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Analysis of a Sprint Biathlon Competition and Associated Laboratory Determinants of Performance

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ABSTRACT

Background: Biathlon is a traditional Olympic winter sport combining cross-country skiing using the skating technique with rifle shooting. Thus, biathlon is a complex sport, that in addition to a high endurance capacity and efficient skiing technique, demands rapid and accurate shooting performed directly after intense exercise. There exist only a few studies on biathlon today, and in particular analysis of high-level competitions are lacking. **Purpose:** The present study was designed to investigate a sprint biathlon competition with respect to the contribution of XC skiing and shooting performance on the overall biathlon performance, as well as the relationship to laboratory determinants of performance obtained during treadmill roller skiing. **Methods:** Eleven elite male biathletes were tracked by a global positioning system (GPS) device and heart-rate monitor during an international sprint biathlon competition. Within a period of 6 weeks prior to the competition, the participants completed laboratory testing while submaximal and maximal roller skiing on a treadmill. **Results:** (1) the XC skiing and shooting performance explained 84% and 14%, whereas shooting time and range time together explained 2% of the overall performance, respectively (all $p < 0.01$), (2) time in uphill terrain explained 91% of the variation in XC skiing performance ($p < 0.01$), (3) the shooting performance was not significantly correlated with the biathletes pacing towards shooting, the intensity of exercise or shooting time, and (4) relative heart-rate and rating of perceived exhaustion during submaximal, and time to exhaustion during maximal roller skiing in the laboratory correlated significantly with the XC skiing performance, as well as time in different terrains ($r = 0.64$-0.95, all $p < 0.05$). **Conclusion:** The present findings reveal that the XC skiing performance exerts greatest influence on the overall performance in the sprint biathlon competition, with rating of perceived exhaustion and relative heart-rate while submaximal roller skiing and treadmill roller skiing performance being significant correlates of the XC skiing performance.

Keywords: competition analysis, heart-rate, GPS, shooting, endurance performance

SUMMARY IN NORWEGIAN

Bakgrunn: Skiskyting er en Olympisk vinteridrett som kombinerer langrenn ved bruk av skøyteteknikken med rifleskyting. Skiskyting er dermed en kompleks idrett som stiller store krav til høy utholdenhetskapasitet og effektiv langrennsteknikk, i tillegg til rask og feilfri skyting utført direkte etter intens fysisk anstrengelse. Det eksisterer per i dag få vitenskapelige studier på skiskyting og særlig studier som inkluderer analyser gjennomført under konkurranse. **Formål:** Det overordnende formålet med denne studien var detaljert å undersøke sprintdistansen i skiskyting med henhold til betydningen av langrennsprestasjonen og skyteprestasjonen på den totale prestasjonen, samt å se på sammenhengen mellom ulike forklaringsvariabler målt på rulleskitredemølle i laboratoriet og sprintprestasjonen på snø. **Metode:** Elleve elite mannlige skiskyttere deltok i studien og ble kontinuerlig målt ved hjelp av en GPS og hjertefrekvens-måler under en internasjonal sprintkonkurranse. I løpet av en periode på seks uker i forkant av konkurransen, gjennomførte alle deltakerne rulleskitesting i laboratoriet på submaksimale og maksimale arbeidsbelastninger. **Resultat:** (1) langrennsprestasjonen og skyteprestasjonen forklarte henholdsvis 84% og 14%, mens skytetid og standplasstid til sammen forklarte 2% av totalprestasjonen (alle $p < 0.01$), (2) tid i motbakke forklarte 91% av variasjonen i langrennsprestasjon ($p < 0.01$), (3) skyteprestasjonen var ikke påvirket verken av skiskytternes inngangsfart, arbeidsintensitet eller skytetid, (4) relativ hjertefrekvens og selvopplevd anstrengelse ved submaksimal testing og tid til utmattelse ved maksimal testing målt i laboratoriet var signifikant korrelert med langrennsprestasjonen og tid brukt i ulike typer terreng ($r = 0.64$-0.95, alle $p < 0.05$). **Konklusjon:** Hovedfunnene i denne studien viser at langrennsprestasjonen er av større betydning enn skyteprestasjonen på den totale sprintprestasjonen i skiskyting. Studiet demonstrerer også at relativ hjertefrekvens og selvopplevd anstrengelse ved submaksimal testing og prestasjon målt på rulleskitredemølle i laboratoriet er viktige forklaringsvariabler på langrennsprestasjonen.

Nøkkelord: konkurranseanalyse, hjertefrekvens, GPS, skyting, utholdenhetsprestasjon

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ABBREVIATIONS AND FREQUENTLY USED PHRASES

CV	Coefficient of variation
GE	Gross efficiency
GPS	Global position system
G4	One of the three main skating sub-techniques
G3	One of the three main skating sub-techniques
G2	One of the three main skating sub-techniques
HR_{max}	Maximal heart-rate
P	Level of significance
RPE	Rating of perceived exhaustion
r	Correlation coefficient
SD	Standard deviation
TTE	Time to exhaustion
VO_{2peak}	Peak oxygen uptake
VO_{2max}	Maximal oxygen uptake
XC	Cross-country

INTRODUCTION

Biathlon is a traditional Olympic winter sport combining cross-country (XC) skiing using the skating technique with rifle shooting. In an official biathlon competition, biathletes ski loops of 2 to 5 km before and after each shooting while carrying the rifle on their back. Depending on the type of competition, two or four stages of shooting which alternate between the prone and standing position are included. Penalty distance or time is added for each target that is missed and the biathlete with the shortest total time wins the race (1). Thus, biathlon is a complex sport, that in addition to a high endurance capacity, demands rapid and accurate shooting performed directly after intense exercise.

Due to the high complexity of biathlon, the overall performance depends on adequate performance in several components. In addition to well-developed XC skiing and shooting performance, shooting time and range time is also of relevance to the overall performance. Previous research has indicated that the XC skiing performance is of more influence on the overall performance than the shooting performance in the sprint biathlon competition (2, 3), whereas shooting time and range time is of less importance (2). However, it its important to note that biathlon has developed considerable as a competitive sport since these studies were conducted more than one and two decades ago. Better track preparations and skiing equipment has led to increased speeds in combination with greater participation and popularity of the sport in general (4). Therefore, the contribution of all these components to the overall performance in the sprint competition needs new examination.

The demands of skiing in biathlon are highly comparable to that in XC skiing, with racecourses consisting of approximately one-third uphill, one-third flat, and one-third downhill terrain performed at highly varying speeds (5). In XC skiing, there has been an increase of field studies performing competition analysis over the last decade due to the technological development of wearable GPS and heart-rate monitors. In general, more than 50% of the racing time is spent uphill and uphill terrain is also regarded as the most performance-differentiating terrain in XC skiing (6-9). However, biathletes only compete in the skating technique and the rifle carried on the back during competition alters the energy cost and kinematical aspects of skiing (10). This in combination with the importance of shooting performance might lead to less effort in the uphill terrain sections in biathlon and thereby also different characteristics of the XC skiing performance.

Another interesting aspect of biathlon is the role of pacing strategy towards shooting, where biathletes previously have been suggested to reduce their speed and thereby decrease heart-rate and minimize the possible negative effect of high exercise intensity on the shooting performance (11). However, previous studies found a minimal or non-existing effect of exercise intensity on the shooting performance in biathlon (12, 13), and the relationship between optimal pacing towards shooting, exercise intensity and shooting performance is therefore unclear. Additionally, no previous studies have examined the role of time spent between each individual shot and how this is related to the shooting performance in biathlon.

XC skiing involves repeated changes between techniques, combining upper and lower body exercise of varying intensity and duration. Thus, world-class XC skiers (14-20), and world-class biathletes (19, 20), have demonstrated some of the highest maximal oxygen uptakes (VO_{2max}) ever reported in the literature. However, the existing literature considering how peak oxygen uptake (VO_{2peak}) determines performance in biathlon is scarce and somewhat conflicting (21, 22). Furthermore, the ability to effectively convert metabolic energy into external work rate and speed (i.e., gross efficiency) while performing different skating techniques has been positively correlated to performance in XC skiing. However, the role of efficiency has not been examined adequately in biathlon and since biathletes to a certain extent can compensate for lower XC skiing performance with an optimal shooting performance, the determinants of performance could possibly differ compared to those observed in XC skiing.

Although physiological characteristics and analysis during high-level competitions has been conducted investigating XC skiers over the last decades, there exists only a limited amount of research examining these aspects in biathlon. Therefore, the present study was designed to investigate; (1) the contribution of XC skiing and shooting performance on the overall biathlon performance (2) the contribution of different terrain on the XC skiing performance (3) the role of pacing strategies, exercise intensity and shooting time on the shooting performance and (4) the relationship to laboratory determinants of performance obtained during treadmill roller skiing. It was hypothesized that excellence in both the XC skiing and shooting performance are necessary to achieve an excellent overall performance in biathlon, and that uphill terrain is the most important determinant of the XC skiing performance and explained by differences in technique-specific aerobic capacity.

METHODS

Participants

Eleven elite male biathletes, mostly members of the junior and U-23 national team of the Norwegian Biathlon Association, including one junior world-champion volunteered to participate in the study. The participant's age, anthropometrics and training characteristics, are presented in **Table 1**. The study was approved by the Norwegian Social Science Data Services (NSD) and conducted in accordance with the Declaration of Helsinki. All participants signed an informed consent and were allowed to withdraw from the study at any time without providing further explanation.

Table 1. Characteristics (mean ± SD) of the eleven elite male biathletes participating in the study.

Variables	
Age (yrs)	21.4 ± 2.1
Body height (cm)	181.1 ± 4.7
Body mass (kg)	76.5 ± 4.8
Body mass index ($kg \cdot m^{-2}$)	23.5 ± 1.3
Rifle weight (kg)	4.0 ± 0.3
Total training[a]	685 ± 115
Physical training[a]	585 ± 87
Shooting training[a]	100 ± 34
Maximum heart-rate (HR_{max})[b]	198 ± 8

[a] Training volume categorized into hours of total training, physical training and shooting training during the last twelve months prior to the competition.
[b] Self reported maximum heart-rate

Overall design

During an international competition regulated by the International Biathlon Association (IBU) in November 2016, all the participants were tracked by a global positioning system (GPS) device and heart-rate monitor. The 10-km sprint competition consisted of three laps of 3.3-km interspersed with two stages of rifle shooting in the order of the prone and standing position, respectively. For each missed shot, the biathletes were penalized with a 150-m penalty loop. The racecourse was mapped with a coupled GPS and barometer to provide a valid course and elevation profile, and was further divided into a XC skiing course and shooting component. The participant's data were adapted to the standardized racecourse and shooting component for detailed analysis of time and speed within different parts of the race, as well as heart-rate characteristics. Within a period of 6 weeks prior to the competition, all the participants completed laboratory testing while roller skiing on a treadmill. The test consisted of 6x5-min submaximal stages at constant workloads to measure physiological response and determine gross efficiency (GE). The three main sub-techniques (G2-G4) in the skating technique were utilized and every second stage was performed while carrying the rifle on their back. Additionally, all participants conducted an incremental test to determine VO_{2peak} and time to exhaustion (TTE).

Competition analysis

Prior to the competition, all the participants completed zeroing and low-intensity warm up procedures according to their own optimized protocols used in both training and competition. All participants used their own equipment during the competition, including the rifle (4.0 ± 0.3 kg), pole length (91 ± 1% of body height), skating XC skiing shoes and skating XC skies. The skies were individualized and prepared for the current conditions with appropriate ski base material and chamber stiffness. The weather conditions were stable throughout the entire competition with average ambient air and snow temperatures of -5.5 ˚C and -7.5 ˚C, respectively. The average relative humidity was 85% during the competition and the wind was low and stable at the shooting range, varying between 0.3-1 m/s. The racecourse consisted of a combination between artificially and natural snow and was machine-groomed the same morning as the competition day. The course was set in an open area with minimal tree cover and no mountains to interfere with the GPS signals. Course and elevation profiles of the racecourse were standardized with an integrated GPS and barometry (Garmin Ltd., Olathe, Kansas, USA), collecting position and altitude data at a 1 Hz sampling rate as previously described by Bolger et al (7) and Sandbakk et al (9). The racecourse was divided into a XC skiing course and shooting component to determine shooting time, penalty time and range time. Shooting time was defined as the time from the biathletes stops skiing to they start skiing again at the shooting range, whereas penalty time was defined as the time spent between the end of the shooting range to the start of a new lap, including time in the penalty loop. Range time was defined as the time spent from the end to the start of a new lap minus shooting time and penalty time, and differs somewhat from the defined range time in the official shooting results to ensure valid GPS data. The average shot rate and time spent between each individual shot in relationship to the number of hits were identified based on the official competition shooting results using a electronic target system (23). However, penalty time was used as the measure of shooting performance in the final analysis due to the statistical advantage of using a non-dichotomous variable. Heart-rate characteristics were obtained and a section of the XC skiing course prior to the shooting range was defined to examine pacing towards shooting. This section included terrain section 12 defined as uphill and section 13 defined as varied terrain (**Figure 1, Table 3**). In addition, each participant's time spent in this section were divided by the overall XC skiing time and presented as a percentage. Furthermore, the XC skiing course was divided into uphill, varied and downhill terrain that amounted for 37%, 29% and 34% of the total course distance, respectively. The classification of different terrain sections were based on the International Ski Federation (FIS) homologation manual for XC skiing racecourses (24). A section boundary was defined where there was a change between positive and negative gradient in the XC skiing course profile. Terrain sections with climb > 10 m and gradient > 6% were classified as uphill sections. Sections with descent > 10 m and negative gradient > 6 % were classified as downhill sections. Remaining sections were classified as varied terrain, including short uphill and downhill parts interspersed with flat parts. The exact distance for each lap of the XC skiing racecourse was 3015m and a part of the racecourse consisting of flat terrain in the start and finish of the competition was not included in the final analysis comparing the three laps with respect to pacing strategies.

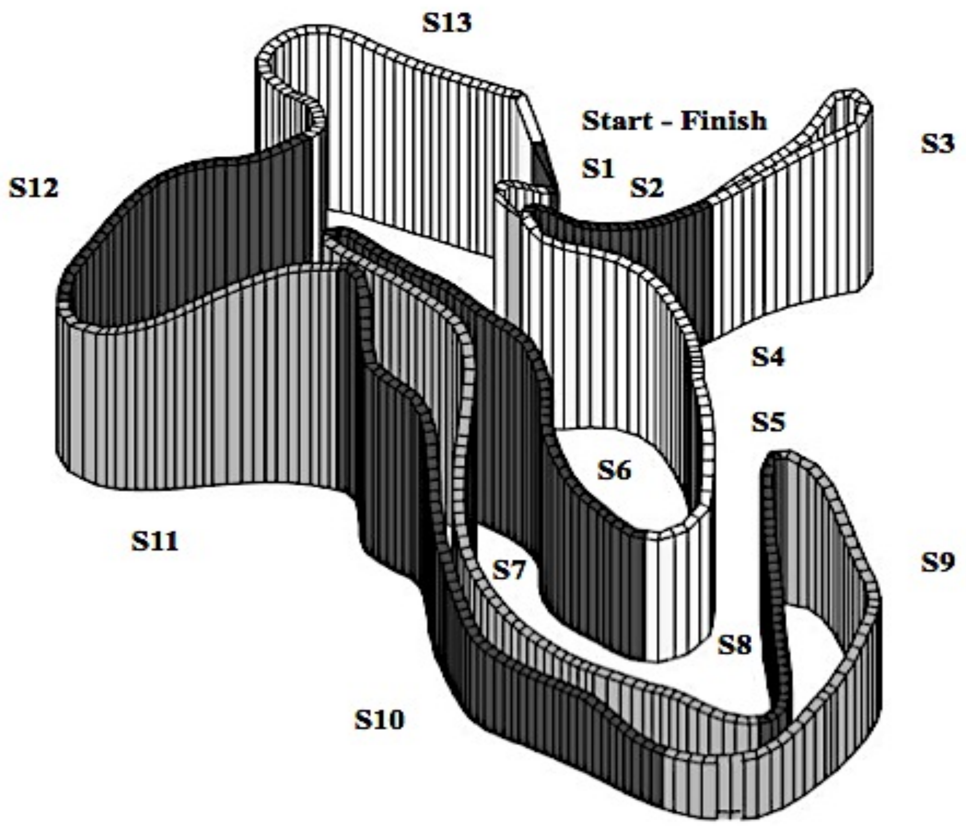

Figure 1. 3D illustration of the 3015 m XC skiing racecourse divided into 13 different terrain sections.

During the competition, each participant was tracked by a Polar V800 GPS (Polar Electro Oy, Kempele, Finland), which collected position and heart-rate data at a 1 Hz sampling rate. All the GPS watches were turned on at least 30-min before the start of the race to ensure proper GPS fixing and a low resultant inaccuracy in the GPS data according to Bolger et al (7) and Sandbakk et al (9). Furthermore, data for all the participants were adapted to the standardized racecourse and virtual split time positions were defined every 10-15 meters along the course. In addition, virtual split times for time and heart-rate during shooting were based on the GPS position and speed data. The time each participant spent in the different components of the race, as well as heart-rate characteristics were calculated based on these virtual split times.

Laboratory testing

Treadmill testing was performed on a 5 x 3m motor-driven treadmill (Forcelink B.V., Culemborg, The Netherlands). The treadmill belt consisted of non-slip rubber surface, allowing the participants to use their own poles with special carbide tips. In order to minimize variations in roller resistance, the participants used the same pair of skating roller skies with standard category 2 wheels (IDT Sports, Lena, Norway). Before the tests, rolling friction force (F_f) was tested with a towing test as previously described by Sandbakk et al (25). The rolling friction coefficient (μ) was determined by dividing F_f by the normal force (F_n) ($=F_f/F_n$), and provided an average μ value of 0.0195, which was included in the calculation of work rate. The biathletes used their own rifle with a mean weight of (4.0 ± 0.3 kg) during testing.

Respiratory variables were measured using open-circuit indirect calorimetry with mixing chamber and 30 s sampling time (Oxycon Pro, Jaeger GmbH, Hoechberg, Germany). The instruments were calibrated against ambient air conditions and certified gases of known concentrations of O_2 (15.0%) and CO_2 (5.0%) before each test session. The flow transducer (Triple V, Erick Jaeger GmbH, Hoechberg, Germany) was calibrated using a 3-L high-precision calibration syringe (Calibration syringe D, SensorMedics, Yorba Linda, CA, USA). Heart-rate was continuously measured with a Polar V800 monitor (Polar Electro Oy, Kempele, Finland) and synchronized with the Oxycon Pro system. Blood lactate values in 20 μL of blood was taken from the fingertip and measured using the stationary Biosen C-Line lactate analyzer (Biosen, EKF Industrial Electronics, Magdeburg, Germany). The device was calibrated every 60 min with a 12 $mmol \cdot L^{-1}$ standard concentration. Rating of perceived exertion (RPE) was determined using the Borg Scale (26). The participant's body-mass and mass of the rifle were measured with a weight (Seca, model 708, GmbH, Hamburg, Germany), and body-height using a calibrated stadiometer (Holtain Ltd, Crosswell, UK) prior to the test.

Initially, the participants performed fifteen minutes of low-intensity warm up and familiarization to the treadmill. The first ten minutes was conducted without the rifle and the last five minutes while carrying the rifle on their back. Thereafter, the submaximal test consisting of 6x5-min stages with a 2-min recovery in-between was conducted at different speeds and inclines using the three most important sub-techniques (G2-G4) in the skating technique. The first two stages were conducted utilizing the G4 sub-technique at 3%

inclination and 20 $km \cdot h^{-1}$, followed by two stages using the G3 sub-technique at a 5% incline and 15 $km \cdot h^{-1}$. The two last stages were performed with the G2 sub-technique at an incline and speed of 12% and 8 $km \cdot h^{-1}$, respectively. For each sub-technique, the first stage was performed without the rifle and the second stage while carrying the rifle. The inclines were based on previous research indicating the different sub-techniques to be pre-dominant at these inclines and representative for different terrain in XC skiing racecourses. The speeds were based on previous testing of biathletes and XC skiers in the laboratory. Respiratory variables and heart-rate were measured continuously and the average of the last two minutes of each stage were used for steady-state analysis. Blood lactate concentrations and RPE were determined directly after completing each submaximal stage. In the final analysis, only the three submaximal stages performed with the rifle were used in the correlation between different components of the race and the laboratory capacities.

Work rate was calculated as the sum of power against gravity and friction: $P_g + P_f = m \cdot g \cdot v \cdot (\sin(\alpha) + \cos(\alpha) \cdot \mu)$, with P_g being power against gravity, P_f power against friction, m the biathletes body-mass including skiing shoes, roller skies and their rifle at the stages performed with the rifle, g the gravitational constant, α the treadmill incline, μ the frictional coefficient and v the treadmill speed. The metabolic rate was calculated as the product of VO_2 and the oxygen energetic equivalent using the associated respiratory exchange ratio and standard conversion tables (27). GE was then defined as the ratio of work generated to the metabolic rate expended and presented as a percentage as previously described by Sandbakk et al (25).

After a period of 5-min recovery, the participants conducted an incremental test in order to determine VO_{2peak} and performance in the laboratory measured as TTE. The starting incline and speed was 10% and 11 $km \cdot h^{-1}$. The initial speed was kept constant, while the incline was increased by 2% every minute up to 14%. Thereafter, the speed was increased by 1 $km \cdot h^{-1}$ every minute until exhaustion. Respiratory variables and heart-rate were measured continuously and VO_{2peak} was defined as the average of the three highest and consecutive 10-seconds measurements. Peak heart-rate (HR_{peak}) was defined as the highest 5-seconds heart-rate measurement during the test. Blood lactate concentrations and RPE were determined approximately 1-min after each test.

Statistical analysis

All data were tested for normality using a Shapiro-Wilk test in combination with visual inspection and are presented as mean ± SD. Correlations between the overall performance, XC skiing performance and the different components of the race were calculated using the Pearson's product-moment correlation coefficient, or with the non-parametric Spearman's rank correlation when the data were not normally distributed. The coefficient of variation (standard deviation/mean) of time was calculated within the different terrain sections of the XC skiing racecourse and presented as a percentage. Differences between the prone and standing position with respect to shooting time and heart-rate were tested using the paired sample t-test procedure. In addition, stepwise multiple regression analysis were used with the overall performance and XC skiing performance as dependent variables (DP), and XC skiing performance, shooting performance, shooting time, range time, together with time in different terrains as independent variables (IVs). Alpha values of < 0.05 were used as the level of statistical significance and alpha values between 0.05 and 0.1 were considered to indicate trends. All statistical analyses were performed using IBM SPSS Software for Mac, Version 21.0 (SPSS Inc., Chicago, IL).

RESULTS

Overall performance

The participants mean overall time in the sprint competition was 1574 ± 52 s, and the relative contribution of XC skiing time, penalty time, shooting time, and range time to the overall time was 86%, 5%, 4% and 5%, respectively (**Table 2**). The XC skiing time was significantly correlated to the overall time ($r = 0.92$, $p < 0.01$), whereas penalty time, shooting time and range time revealed no significant relationships ($r = 0.50$, 0.32, 0.17, respectively, **Figure 2**). In addition, stepwise multiple regression analysis demonstrated that the XC skiing time, penalty time, shooting time and range time explained 84.0% (R^2 change = 0.84, semi-partial $R^2 = 0.60$), 14.0% (R^2 change = 0.14, semi-partial $R^2 = 0.14$), 1.8% (R^2 change = 0.018, semi-partial $R^2 = 0.02$) and 0.2% (R^2 change = 0.002, semi-partial $R^2 = 0.002$) of the overall time, respectively (all $p < 0.01$). Together, the participant's mean time in the shooting component, including penalty time, shooting time and range time was 220 ± 23 s and amounted for 14% of the overall time. The shooting component was significantly correlated to the overall time ($r = 0.60$, $p < 0.05$) and multiple regression analysis revealed that the shooting component explained 16% (R^2 change = 0.16, semi-partial $R^2 = 0.16$) of the variation in overall time.

Table 2. Shot rate and time (means ± SD) spent in the different components of a sprint biathlon competition in eleven elite male biathletes.

Variables		**Time (s)**
Overall time (s)		1574 ± 52
XC skiing time (s)		1355 ± 43
Shooting component (s)		219 ± 23
Terrain sections (s)	Uphill	701 ± 31
	Varied	339 ± 11
	Downhill	315 ± 6
Shot rate (%)	Prone	91 ± 7
	Standing	86 ± 6
	Total	77 ± 9
Penalty time (s)	Prone	34 ± 15
	Standing	44 ± 15
	Total	78 ± 21
Shooting time (s)	Prone	31 ± 5
	Standing	27 ± 4
	Total	58 ± 8
Range time (s)	Prone	41 ± 1
	Standing	42 ± 1
	Total	83 ± 2

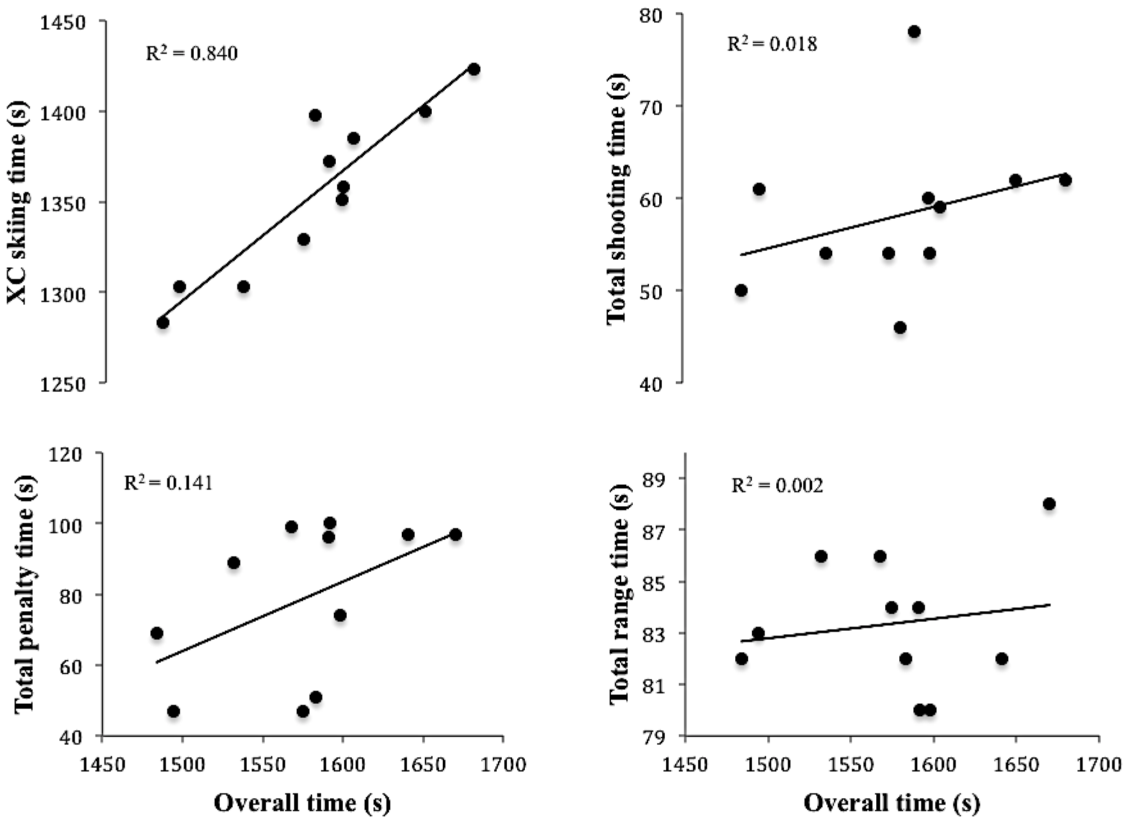

Figure 2. Overall time in relationship to XC skiing time, penalty time, shooting time and range time during a sprint competition in eleven elite male biathletes. Presented with individual data points and trend lines based on linear regression.

XC skiing performance

The mean XC skiing time was 1355 ± 43 s with an average speed of 6.7 m·s^{-1} during the competition. Time, CVs of time and speed in the different terrain sections of the racecourse are presented in **Table 3**. The relative contribution of time in uphill, varied and downhill terrain to the total XC skiing time were 52%, 25% and 23%. Time in uphill, varied and downhill terrain were significantly correlated to the total XC skiing time (r = 0.95, 0.82, 0.72, respectively, all $p < 0.05$), and similar relationships were observed for the CVs of time within the different sections of terrain. In addition, the stepwise multiple regression analysis demonstrated that time in uphill, varied and downhill terrain explained 91% (R^2 change = 0.907, semi-partial R^2 = 0.31) 8% (R^2 change = 0.084, semi-partial R^2 = 0.02) and 1% (R^2 change = 0.007, semi-partial R^2 = 0.004) of the total variation in XC skiing time, respectively (all $p < 0.01$).

Table 3. Section length and elevation, in addition to time spent and speed within different sections of terrain during the three laps of the sprint competition in eleven elite male biathletes.

XC skiing performance	Section	Mean Section time (s)	Time CV (%)	Section length (m)	Elevation (m/%)	Mean section speed (m/s)
Uphill terrain	S4	70 ± 3	3.8	125 x 3	11/9	5.4
	S6	170 ± 9	5.4	279 x 3	18/7	4.9
	S8	98 ± 5	5.5	183 x 3	14/7	5.6
	S10	256 ± 14	5.6	363 x 3	31/9	4.3
	S12	107 ± 4	4.1	179 x 3	14/8	5.1
	Total	701 ± 31	4.5	1129 x 3	88/8	5.1
Varied Terrain	S1	35 ± 3	8.2	45 x 3	5/10	3.8
	S3	86 ± 3	3.5	226 x 3	1/0	7.9
	S5	112 ± 5	4.3	304 x 3	14/5	8.2
	S13	106 ± 2	2.1	289 x 3	10/3	8.2
	Total	339 ± 11	3.3	864 x 3	30/6	7.0
Downhill Terrain	S2	42 ± 2	4.3	128 x 3	14/11	9.2
	S7	126 ± 2	1.8	428 x 3	27/6	10.2
	S9	91 ± 3	3.3	288 x 3	18/6	9.5
	S11	56 ± 2	2.9	178 x 3	15/8	9.5
	Total	315 ± 6	2.0	1022 x 3	74/8	9.6

XC skiing pacing strategies

Speed and heart-rate profiles of the three laps are depicted in **Figure 3** and **Figure 4**. The participants mean time at the first, second and third lap was 441, 460 and 454 s, respectively, and all three laps were significantly correlated to the overall XC skiing time ($r = 0.84$, 0.95, 0.85 $p < 0.01$). However, the second and third lap was conducted with 4.4% and 2.9% slower speeds in comparison to the first lap, respectively ($p < 0.05$). With regards to pacing towards shooting, the participant's mean time in the defined section prior to shooting was 71 ± 2 s and 74 ± 2 s for the prone and standing position, respectively. Relative to the total XC skiing time, mean time in this section was 5.3 ± 0.1% and 5.4 ± 0.2% before the prone and standing shooting. There were no significant correlations observed between absolute or relative time spent in the last section before shooting and the shooting performance, neither in the prone nor the standing position.

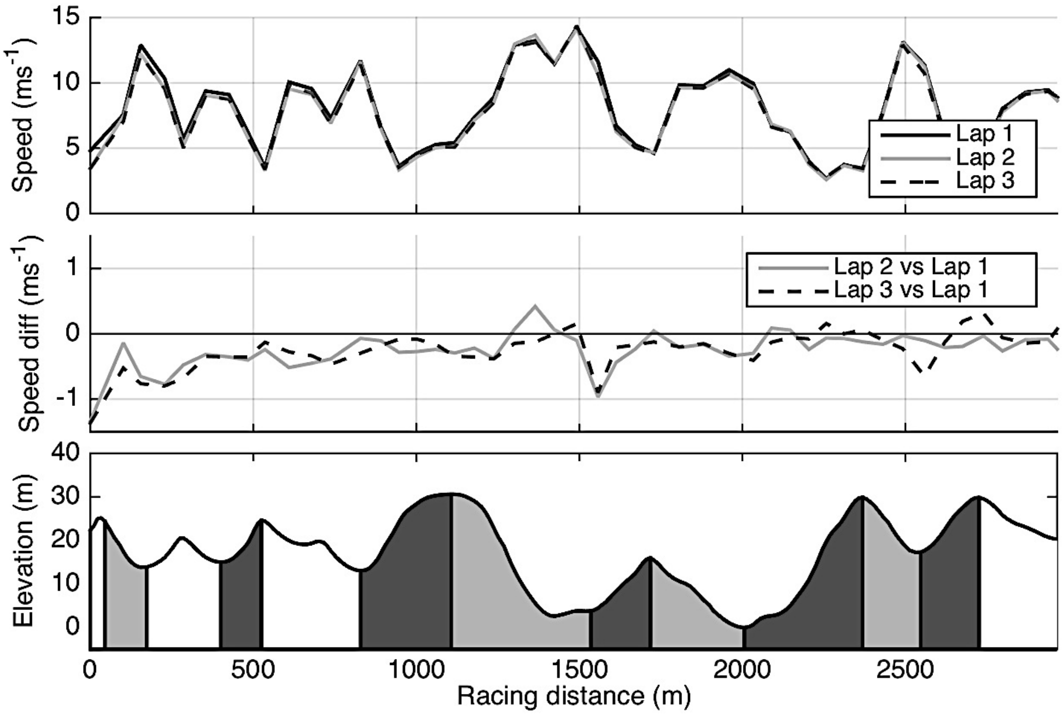

Figure 3. Mean XC skiing speed ($m \cdot s^{-1}$) for each of the three laps and speed differences compared to the first lap during a sprint competition in eleven elite male biathletes.

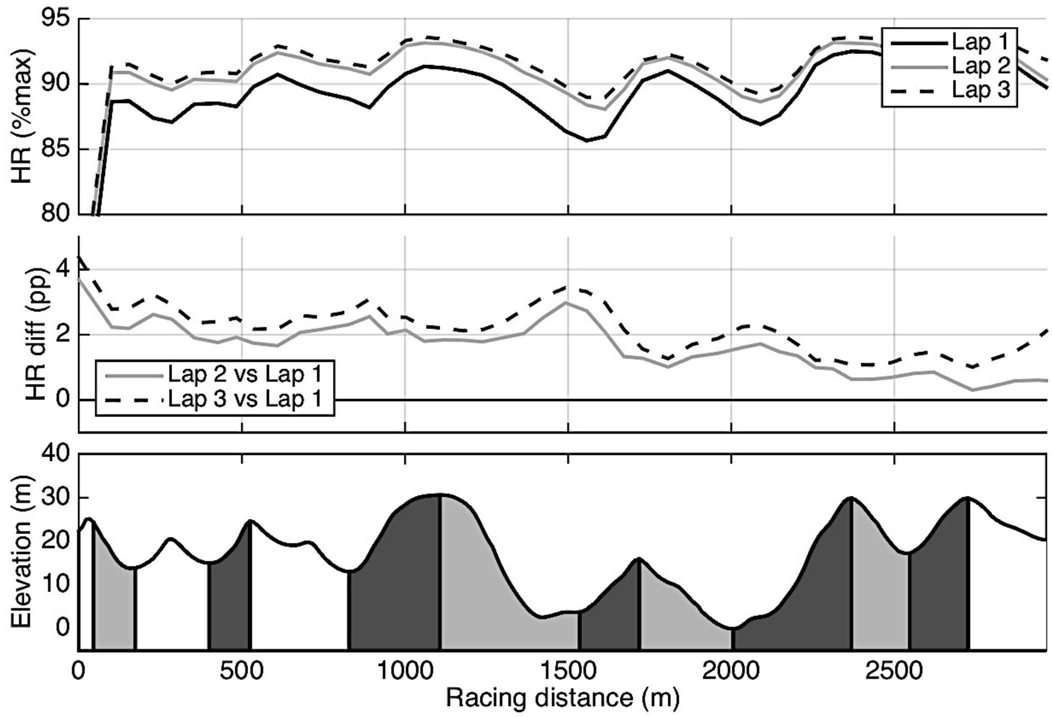

Figure 4. Mean heart-rate ($\%HR_{max}$) for each of the three laps and heart-rate differences compared to the first lap during a sprint competition in eleven elite male biathletes.

Shooting performance

Relative heart-rate characteristics from the sprint competition are depicted in **Figure 5**. The participants maximum heart-rate during the first lap before prone shooting was 93 ± 2%, and increased to 94 ± 2% during the second lap prior to the standing shooting ($p < 0.05$). On average, heart-rate decreased to 87 ± 2% and 87 ± 3% at the start of shooting in the prone and standing position, respectively ($p < 0.01$). During shooting, heart-rate decreased to 69 ± 6% in the prone position, whereas this drop was significantly less, decreasing to 79 ± 4% in the standing position ($p < 0.01$). There was no significant relationship observed between relative heart-rate at the start of shooting and the shooting performance, neither in prone nor standing shooting. Furthermore, no significant correlations were identified between any of the relative heart-rate characteristics presented in **Figure 5** and the shooting performance in the sprint competition.

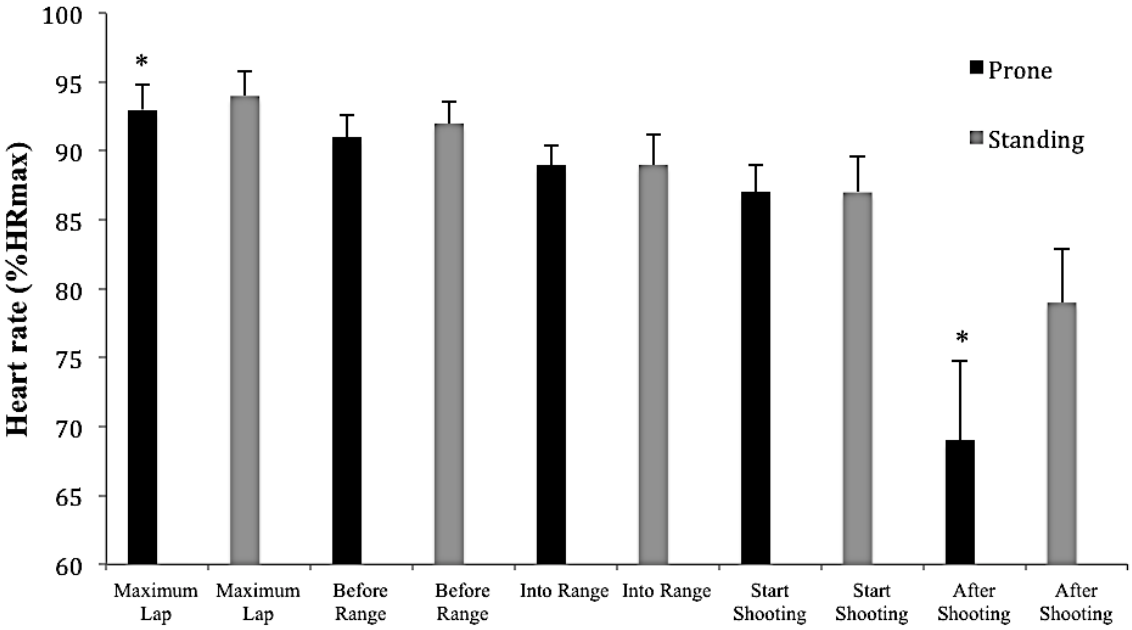

Figure 5. Heart-rate characteristics (means ± SD) during a sprint competition in eleven elite male biathletes. * $p < 0.05$ in comparison to the standing position

The participants shooting time was 31 ± 5 and 27 ± 4 s for the prone and standing position, respectively, and there was no significant relationship observed between shooting time and the shooting performance in neither of the two shooting positions. However, shooting time was 13% shorter in the standing position compared to the prone position ($p < 0.05$), mainly resulted by a longer time spent before the first shot in this position (**Figure 6**). In further detail of the shooting time, no significant correlations were observed between time spent between each individual shot and the number of hits, neither in the prone nor the standing position, respectively (**Figure 6**). However, the participants used 23% shorter time before the first shot and 14% shorter time between the first and second shot in the standing position compared to the prone position (both $p < 0.05$).

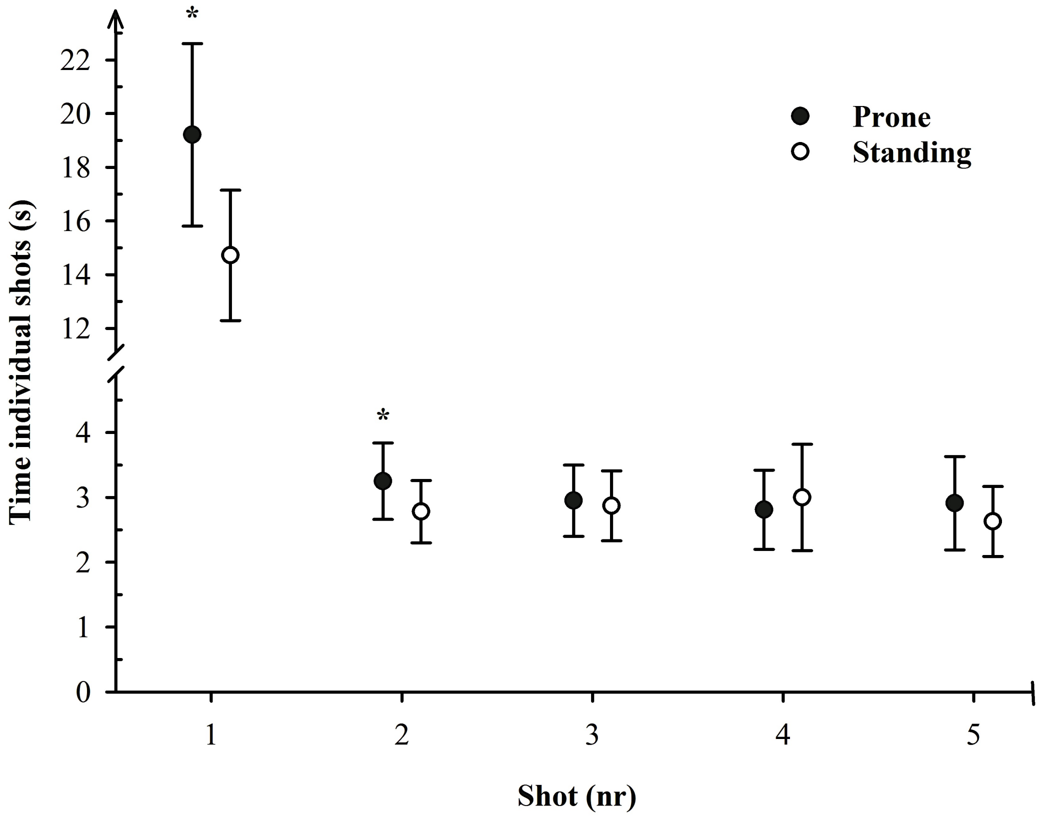

Figure 6. Time spent between each individual shot (means ± SD) in the prone and standing position during a sprint competition in eleven elite male biathletes. * $p < 0.05$ in comparison to the standing position

The participants range times were 41 ± 1 and 42 ± 1 s during prone and standing shooting, and did not differ significantly. Furthermore, the average shot rates were 91 ± 7% and 86 ± 6% for the prone and standing shooting, respectively. The lower shot rate in the standing position was accompanied by a 23% higher penalty time in comparison to the prone position ($p < 0.10$)

Laboratory determinants of the XC skiing performance

Results of laboratory testing obtained while treadmill roller skiing are presented in **Table 4**, and correlations between the different laboratory capacities and the XC skiing performance are presented in **Table 5** and **Figure 7**. During submaximal roller skiing, RPE and $\%HR_{max}$ for all sub-techniques were significantly correlated, or tended to significantly correlate with XC skiing time and time spent in different terrain (all $p < 0.10$). Furthermore, blood lactate concentrations in the G3 and G2 sub-technique were significantly correlated to the XC skiing time and time spent in downhill terrain (all < 0.05), whereas blood lactate concentrations only tended to significantly correlate with time spent in uphill and varied terrain ($p < 0.10$). There were no significant relationships observed for submaximal oxygen cost and GE in neither of the three sub-techniques.

Table 4. Physiological characteristics and performance (mean ± SD) during submaximal roller skiing using the G4-2 sub-technique and maximal roller skiing in eleven elite male biathletes.

Variables	**G4**	**G3**	**G2**
VO_2 ($L \cdot min^{-1}$)	4.45 ± 0.28	4.44 ± 0.24	4.40 ± 0.26
VO_2 ($mL \cdot min^{-1} \cdot kg^{-1}$)	57.9 ± 2.8	57.7 ± 2.0	57.3 ± 2.4
% VO_{2peak}	79 ± 5	78 ± 4	78 ± 4
Heart-rate ($beats \cdot min^{-1}$)	176 ± 8	178 ± 8	178 ± 8
$\%HR_{max}$ [a]	89 ± 3	90 ± 3	90 ± 3
RPE (6-20) [b]	13 ± 1	14 ± 1	14 ± 1
Blood lactate ($mmol \cdot L^{-1}$)	3.8 ± 1.3	4.3 ± 1.9	4.3 ± 2.0
Gross efficiency (%)	14.7 ± 0.7	15.4 ± 0.5	16.7 ± 0.7
Variables		**VO_{2peak}**	
VO_{2peak} ($L \cdot min^{-1}$)		5.63 ± 0.41	
VO_{2peak} ($mL \cdot min\text{-}1 \cdot kg^{-1}$)		73.7 ± 3.9	
Peak respiratory exchange ratio		1.12 ± 0.30	
Peak heart-rate		193 ± 8	
Peak blood lactate ($mmol \cdot L^{-1}$)		13.5 ± 1.3	
RPE (6-20) [b]		19 ± 1	
Time to exhaustion (s)		260 ± 20	

[a] Percentage of self reported maximal heart-rate

[b] Rating of perceived exhaustion (Borg Scale)

Table 5. Correlations (r-values) between laboratory determinants of performance obtained during submaximal and maximal roller skiing and the different XC skiing components in eleven elite male biathletes

	Total time (s)	**XC time (s)**	**Uphill terrain (s)**	**Varied terrain (s)**	**Downhill terrain (s)**
Submaximal G4					
VO_2 ($L \cdot min^{-1}$)	-0.07	0.07	0.17	-0.27	0.17
VO_2 ($mL \cdot min^{-1} \cdot kg^{-1}$)	0.05	0.16	0.16	-0.02	0.34
% VO_{2peak}	0.26	0.29	0.25	0.13	0.55
Heart-rate ($beats \cdot min^{-1}$)	0.28	0.07	-0.05	0.34	0.15
% of HR_{max}[a]	0.91**	0.89**	0.87**	0.71*	0.58
RPE (6-20)[b]	0.81**	0.93**	0.95**	0.64*	0.57
Blood lactate ($mmol \cdot L^{-1}$)	0.45	0.49	0.43	0.35	0.63*
Gross efficiency (%)	-0.05	-0.11	-0.15	0.09	-0.19
Submaximal G3					
VO_2 ($L \cdot min^{-1}$)	-0.00	0.17	0.28	-0.21	0.12
VO_2 ($mL \cdot min^{-1} \cdot kg^{-1}$)	0.18	0.30	0.34	0.11	0.33
% VO_{2peak}	0.40	0.43	0.39	0.26	0.58
Heart-rate ($beats \cdot min^{-1}$)	0.31	0.14	0.00	0.37	0.27
% of HR_{max}[a]	0.85**	0.89**	0.87**	0.67*	0.69*
RPE (6-20)[b]	0.76**	0.84**	0.82**	0.58*	0.71*
Blood lactate ($mmol \cdot L^{-1}$)	0.51	0.61*	0.53	0.48	0.78**
Gross efficiency (%)	-0.19	-0.31	-0.37	-0.07	-0.21
Submaximal G2					
VO_2 ($L \cdot min^{-1}$)	0.02	0.29	0.37	-0.07	0.28
VO_2 ($mL \cdot min^{-1} \cdot kg^{-1}$)	0.19	0.46	0.44	0.26	0.54
% VO_{2peak}	0.39	0.53	0.47	0.36	0.72*
Heart-rate ($beats \cdot min^{-1}$)	0.27	0.13	-0.01	0.37	0.30
% of HR_{max}[a]	0.80**	0.89**	0.85**	0.67*	0.73*
RPE (6-20)[b]	0.80**	0.90**	0.86**	0.70*	0.70*
Blood lactate ($mmol \cdot L^{-1}$)	0.46	0.63*	0.56	0.46	0.75**
Gross efficiency (%)	-0.21	-0.48	-0.50	-0.23	-0.44
Maximal roller skiing					
VO_{2peak} ($L \cdot min^{-1}$)	-0.25	-0.11	-0.01	-0.30	-0.16
VO_{2peak} ($mL \cdot min^{-1} \cdot kg^{-1}$)	-0.22	-0.16	-0.12	-0.14	-0.30
Time to exhaustion (s)	-0.67*	-0.72*	-0.56	-0.75**	-0.85**

[a] Percentage of self reported maximal heart-rate

[b] Rating of perceived exhaustion (Borg scale)

*$p < 0.05$, **$p < 0.01$.

Performance in the laboratory measured as TTE during maximal roller skiing correlated significantly with XC skiing time, as well as time spent in varied and downhill terrain (all $p < 0.05$), whereas TTE only tended to significantly correlate with time in uphill terrain ($p < 0.10$). Furthermore, no significant correlations were observed between VO_{2peak}, neither in absolute or relative terms and XC skiing time, nor time spent in the different sections of terrain. In addition, no significant correlations were observed between any of the laboratory capacities obtained during treadmill roller skiing and the shooting components, penalty time, shooting time and range time.

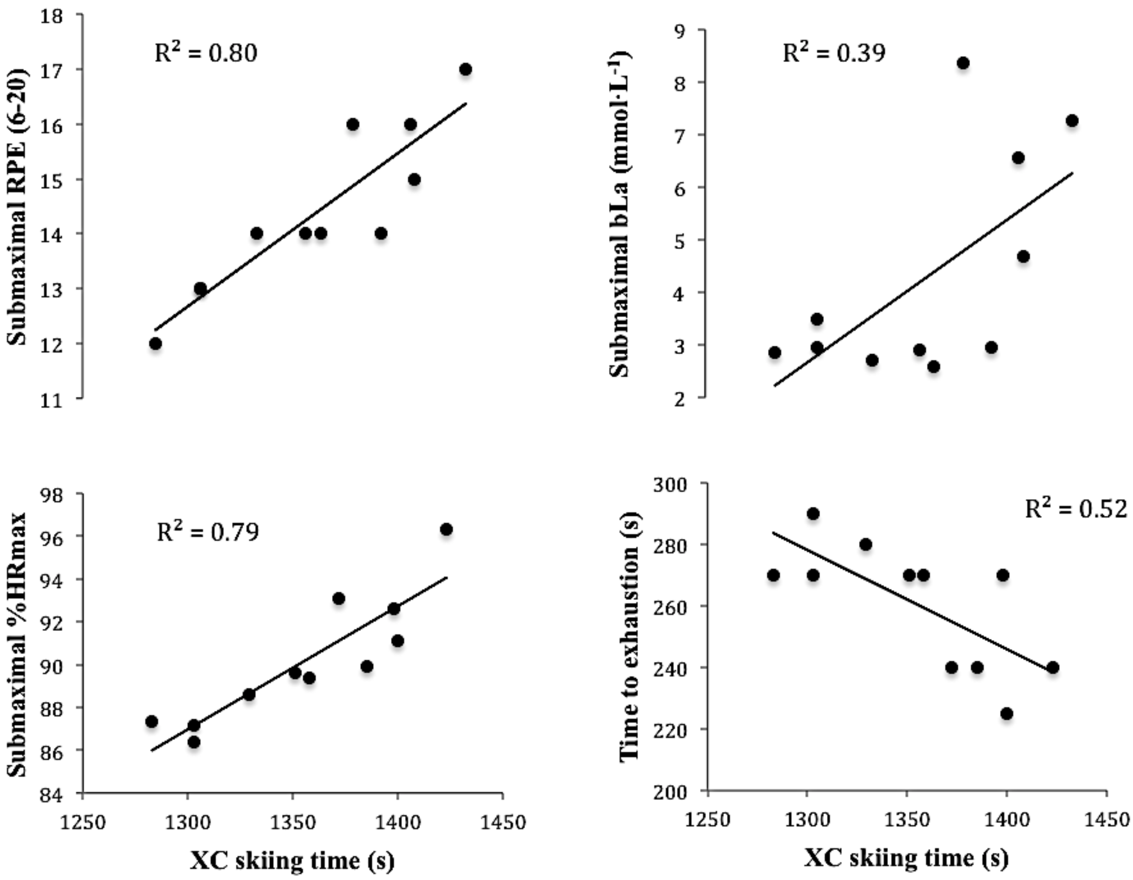

Figure 7. XC skiing time in relationship to rating of perceived exhaustion, relative heart-rate, blood lactate concentrations during submaximal roller skiing using the G2 sub-technique, and time to exhaustion during maximal roller skiing in eleven elite male biathletes. Presented with individual data points and trend lines based on linear regression.

DISCUSSION

The primary aim of the present study was to investigate the contribution from XC skiing and shooting performance to the overall performance in a sprint biathlon competition in eleven elite male biathletes. In addition, time spent in different terrains, pacing strategies, exercise intensity and shooting time were investigated in more detail, as well as the relationship between the XC skiing performance and laboratory roller skiing tests. The main findings were as follows: (1) the XC skiing and shooting performance explained 84% and 14%, whereas shooting time and range time together explained 2% of the overall performance, (2) 91% of the variation in XC skiing performance could be explained by time spent in the uphill terrain sections, (3) the shooting performance was not significantly correlated with the biathletes pacing towards shooting, the intensity of exercise or shooting time, and (4) rating of perceived exhaustion and relative heart-rate during submaximal roller skiing, and time to exhaustion during maximal roller skiing in the laboratory were revealed as significant correlates of the XC skiing performance.

Overall performance

The XC skiing performance was revealed as the most important contributor to the overall sprint biathlon performance. In fact, stepwise multiple regression analysis demonstrated that the XC skiing performance explained 84% of the variation in overall performance, while only 16% of the performance variability could be explained by the shooting component. These findings extends upon Groslambert et al (3) who investigated the comparable relay event in the 1992 Olympic Games and Cholewa et al (2) examining results of the sprint competition in World Cup and Olympic Games during the 2001/2002 season. Since biathlon has developed considerable as a competitive sport since these studies were conducted, the present findings provide new insight into the contribution of the different components of the sprint competition in biathlon. Clearly, XC skiing is the most important component of the sprint competition, indicating that a high overall performance could be achieved with an excellent XC skiing performance combined with only an adequate shooting performance. However, it is reasonable to suggest that the best performing biathletes achieve excellence both in the XC skiing and shooting performance. Furthermore, shooting time and range time explain only 2% of the overall performance variation, thereby contributing only to a minor extent to the overall performance. However, minimizing time loss in these two components of the race could still be of importance if both the XC skiing and shooting performance already are performed with excellence.

XC skiing performance

As expected from previous research on XC skiing (7-9), time in uphill terrain was revealed as the most performance-differentiating terrain of the XC skiing performance. The relative contribution of time in the uphill sections amounted for 52% of the total XC skiing time, and time in uphill revealed a near perfect correlation ($r = 0.95$) with the XC skiing time, which tended to be stronger than for time in varied and downhill terrain ($r = 0.82$ and 0.72). The present correlations were also supported by higher coefficient of variation within the uphill terrain sections, indicating greatest variation in time spent uphill, followed by time spent in the varied and downhill sections, respectively. Furthermore, the stepwise multiple regression analysis demonstrated that time in uphill explained 91% of the variation in XC skiing performance. However, it should be noted that when the semi-partial R^2 for time in uphill was removed from the final model, time in varied and downhill terrain then explained 69% of the variation in XC skiing performance. The semi-partial R^2 indicates the decrease in R^2 when an independent variable is removed from the final model due to high multi-collinearity between the independent variables as present between times in different terrains in this case. Thus, the current findings indicates that time in all types of terrain are crucial for achieving an excellent XC skiing performance and that the best performing biathletes are typically faster in all terrain sections of the competition.

XC skiing pacing strategies

The biathletes reduced their speeds during the second and third lap compared to the first lap of the competition, and thereby utilized a positive pacing strategy as previously described in XC skiing (7, 9, 28, 29). Interestingly, the third lap was performed faster compared to the second lap, indicating increased speeds during the latter part of the race. This finding also argues that the biathletes uses a pacing strategy with reduced speeds during the second lap prior to shooting in the standing position, to minimize the possible negative effect of exercise intensity on the shooting performance. This is supported by Hoffman and Street (11), suggesting that biathletes utilizes a pacing strategy with reduced speeds towards shooting in the sprint competition. Furthermore, the lack of relationship between time spent in the last section before shooting and shooting performance indicates that there is a minimal effect of the biathletes selected speed during the last ~500 m prior to shooting on the shooting performance. This is most likely explained by the fact that biathletes uses a pacing towards shooting in competition that they are experienced with and trained for to optimize their own shooting performance. Further research should in more detail examine the relationship between pacing towards shooting and shooting performance in biathlon, and if pacing strategies differs between the sprint competition and the individual competition where the shooting performance is likely more crucial due to the addition of one-minute in penalty time for each missed shot.

Shooting performance

The reduction in exercise intensity seen from 93 ± 2% and 94 ± 2% of HR_{max} as the maximum heart-rate during the first and second lap to ~87 ± 3% of HR_{max} immediately before shooting were similar for both shooting positions, and somewhat in agreement with previous findings of Hoffman and Street investigating the sprint competition in biathlon (11). However, the reduction of heart-rate to 69 ± 6% of HR_{max} in the prone position and 79 ± 4% of HR_{max} in the standing position during shooting is considerable less compared to the findings reported by Hoffman and Street (11). This may be a result of the shorter shooting and range time in this study, allowing less time to reduce heart-rate during shooting. Furthermore, more reduction of heart-rate during shooting in the prone position compared to the standing position were also in agreement with Hoffman and Street (11), and likely explained by the biathletes spending longer time and decreases their heart-rate more rapidly in a prone compared to standing position. The present results revealed no significant relationship between heart-rate immediately before shooting and the shooting performance in neither of the two shooting positions. This relationship is supported by previous findings in biathlon, demonstrating a minimal or non-existing influence of exercise intensity on the shooting performance (12, 13). It is therefore reasonable to suggest that biathletes are well adapted to shooting after intense exercise, possibly explained by different shooting strategies utilized depending on the intensity of exercise. However, this could also in part be explained by the fact, that the biathletes utilizes a pacing towards shooting and thus, exercise intensity that are optimal for their own shooting performance. Further research should therefore in more detail examine the underlying mechanisms behind the role of exercise intensity on the shooting performance in biathlon using a within-subject design and a more laboratory-based approach.

It has been suggested by Grebot et al (30) that there is an optimal shooting time in biathlon estimated between 15 and 20 s in the standing position due to visual adjustments and cardiorespiratory responses resulted by the intense exercise of XC skiing. However, this relationship is not supported by the present findings, demonstrating a mean shooting time of 27 ± 4 s in the standing position, and no significant correlations between shooting time and shooting performance in neither of the two shooting positions. Furthermore, there was no significant relationship observed between time spent between each individual shot and the number of hits, most likely a result of individual shooting strategies used to obtain an optimal rhythm during shooting. In addition, the longer shooting time and time spent before the first shot in the prone compared to the standing position were in agreement with Hoffman and Street (11) examining the sprint competition, and mainly explained by the longer time it takes to obtain a prone position. Furthermore, the lower shot rate accompanied by a 23% higher penalty time in the standing compared to the prone position were also in line with previous findings of Hoffman and Street (11). This implies that performance during shooting in the standing position is more crucial than shooting in the prone position to the total shooting performance in the sprint biathlon competition. Another study by Hoffmann and colleagues (12) demonstrated that the exercise intensity negatively influenced parameters related to shooting technique in the standing position and could therefore possibly explain the lower shot rate observed in this position. It should, however be noted that in the study by Hoffmann et al (12), the exercise intensity did not influence the shooting performance measured as number of hits, which is also supported by the findings of the present study. Moreover, the stability of hold is increased in the prone position by use of a shooting-strap. Thus, perfect aiming and fine motor control involved with pulling the trigger have been related to performance in this position, whereas increased postural stability and reduced movement of the rifle barrel in the standing position has been suggested as more demanding and important to performance in this position (31-33). In addition, several factors such as wind, light and temperature influences the shooting performance in biathlon and could have contributed to the observed difference in average shot rate between the two shooting positions in this study. Hopefully, future research will in more detail investigate the shooting performance in biathlon and also develop laboratory capacities and explanatory factors of the shooting performance to further increase this understanding.

Laboratory determinants of the XC skiing performance

The significant correlations between RPE and $\%HR_{max}$ versus XC skiing time and time spent in different terrain indicate that the submaximal stages were less demanding for the best performing biathletes in the competition. Thus, highlighting the relevance of using RPE and $\%HR_{max}$ as laboratory capacities and determinants of performance in this group of endurance athletes. In addition, blood lactate concentrations in the G3 and G2 sub-technique were significantly correlated to the XC skiing time and time spent in downhill terrain. The lack of significant relationship for the G4 sub-technique may be due to the reason that this stage was performed first and that there was a small accumulation of the exercise intensity throughout the test session. In addition, the significant correlations seen between blood lactate concentrations and time in downhill, and only the trends observed for time in uphill and varied terrain could be explained by the faster speeds seen by the best biathletes at the end of the uphill terrain sections, which further could have contributed to even larger speed differences in the downhill sections. Another methodological limitation that should be taken into consideration is differences between the participants with respect to skies and gliding properties, which are highly difficult to standardize in this type of field analysis. Furthermore, submaximal oxygen cost and GE demonstrated no significant relationships and these results differ from previous findings in XC skiing that generally indicates submaximal oxygen cost and efficiency in the skating technique as important laboratory determinants of performance (8, 25, 34, 35). In addition, the present results did not reveal any tendencies towards stronger correlations between physiological responses in the specific sub-techniques comparing to the terrain sections were these sub-techniques normally are pre-dominant during competitions. Thus, supporting the fact that the best performing biathletes are faster in all terrain types of the competition and, in addition generally better performers in all sub-techniques during laboratory testing.

Performance in the laboratory measured as TTE was the only parameter during maximal roller skiing significantly correlated to XC skiing time and time spent in different terrain. Hence, this emphasizes the importance of using performance as a laboratory capacity in these athletes monitoring their training and development of performance level. Furthermore, no significant relationships were identified between VO_{2peak} and XC skiing time, nor time spent in different terrain. These findings are in agreement with Rundell et al (21), indicating that TTE during treadmill running and performance during a 1 km double-poling time trial on snow rather than VO_{2max} explained most of the variation in performance during a sprint competition in elite male biathletes. Moreover, a second study by Rundell et al (22) demonstrated a significant relationship between VO_{2peak} in the skating technique and XC skiing time during an individual competition in elite female biathletes. However, the findings of the present study are in contrast to the latter study by Rundell et al (22) and previous observations in XC skiing that generally highlights a high VO_{2peak}, in combination with production and utilization of VO_{2peak} within the different sub-techniques as key determinants of performance (5, 14). These conflicting findings can in part be explained by the fact that biathletes to a certain extent can compensate for a lower XC skiing performance with an optimal shooting performance and thus, represents a different group of XC skiers or endurance athletes. It is also reasonable to assume that the relatively small number of participants could have been a limitation of the present study and thereby contributed to these conflicting findings. Another interesting aspect of biathlon is the role of interspersed stages of rifle shooting, leading to periods of ~60-90 s with a considerable reduction in exercise intensity due to slower speeds towards shooting in addition to the time spent at the shooting range. It is highly discussed in XC skiing that the speed, work and exercise intensity fluctuates during competitions due to varying terrain and speeds, with an increased effort seen in the uphill sections, whereas the downhill sections are primarily used for recovery (5). These characteristics are unique for XC skiing and reveal XC skiing as a clearly interval-based endurance sport. Considering these aspects, it is reasonable to suggest that biathlon is even more interval-based due to the relatively long periods with reduced exercise intensity during shooting, and this could possibly lead to the requirement of different demands and performance determinants in biathlon. Future research should in more detail elucidate this relationship and the potential differences between biathlon and XC skiing with regards to physiological demands, as well as physiological characteristics between these two groups of endurance athletes.

CONCLUSION

The present findings reveal the XC skiing performance as the most important contributor to the overall performance in the sprint biathlon competition, and that most of the variation in XC skiing performance could be explained by time spent in uphill terrain. The shooting performance was not influenced neither by the biathletes pacing towards shooting, the intensity of exercise nor shooting time. Furthermore, rating of perceived exhaustion and relative heart-rate during submaximal and time to exhaustion during maximal roller skiing strongly determined the XC skiing performance, as well as performance in the different sections of terrain. Overall, the knowledge gained in this study contributes to an increased scientific understanding of the different demands and determinants of performance in biathlon and hopefully, the revealed findings have implications for athletes and coaches developing the field of best practice.

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