Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Circulation and Medical Imaging

Vilde Marie Qu Nordby

The Relationships between, and Seasonal Variations in; Physiology, Technique, and Performance in Cross Country Skiing

Master's thesis in Physical Activity and Health (Exercise Physiology)
Supervisor: Jørgen Danielsen
Co-supervisor: Knut Skovereng
May 2023

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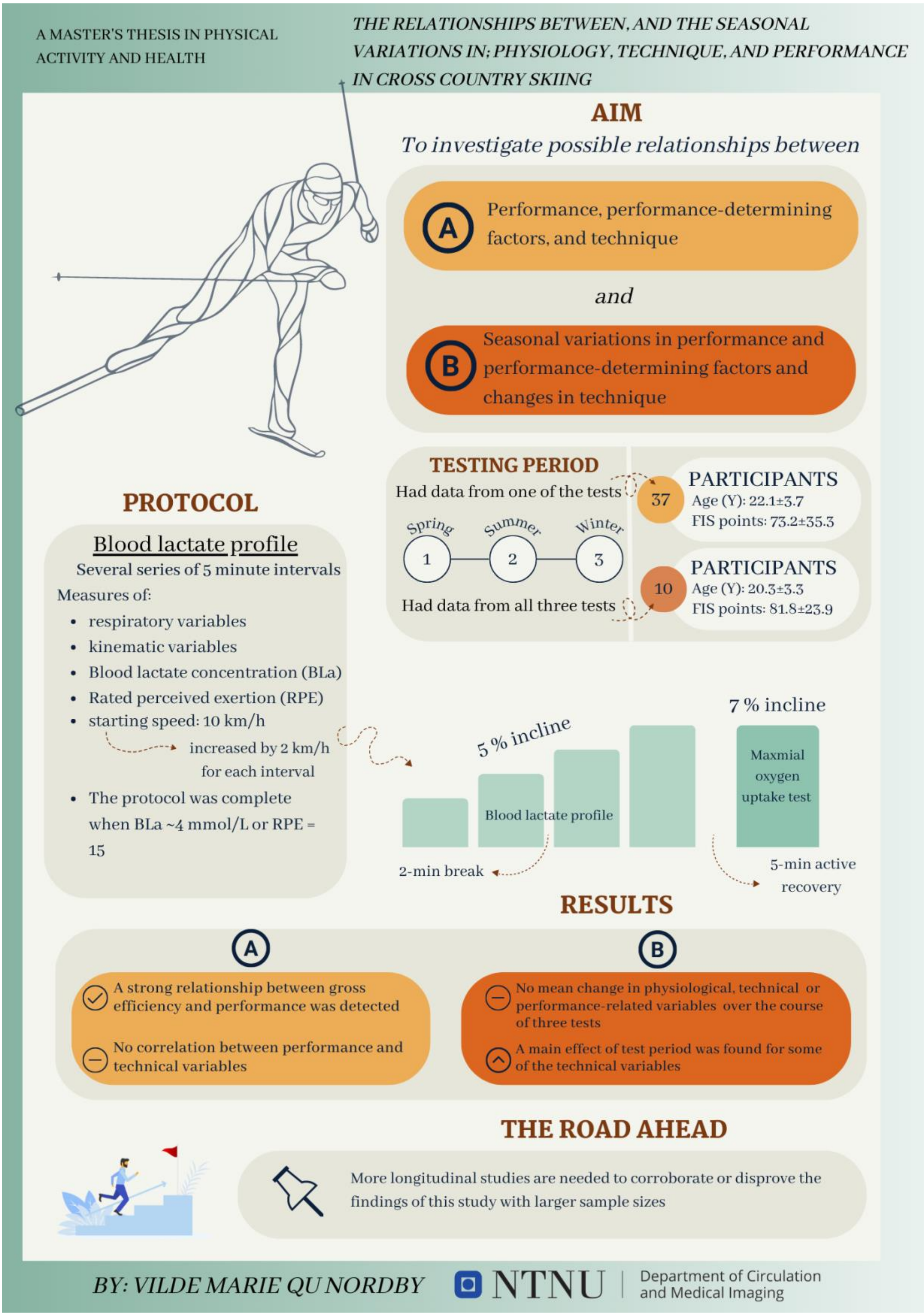
Infographic



Sammendrag

Formål: Hensikten med denne studien var å undersøke mulige forhold mellom a) prestasjon, prestasjons-relaterte faktorer og teknikk, og b) sesongvariasjoner i prestasjon, prestasjons-relaterte faktorer og endringer i teknikk.

Metode: Til sammen deltok 48 langrennsløpere i studien. Av de 48 deltakere, hadde 37 (Alder: 22.1±3.7, FIS poeng: 73.2±35.3) komplette datasett fra test dag 1, disse ble brukt til å undersøke forholdene i a). Utfra de 37 som hadde gjennomført første test, hadde 10 (Alder: 20.3±3.3, FIS poeng: 81.8±23.9) deltakere komplette datasett for tre ulike tester (vår, sommer, vinter), disse ble brukt til å undersøke sesongvariasjonene beskrevet i b). Alle deltakerne utførte den samme protokollen, som besto av flere serier med 5-minutter intervaller for å fastslå en laktatprofil. Respiratoriske (submaksimalt oksygenopptak, hjertefrekvens, blodlaktatkonsentrasjon og effektivitet) og tekniske (syklus lengde, syklus frekvens, stavtid, relativ stav tid, stav-vinkel ved landing og oppstigning) variabler ble samlet inn underveis i intervallene. Intervallene ble utført på bestemte hastigheter og en bestemt stigning med en forhåndsbestemt skøyteteknikk kjent som dobbeldans eller G3 teknikk. Etter laktatprofilen utførte deltakerne en maksimal oksygenopptakstest med konstant økende hastighet til utmattelse.

Resultat: Studien fant en sterk sammenheng mellom prestasjon og effektivitet ($R = 0.68$, $R^2 = 0.46$, $p < 0.001$) på to ulike hastigheter, men ingen sammenheng mellom effektivitet og tekniske variabler. Det var heller ingen positive forandringer i fysiologiske og tekniske variabler eller prestasjonsrelaterte faktorer gjennom testperioden og ingen total effekt av test periode.

Konklusjon: Studien fant et sterkt forhold mellom prestasjon og effektivitet, men ingen sammenheng mellom effektivitet og tekniske variabler. Det var heller ingen forandringer eller betydningsfulle forskjeller i fysiologiske og tekniske variabler eller prestasjonsrelaterte faktorer over en sesong.

Abstract

Aim: The aim of this study was to investigate possible relationships between a) performance, performance-determining factors and, technique and b) seasonal variations in performance and performance-determining factors and, changes in technique.

Methods: A total of 48 cross country skiers participated, of which 37 participants (Age: 22.1±3.7, FIS points: 73.2±35.3) had complete datasets from test day 1 and were used to analyze the relationships described in a). A total of 10 participants (Age: 20.3±3.3, FIS points: 81.8±23.9) had complete datasets for three separate test days (spring, summer, autumn) and were used to investigate seasonal variations as described in b). All participants performed a blood lactate profile which consisted of several 5-minute intervals at increasing intensities. During the intervals respiratory variables (submaximal oxygen uptake, heart rate, blood lactate concentration, gross efficiency) and kinematic variables (cycle length, cycle rate, poling time, relative poling time, pole angle at touchdown and liftoff) were measured at fixed speeds and incline, with a predefined skating technique known as double dance or G3 technique. Participants also performed a time to task failure test to determine maximal oxygen uptake at a set incline with increasing speed.

Results: A strong relationship was detected between $V_{Threshold}$ and gross efficiency at two fixed submaximal speeds ($R = 0.68$, $R^2 = 0.46$, $p < 0.001$), however, no relationship was detected between gross efficiency and technical parameters for the same speeds. No changes in either physiological, technical variables over the course of three tests, with no overall effect of time. No effect of test period was detected for performance-related factors.

Conclusion: The study identified a strong relationship between performance and gross efficiency. However, no correlation between any of the technical parameters and $V_{Threshold}$. Lastly, no change or meaningful difference in physiological or technical variables over the course of the testing period occurred.

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Firstly, I would like to thank my supervisor Jørgen Danielsen for his continuous and around the clock help, encouragement, and wisdom. I would also like to thank my co-supervisor Knut Skovereng for all the help regarding testing and throughout the data analysis. Secondly, I would like to thank the athletes that participated in this study, both for their time and commitment, and to Olympiatoppen for giving me the opportunity and means to perform this project.

Lastly, I would like to thank my friends and my family for their encouragements and support, especially my parents, and to my fellow master students, thank you for the cooperation and for the long lunchbreaks.

Sincerely,

Vilde Marie Qu Nordby.

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Abbreviations

XC	Cross Country.
LDs	Long distance skiers.
ARs	All around skiers.
WC	World-class skiers.
NL	National-level skiers.
FIS	International Ski Federation.
DP	Double poling technique, Classic skiing technique.
CL	Cycle length.
CR	Cycle rate.
P_{Time}	Poling time.
P_{Trel}	Relative poling time.
$P\theta_{LO}$	Pole angle at liftoff.
$P\theta_{TD}$	Pole angle at touchdown.
G	Gear, used to categorize Cross Country skating technique.
BLa	Blood lactate concentration.
MR	Metabolic rate.
WR	Work rate.
GE	Gross efficiency.
HR	Heart rate.
VO2	Oxygen uptake.
VO2max	Maximal oxygen uptake.
RPE	Rated perceived exertion.
$V_{Threshold}$	Threshold velocity at 4 ~mmol/L BLa.
S12	Speed is equal to 12 km/h.
S14	Speed is equal to 14 km/h.

1 Introduction

Cross County (XC) skiing involves competing on varying terrain (uphill, downhill, and flat terrain) and is an endurance sport with requirements of upper-and lower body work, technical skills as well as a considerable physiological capacity (1, 2). Maximal oxygen uptake (VO2max), speed or power at a certain blood lactate threshold and gross efficiency (GE) are often used as performance predicting measures in endurance sports performance (3), including XC skiing(4). Studies have indicated that GE, the ratio of work generated to the total energy expenditure (5), is especially important in understanding XC skiing performance (6, 7), due to the technical complexity of the sport. Further, research have also found that cycle length (CL), the distance traveled during each cycle of movement (8), seems to be related to GE (7) and performance (1, 2). At a given speed, a higher CL equals a lower cycle rate (CR), which indicates less wasted movements and better force production. XC skiers are among athletes with the highest recording of VO2max (3, 9, 10), however, a great physiological capacity alone is insufficient without proper technical skills. This obvious fact was further emphasized in a study performed by Talsnes, Hetland (11), who found that athletes with great physiological capacity were not able to utilize their capacity in XC skiing due to the lack of sport-specific technique.

Fluctuations in speed and terrain calls for quick adaptations in the different techniques in order to optimize performance (1). The different techniques in skate skiing are often referred to and categorized into different gears, G1-G7 (12, 13). G3 technique, also known as double dance (14); V2-skate (15); and 1-skate (16) is often considered the main skating style technique on various terrain. This includes low to moderate inclines, in transitions to flat terrain, and when increasing speed, and is characterized by a double pole push on every leg push (12, 17). A study performed by Sandbakk, Holmberg (7), using the G3 technique, found that world-class (WC) skiers had longer CL, lower cycle rate (CR), and an overall better physiological capacity than their lower ranked counterparts (national level (NL) skiers), emphasizing the importance of an effective technique at higher speeds. The rank was determined based on scoring system of the International Ski Federation (FIS), also referred to as FIS-points (7, 18). FIS points determine the best skiers in each race, with the best skier obtaining a score of 0. In Sandbakk, Holmberg (7), the WC and NL skiers differed by ~0.8 m in CL and 0.5 percentage points in GE.

Several studies have reported similar findings with regards to kinematic data for other XC skiing techniques. Stöggl and Holmberg (19) found that the fastest elite skiers had longer CL and a longer swing and poling time, with more vertical pole angle at pole plant, and a later peak pole force, compared to their slower counterparts. Another study on DP found that the more skilled XC skiers had a more dynamic technique with a larger range of motion in most joints than the less skilled skiers (20). A different study found a relationship between cycle rate (CR), which means the number of times the body moves through a complete cycle during 1 second, and performance when studying XC skiing on an uphill terrain on shorter distances using the G2 and G4 technique. This suggested that that the importance of a higher CR is more present in maximal effort tasks, shorter distances, and steeper terrain (8, 21). More recent studies have, however, found almost no differences in technical parameters when comparing long-distance (LD) and all-around (AR) XC skiers in DP, although they did find group differences in performance-related factors such as GE and O2-cost (10, 22).

Overall, XC skiers perform large amounts of training, both specific (skiing, roller-skiing) and general (running, strength training), with the aim of improving physiological and technical parameters, to possibly enhance performance. Recordings of seasonal variations in physiological capacity and technical skills can provide important insight into which types of training loads contributes to improved performance in already well-trained high-level individuals, and in younger developing athletes. For example, in a study conducted by Ingjer (23) smaller improvements in physiological capacity over a six-year period (from age 14 to 20) was detected when examining changes in VO2max in junior XC skiers. While another study, performed by Losnegard, Myklebust (24), found an increase in O2-deficit (oxygen deficit), O2-cost (oxygen cost), and performance, however, no significant changes in VO2max when investigating seasonal variations in physiological indices for male elite senior XC skiers (24). They also found an increase in performance and argued that these changes could likely be explained by technical improvements. However, because kinematic data was not collected, they could not be certain if technique had changed or affected performance. Ingjer (23) did not measure kinematic data either, so the effects of changes in technique on performance for his participants is also unknown. Losnegard, Myklebust (24) concluded that training induced changes in already well-trained athletes might require several years to develop and given that majority of the developments (both physiological and technical) occur during puberty, older athletes should aim to improve other factors that can enhance performance, such as threshold velocity and technique. Other studies have also investigated seasonal variations in physiological and/or performance-related parameters in other endurance sports, such as cycling, finding some enhancements in physiological indices over the course of a season (25, 26).

XC skiing training is often periodized into a general preparation phase, a specific preparation phase, and a competition phase. The training modalities are emphasized differently in the three phases, and the volume of each modality (endurance-, strength and sport-specific training) will vary based on which part of the season you are in (27). It is therefore likely to observe enhancements or alterations in both physiological and technical aspects when sport-specific training is intensified closer to the beginning of the season’s competitive phase. The aim of this study is therefore to investigate, among participants with wide a range in age and level (FIS-points), possible relationships between a) performance, and performance-determining factors and technique, and b) seasonal variations in performance and performance-determining factors, and changes in technique.

2 Methods

2.1 Participants and study design

A total of 48 XC skiers, 12 women and 36 men of different levels (FIS-point) participated in this study. Participants were tested during different parts of the training/competitive season, how many test each person performed was dependent on the athlete's availability, with a maximum of three tests. Each test session lasted approximately 45 minutes. The testing sessions consisted of different measures of physiological parameters to assess endurance performance. This included maximal oxygen consumption at peak exercise (VO2peak), submaximal oxygen uptake (VO2 ml/kg/min) and blood lactate concentration (BLa) on roller skis through a range of speeds at a fixed incline and with a predefined technique (G3). Kinematic data was also measured to assess possible relationships between performance and technique, as well as changes in technique. Of the 48 XC skiers who took part in this study, 37 participants had complete datasets (both physiological and kinematic parameters) from the first test (T_1). These were used for the first part of the analysis (Part a)) investigating a possible relationship between performance, performance-determining factors, and technique. Further, 10 of the 37 participants from the previous analysis had complete datasets for all three tests. Which were used in the second part of the analysis (part b)) investigating seasonal variations in performance, performance-related factors, and changes in technique. All participants signed a written informed consent and were given the protocol verbally on the first test day. The athletes could withdraw from the study at any given point without reasoning, ensuring that participation was voluntary. The data management was approved by the Regional Ethics Committee (REC), Trondheim, Norway, and the study was approved by the Norwegian Social Science Data Services (NSD). Test-leaders had supervised trials in which they performed the protocol on each other before the test-period started. This was to assure a safe and efficient data collection. No risks associated with the protocol or data collection were identified. Testing is also a part of the athletes testing and training regime, making the tasks familiar, and is presented as non-invasive. The data collection period was from June to December of 2022. Descriptive statistics of the participants for analysis part a) and b) can be found in the results section.

2.2 Protocol

2.2.1 Blood lactate profile

Firstly, participants had the opportunity to get acquainted with the treadmill at a self-selected speed at a 5 % incline before the testing started. Participants performed several series (between 2 and 6 series) of 5-minute submaximal interval on roller skis (illustrated in figure 1). The participants had a two minute break between each interval where blood lactate concentration (BLa) and rated perceived exertion (RPE) using the Borg scale (28) was measured and noted. All intervals were performed at a set incline of 5 % with a starting speed of 10 km/h, which increased by 2 km /h (or 1 km/h if BLa was ~ 3.2 mmol/L or RPE = 14) until the participant reached a BLa of ~ 4 mmol/L, a common threshold for anaerobic work (29), or when RPE reached 15 (which was chosen as the threshold for subjective submaximal work).

2.2.2 VO2 max test

Secondly, followed by a 5-minute active recovery phase, participants performed an incremental time to task failure test (TTF) to determine VO2max at a set incline of 7 %.

Starting speed was calculated by subtracting the speed of the last submaximal interval with 2 to ensure that VO2max was reached within 5 – 10 minutes. The speed was increased by 1 km/h every minute until failure, the duration of last successful speed was noted. Before starting the test, participants were instructed to spit out their mouthpiece, to communicate exhaustion. A ceiling-mounted harness was used for all participants during the VO2max test. The sport specific VO2peak was defined as the average of the two highest 30 second consecutive measurements. HRmax was defined as the highest 5-second measurement during the test. BLa was measured at the end of the test.

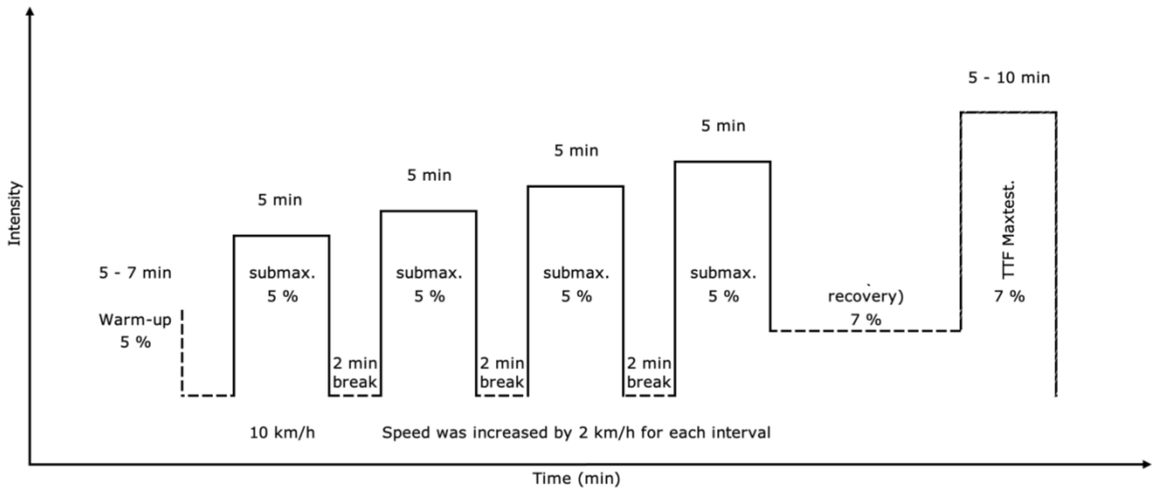

Figure 1: Schematics of the protocol for this study. Measures of BLa and RPE was done in-between each interval. For the TTF test, BLa and RPE was measured directly after the tested had ended.

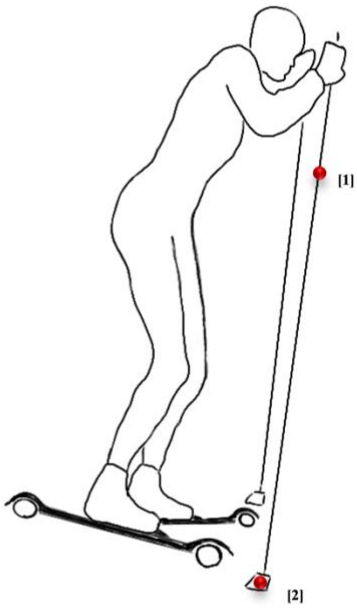

Figure 2: Illustrates the marker placement on the right side of the body (pole). Where [1] is located at top of the pole and [2] is located on the carbine tip.

2.3 Equipment and instruments

Body mass was measured using a medical weight (Seca, model 708, GmbH, Hamburg Germany) and height was measured using a stadiometer (Holtain Ltd, Crosswell, UK). Respiratory variables were recorded on an open-circuit indirect calorimetry (Vyntus CPX, JAEGER, CareFusion, Germany 234 GmbH) which was connected to a breathing tube and a mouthpiece. The respiratory flow transducer was calibrated, against 2L/min automatic pump attached to the Vyntus CPX, for each testing day. Oxygen and carbon dioxide were calibrated using a fixed gas mixture (15% ± 0.04 O_2, and 5% ± 0.1 CO_2). BLa was measured in a glucose/lactate hemolyzing solution, blood samples (20 µL) were taken from the fingertip and analyzed using Bioson C-line (Biosen, EKF Industrial Electronics, Magdeburg, Germany). Heart rate (HR) was measured on a Polar heart rate monitor (V800, Polar Electro, Finland) or by the participants own wearables. All roller ski tests were performed on a 5 x 3-m motor driven treadmill (Forcelink B.V., Culemborg, Netherlands). The participants used their own ski boots and poles during testing, and the poles were equipped with special carbide tips during treadmill testing. Athletes were secured with a roof-mounted harness during the maximal oxygen uptake test, and if the athlete felt unsecure – the harness was used during the submaximal intervals as well. All participants used the same pair of skating roller skis with standard wheels (IDT, Sports, Lena, Norway) with a resistance category 2 to prevent large variations in rolling resistance. Rolling resistance was found by conducting a towing test where one of the test-leaders stood on the roller skis, holding a rope connected in series with a force transducer with no effect of incline and speed. The rolling resistance coefficient was averaged to a value of 0.02 by dividing roller friction force by the normal force.

Kinematic data from the submaximal tests were collected by recordings of pole position through motion a capture system (Qualisys AB, Gothenburg, Sweden) and Qualysis Track manager software. Reflective markers were placed on the right side of the pole, just below the elbow [1] and on the carbine tip [2], as illustrated in fig. 2. The laboratory was equipped with six infrared Oqus cameras that captured and recorded the markers on the right side of the body in 15-second intervals. The length of the time interval was chosen to ensure that there were enough kinematic data to calculate gross technical parameters (see 2.4). The recordings occurred at around the middle of each interval and was performed by the same test-leader at all tests. The cameras captured the three-dimensional position characteristics of the passive reflective marker at a 100 Hz sampling frequency, with an overall accuracy of <1mm.

2.4 Data collection and analysis

Throughout the testing periods, physiological data was consistently collected by the same group of test-leaders. Respiratory variables were continuously measured throughout each interval. The average and steady-state values of VO2 ml/kg/min and HR during the last 1.5-2 minutes were used for further analysis. BLa was measured and RPE was noted immediately after each interval during the 2-minute breaks. Marker placement and kinematic data recordings were also done by the same test-leader for each test in each test-period. The same test-leader also calibrated the motion capture system for each test day. Further, raw position data for both markers was low-passed filtered (Butterworth, 8^{th} order, 15 Hz cut-off) in MATLAB 9.8.0 (R2020a). Gross technical parameters included CL, CR, poling time (P_{Time}), relative poling time (P_{Trel}), pole angle at lift off ($P\theta_{LO}$), and pole angle at touchdown ($P\theta_{TD}$) and were calculated based of the marker-recording data in MATLAB 9.8.0 (R2020a).

$V_{Threshold}$ was obtained through an interpolation from nearest velocity over and under 4 ~ mmol/L BLa and was performed in Microsoft Excel. CL was defined as the distance traveled by the skier per cycle and is reported in meters (m). One cycle was described as the distance from one pole touchdown (P_{TD}) to the next P_{TD}, and CR was the frequency (Hz) of CLs during 1 second. P_{TD} was defined as the occurrence of peak acceleration of the pole tip marker in the vertical plane. While Pole liftoff (P_{LO}) was characterized as the point in time where the pole tip marker started to increase its vertical position. Poling time (P_{Time}) was the duration between P_{TD} and P_{LO} reported in seconds (s). P_{Trel} was the relative duration in of P_{Time} relative to cycle time and is expressed as % of cycle time. Pole angle ($P\theta$) was defined as the angle of the pole relative to the horizontal, where a vertical $P\theta$ equals 90°. $P\theta_{TD}$ was the angle of the pole at P_{TD}, while $P\theta_{LO}$ was the angle of the pole at P_{LO}, reported in degrees.

2.4.1 Calculations

The following calculations were performed to retrieve metabolic rate (MR), work rate (WR), and lastly GE.

Power against friction ($P_f = WR_f$) and Power against gravity ($P_g = WR_g$) was calculated using the following formulas (F):

$$F1: WR_f = \cos(\alpha) * \mu * m * g * v$$
$$F2: WR_g = \sin(\alpha) * m * g * v$$

Where α was the angle of the treadmill, μ was the rolling friction coefficient (in F1), m was body mass, g was the gravitational acceleration and v was the speed of the treadmill in m/s.

The total power output ($P_{tot} = WR_{tot}$) was calculated using the following formula:

$$WR_{Tot} = WR_f + WR_g$$

MR was calculated using the following formula:

$$MR = \frac{VO2\ (L/min) * k * j}{60}$$

Where VO2 is in L per minute multiplied with a constant (k) converting oxygen to kcal (adjusted for RER value, 4.8-5), and a constant (j = 4186), divided by 60 converting kcal to joules per second (30).

GE is obtained by dividing the WR_{tot} by the MR, and is, in the further analysis, reported as a fraction and was calculated using the following formula:

$$GE = \frac{WR_{Tot}}{MR}$$

2.5 Outcome variables

Physiological outcome variables included VO2 ml/kg/min, HR, BLa, and GE. Gross technical outcome variables consisted of CL, CR, P_{Time}, P_{Trel}, $P\theta_{LO}$ and $P\theta_{TD}$, while performance-related outcome variables were $V_{Threshold}$, RPE and FIS points. FIS points were retrieved from the FIS point lists that were available during the three different periods when testing occurred (18).

2.6 Statistical analysis

The data was grouped by test sessions categorized into spring (T_1), summer (T_2) and winter (T_3). Participation ID was specified as a random factor (intercept only), because the data was nested within participants (repeated measure). All statistical analysis was conducted in R studios for Intel Macs (R4.2.3, Postit, PBC, USA) and Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA) for Mac OSX. Statistical significance was set at $p = 0.05$. The following package in R studios was installed and used for the statistical analysis and graphics; library readxl, tidyverse, dplyr, ggpubr, reshape, lme4, emmeans and patchwork.

The results are divided into two parts. In the first part of the analysis, the relationships between a) $V_{Threshold}$ and FIS points (performance), $V_{Threshold}$ and GE, $V_{Threshold}$ and technical parameters (displayed in Table 5), and GE and technical parameters were investigated (Library ggpubr and lme4). In the second part, possible seasonal variations in performance, physiological parameters, and technical parameters were examined by fitting linear mixed models (Library lme4 and library emmeans) on pre-defined outcome variables of interest (presented in table 2) with time (T_1, T_2, T_3) as the predictor. Mean change and standard deviation of seasonal variations was presented graphically (library ggpubr), see fig. 4, while correlation was explained in text, see 3.2. Possible gender differences were assessed and carefully examined and did not affect the results of the present study. The assumption of approximately normally distributed residuals was confirmed by visual inspection of QQ-plots for all outcome variables in R studios for Intel Macs (R4.2.3, Postit, PBC, USA).

3 Results

3.1 a) Performance, performance-determining factors, and technique

After retrieving and processing the data, 48 participants had datasets from their first test day (T_1). Of those 48, 13 were excluded due to too many missing values. To organize the dataset, two specific speeds, 12 km/h (S12) and 14 km/h (S14), were selected since most participants had data available at these speeds. This resulted in 37 participants for S12 and 34 participants for S14 which were used to analyze the relationship between a) FIS points and $V_{Threshold}$, GE and $V_{Threshold}$, $V_{Threshold}$ and technical variables and GE and technical parameters. Descriptive statistics for this group are presented in table 1 are presented as mean (M) and standard deviation (SD), showing a large range in especially age and FIS points.

Table 1: descriptive statistics, n = 37

	M	SD	Range
Age	22.1	3.7	17 – 30
Height	178.2	7.4	162 – 191
Body mass	71.4	8.4	49.1 – 86
FIS points	73.2	35.3	17.7 – 157.21

A strong relationship was found between $V_{Threshold}$ and FIS points (ß = -12.7, R = 0.68, R^2 = 0.46, $p < 0.001$), showing that an increase of 1 km/h in $V_{Threshold}$ corresponded to a decrease in FIS points of ~13. In all further analysis, we therefore use $V_{Threshold}$ as the measure of performance. This measure was chosen to represent a lab-specific measure of performance (Spring, summer, winter) since FIS points in general change much less over the summer period. In addition, a laboratory-specific measure of performance ($V_{Threshold}$) is in this instant, believed to correlate stronger, if at all, to technical parameters collected simultaneously. Fig. 1 shows the relationships between $V_{Threshold}$ and GE and CL with associated R and p-value. A strong relationship between $V_{Threshold}$ and GE was detected for both speeds (adjusted for body mass). Linear regression was performed for FIS points and GE, revealing a weak, however non-significant, relationship for S14 reported as a fraction (ß = -1637.2, p = 0.07), but no relationship at S12 (ß = -1203.6, p = 0.15). No relationships between GE and any of the technical variables presented in table 2 and CL (fig. 3.2a and 3.2.b) were detected using a Pearson correlation and linear regression.

Table 2: The relationships between VThreshold and technical parameters for S12 and S14.

	S12				S14			
	n = 37				**n = 34**			
	ß	R	R^2	p-value	ß	R	R^2	p-value
P_{Time}	0.003	0.077	0.006	0.282	0.004	0.167	0.028	0.183
P_{Trel}	0.002	0.141	0.020	0.210	0.002	0.1	0.010	0.262
$P\theta_{LO}$	-0.526	0.167	0.028	0.178	-0.138	0	0	0.329
$P\theta_{TD}$	-0.292	0.275	0.076	0.06	-0.156	0.122	-0.015	0.457
CR	-0.002	-0.158	-0.025	0.632	-0.004	0.031	0.001	0.313

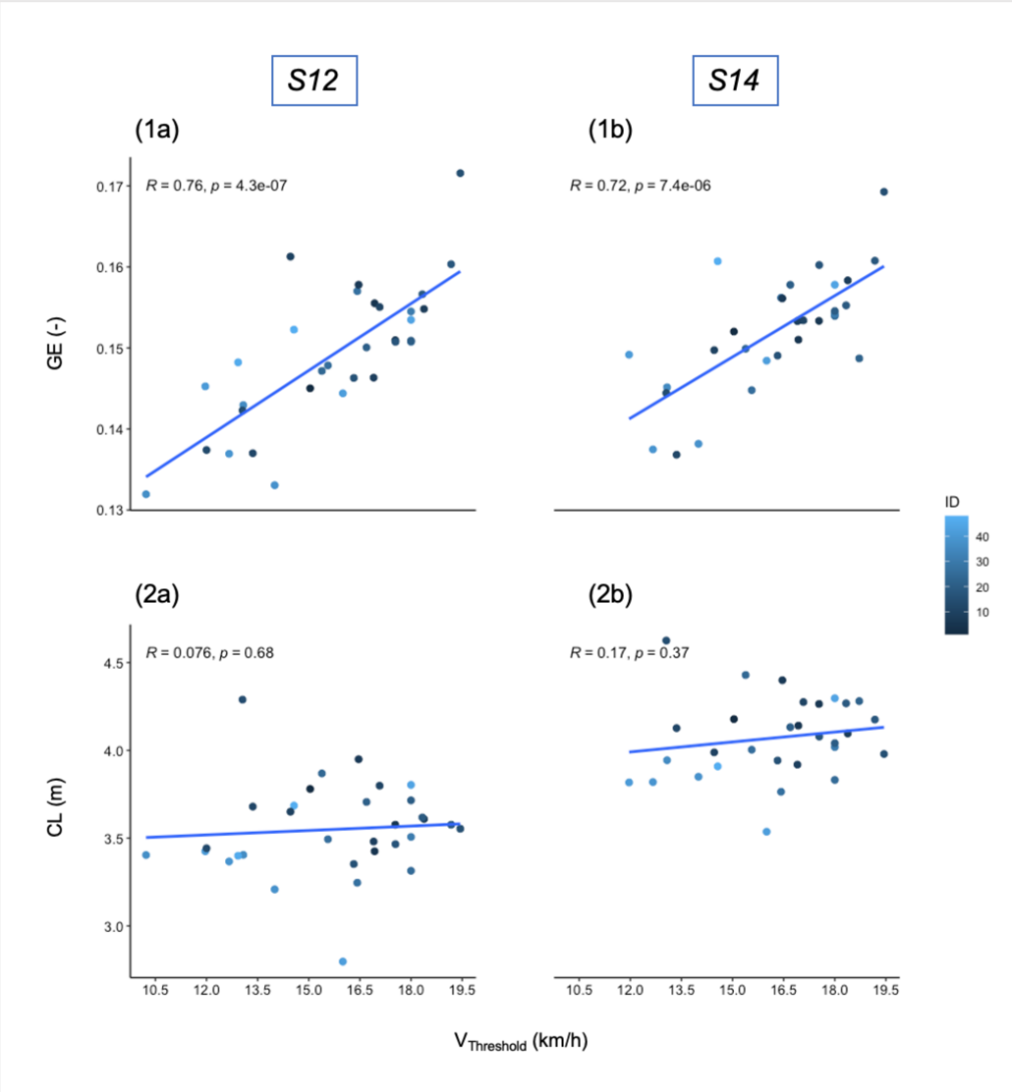

Figure 3: A Pearson correlation test was used to investigate the relationship between $V_{Threshold}$ and GE (1a and 1b), and between $V_{Threshold}$ and CL (2a and 2b) at S12 and S14 and is displayed with the associated R, P-values, and regression lines for each plot.

3.2 b) Seasonal variations in performance, performance-determining factors, and changes in technique

Of the 37 participants from the previous analysis, ten people had complete datasets for all three tests. These participants (n = 10) were used to look at seasonal changes in various parameters regarding performance, physiological-and technical parameters. Table 3 provides descriptive statistics for this group.

Table 3: Descriptive statistics, n = 10.

	M	SD	Range
Age	20.3	3.3	18 – 29
Height	175.4	8.2	165 – 185.5
Body mass	67.9	10.5	53.3 – 79.9
FIS points	81.8	23.9	45.4 – 112.1

Table 4 displays the mean and SD for physiological variables and GE at S12 and S14 for all three tests, where T_1 (June/July) is defined as the summer, T_2 (August/September) is the pre-competition phase and T_3 (December) is during the competitive season. Overall, there were no changes in the mean difference for any of the variables (Table 4).

Table 4: Changes in physiological and performance related variables presented as M and SD for all three tests (T_1, T_2, T_3) at S12 and S14.

Variables	**T_1**		**T_2**		**T_3**	
	S12	S14	S12	S14	S12	S14
VO2 ml/kg/min	43.9±1.6	50.2±2.1	44.5±2.8	50.6±3.2	42.7±1.9	48.6±2.9
HR	161±7	172±8	158±14	171±13	162±12	171±14
BLa (mmol/L)	1.70±0.65	2.69±1.26	2.13±0.58	2.70±1.17	2.22±0.82	2.87±1.22
RPE	9.5±1.08	11.9±1.52	9.1±2.08	11.3±2.5	8.6±1.7	10.9±2.1
GE (-)	0.149± 0.005	0.150± 0.008	0.146± 0.009	0.149± 0.006	0.151± 0.008	0.155± 0.008

As seen in fig. 4 no mean change was found for any of the technical variables (CL, CR, P_{Time}, P_{Trel}, $P\theta_{LO}$ and $P\theta_{TD}$) or for GE. For CL, there was a main effect of test period (F2,18=5, p = 0.01) in S14. A Pairwise t-test revealed a significant difference between T_1 and T_2 (ß = 0.14, p = 0.01). However, a non-significant difference between T_2 and T_3 (ß = -0.11, p = 0.06) and T_1 and T_3 (ß = 0.03, p > 0.05) for the same speed. No main effect was detected between CL and test period for S12. A main effect of test period was also found for CR (F2,18 = 5, p = 0.012), with pairwise t-tests revealing a difference between T_1 and T_2 for S14 (ß = 0.017, p = 0.05) and a slight, however non-significant, difference from T_2 to T_3 (ß=0.026, p = 0.06). No main effect was detected for CR and test period at S12. For $P\theta_{LO}$, a main effect of test period was detected (F2,18 = 7, p = 0.005) at S12 and for S14 (F2,18 = 21, p < 0.001). A pairwise t-tests revealed a significant difference from T_1 to T_2 (ß = -1.493, p = 0.01) and from T_1 to T_3 (ß = -1.432, p = 0.01) for S12. Similar results were found for S14, revealing a significant difference from T_1 to T_2 (ß = -2.010, p < 0.001) and T_1 to T_3 (ß = -1.363, p = 0.001). An effect of test period was detected for P_{Time} (F2,18 =, P = 0.05) at S14, with a significant difference from T_1 to T_2 (ß = 0.017, p = 0.04), however no main effect of test period was detected at S12 (F2,18 = 0.8, P =0.45) for the same variable. There were no effects of test period for $P\theta_{TD}$ at (F2,18 ~ 2,8, p > 0.08), P_{Trel} (F2,18 = 0.39;0.72, P > 0.05), or GE (F2,18 = 2.4;2.5, p > 0.05) in S12 or S14, respectively.

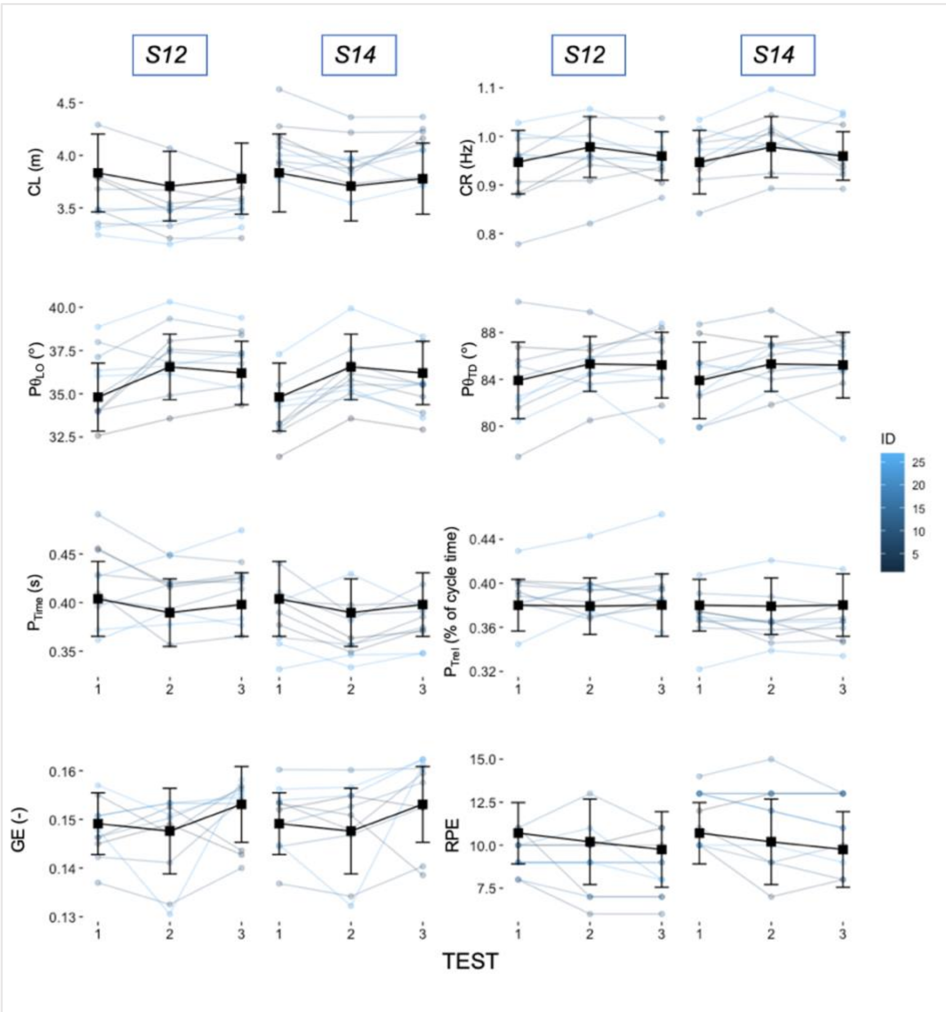

Figure 4: Individual (●) and mean changes (■) in seasonal variations in technical parameters (CL, CR, P_{Time}, P_{Trel}, $P\theta_{LO}$ and $P\theta_{TD}$), RPE and GE for the three different testing periods (T_1, T_2, T_3).

Additionally, a main effect of test period was found for RPE at S14 ($F_{2,18} = 3$, $p = 0.04$) where a pairwise t-test showed a significant difference from T_1 to T_3 ($ß = 1.0$, $p = 0.03$). A weak, non-significant, effect of test period was detected for FIS points ($F_{2,18} = 3$, $p = 0.06$) with a significant difference from T_1 to T_3 ($ß = 9.52$, $p = 0.05$). However, no main effect of test period was found regarding $V_{Threshold}$ ($F_{2,18} = 0.04$, $p > 0.05$) at S12 and S14 (fig.5), or for RPE at S12 ($F_{2,18} = 2$, $p = 0.16$).

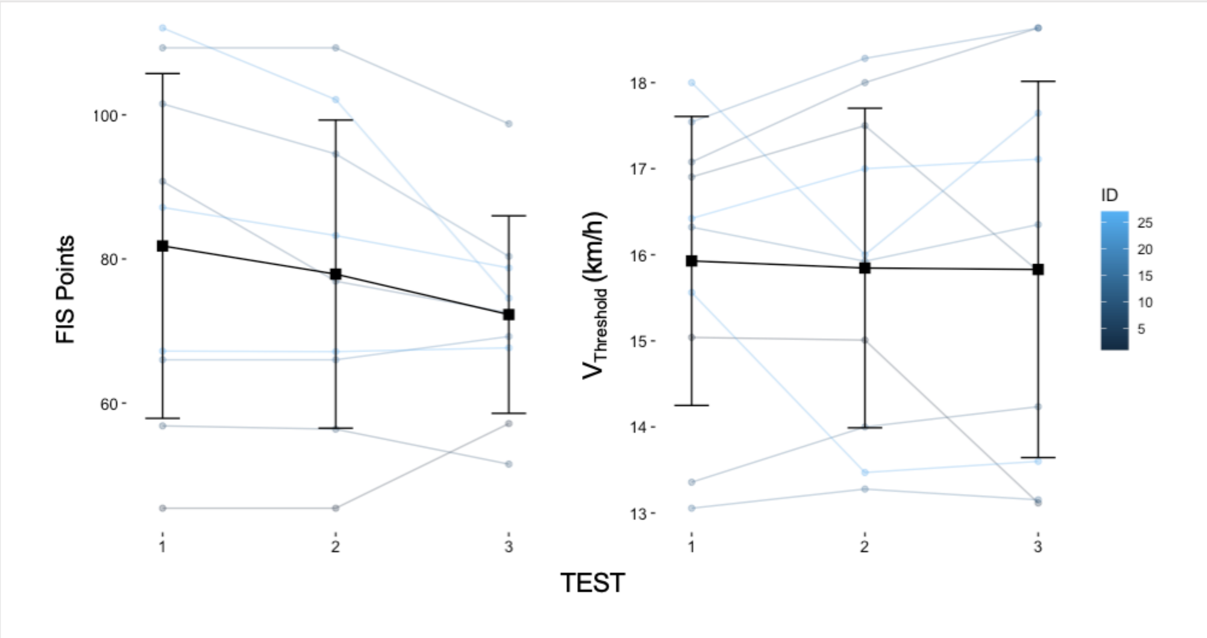

Figure 5: Individual (●) and mean changes (■) in seasonal variations in performance-related factors ($V_{Threshold}$ and FIS Points) for the three different test period (T_1, T_2, T_3).

4 Discussion

The aim of this study was to investigate possible relationships between a) performance, performance-determining factors, and technique, and between b) seasonal variations in performance and performance-determining factors, and changes in technique. The main findings of this study identified a) a strong correlation between GE and $V_{Threshold}$ for S12 and S14, however, no relationships were found between $V_{Threshold}$ and technical variables (CL, CR, P_{Time}, P_{Trel}, $P\theta_{LO}$ and $P\theta_{TD}$) in both speeds. Further, findings in b) showed no mean change in physiological variables (VO2 ml/kg/min, HR, BLa, GE) or gross technical variables (CL, CR, P_{Time}, P_{Trel}, $P\theta_{LO}$ and $P\theta_{TD}$) over the course of the testing period (June – December). However, a main effect of test period was detected for some of technical variables at S14 (CL, CR, P_{Time}, $P\theta_{LO}$). No statistically significant main effects of test periods were found for the performance-determining factors FIS points and $V_{Threshold}$.

4.1 a) Performance, performance-determining factors and, technique

In the present study, a strong correlation between performance ($V_{Threshold}$, FIS points) and GE was revealed. This meant that participants with higher $V_{Threshold}$ had corresponding lower FIS points and an overall higher GE. This finding is consistent with Sandbakk, Holmberg (7) who found that WC skiers (better skiers) had an overall higher GE than their lower ranked counterparts. Other studies have also found higher GE among the better skiers for different techniques, which further supports the findings of this study regarding the relationship between performance and GE (6, 22, 31). It is worth noting that at fixed speeds and a fixed incline, a higher body mass equals a higher power output (5). This means that a higher power output may lead to a higher GE because of the diminishing effect of the non-zero offset on the MR-WR relationship (5). Athletes with higher power outputs, typically, also have higher body mass, with larger and more working muscles. However, adjusting for body mass had no inflictions on the relationship between $V_{Threshold}$ and GE in the present study. Sandbakk, Holmberg (7) also suggested that efficiency is strongly affected by the execution of technique, which is why we also are likely to find higher GE in better skiers (7). Despite this, no relationships between performance and technical parameters were found in the present study, which is contrary to the findings of Sandbakk, Holmberg (7) who found a difference in CL and CR (approximately 0.8 m difference) between the different performance level groups. This difference in CL constitutes to a 0.5 percentage-point difference in GE between the two performance level groups. The difference Sandbakk, Holmberg (7) reported is quite large and therefore it is surprising that the present study did not find any relationship whatsoever, when examining the relationship between GE and CL among our best-ranked skiers (FIS points < 20) versus our lower-ranked skiers (FIS points > 150). One could argue that such findings could become present in this study if participants were categorized based on their performance level, as done in Sandbakk, Holmberg (7). However, treating continuous variables as continuous has, according to Altman and Royston (32), a higher statistical power. Additionally, in the present study, no group level difference occurred (e.g., in CL related to $V_{Threshold}$ in fig. 3) when the data set was divided into low- and high-performance groups (according to FIS points). Furthermore, there were no tendencies that the higher ranked skiers of this study had higher CL (fig. 3.2a and 3.2b) than their lower ranked counterparts at the chosen speeds. Therefore, if technical parameters, such as CL is a strong predictor of GE and $V_{Threshold}$ as found in existing research (7, 19, 21), it should be evident in such a dataset, considering the large range in FIS points among our participants.

Similarly to the findings of this study, more recent studies have not found a clear relationship between performance-related factors (such as GE, O2-cost) and technical parameters. Torvik, Sandbakk (22), who compared specialized long distance (LD) -and All-round (AR) skiers, found a higher GE in the specialized LD skiers. However, they found essentially no difference in technique at submaximal speeds. Similar results were found in a study conducted by Skattebo, Losnegard (10), who found almost no difference in movement pattern between AR-and LD skiers, however, large differences in O2-cost, where LD skiers had a lower O2-cost than AR skiers. Skattebo, Losnegard (10) suggested that differences in physiological composition such as age could have an infliction on the results, and that the occurrence of kinematic differences might have been more present if they had a larger sample size. For the present study, the large differences in age (table 1) contributes to the differences in training hours among the participants, where an older athlete evidentially has more trainings hours than a junior athlete. One could argue that older athletes might have had more time to develop adaptations in mechanisms that does not specifically relate to technique than their younger counterparts. This includes mechanisms such as muscle fiber distribution, aerobic enzymes, muscle-activation pattern, and mitochondrial efficiency, some of which are mentioned by Skattebo, Losnegard (10). Even though these mechanisms were not investigated in the present study, they could be of interest for future research. Furthermore, there is a possibility that including more skiers with higher $V_{Threshold}$ (< 20) could generate such a relationship, although the present data suggest that this might not be the case.

4.2 b) Seasonal variations in physiological variables

Contrary to the results of Losnegard, Myklebust (24), who found improvements in O2-cost and O2-deficit among XC skiers, no change in mean difference was detected for any of the physiological variables with no main effect of time-period in this study. A study performed by Ingjer (23), who conducted a series VO2max tests over the course of ~ six years, found, similarly to Losnegard, Myklebust (24), an increase in physiological variables for junior level XC skiers. Additionally, Ingjer (23) also reported seasonal variations in physiological parameters among the participants within the training year. As opposed to the present study, which looked at seasonal variations in submaximal data (such as VO2, GE), Ingjer (23) primarily investigated physiological parameters at maximal effort. Additionally, the participants in Ingjer (23) study was selected as the best skiers from a large pool of junior XC skiers, with a considerable physiological capacity (VO2max > 80 ml/kg/min), and the participants were all members of the junior national team at the time of the study. Whereas the participants of this study were more fluctuant in performance level, ranging from national team level athletes to top sports high school students. Thus, (positive) changes in physiological variables were to be expected here, due lower levels of physiological capacities among the participants of this study. Although some individuals improved in some of the parameters (e.g., VO2, HR), no simultaneous increase in other parameters (physiological or technical variables) was detected. Overall, no trend was detected for any of the physiological parameters on a group level, contrary to previous research.

Another important contributor to the lack of (positive) change in mean difference for the different testing periods might come from the expectation to find changes within in a group (or at a group level) of athletes who spend a considerable time and effort to improve performance. Participants of this study are both junior and senior national level skiers, just below or at "national team" status. Nonetheless, some participants are still in high school and have other obligations (e.g., working to fund the sport effort, academic work, and friends) in addition to the training hours they put into sport. Constant stressors outside the sports environment could be detrimental for (optimal) performance development, especially for junior athletes, and could lead to underperformance and burnout at an already early age (33, 34). It is, however, difficult to assess how or if these types of environmental stressors affected the participants (especially the younger participants) of the present study, and this requires further research. There is also reason to speculate that some of the participants of the present study may already have reached their individual maximal potentials and will likely not improve much over the following years. Additionally, Losnegard, Myklebust (24) suggested that already well-trained athletes have fewer variations and improvements in physiological indices, because they already obtain a considerable physiological capacity. Furthermore, Lucía, Hoyos (25) also indicated that the age of the athlete also has an effect on the ability to improve physiological parameters considerably.

4.3 b) Seasonal variations and changes in technique

For the technical parameters, some main effects of time-period were detected for CL and P_{Time} at S14 and $P\theta_{LO}$ at both speeds. However, these differences were small and overall, no change in mean difference for the test periods was detected for the technical variables. The present study is, to our knowledge, the first to have investigated seasonal variations in XC skiing technique. However, studies have investigated seasonal variations in physiological parameters and technique for other endurance sports such as cycling. Their findings reported smaller improvements in both physiological parameters and technique over the course of a season, and that these parameters mostly stabilized during the competitive phase (25, 26). Since this is study is among the first to investigate seasonal variations in technical parameters, it is difficult to predict possible changes. However, Sandbakk, Holmberg (7) argued that the technical complexity of XC skiing might affect GE on a higher level than in other endurance sports. Even though there were no mean difference in technical parameters over the course of this season, one could argue that the time it takes to develop and enhance technical improvements were not sufficient in the present study. Additionally, only gross measures of technical parameters were assessed in this study, meaning that there could possibly be changes in other kinematic variables such as joint angles (e.g., hips, knee, elbow), movement pattern, and force interaction (of the poles and skis). Another point that needs to be considered when studying seasonal variations is, again, what amount of change in technique is reasonable to assume over the course of a training year. Furthermore, one should consider what type of training that could lead to a somewhat meaningful increase in technical improvements. A factor that could contribute to the lack of positive changes is that the participants of the present study (over the course of this season) did not endure enough training, or simply is not at the level they should be technically. Thus, assessing training diaries and training regime could be of interest for future studies when investigating changes and factors affecting technique in both shorter durations (months) and longer durations (years) and how they relate to performance.

4.4 Methodological considerations

Laboratory testing is often used in the assessment of physiological and technical parameters as it is believed that it can contribute to the planning of training and performance developments. The population was predefined before the start of the present study, and testing during the training year posed several different challenges in relation to adherence. Even though 48 XC skiers participated in the study, only ten athletes had complete datasets with both physiological and kinematic variables for all three tests. This was a result of several different reasons, such as illness, lack of motivation to complete the protocol in its entirety, and some technological problems regarding lab equipment. Since most of the participants are still enrolled in high school, it is likely that other stressors, as mentioned in 4.2, might also affect their adherence to this project. This study does not maintain the same number of participants throughout the analysis and presents with a small number of participants in the second part of the analysis (b), ultimately reducing statistical power for data with apparently low effect size (24). However, the few individuals that presented with a clear positive change in $V_{Threshold}$ had no corresponding change in technique at the selected speeds. Other speeds were also analyzed, with no trend to indicate any other correlations in a) or changes in b).

4.5 The road ahead

The question remains whether findings of the present study are representative. Future studies, preferably with a larger sample size, should be conducted to corroborate or disprove these findings. By conducting larger studies on the same population of skiers over several years, it may be possible to reveal the number of skiers who experience significant improvements and "descended the FIS point ladder (climbed the performance ladder)", as well as identify the skiers who stop improving after a certain amount of time. Long term data collections are therefore necessary if one is going to be able to retrospectively predict future champions from a pool of XC skiers (or any athletes) of a range in level. However, longer studies are often time consuming and generally not that easy to conduct, for example due to dropouts or if an athlete retires, becomes injured, loses interest, or is restricted in terms of budget/funding.

5 Conclusion

The finding of the present study revealed a strong relationship between GE and performance ($V_{Threshold}$ and FIS points). Contrary to former research, no correlations were found between GE and technical parameters. Furthermore, no overall or meaningful differences was detected for performance-, physiological- and technical parameters when tested three times over the course of one season. More research is needed to establish if, in fact, there is any reason to assume a strong relationship between GE and technical parameters. Similarly, long-term studies (following a larger group of athletes over several years) are needed to see how much, and for how many athletes, these variables meaningfully improve or change over time.

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