Title

Using multivariate data analysis to project performance in biathletes and cross-country skiers

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Abstract

Purpose: To determine whether competitive performance, as defined by International Biathlon Union (IBU) and International Ski Federation (FIS) points in biathlon (BIA) and cross-country (XC) skiing, respectively, can be projected using a combination of anthropometric and physiological metrics. Shooting accuracy was also included in the biathlon models.

Methods: Data were analyzed using multivariate methods from 45 (23 female, 22 male) biathletes and 202 (86 female, 116 male) XC skiers who were all members of senior national teams, national development teams, ski-university or high-school invite-only programs (age range: 16–36 yr). Anthropometric and physiological characteristics were assessed via dual-energy X-ray absorptiometry and incremental roller-ski treadmill tests, respectively. Shooting accuracy was assessed via an outdoor standardized testing protocol.

Results: Valid projective models were identified for female biathletes' IBU points (R^2=0.80 / Q^2=0.65) and female XC skiers' FIS distance (R^2=0.81 / Q^2=0.74) and sprint (R^2=0.81 / Q^2=0.70) points. No valid models were identified for the men. The most important variables for the projection of IBU points were shooting accuracy, speeds at blood lactate concentrations (BLa) of 4 and 2 mmol·L^{-1}, peak aerobic power ($\dot{V}O_{2peak}$) and lean mass. The most important variables for the projection of FIS distance and sprint points were speeds at BLa of 4 and 2 mmol·L^{-1} and $\dot{V}O_{2peak}$.

Conclusions: This study highlights the relative importance of specific anthropometric, physiological, and shooting accuracy metrics in female biathletes and XC skiers. The data can help to inform which specific metrics should be targeted when monitoring athletes' progression and designing training plans.

Key Words

athlete testing; FIS points; IBU points; endurance; winter sports

Introduction

Biathlon (BIA) and cross-country (XC) skiing are complex and demanding winter sports. In both sports similar physiological and anthropometric qualities correlate with competitive performance, including peak aerobic power ($\dot{V}O_{2peak}$),[1–3]. gross efficiency (GE)[4–6], speed and oxygen uptake ($\dot{V}O_2$) at a blood lactate concentration (BLa) of 4 $mmol\cdot L^{-1}$ [6,7] and lean mass.[3] There are additional similarities between the two sports, with both involving skate skiing, multiple competition formats and variable course profiles, race distances and durations.[8,9] However, the obvious distinction is the shooting component in BIA, where biathletes are required to complete two or four shooting bouts lasting approximately 25–35 s each, interspersed between three or five bouts of variable-intensity skate skiing over undulating terrain lasting approximately 5–8 min each.[8] Biathletes are also required to carry their rifle, weighing ≥ 3.5 kg, which alters the physiological and kinematical responses to XC skiing.[10,11]

Biathlon and XC skiing performance over a competitive season is typically reflected by International Biathlon Union (IBU) and International Ski Federation (FIS) points, respectively.[12,13] Researchers have previously employed bivariate and multiple linear regression (MLR) statistical approaches to identify anthropometric and physiological predictors of long-term or seasonal competitive performance (i.e., FIS points) in XC skiing[2–4,7,12,14] or acute (i.e., single-race or laboratory-simulated) competitive performance in BIA.[6,15] However, these commonly employed approaches may be insufficient to reveal complex interactions between variables and their influence on specific responses.[16] Therefore, a more robust and informative procedure may be to employ multivariate data analysis (MVDA) methods such as principle component analysis (PCA) and orthogonal projection to latent structures (OPLS), which account for interactions between a broad spectrum of qualities, to identify valid projective models of competitive performance. Specifically, these methods are better able to cope with collinearity of projector variables and this facilitates analysis of a greater range of variables compared with hierarchical regression models (such as MLR). Furthermore, previous work has reported that OPLS models have good agreement with other MVDA methods including random forest and support vector machines.[17] Both PCA and OPLS methods have been used for feature selection in omics fields[18,19] and have been used within winter sports to project competitive performance and identify key performance indicators.[20–22]

Jones *et al*.[20] recently reported that seasonal skiing distance performance could be projected in female national development team athletes using a combination of anthropometric and physiological qualities via PCA and OPLS methods. However, the sample was limited to 30 (14 female, 16 male) XC skiers. Although small sample sizes are common in applied studies of high-performance athletes, analyses of performance determinants in a much larger sample of biathletes and skiers would enable coaches and practitioners to confidently identify key performance indicators that are most relevant in each of these sports. Specifically, analyzing a large sample of high-performing biathletes and XC skiers using a consistent statistical approach will provide new information on the relative importance of common laboratory-derived test variables for BIA and XC skiing performance.

The primary aim of the present study was to investigate the relative importance of anthropometric and physiological characteristics for projecting seasonal BIA and XC skiing performance by constructing robust models using PCA and OPLS methods with relatively large samples of biathletes and XC skiers. A secondary aim was to compare the anthropometric and physiological characteristics between sports and performance levels.

Methods

Participants

Data were analyzed for 45 (23 female, 22 male) biathletes and 202 (86 female, 116 male) skiers (for descriptive characteristics see Table 2). All athletes were aged 16–36 years at the time of data collection and were members of senior national teams, national development teams and/or ski-university or high-school invite-only programs. At the end of the data collection period (November 2019), the senior national BIA and XC skiing teams were ranked 4th (women) and 6th (men) by the IBU and 2nd (women) and 4th (men) by FIS, respectively, reflecting a strong international standard in both sports. Prior to testing, all athletes provided written informed consent for their data to be used in analyses for subsequent publication and the study was preapproved by the regional ethical review board.

Design

Data were collected at a national test center over a 7-year period (from January 2013 to November 2019) and analyzed to assess how anthropometric and physiological characteristics measured in a laboratory setting were predictive of competitive performance. Field-based shooting test data was also included in the biathletes' projective models. Performance was defined as IBU and FIS points for BIA and XC skiing, respectively. The anthropometric, physiological and shooting data selected for analysis were those collected at the time point closest to when the athletes had achieved their best IBU or FIS points. Best IBU and FIS points were taken from the end-of-season calculations to ensure that data were representative of an entire season. Descriptive and anthropometric characteristics included age, stature, body mass, body mass index (BMI), lean body mass (LBM) separated into whole-, upper- and lower-body sections, and whole-body fat mass. Submaximal physiological characteristics included GE and speed, heart rate (HR) and $\dot{V}O_2$ at a BLa of 2 and 4 $mmol \cdot L^{-1}$, while maximal physiological variables included $\dot{V}O_{2peak}$ and peak BLa.

IBU and FIS points

In both IBU and FIS scoring systems, lower race points indicate better performance. Specific information on the calculation and distribution of IBU and FIS points is presented in the respective competition rulebooks.[23,24] IBU and FIS points were retrieved via communication with the IBU race director and fis-ski.com,[25] respectively. Four performance standards (world class, elite, national level and highly trained[26]) were defined by the following cut-offs: IBU points ≤ 20.0 = world class, 20.1–50.0 = elite, 50.1–75.0 = national level, > 75.0 = highly trained; FIS points ≤ 25.0 = world class, 25.1–50.0 = elite, 50.1–75.0 = national level, > 75.0 = highly trained.

Body composition assessments

All body composition measurements were conducted using dual-energy X-ray absorptiometry and followed previously published procedures.[10]

Roller-ski exercise assessments

All roller-ski exercise assessments involved the G3 skating sub-technique (i.e., one poling action for each leg stroke) for biathletes or diagonal-stride roller-skiing for skiers. Details of equipment (including calibration and validation), the determination of rolling resistances, expired air and HR sampling, as well as the calculation of speed, HR and $\dot{V}O_2$ corresponding to a BLa of 2 and 4 $mmol \cdot L^{-1}$, $\dot{V}O_2$ and GE are presented in previous publications.[6,20,27] The same equipment was used for all tests and respiratory variables were measured using an AMIS 2001 model C ergospirometry system (Innovision A/S, Odense, Denmark), while BLa was determined using a Biosen S-line (EKF diagnostic GmbH, Magdeburg, Germany). The submaximal exercise protocols consisted of 4–7 stages lasting 4 min and separated by 1-min rest intervals. For BIA, the women began the submaximal test at 7 $km \cdot h^{-1}$ and a gradient of 3.5°

and the men commenced at 8 km·h^{-1} and 4.5°. Speed was increased by 2 km·h^{-1} per stage and gradient was constant throughout the test. For XC skiing, the women began the submaximal test at 8 km·h^{-1} and a gradient of 3° and the men commenced at 9 km·h^{-1} and 4°. Speed was increased by 0.5 km·h^{-1} and gradient by 1° per stage. The submaximal test was terminated after the stage at which the RER exceeded 1.00, $\dot{V}E/\dot{V}O_2$ exceeded 30 and HR exceeded 90% of the maximal HR (HR_{max}) previously reported by the athletes.

Biathletes and skiers performed either maximal incremental or TT roller-ski assessments. The incremental protocol for BIA was performed at a constant incline of 3.5° for women and 4.5° for men and a starting speed of 12 km·h^{-1} for both sexes. Treadmill speed was increased by 2 km·h^{-1}·min^{-1} until speed reached 16 km·h^{-1} for women or 18 km·h^{-1} for men, after which incline was increased by 0.5°·min^{-1} until volitional exhaustion. The incremental protocol for XC skiing started at a 4° incline for both women and men with starting speeds of 11 km·h^{-1} for women and 12 km·h^{-1} for men. Treadmill incline was increased by 0.5°·min^{-1} until a maximum of 9°, after which the treadmill speed was increased by 0.3 km·h^{-1}·min^{-1} until volitional exhaustion. The maximal TT protocol for biathletes was completed at a 3.5° incline over 900 m for women (starting speed: 13 km·h^{-1}) and a 4.5° incline over 1000 m for men (starting speed: 14 km·h^{-1}). For skiers the maximal TT incline was 7° and the distance was 700 m for women (starting speed: 10 km·h^{-1}) and 800 m for men (starting speed: 13 km·h^{-1}). All athletes were able to adjust the treadmill speed throughout the TT by way of a laser system detecting the skier's position, which has been described previously.[28]

While different types of maximal test were used, $\dot{V}O_{2peak}$ was not different between the incremental (n=152) and TT (n=95) protocols (independent comparison, Mann Whitney U Test: 4.51±1.02 L·min^{-1} and 4.63±0.91 L·min^{-1}, respectively; p=0.356; Hedges' g=0.11), which is consistent with previous findings.[29] Furthermore, $\dot{V}O_{2peak}$ was not different between roller-ski assessments conducted in G3 skating (n=45) and diagonal-stride classic (n=202) sub-techniques (independent comparison, Mann Whitney U Test: 4.03±0.88 L·min^{-1} and 4.33 ± 0.86 L·min^{-1}, respectively; p=0.101; Hedges' g=0.35). As such, maximal physiological characteristics were compared for BIA and XC skiing, which was not the case for the sub-maximal characteristics where the different protocols for the two sports and sexes resulted in incomparable exercise intensities.

Shooting accuracy assessment

Shooting accuracy was assessed outdoors in a rested state at a standard 50-m biathlon shooting range using a bespoke standardized testing protocol employed by the national biathlon federation. After zeroing their own rifles (i.e., adjusting the sights), the biathletes fired 60 shots as close to the center of a 10-ring target as possible. The 60 shots were performed as 6 series of 5 shots in a prone position followed by 6 series of 5 shots in a standing position. A short (15–30 s) rest was permitted between each shooting series. Shooting accuracy was calculated as the sum of the scores from each shot ranging from 0 (outside the outer ring) to 10 (the center of the target), resulting in a maximum possible score of 600.

Statistical analyses

Data are presented as mean±*SD* and the alpha level of 0.05 was set *a priori*. Analyses were conducted using Jamovi 1.0.7.0[30] and SIMCA 16.0 (MKS AB, Umeå, Sweden). Prior to analyses, the Shapiro-Wilk normality test was employed to assess whether test variables were normally distributed. The IBU, FIS distance and sprint points, many of the anthropometric and physiological metrics and shooting accuracy were not-normally distributed ($p < 0.05$). Furthermore, the number of biathletes and XC skiers analyzed was uneven, so for comparisons between sports and across performance standards non-parametric statistical analyses were employed.

MVDA methods were used to examine whether IBU and FIS points could be projected by anthropometric and physiological characteristics, as well as shooting accuracy for the biathletes only. PCA was used to analyze the relationships between the anthropometric and physiological characteristics and shooting accuracy and to assess any hidden structures and patterns via the reduction of data dimensions. OPLS was employed to identify linear relationships between three groups of variables: (1) FIS points, (2) anthropometric and physiological characteristics, and (3) shooting accuracy. Specific details of these methods have been published previously.[16,31]

The IBU and FIS points (*Y* variables) were projected from anthropometric and physiological characteristics and shooting accuracy (*X* variables) and R^2VY is the cumulative percent of the variation of the response explained by the model after the last component. R^2 is a measure of how well the model fits the data. R^2VYAdj is the cumulative percent of the variation of the response, adjusted for degrees of freedom, explained by the model after the last component. Q^2VY is the cumulative percent of the variation of the response predicted by the model, after the last component, according to cross-validation. Q^2 indicates how well the model projects new data and permutations (22 for IBU points and 21 for FIS points, one less cycle than number of *X* variables) of models were deemed valid if the intercept was < 0 or if all permuted Q^2 values were below the original model value. R^2 and Q^2 should be > 0.8 and > 0.5 for well-modelled data (extract from the SIMCA-P + Handbook).

To evaluate the importance of specific anthropometric and physiological characteristics, as well as shooting accuracy in biathletes, for projecting IBU and FIS points, variable influence on projection (VIP) analyses were conducted. In an OPLS model, VIP summarizes the importance of the *X* variables, both for the *X* and *Y* models. VIP is normalized and the average squared VIP value is 1; thus, a VIP > 1 indicates that the variable is important for projection and a value < 0.5 indicates that the variable is not important for the projection.[16]

Differences in anthropometric and maximal physiological variables within sexes and between sports were analyzed using Mann-Whitney U tests. Differences between performance standards within sexes and sports were analyzed using Kruskal-Wallis ANOVA analyses with Dwass-Steel-Critchlow-Fligner pairwise *post-hoc* comparisons. Mann-Whitney U rank biserial correlation and Kruskal-Wallis ε^2 were employed to determine effect sizes.

Results

Details of the multivariate models for IBU, FIS distance and FIS sprint points (*Y* variables) constructed using anthropometric, physiological and shooting accuracy test data (*X* variables) are presented in Table 1. Valid projective models were identified for IBU points in the female biathletes and for FIS distance and sprint points in the female XC skiers. The regression coefficients of the underlying models for projecting new observations of IBU, FIS distance and FIS sprint points in the women were $R^2 = 0.77$, 0.79 and 0.75, respectively.

Table 1 about here

Shooting accuracy was identified as the most important variable for the projection of IBU points in the female biathletes (Figure 1A), while speed at a BLa of 4 mmol·L^{-1} was most important for the projection of FIS distance (Figure 1B) and sprint (Figure 1C) points in the female XC skiers. Other variables identified as important (VIP > 1) for the projection of IBU, FIS distance and/or FIS sprint points included age, average sub-maximal $\dot{V}O_2$, speed at a BLa of 2 mmol·L^{-1}, stature, total body mass, $\dot{V}O_{2peak}$ (L·min^{-1}, mL·kg^{-1}·min^{-1} and mL·kg LBM·min^{-1}), whole- and upper-body lean mass.

Figure 1 about here

Comparisons between the biathletes and skiers are displayed in Table 2. Both the female and male biathletes were older than their XC skiing counterparts ($p < 0.05$). The male XC skiers exhibited greater whole- and upper-body lean mass than the male biathletes ($p < 0.05$), while the female XC skiers exhibited greater $\dot{V}O_{2peak}$ values ($mL \cdot kg^{-1} \cdot min^{-1}$ and $mL \cdot kg\ LBM^{-1} \cdot min^{-1}$) than the female biathletes ($p < 0.05$).

Table 2 about here

Comparisons between performance standards within the BIA and XC skiing cohorts are presented in Tables 3 and 4, respectively. Female national level biathletes were older than the highly trained biathletes. Female elite biathletes exhibited greater speeds at a BLa of 2 and 4 $mmol \cdot L^{-1}$ than the highly trained biathletes. For both the women and men, world-class biathletes outperformed their highly trained counterparts on the shooting accuracy test.

Table 3 about here

Female world-class, elite and national-level XC skiers were older than the highly trained skiers, with national-level skiers also being older than the elite women. National-level male XC skiers were older than the world-class, elite and highly trained skiers. Both world-class and elite female and male skiers had lower whole-body fat mass than their highly trained counterparts. Additionally, world-class male skiers had lower whole-body fat mass than national-level skiers. World-class, elite and national-level female skiers had superior speeds at a BLa of 2 and 4 $mmol \cdot L^{-1}$ and $\dot{V}O_{2peak}$ ($mL \cdot kg \cdot min^{-1}$) than highly trained skiers, while elite and national-level females also exhibited a greater $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) than the highly-trained women. Among the men, world-class, elite and national-level skiers exhibited a greater GE, submaximal $\dot{V}O_2$ ($mL \cdot kg \cdot min^{-1}$), speeds at a BLa of 2 and 4 $mmol \cdot L^{-1}$ and $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$ and $mL \cdot kg \cdot min^{-1}$) than highly trained skiers, with world-class and elite skiers also exhibiting a greater submaximal $\dot{V}O_2$ ($L \cdot min^{-1}$) than highly-trained skiers. World-class male skiers also had superior speeds at a BLa of 2 and 4 $mmol \cdot L^{-1}$, $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$ and $mL \cdot kg \cdot min^{-1}$) than national-level skiers. Additionally, world-class male skiers exhibited a greater speed at a BLa of 4 $mmol \cdot L^{-1}$ and $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$ and $mL \cdot kg \cdot min^{-1}$) than their elite counterparts.

Table 4 about here

Discussion

The present study has detailed a range of laboratory-assessed anthropometric and physiological characteristics for a large sample of biathletes and XC skiers. The primary aim was to analyze whether these characteristics, and shooting accuracy among the biathletes, were projective of seasonal competitive performance. The study employed PCA and OPLS methods, which facilitate the construction of robust predictive models that consider complex interactions between variables. These models also better cope with multicollinearity and enable analysis of a greater range of projector variables compared with hierarchical regression models.[16] Therefore, the findings provide an expansion of previous research that has employed correlational and MLR statistical approaches to project BIA and XC skiing performance from experimentally-derived variables.

The present study is the first to examine the combined influence of anthropometric, physiological and shooting accuracy metrics on seasonal competitive performance. A single valid predictive model was identified for IBU points in the female biathletes. Several variables were considered important for projection (i.e., a VIP ≥ 1), with shooting accuracy being the most important. Important physiological variables for the projection of IBU points in females included $\dot{V}O_{2peak}$ and skiing speed at a BLa of 2 and 4 $mmol \cdot L^{-1}$. These observations are partly consistent with previous research employing MLR analyses, which identified significant models for predicting competition performance in female biathletes using $\dot{V}O_{2peak}$, anaerobic energy contribution, GE and $\dot{V}O_2$ at a BLa of 4 mmol·L^{-1}.[6] Similar to the present study, no significant models were previously identified for the men and this was suggested to be attributable to considerably greater between-athlete variation for $\dot{V}O_{2peak}$ and skiing performance among the women than the men. This explanation could also be valid in the present study, as greater variation in IBU points and key anthropometric and physiological qualities was observed in the women compared to the men. Greater whole- and upper-body lean mass were important anthropometric predictors of seasonal performance in the female biathletes. It has been suggested that increasing lean mass and upper-body strength may be particularly important in women, due to the greater additional relative load associated with rifle carriage when compared with men.[32] As such, female biathletes may have greater potential for improvement and more to gain by increasing their lean mass than the men. When comparing performance standards, shooting accuracy was significantly better for the world-class biathletes compared to their highly-trained counterparts (by 4.9% and 8.8% for the women and men, respectively), which supports the well-documented importance of shooting proficiency in BIA.[33] The only differences in physiological characteristics between BIA performance standards were present in the women, with the elite group exhibiting greater speeds at a BLa of 2 and 4 mmol·L^{-1} than their highly-trained counterparts.

In the present study, FIS distance and sprint points could be projected in the female but not male XC skiers. Similarly, previous research employing OPLS methods reported valid models for the prediction of FIS distance points in female but not male XC skiers.[20] However, in that study no valid models were identified for FIS sprint points in the women. It may be that the substantially larger number and greater heterogeneity of female XC skiers in the present study compared with the previous work of Jones *et al.*[20] (which included 14 female development-team XC skiers) could at least partly explain this disparity in findings. In the present study, speed at a BLa of 4 mmol·L^{-1} was the most important variable for projecting both distance and sprint XC skiing performance in the women. Previous research has indicated that this variable, or similar fixed BLa-based thresholds, are important for successful skiing competition performance.[4,7,20] We acknowledge that fixed-speed thresholds can be influenced by other factors, and do not always account for interindividual differences in responses to changes in workloads, but all BLa-based thresholds have relative strengths and limitations.[34] Therefore, we adopted the BLa variables typically used by our study population.

Both absolute and relative $\dot{V}O_{2peak}$ (L·min^{-1} and mL·kg^{-1}·min^{-1}) were also important for the projection of distance and sprint points in female XC skiers, which again is consistent with previous reports.[2,3,7,20] Relative $\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1}) was more important than absolute $\dot{V}O_{2peak}$ (L·min^{-1}) for the projection of FIS distance points in women and *vice versa* for the projection of sprint points. This may be due to the different durations of the women's distance (~ 30 min) and sprint (~ 3 min) XC skiing competitions. For example, performance in longer events is typically influenced to a greater extent by efficiency and aerobic power relative to body mass, whereas performance in shorter events is more dependent on absolute aerobic power.[35] The importance of the aforementioned physiological variables for XC skiing performance is also highlighted by the fact that the female world-class and elite skiers exhibited superior speeds at a BLa of 4 mmol·L^{-1} and $\dot{V}O_{2peak}$ (L·min^{-1} and mL·kg·min^{-1}) than the national-level and highly-trained skiers. The only noteworthy anthropometric differences across performance standards within the XC skier cohorts were in whole-body fat mass in both the women and men, with the world-class and elite skiers exhibiting lower whole-body fat mass than their highly trained counterparts. While speculative, it is possible that the world-class and elite skiers, who are typically full-time athletes and have more extensive practitioner support, adopt more rigorous training and dietary habits than the lower-performing skiers, which could influence their body composition characteristics.

When comparing sports, we observed that male XC skiers exhibited 6.0–6.5% greater whole- and upper-body lean mass than male biathletes. Similarly, there was a medium (although not statistically significant) effect for female XC skiers to exhibit a greater upper-body lean mass (by 4.7%) than the female biathletes. Previous research has shown that world-class biathletes fire more than 20,000 shots per year during more than 200 training sessions, with approximately 8,000 of these shots taken at rest and an additional 120–130 training sessions involving shooting without ammunition (i.e., “dry shooting”)[8]. Given this significant requirement for shooting practice in addition to ski training, biathletes may have a reduced capacity (e.g., less available time and energy) for other training methods, such as strength training. Therefore, the greater lean mass observed in XC skiers could be attributable to the fact that skiers are able to allocate more time to strength training. This suggestion is supported by recent research reporting that Russian XC skiers performed greater annual volumes of strength training than biathletes over a 5-year period, and the XC skiers engaged in more upper-body-specific strength training.[36] In the present study, the female XC skiers exhibited greater $\dot{V}O_{2peak}$ values ($mL\cdot kg^{-1}\cdot min^{-1}$ and $mL\cdot kg\ LBM^{-1}\cdot min^{-1}$) than the female biathletes. By contrast, no such differences in $\dot{V}O_{2peak}$ were observed in the men. The potential reasons for this sex difference are unclear and cannot simply be attributed to different demands of the two sports. However, $\dot{V}O_{2peak}$ ($mL\cdot kg^{-1}\cdot min^{-1}$) could be an area where female biathletes have room to improve, relative to other competitors, within their own sport.

Practical applications

The data presented here indicate that physiological metrics including blood lactate-derived threshold speeds and $\dot{V}O_{2peak}$ (both absolute and relative) should be regularly assessed as markers of athletes’ physical progression. These qualities should also be targeted across the periodized training plan, together with shooting accuracy for the biathletes. The relative importance of $\dot{V}O_{2peak}$ and lean body mass appears to be greater for female XC skiers than biathletes, which could also be reflected in athletes’ training plans. To balance the demands of long-term athlete health and leanness (which was found to be important for both female biathletes and XC skiers), periodization of body composition manipulation under expert supervision is recommended.

Conclusions

Seasonal competitive performance in female but not male biathletes and XC skiers could be projected by a combination of laboratory-assessed anthropometric and physiological variables, as well as biathletes’ shooting accuracy data. The data presented here provide an expansion on previous work investigating performance determinants in BIA and XC skiing by analysing a larger sample of athletes and employing more sophisticated statistical models. It is worth noting that other advanced statistical methods besides OPLS are capable of modeling and describing the data analyzed in this study and the application of these methods is becoming increasingly popular in applied sport science. While beyond the scope of the present study, an interesting and impactful line of future research would be to compare the outcomes generated by these various modeling techniques using a standardized data set containing physical and competitive performance metrics.

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Figure captions

Figure 1. The importance of the *X* variables (anthropometric, descriptive, physiological and shooting) for predicting *Y* (IBU points, **A**; FIS distance points, **B**; FIS sprint points, **C**). Characteristics with VIP > 1 are most relevant for explaining *Y*. The plot is displayed with 95% jackknife uncertainty bars. AU = arbitrary units, BLa = blood lactate concentration, BMI = body mass index, HR = heart rate, LBM = lean body mass, $\dot{V}O_2$ = oxygen uptake.