristics in the Year Prior to a Gold Medal Endurance Performance. *PLOS ONE*. 2014;9(7):e101796. doi:10.1371/journal.pone.0101796

3. Laaksonen MS, Jonsson M, Holmberg HC. The Olympic Biathlon – Recent Advances and Perspectives After Pyeongchang. *Front Physiol*. 2018;9. doi:10.3389/fphys.2018.00796

4. Sandbakk Ø, Holmberg HC. Physiological Capacity and Training Routines of Elite Cross-Country Skiers: Approaching the Upper Limits of Human Endurance. *Int J Sports Physiol Perform*. 2017;12(8):1003-1011. doi:10.1123/ijspp.2016-0749

5. Myakinchenko EB, Kriuchkov AS, Adodin NV, Feofilaktov V. The Annual Periodization of Training Volumes of International-Level Cross-Country Skiers and Biathletes. *Int J Sports Physiol Perform*. 2020;15(8):1181-1188. doi:10.1123/ijspp.2019-0220

6. Myakinchenko EB, Heil DP, Kriuchkov AS, Feofilaktov VV, Kuzmichev VA, Adodin NV. Physiological profiles and training loads of international level male and female cross-country skiers and biathletes. *Sci Sports*. 2022;37(5):490.e1-490.e10. doi:10.1016/j.scispo.2021.09.004

7. Schmitt L, Bouthiaux S, Millet GP. Eleven Years' Monitoring of the World's Most Successful Male Biathlete of the Last Decade. *Int J Sports Physiol Perform*. 2021;16(6):900-905. doi:10.1123/ijspp.2020-0148

8. Losnegard T, Myklebust H, Spencer M, Hallén J. Seasonal Variations in VO2max, O2-Cost, O2-Deficit, and Performance in Elite Cross-Country Skiers. *J Strength Cond Res*. 2013;27(7):1780-1790. doi:10.1519/JSC.0b013e31827368f6

9. Solli GS, Tønnessen E, Sandbakk Ø. The Training Characteristics of the World's Most Successful Female Cross-Country Skier. *Front Physiol*. 2017;8:1069. doi:10.3389/fphys.2017.01069

10. Karlsson Ø, Laaksonen MS, McGawley K. Training and illness characteristics of cross-country skiers transitioning from junior to senior level. *PLOS ONE*. 2021;16(5):e0250088. doi:10.1371/journal.pone.0250088

11. Sandbakk Ø, Hegge AM, Losnegard T, Skattebo Ø, TØnnessen E, Holmberg HC. The Physiological Capacity of the World's Highest Ranked Female Cross-country Skiers. *Med Sci Sports Exerc*. 2016;48(6):1091-1100. doi:10.1249/mss.0000000000000862

12. Engseth TP, Andersson EP, Solli GS, et al. Prevalence and Self-Perceived Experiences With the Use of Hormonal Contraceptives Among Competitive Female Cross-Country Skiers and Biathletes in Norway: The FENDURA Project. *Front Sports Act Living*. 2022;4. doi:10.3389/fspor.2022.873222

13. McKay AKA, Stellingwerff T, Smith ES, et al. Defining Training and Performance Caliber: A Participant Classification Framework. *Int J Sports Physiol Perform*. 2022;17(2):317-331. doi:10.1123/ijspp.2021-0451

14. Foster C, Florhaug JA, Franklin J, et al. A New Approach to Monitoring Exercise Training. *J Strength Cond Res*. 2001;15(1):109-115.

15. Seiler S. What is best practice for training intensity and duration distribution in endurance athletes? *Int J Sports Physiol Perform*. 2010;5(3):276-291. doi:10.1123/ijspp.5.3.276

16. Sylta Ø, Tønnessen E, Seiler S. From Heart-Rate Data to Training Quantification: A Comparison of 3 Methods of Training-Intensity Analysis. *Int J Sports Physiol Perform*. 2014;9(1):100-107. doi:10.1123/ijspp.2013-0298

17. Tønnessen E, Svendsen IS, Rønnestad BR, Hisdal J, Haugen TA, Seiler S. The Annual Training Periodization of 8 World Champions in Orienteering. *Int J Sports Physiol Perform*. 2015;10(1):29-38. doi:10.1123/ijspp.2014-0005

18. Bates D, Mächler M, Bolker B, Walker S. Fitting Linear Mixed-Effects Models Using lme4. *J Stat Softw*. 2015;67:1-48. doi:10.18637/jss.v067.i01

19. Hartig F. DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. Published online 2022. http://florianhartig.github.io/DHARMa/

20. Lenth R, Buerkner P, Herve M, Love J, Riebl H, Singmann H. emmeans: Estimated Marginal Means, aka Least-Squares Means. Published online September 18, 2020. Accessed September 28, 2020. https://CRAN.R-project.org/package=emmeans

21. Solli GS, Flom AH, Talsnes RK. Long-term development of performance, physiological, and training characteristics in a world-class female biathlete. *Front Sports Act Living*. 2023;5. Accessed July 10, 2023. https://www.frontiersin.org/articles/10.3389/fspor.2023.1197793

22. Sandbakk Ø, Holmberg HC. A Reappraisal of Success Factors for Olympic Cross-Country Skiing. *Int J Sports Physiol Perform*. 2014;9(1):117-121. doi:10.1123/ijspp.2013-0373

23. Stöggl T, Bishop P, Höök M, Willis S, Holmberg HC. Effect of carrying a rifle on physiology and biomechanical responses in biathletes. *Med Sci Sports Exerc*. 2015;47(3):617-624. doi:10.1249/MSS.0000000000000438

24. Stöggl TL, Sperlich B. The training intensity distribution among well-trained and elite endurance athletes. *Front Physiol*. 2015;6. doi:10.3389/fphys.2015.00295

25. Laursen PB, Jenkins DG. The scientific basis for high-intensity interval training: optimising training programmes and maximising performance in highly trained endurance athletes. *Sports Med Auckl NZ*. 2002;32(1):53-73. doi:10.2165/00007256-200232010-00003

26. Solli GS, Tønnessen E, Sandbakk Ø. Block vs. Traditional Periodization of HIT: Two Different Paths to Success for the World's Best Cross-Country Skier. *Front Physiol*. 2019;10. doi:10.3389/fphys.2019.00375

27. Zoppirolli C, Modena R, Fornasiero A, et al. Talent Development in Young Cross-Country Skiers: Longitudinal Analysis of Anthropometric and Physiological Characteristics. *Front Sports Act Living*. 2020;2. Accessed July 7, 2023. https://www.frontiersin.org/articles/10.3389/fspor.2020.00111

Figure Captions

Figure 1. Distribution of monthly training per phase for XC and biathlon, split by competition level and age category. Group data for each sport are presented as total training hours per month, annually and per phase, with the mean indicated as a black shape (XC = circle; biathlon = triangle) and black vertical lines indicating 95% confidence intervals. Individual athlete data points are shown for each sport, with the shape indicating sport and point colour indicating phase (GP1 = red; GP2 = gold; SP = green; CP = aqua; REC = blue; Total = pink). Note: XC = cross country skiers; GP1 = general preparatory phase 1; GP2 = general preparatory phase 2; SP = specific preparatory phase; CP = competition phase; REC = recovery phase.

Figure 2. Annual training distribution per month and phase for XC and biathletes of different age categories. (A) junior XC; (B) senior XC; (C) junior biathlon; and, (D) senior biathlon. Data are presented as mean monthly training hours per modality (indicated by bar colour). Months are grouped per phase, as indicated by the dashed separator lines, with phases abbreviated: GP1 = general preparatory phase 1; GP2 = general preparatory phase 2; SP = specific preparatory phase; CP = competition phase; REC = recovery phase; Total = annual mean. Note: XC = cross country skiers; LIT = low-intensity training; MIT = medium-intensity training; HIT = high-intensity training; End. = cumulative LIT, MIT and HIT endurance training; Str. = strength training. Comparisons are within and between sports and age categories, for End and Str. Statistically different ($p < .05$) from subsequent phase, within the same sport and competition level: ε = XC; ρ = Biathlon. Statistically different ($p < .05$) within the same phase: * = sport difference compared to BI, within age category; $ = age category difference compared to senior, within the sport.

Figure 3. Annual distribution of ski training (on-snow and roller-ski) per phase for XC and biathletes of different competition levels. (A) monthly ski training per phase in hours; (B) proportion of monthly endurance training as ski training per phase. Group data for each sport are presented per phase and annually, with the mean indicated as a black shape (XC = circle; biathlon = triangle) and black vertical lines indicating 95% confidence intervals. Individual athlete data points are shown for each sport, with the point colour indicating phase and shape indicating sport (XC = circle; biathlon = triangle; GP1 = red; GP2 = gold; SP = green; CP = aqua; REC = blue; Total = pink). Note: XC = cross country skiers; GP1 = general

preparatory phase 1; GP2 = general preparatory phase 2; SP = specific preparatory phase; CP = competition phase; REC = recovery phase. Statistically different ($p < .05$) from subsequent phase within the same sport: ε = XC; ρ = Biathlon. * = statistically different ($p < .05$) between sports, within the same phase and competition level. Statistically different ($p < .05$) from non-national competition level within the same phase: # = XC; $ = Biathlon.